European Commission

Benefit and Feasibility of a Range of New Technologies and Unregulated Measures in the fields of Vehicle Occupant Safety and Protection of Vulnerable Road Users

Final Report

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Executive Summary

Regulation (EC) 661/2009 of the European Parliament and Council, amended by Commission Regulations (EU) number 407/2011, 523/2012 and 2015/166 (the 'General Safety Regulation') governs the type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units. The Regulation lists the implementing measures that apply on a compulsory basis and the vehicle types to which each regulation applies. To date, a number of amendments have been made to the General Safety Regulation including mandating:

- Electrical safety
- Electronic Stability Control (ESC) systems on cars, vans, trucks and buses
- Fitment of tyre pressure monitoring systems on cars
- Lane Departure Warning Systems (LDWS) and Advanced Emergency Braking Systems (AEBS) for trucks and buses
- Gear shift indicators on cars
- Rolling resistance limits, noise emission limits and wet grip performance of tyres
- Driver seat-belt reminder on cars
- ISOFIX child restraint anchorages on cars
- Cab strength crash protection of vans and trucks
- A large number of UN Regulations replacing repealed Directives

In addition, Regulation (EC) 78/2009 on the type approval of motor vehicles with regard to the protection of pedestrians and other vulnerable road users (the 'Pedestrian Safety Regulation') replaced Directive 2003/102/EC with modified and more advanced provisions, adapted to the technical progress. This includes passive safety requirements to mitigate the risk of critical injury in case of a collision between a vehicle and a person.

The General Safety Regulation requires that the Commission report to the European Parliament every three years with proposals for amendment to the Regulation or other relevant Community legislation regarding the inclusion of further new safety features that meet the CARS 2020 and the Policy Orientations on Road Safety 2011-2020 criteria. Commission monitoring reports to the European Parliament are also required, as appropriate, by the Pedestrian Safety Regulation.

As part of these requirements, this report concerns an overview feasibility and cost-benefit assessment of a wide range of candidate measures for inclusion in the General Safety Regulation. The outputs are indicative cost-benefits provided in order to differentiate those measures that are very likely, moderately likely or very unlikely to provide a benefit consistent with the cost of implementation. This information will enable prioritisation of possible future legislation or amendments thereto relevant to vehicle safety and to the relevant EU type-approval requirements. This report also provides advice on the necessity and feasibility of including the complimentary upper legform to bonnet leading edge and adult headform to windscreen tests in pedestrian safety legislation, until recently carried out by vehicle manufacturers only with a view to monitor the situation in the field.

The following sections highlight the key findings for measures in the following areas:

- Active safety
- Car occupant and pedestrian safety

- Crashworthiness, HGV safety and fuel systems
- Driver interface, distraction and ITS

Active Safety Measures

All of the active safety measures reviewed in this study were found to be feasible in terms of the technology required, and most systems are available on current production models either in Europe or in other jurisdictions. The primary exception to this is the cyclist detection part of the pedestrian/cyclist detection measure; pedestrian detection and warning or autonomous braking is available on production cars, but reliable detection of cyclists is considered to be more difficult and is some way from being ready on a mass-production scale.

For many of the measures, the feasibility in terms of legislation is likely to require significant resources in terms of regulatory development. Although the systems exist, regulation-ready test procedures and performance requirements have not been developed and agreed. For many of the systems there may be ISO or other standards that define test procedures and/or require a certain minimum performance, but no evidence was identified that these have been assessed as suitable for application in legislation. Significant work may therefore be required to develop and/or validate suitable test procedures and performance requirements.

Based on the evidence reviewed, the following measures were considered to be likely to be cost-beneficial and could on that basis be taken into consideration:

- Enhanced AEB with collision mitigation
- Intelligent speed adaptation
- Lane keep assist
- Reversing detection and reversing camera systems
- Emergency brake light display

In addition, pedestrian/cyclist detection systems may become cost beneficial in the future as system costs come down, and ACC could be considered if enhanced AEB is mandated for cars, because most of the cost would be covered by the AEB system.

Furthermore, there was an indication in the evidence review that one lighting option – automatic main and dipped beam – may actually be disbeneficial; the number of accidents may be reduced, but the severity of the remaining collisions may increase. Consideration should be given to investigating this further with a view to establishing more robustly whether this type of lighting system should be allowed.

Traffic sign recognition had undemonstrated cost-benefit and far reaching standardisation of signs across Europe may be required before this technology would become reliable. Similarly, maximum benefit from lane departure, lane change and lane keep assistance systems may require action on the EU level to improve the provision and maintenance of road markings.

Car Occupant and Pedestrian Safety Measures

Of the measures reviewed, only two were clearly feasible and cost-beneficial with the current technology capability and costs:

- Protection of far-side occupants in side impact collisions (M1 vehicles)
- Seat-belt reminders (M1, M2, M3, N1, N2 and N3 front seats; possible also other M1 seating positions on the basis of safety equality)

For several other measures cost information was either incomplete or out-of-date, but the study team considered that the measures were reasonably likely to be cost-beneficial, particularly if other complimentary measures are considered:

- Improved protection of seniors and small stature occupants through the adoption of advanced anthropometric test devices, which links with the application of advanced ATDs in a potential small overlap frontal impact test procedure
- Improved side impact protection, which links with potential measures on ejection mitigation and small overlap frontal impact testing

It is also recommended that some aspects of head-to-windscreen impact protection should be investigated further and that the mitigation of serious injuries to rear row occupants, which may include children on booster cushions, could be considered on an equality of protection basis.

For the third-party (non-OEM) replacement parts measure, no cost or benefit information was obtained. No specific parts were identified as having a known and generic safety risk associated with them (though it is acknowledged that some research tests have shown safety degradation with certain aftermarket parts and/or their fitting). It was proposed that where a concern is raised, this could be addressed by setting specific performance requirements for that type of part (e.g. brake linings). This creates a level trading platform for all (OEM and non-OEM, etc.) parts suppliers. It was also mentioned that alternatively these specific parts, once identified, could be included in the currently empty Annex 13 of Framework Directive 2007/46/EC.

Crashworthiness, HGV Safety and Fuel System Measures

All but two of the measures were found to be technically feasible. The following measures were considered to be feasible and likely to be cost-beneficial for Europe:

- Improved HGV rear under-run guards for compatibility with M1 and N1 vehicles
- Removal of some exemptions to the requirements for side guards on HGVs (by improving the definition of those vehicles that are allowed an exemption)
- Safer HGV front-end design (for improved direct vision to improve VRU safety, self-protection of the driver and partner protection for collisions with other vehicles)
- Specific enhanced requirements for CNG vehicles in case of fire

Note that consideration may also need to be given to improving the coverage of side guards. For this study the scope was to consider the current regulation only. However, the review and the casualty benefit numbers indicated that current side guard designs may not be effective in preventing all accidents where a vulnerable road user is run-over (allowing sufficient ground clearance for the VRU to pass underneath). It is conceivable that side guards could be improved in this respect, to cover more of the vehicle’s length and extend closer to the ground. A revision of the existing regulation could be considered in addition to the removal of exemptions from the requirement to fit lateral protection to HGVs.

Driver Interface, Distraction and ITS Measures

It was found that the technical feasibility of vehicle/infotainment controls and distraction measures were not adequately demonstrated at the time of the review. Nevertheless, distraction is a significant and possibly increasing factor in road traffic accidents and further work is recommended to develop the evidence base and requirements that would be necessary to implement a technology-neutral measure to reduce driver distraction. The study identified that the technology exists to implement mobile phone interlocks; however, these would either block all signals within the car (and therefore block important functions such as mobile phone based satellite navigation systems that may have benefits such as reducing congestion and re-routing traffic away from the scene of accidents and penalise passengers in the vehicle) or require the voluntary installation and use of an application on the driver’s phone. It is not clear how this could be applied in type approval legislation, but it could be encouraged in commercial fleets where the use of the technology can be made a condition of employment.

Based on the evidence reviewed, the following measures could be considered for further legislative development:

- Driver distraction and drowsiness recognition, noting that further work would be required to determine how to define and test the effectiveness of distraction and/or drowsiness monitoring systems
- Allowing the option for cameras to replace rear view mirrors, provided that adequate standards for the system (camera and screen) can be defined to ensure image quality at least equivalent to conventional mirrors in all lighting and weather conditions
- Alcohol interlocks
- Event data recorders

Regarding alcohol interlocks, the study focussed initially on the provision of a standard interface to ensure that it would continue to be possible to fit interlocks to future vehicles. ACEA indicated that rather than a standard interface, it would be preferable for all manufacturers to provide authorised installers with standardised information on how an interlock system may be fitted to their vehicles, so as to reduce the potential for unintended exploitation of a standard interface.

Intelligent transport system measures were found to be feasible and many potential safety benefits have been proposed for vehicle-to-vehicle and vehicle-to-infrastructure communications. However, the costs and benefits remain unknown and the systems and test procedures were considered to be not sufficiently mature for application in type approval.

Summary of findings for 'green' measures

'Green' Measures

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
AEB	Expansion and enhancement of AEB, BAS and LDW to avoid or mitigate collisions, including inter-urban, city and those with VRU	✓	~1	●	Greatest casualty benefit for AEBS is for M1 then N1 vehicles, although cost-benefit less clear than for N2/N3. System cost estimates suggest 'city safety' systems may be getting to the breakeven cost point
ISA	Speed limiters controlled by road speed limit (speed assist, intelligent speed adaptation)	✓	>1	●	BCR>1 for 6 Member States, for voluntary activation (switched on/off by the driver) and mandatory activation, and public acceptability of the systems considered to be growing. BCR higher for mandatory activation system, but both have positive BCR
LKA	Lane keeping system	✓	>1	●	Costs higher than LDW and similar to LCA, but benefits higher because higher expected effectiveness than LDW/LCA
REV	Reversing detection and reversing camera systems to prevent accidents involving children behind reversing cars	✓	>1	●	BCR>1 when including damage-only accident mitigation and regulatory requirements are being introduced in the US (mandated from May 2018), so the technology is likely to become commonplace and costs are likely to reduce further
EBD	Standard fitment of the emergency brake light display (i.e. rapidly blinking brake lamps) in case of hard braking	✓	>1	●	No formal BCR for EBD were identified, but costs likely to be very low and collision and injury benefits expected - therefore BCR may be >1
SFS	Protection of far-side occupants in side impact collisions	✓	>1	●	Likely to be cost-beneficial (spans 1, and cost estimate considered to be high) and already in production vehicles. Work would be required to define suitable test and assessment procedures
SBR	Seat-belt reminder systems in front and rear passenger seating positions	✓	>1	●	Cost-beneficial for M1 driver and outboard passenger seat, M2 and M3 passengers, all seat positions for N1, N2, N3. Could consider legislation for M1 second and other row seats on basis of safety equality and being nearly cost effective
FCO	Compatibility with crash partners (incorporating HGV rear under-run)	✓	<1 (>1)	●	Insufficient benefit from testing for geometric alignment of M1 frontal energy absorbing structures; consideration could be given to a voluntary agreement for height of energy absorbing structures in a similar way as in the US. For HGV, improved rear under-run guard likely to have BCR>1
LAT	Lateral protection of trailers/trucks (removal of some exemptions)	✓	<1 to 1	●	Cost benefit likely to be less than 1 for vehicles that genuinely need either an exemption or adjustable side guards; however, the classification of these vehicles should be improved, which will reduce the number of vehicles receiving an exemption
DIM	Safer HGV front end design (enabled by changes to the weights and dimensions legislation)	✓	>1	●	Breakeven cost per vehicle €1,448–€4,889, so likely to be cost-beneficial. Further work needed to define suitable requirements, which will affect costs, so final BCR should be updated. Alternative active safety systems should also be investigated to ensure that the best benefit is delivered for a given cost

'Green' Measures

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
CNG	Specific enhanced requirement for CNG vehicles in case of fire (as proposed by the Dutch delegation in GRSG of UNECE)	✓	?	●	Recommend updates to regulation in line with hydrogen vehicle requirements and application of regulation to class I vehicles with CNG propulsion; requirements for emergency responder access to the engine compartment may also be considered. Cost-benefit for automatic fire extinguishers not clear; these have been encouraged as after-market equipment in some markets
DDR	Driver distraction and drowsiness recognition	?	>1	●	BCR likely >1 for private cars and commercial vehicles, due to the large number of collisions involving distraction as a causative factor. However, further work required to determine how to define and test effectiveness of distraction/drowsiness monitoring systems and to define what action the system should take if inattention is detected
RVC	Cameras to replace all the rear view mirrors	✓	?	●	No BCR studies identified and the main benefit would be reduced fuel consumption. Legislation could be considered that would permit, rather than require, cameras to replace wing mirrors, provided that adequate standards for system (camera and screen) can be defined to ensure image quality at least equivalent to conventional mirrors in all lighting and weather conditions
ALC	Alcohol interlock devices to prevent drink driving	✓	?	●	Legislate to ensure that it remains possible to connect an alcohol interlock to the vehicle in the future (not for fitment of the interlock), e.g. via a standard interface
EDR	EDR acting as a possible psychological stimulant to safe driving (from DG MOVE study)	✓	>1	●	Real benefits identified, although difficult to monetise. However, most new European vehicles have EDR functionality (although currently not accessible in most), so most of the cost has already been spent. Recommend legislating to standardise specification for EDR and standardising technical protocols for access to the information (the latter most likely to be harmonised with US Part 563)

Summary of findings for 'orange' measures

'Orange' Measures

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
PCD	Pedestrian/cyclists detection systems	✓	<1	●	No BCR studies were identified and breakeven costs exceed current system costs. If other systems that share hardware with PCD systems are mandated and reliable system cost estimates can identified, this measure should be re-evaluated
NVIS	Night vision systems to detect obstacles and persons in unclear ambient lighting conditions	✓	<1	●	Issues with distraction with always-on systems; warning systems may be helpful, but the BCR is not yet clear
SURC	Surround camera systems, aiding the driver at visually obstructed intersections	✓	?	●	BCR not sufficiently well defined; better information needed on target population, system effectiveness and system costs
VIS	Better field of vision in the close surroundings of the vehicle (e.g. Japanese requirements)	✓	?	●	Benefits similar to reversing cameras, but likely to involve high design cost that could affect safety in other ways and may not be as effective at preventing accidents compared with alerting systems or well-positioned cameras
AFL	Fully automatic lighting and advanced adaptive front lighting combined	✓	?	●	US insurance data indicates high intensity lights and dynamic beam patterns reduce collisions and injuries, and that automatic high-beam assist reduces damage claims but greatly increases injury claims (suggesting that collisions are reduced, but those that occur are more severe). May want to consider legislating *against* high-beam assist
SML	Side marker lamps on passenger cars and vans to improve conspicuity	✓	>1?	●	Insufficient accident data to determine benefit and effectiveness, but implementation costs likely to be low. US study based on 1970s data may not apply to modern vehicles or to Europe. Specific study required.
TMP	Temperature sensors warn in for unexpected icy road conditions	✓	?	●	No BCR information identified, but external temperature warning displays are already almost universally fitted. Requirements to standardise visual and audible warnings may be worth considering
SEN	Improved protection of seniors and small stature occupants through the adoption of advanced anthropometric test devices	✓	?	●	No BCR due to lack of cost information. However, at least two different test severities would be required before significant benefit would be expected to accrue in the current (R94) and full-width test conditions. An advanced ATD would be necessary for small overlap (see crashworthiness/ small overlap frontal crashes 'FSO')
SIP	Side impact protection for occupants of all sizes and prevention of ejection (e.g. using full-size window airbags)	✓	<1	●	Costs likely to exceed benefits, but cost information not very reliable. Costs would also have to be re-evaluated if a small overlap test procedure was introduced because this may encourage improved side airbags for front seat occupants. Legislation could also be considered on the basis of providing equality of protection for all occupants, including rear seat occupants

'Orange' Measures

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
RRR	Rear row occupants in rear impacts	?	?	●	No information on feasibility, costs or benefits was identified. However, some evidence that rear-row occupants have twice the fatality risk of front row occupants in a rear impact. Legislation could be considered on an equality of protection basis, but considerable further work would be required to demonstrate feasibility and cost-benefit. Rear occupant safety is currently assessed on vehicle system level (in some cases restraint system tests and in all cases interior fittings energy dissipation tests)
HED	Adult head to windscreen protection	✓	<1 to 1	●	BCR from 0.25 to 1, depending on real-world effectiveness of measures. There are indications that performance of the central area of the windscreen can be controlled better at negligible cost and this should be investigated further
3RD	Influence on safety of third-party (non-OEM) replacement parts on pedestrian protection	?	?	●	No cost or benefit information identified
ISO	Strength of ISOFIX connectors installed in vehicles to provide appropriate protection of heavier children	✓	?	●	No evidence of real-world injuries due to failure of ISOFIX connectors was identified; however CRS designs are changing and there is strong evidence that CRS load the anchorages to as much as 13 kN dynamically, compared to a static requirement in Reg.14 of 8 kN, and that loads may increase with some R.129 designs. Further work recommended to look at requirements if different materials for ISOFIX connectors are used in the future
HOT	Raising alarm if small children are detected being abandoned in hot cars	?	?	●	It was not possible to predict reliably the benefit:cost ratio due to lack of EU-wide data on accidents and costs of systems, but likely BCR<1. There is evidence that the performance of current systems is unreliable, which affects feasibility and end-user acceptance (false alarms), and a number of manufacturers and developers have withdrawn potential systems due to liability concerns
FSO	Crashworthiness in small-overlap frontal crashes	✓	1?	●	Maximum benefit likely from NHTSA-style low overlap, for which there is less info available on likely EU benefits and particularly costs. Further work may be required
FFW	Crashworthiness in full-overlap frontal crashes to better assess occupant restraint systems	✓	1	●	Current proposal unlikely to lead to improved restraint systems, so minimal cost and minimal benefit. Further work needed in order to define requirements that would ensure improved restraint systems for a wider range of occupants in a wider range of collision severities
AFE	Comprehensive testing of fuel systems to avoid fires; possible inclusion of automatic fire extinguishers (LCV and HCV)	✓	?	●	Required by insurers for buses in some countries and has been effective; further work would be required on costs and benefits before legislation could be considered

'Orange' Measures

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
RFT	Rear impact protection of the tank (e.g. US, Canadian and Japanese requirements)	?	?	●	Insufficient cost and benefit information identified. Fuel tanks are tested on component level (impacted with pendulum) and the fuel system installation is verified through EU legislation
INF	Driver interface provisions and restrictions for on-board infotainment systems;	?	1	●	Currently handled by voluntary agreements and standards, which allows innovation but also non-standardised, non-intuitive controls that do not necessarily comply with the standards. Suggest development of tests to quantify compliance with the guidelines and continuous monitoring of effect on collision rates as systems become more commonplace
DIS	Reducing driver distractions	?	1	●	BCR likely to be close to 1, but it is currently not clear how to legislate effectively to reduce distractions within the Type Approval system. Various standards committees are active on this topic and the situation should be monitored
MOB	Interlock to prevent the use of non 'hands free' mobile telephone systems while driving	✗	?	●	Technology exists to apply this voluntarily, e.g. for commercial fleets, where use of the technology can be a condition of employment; however, it is not clear how this could be implemented within Type Approval. If distraction and drowsiness recognition is implemented, specific requirements for mobile phones may become less important

Summary of findings for 'red' measures

'Red' Measures

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
ACC	Automatic cruise control	✓	<1	●	Do not consider on its own (not cost-beneficial and may have disbenefits in some situations). Consider if AEBS is mandated (much of the hardware cost would be borne by the AEBS)
LDW	Lane departure warning system	✓	<1 to >1	●	Insurance data suggests LDW not as effective for passenger cars as originally predicted, so BCR currently uncertain, although systems may not have been switched on
LCA	Lane change assist (incorporating blind spot detection systems)	✓	<1	●	Benefits may be more robust than for LDW, but system costs (based on retail price) currently too high for BCR>1
TSR	Traffic sign recognition	✓	?	●	No appropriate test procedures available from which to set legislative performance requirements and the cost-benefit is not clear (dependence on infrastructure). Recommend encouragement through other means
ICS	Integrated cleaning system (water comes from the wipers)	✓	?	●	Scale of benefits and costs are unknown, but benefits considered to be very low so BCR likely to be <1
PRE	Pre-crash seat-belt tensioners and occupant position adjustments in case of an inevitable impact	✓	?	●	Feasible technology (already on production vehicles), but not obvious how to encourage fitment and benefit:cost unknown. May be better encouraged through rewards in consumer information testing
BLE	Pedestrian upper leg and pelvis to bonnet leading edge	?	<1	●	Small numbers of pelvis and upper leg injuries caused by the bonnet leading edge of modern cars. Potential benefit for head, thorax and abdomen protection for children not yet quantified and should be further reviewed in depth, if considered. Adding other body regions and harmonisation with other tests could take the BCR>1; otherwise, BCR likely to be <1
REG	Influence of front registration plates (not present in type-approval testing) on pedestrian protection	?	0	●	No evidence of an injury risk identified and therefore no benefit predicted, while costs would be incurred
VEL	Increased crash speeds	✓	?	●	Higher speed test unlikely to change vehicle design, because vehicles already meet Euro NCAP; may affect some vehicles where the worst case model (tested in UN Regulations) is significantly different (e.g. much larger engine) than the most popular model (that is tested in Euro NCAP)
ROL	Roof strength testing to protect occupants in case of roll-over accidents	✓	?	●	Unlikely to be of sufficient cost-benefit. A number of vehicle types sold world-wide are already likely to meet US requirements

'Red' Measures

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
SUB	Requirements to ensure that occupants are always capable of escaping a vehicle in water	?	<1	●	Unlikely to be cost-beneficial, given the low occurrence of accidents in the EU
SVC	Standardisation of uniform vehicle controls	?	?	●	Considered likely to have an effect on distraction, but no evidence for accidents being caused by variation in vehicle controls was identified, so not possible to estimate the target population or benefit
IOV	Improving the intuitive operation of vehicles	?	?	●	Considered likely to have an effect on distraction, but no evidence for accidents being caused by counter-intuitive vehicle controls was identified, so not possible to estimate the target population or benefit
C2C	Car-to-car communication	✓	?	●	US considering mandating in-vehicle systems so that cars can take advantage of developing car-to-car communication services but not mandating the services themselves. Systems and test procedures not sufficiently mature for type approval
C2I	Car-to-infrastructure communication	✓	?	●	US considering mandating in-vehicle systems so that cars can take advantage of developing car-to-infrastructure communication services but not mandating the services themselves. Systems and test procedures are not sufficiently mature for type approval
NAV	Standard accident avoidance functions in navigation systems; appropriateness of route data for vehicle type/dimensions	✓	?	●	There is a commercial market that appears to be working and it seems unlikely that market intervention would be warranted

1 Introduction

Regulation (EC) 661/2009 of the European Parliament and Council, amended by Commission Regulations (EU) number 407/2011, 523/2012 and 2015/166 (the 'General Safety Regulation') governs the type approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units. The Regulation lists the UN Regulations that apply on a compulsory basis and the vehicle types to which each regulation applies. To date, a number of amendments have been made to the General Safety Regulation including mandating:

- Electrical safety
- Electronic Stability Control (ESC) systems on cars, vans, trucks and buses
- Fitment of tyre pressure monitoring systems on cars
- Lane Departure Warning Systems (LDWS) and Advanced Emergency Braking Systems (AEBS) for trucks and buses
- Gear shift indicators on cars
- Rolling resistance limits, noise emission limits and wet grip performance of tyres
- Driver seat-belt reminder on cars
- ISOFIX child restraint anchorages on cars
- Cab strength crash protection of vans and trucks
- A large number of UN Regulations replacing repealed Directives

In addition, Regulation (EC) 78/2009 on the type approval of motor vehicles with regard to the protection of pedestrians and other vulnerable road users (the 'Pedestrian Safety Regulation') updated Directive 2003/102/EC with modified and more advanced provisions, adapted to the technical progress. This includes passive safety requirements to mitigate the risk of critical injury in case of a collision between a vehicle and a person.

The General Safety Regulation requires that the Commission report to the European Parliament every three years with proposals for amendment to the Regulation or other relevant Community legislation regarding the inclusion of further new safety features. Based on the CARS 2020 communication and the Policy Orientations on Road Safety 2011-2020, a proposed amendment should meet the following criteria:

- Road safety should follow an integrated approach regarding the driver, infrastructure and vehicles
- New measures for improved vehicle safety should be enforceable, compatible with infrastructure, and encourage the development of and progress on innovative active and passive safety measures and promote new technologies
- Specific attention should be given to vulnerable road users as well as vehicle occupants presenting an intrinsic fragility due to their age (i.e. young children and the elderly)
- Particular attention should be given to the assessment of technologies that exploit the interactions between the driver, the vehicle and the driving environment, such as Intelligent Transport Systems (ITS)

This study concerns an overview feasibility and cost-benefit assessment of a wide range of candidate measures for inclusion in the General Safety Regulation.

Commission monitoring reports to the European Parliament are also required, as appropriate, by the Pedestrian Safety Regulation. This monitoring may lead to the adoption of implementing measures for an upper legform to bonnet leading edge test and an adult headform to windscreen test. Data from these tests have been acquired by Technical Services and Type-Approval Authorities for monitoring purposes only.

1.1 Objectives

The primary objective of this project was to provide advice on the likely benefit and feasibility of a range of possible measures to improve vehicle safety. The study involved stakeholders at several stages to ensure that relevant measures were being considered, and that manufacturers, suppliers and other organisations had an opportunity to provide information on the feasibility and costs of state-of-the-art technologies.

The outputs are indicative cost-benefits provided in order to differentiate those measures that are very likely, moderately likely or very unlikely to provide a benefit consistent with the cost of implementation. This information will enable prioritisation of possible future legislation or amendments thereto relevant to vehicle safety and to the relevant EU type-approval requirements.

This study also aimed to provide advice on the necessity and feasibility of including the complimentary upper legform to bonnet leading edge and adult headform to windscreen tests in pedestrian safety legislation, until recently carried out by vehicle manufacturers only with a view to monitor the situation in the field.

2 Structure of the Study

2.1 Introduction

The study included two main activities, one relating to the General Safety Regulation and one relating to the Pedestrian Safety Regulation. An overview of the project structure for each activity is shown in the following sections.

2.2 General Safety Study

The general safety study concerned the collation of overviews of the feasibility and benefit:cost ratios of over 50 potential measures that could be considered for implementation in the General Safety Regulation. The overall structure for the General Safety study is outlined below:

Identification of promising measures	Possible updates following EC publicity of the project
	Agree list of promisng measures with EC
Evidence gathering	Literature review
	Initial stakeholder consultations
Initial overview CBA	Based on literature review and initial stakeholder consultations
	Identification of gaps in the available knowledge
Primary stakeholder consultation	Provide stakeholders with the opportunity for feedback on initial overview CBA
	Provide the research team with the opportunity to request clarification and/or additional information from stakeholders
Final overview CBA	Incorporating stakeholder feedback
	Incoporating additional stakeholder evidence

Evidence gathering has been undertaken by small teams led by a Technical Director with expertise in the specific topic area. The measures have then been grouped further into the following topic areas for reporting and stakeholder engagement:

- Active safety
- Car occupant and pedestrian safety
- Crashworthiness, HGV safety and fuel systems
- Driver interface, distraction and intelligent transport systems

A description of every potential measure considered in the study is given in Annex 1, with the measures grouped into the topic areas listed above.

The findings and recommendations arising from the General Safety review are shown in Section 4. The full reports on each measure are collated in Annexes 3 to 6, which are provided as follows:

Annex 3	Appendix A: Active safety
Annex 4	Appendix B: Car occupant and pedestrian safety
Annex 5	Appendix C: Crashworthiness
	Appendix D: HGV safety
	Appendix E: Fuel systems
Annex 6	Appendix F: Driver interface and distraction
	Appendix G: ITS

The review is based on information available in the open literature; it is intended that it provides an overview of the feasibility, costs and benefits of each measure. No new cost-benefit analyses have been undertaken for this review; however, where insufficient cost-benefit information was identified in the literature the likely benefit:cost ratio has been estimated where sufficient information on technology costs, target population and effectiveness could be identified.

The assessment of feasibility includes two aspects: technical feasibility and legislative feasibility. Technical feasibility concerns whether technical solutions are available and demonstrated such that the safety issue identified by the measure can be addressed robustly by the current level of technical development. Legislative feasibility concerns the availability of test procedures and performance requirements that are suitable for application in a regulation and which would encourage solutions that would address the safety issue identified by the measure. The assessment of feasibility in Section 4 primarily relates to the technical feasibility, but the comments in that section and the assessments in the main reviews include consideration of the legislative feasibility.

2.3 Pedestrian Safety Study

The Pedestrian Safety study differs from the General Safety study in that it is to review measures that have already been implemented, albeit for monitoring purposes only, rather than estimating the costs and benefits of possible future measures. The monitoring tests are the upper legform to bonnet leading edge tests and an adult headform to windscreen tests defined in Regulation (EC) 78/2009. The data from these tests are acquired by the Technical Services and Type-Approval Authorities and are provided to the Commission for monitoring purposes.

The study involved the collation and analysis of high-level test results (i.e. peak injury metrics calculated from the test data by the Technical Service and provided by the Type-Approval Authority) in order to assess the necessity and feasibility of making the monitoring requirements mandatory. The assessment will be based on the test results reviewed and the feasibility study that supported the implementation of Regulation 78/2009.

The structure for the Pedestrian Safety study is outlined below:

Collation of monitoring test results	Contact Technical Services and Type-Approval Authorities
	Collate upper legform to bonnet leading edge and adult headform to windscreen results
Analysis of monitoring test results	Necessity of including the monitoring tests as a new implementing measure
	Feasibility of including the monitoring tests as a new implementing measure
Stakeholder consultation	Provide stakeholders with the opportunity for feedback on the analysis of necessity and feasibility
	Provide the research team with the opportunity to request clarification and/or additional information from stakeholders
Final reporting	Necessity
	Feasibility

2.4 Stakeholder Consultation

The Commission identified in the Service Request for this study that stakeholder engagement was important to the success of the study. This was to ensure that interest groups could raise awareness for specific issues to be incorporated in the study. It was also important that vehicle manufacturers and their suppliers had an opportunity to provide relevant information on the state-of-the-art of technologies, feasibility and cost aspect of specific provisions.

Two rounds of stakeholder engagement were undertaken:

- Informal (initial) stakeholder engagement – to ensure that interest groups were aware of the research to be conducted and had an opportunity to contribute to the understanding of technologies, safety issues and cost-benefit evidence at an early stage
- Formal (face-to-face) stakeholder consultation – to disseminate initial direction of cost-benefit analysis for each subject area, get feedback on the evidence used, and provide an opportunity to ask for contributions to fill in any blanks

2.4.1 Informal Stakeholder Engagement

Some initial stakeholder engagement was undertaken on an *ad hoc* basis by the study team, based on their existing contacts in the industry. The study was also widely publicised by the Commission and the majority of the initial stakeholder engagement involved responding to stakeholders contacting the study team directly or via the Commission. Engagement was undertaken by telephone, email and informal face-to-face meetings in order to allow stakeholders to:

- Get more information on the study
- Register their interest in the project
- Provide additional input to the evidence gathering process, and
- Register their interest in the face-to-face stakeholder consultation

2.4.2 Formal Stakeholder Consultation

A formal stakeholder consultation exercise was undertaken towards the end of the study on 27 and 28 October, in Brussels. Two parallel sessions were held on each day, with the measures grouped as shown in Table 2-1.

Table 2-1: Overview of stakeholder consultation meeting sessions

	Session 1	Session 2
Day 1 **27 October**	Active safety	Driver interface, distraction and ITS
Day 2 **28 October**	Crashworthiness, HGV safety and fuel systems	Car occupant and pedestrian safety

Prior to the meeting, stakeholders were provided with an overview of the project's scope and objectives, a brief overview of the interim benefits and costs for all measures in the subject area (similar to those shown in Section 4), and drafts of the evidence reviews for each potential measure (similar to those shown in the Annexes).

Minutes of the stakeholder consultation meeting may be found in Annex 2. Following the consultation meeting, stakeholders were given three weeks to provide any additional evidence relating to the potential measures under review. The feedback from the consultation meeting and the evidence submitted subsequently were then incorporated into updates of the evidence reviews as presented in this report.

2.5 Assessment of Costs and Benefits

The study focuses on the collation and interpretation of evidence for the feasibility and cost-benefit of various potential measures related to vehicle safety legislation. It therefore aimed to identify existing cost-benefit information for each measure. Where this was not available, an attempt was made to estimate briefly the likely break-even cost for a measure. The following process was adopted:

- Describe the target population for the measure
- Quantify the target population from information in the open literature
    - Where possible, use EU-wide data; if not available, use national data
- Identify the range of benefit from information in the open literature
    - E.g. the predicted percentage reduction in fatal, serious and slight injuries
- Assign a monetary value to the benefits
- For some measures, prevention of vehicle damage was also considered

2.5.1 Casualty Valuation

In order to assign a monetary value to the benefits, casualty prevention values from across the EU28 were considered. The European Commission Mobility and Transport website (EC, 2013), cites data from the HEATCO project (Bickel, 2006) that presents information from a range of countries regarding casualty prevention values (see Table 2-2).

Table 2-2: Recommended monetary values for prevention of road accident casualties by severity (European Commission Mobility and Transport website)

Country	Fatality	Severe injury	Slight injury	Fatality	Severe injury	Slight injury
	(€2002, factor prices)			(€2002 PPP, factor prices)		
Austria	1,760,000	40,300	19,000	1,685,000	230,100	18,200
Belgium	1,639,000	249,000	16,000	1,603,000	243,200	15,700
Cyprus	704,000	92,900	6,800	798,000	105,500	7,700
Czech Republic	495,000	67,100	4,800	932,000	125,200	9,100
Denmark	2,200,000	272,300	21,300	1,672,000	206,900	16,200
Estonia	352,000	46,500	3,400	630,000	84,400	6,100
Finland	1,738,000	230,600	17,300	1,548,000	205,900	15,400
France	1,617,000	225,800	17,000	1,548,000	216,300	16,200
Germany	1,661,000	229,400	18,600	1,493,000	206,500	16,700
Greece	836,000	109,500	8,400	1,069,000	139,700	10,700
Hungary	440,000	59,000	4,300	808,000	108,400	7,900
Ireland	2,134,000	270,100	20,700	1,836,000	232,600	17,800
Italy	1,430,000	183,700	14,100	1,493,000	191,900	14,700
Latvia	275,000	36,700	2,700	534,000	72,300	5,200
Luxembourg	2,332,000	363,700	21,900	2,055,000	320,200	19,300
Malta	1,001,000	127,800	9,500	1,445,000	183,500	13,700
Netherlands	1,782,000	236,600	19,000	1,672,000	221,500	17,900
Poland	341,000	46,500	3,300	630,000	84,500	6,100
Portugal	803,000	107,400	7,400	1,055,000	141,000	9,700
Slovakia	308,000	42,100	3,000	699,000	96,400	6,900
Slovenia	759,000	99,000	7,300	1,028,000	133,500	9,800
Spain	1,122,000	138,900	10,500	1,502,000	161,800	12,200
Sweden	1,870,000	273,300	19,700	1,576,000	231,300	16,600
United Kingdom	1,815,000	235,100	18,600	1,617,000	208,900	16,600

Table 2-2 provides the range of values for 24 EU Member States. The first set of values, denoted factor prices, is based on national currencies. The second set of values, denoted PPP, factor prices, is adjusted for differences in purchasing power and these are therefore intended to be more directly comparable across countries than the first set of values, since the PPP adjusted values account for differences in income and prices between countries.

Weighted averages using the total road accident casualties in each country were calculated for prevention of fatal, severe (serious) and slight casualties. The total number of fatal, serious and slight road accident casualties in each country for the weighting factors were obtained using the CARE database. The weighted values were increased by 20% to current values to account for inflation on the bias of an inflation rate of approximately 2% per year. This exercise resulted in the following 'European monetary values' for prevention of road casualties (EC, 2013), as shown in Table 2-3.

Table 2-3: European casualty prevention values

Casualty severity	Casualty value
EU28 Fatal	€ 1,564,503
EU28 Serious	€ 231,278
EU28 Slight	€ 17,753

The values for the prevention of fatal, serious and slight casualties include the following elements of cost:

- Loss of output due to injury, calculated as the present value of the expected loss of earnings, plus non-wage payments made by employers.
- Ambulance costs and the costs of hospital treatment.
- The human costs of casualties, based on willingness to pay to avoid pain, grief and suffering to the casualty, relatives and friends, as well as intrinsic loss of enjoyment of life in the case of fatalities.

2.5.2 Casualty Statistics

As noted in Section 2.5, this study focuses on the collation of existing evidence for the measures reviewed; however, where existing cost-benefit information is not available, estimates have been made based on estimated casualty savings in the literature. The following estimates of the European road casualty numbers have been used as a baseline for the estimation of target populations and potential casualty savings (Table 2-4).

Table 2-4: European casualty statistics

Casualty severity	Number (2013)	Source
EU28 Fatal	26,000	EU CARE Data (CARE, 2014)
EU28 Serious	312,000	EU CARE Data (CARE, 2014)
Of which permanently disabling	104,000	EU CARE Data (CARE, 2014)
EU28 Slight	1,300,000	EU CARE Data (CARE, 2014)
Total	*Approx. 1,640,000*	

3 Pedestrian Safety Study

The Commission has been collating monitoring data from Technical Services and Type Approval authorities for use in this study. It relates to results from the monitoring tests for both the upper legform to bonnet leading edge and also the adult headform to windscreen. The information collected by the European Commission from the Member States to date and provided to TRL for the present study is summarised in Table 3-1:

Table 3-1: Vehicle approval data available to the study

Country	Legislation	Number of approvals
Austria		No approvals granted
Belgium	Directive 2003/102/EC	No approvals granted
	Regulation (EC) 78/2009	5 vehicles
Bulgaria		No approvals granted
Croatia		No approvals granted
Cyprus		No approvals granted
Czech Republic		No approvals granted
Denmark		No approvals granted
Estonia		No approvals granted
Finland		No approvals granted
France	Directive 2003/102/EC	15 vehicles
	Regulation (EC) 78/2009	27 vehicles
Germany	Directive 2003/102/EC	26 vehicles
	Regulation (EC) 78/2009	45 vehicles
Greece	Directive 2003/102/EC	No approvals granted
Hungary	Directive 2003/102/EC	No approvals granted
Ireland	Directive 2003/102/EC	No approvals granted
	Regulation (EC) 78/2009	7 vehicles, 3 with small market share
Italy	Directive 2003/102/EC	9 vehicles, 1 with very small market share
	Regulation (EC) 78/2009	8 vehicles, 3 with small market share
Latvia		No approvals granted
Lithuania		No approvals granted
Luxembourg	Directive 2003/102/EC	No approval data provided to the Commission
	Regulation (EC) 78/2009	No approval data provided to the Commission
Malta		No approvals granted
The Netherlands	Directive 2003/102/EC	20 vehicles
	Regulation (EC) 78/2009	78 vehicles
Poland		No approvals granted
Portugal		No approvals granted
Romania		No approvals granted

Country	Legislation	Number of approvals
Slovakia		No approvals granted
Slovenia		No approvals granted
Spain	Directive 2003/102/EC	6 vehicles, 3 with very small market share
	Regulation (EC) 78/2009	7 vehicles, 1 with very small market share
Sweden		No approvals granted
United Kingdom	Directive 2003/102/EC	23 vehicles
	Regulation (EC) 78/2009	47 vehicles, 3 with small market share
Total	***Directive 2003/102/EC***	***99***
	Regulation (EC) 78/2009	***224***

In total, this collation of data provided test results for 323 vehicle types (99 according to Directive 2003/102/EC and 224 according to Regulation 78/2009), although some information is duplicated in the Directive and Regulation data. These vehicles span the range of vehicle classes from small city car or electric supermini through to large luxury cars and grand tourer sports and supercars.

One B segment supermini and one C segment small family car (tested in the UK, according to Directive 2003/102/EC) would have passed both the upper legform to bonnet leading edge and adult headform to windscreen tests. However, when tested according to Regulation 78/2009, the later generation of these vehicles no longer met the provisional requirements for the upper legform tests. Instead, it was only one B segment supermini (also tested in the UK, according to Regulation 78/2009) that passed the requirements for both test types. In summary, out of all of the cars currently approved in Europe with regard to the protection of pedestrians and vulnerable road users, only one model meets the limits proposed alongside both of the monitoring tests.

Comparing the requirements stipulated for the upper legform or adult headform monitoring tests, it is clear that the levels suggested for the upper legform test (maximum instantaneous sum of the impact forces of 5 kN and maximum bending moment of 300 Nm) are more stringent for current vehicle designs than those for the adult headform (maximum HPC of 1000). That is, more vehicles would meet the headform limit than the upper legform limits.

3.1 Upper Legform to Bonnet Leading Edge

The only other two vehicles for which the Regulation 78/2009 or Directive 2003/102/EC monitoring test results are available and which would meet the upper legform limits are both S segment small sports cars or compact coupés. Both of these vehicles would be associated with a low bonnet leading edge (assumed to be lower than 750 mm). Test results for vehicles passing the provisional monitoring requirements are shown in Table 3-2.

Table 3-2: Upper legform to bonnet leading edge test results for vehicles meeting the provisional requirements

Segment	Class	Directive 2003-102 or Regulation 78/2009	Test 1		Test 2		Test 3		Result
			Sum of forces (kN)	Bending moment (Nm)	Sum of forces (kN)	Bending moment (Nm)	Sum of forces (kN)	Bending moment (Nm)	Pass/Fail
C	Small family	2003-102	4.80	224	3.60	292	4.10	221	Pass
C	Small family	78/2009	5.82	423	3.03	206	4.57	314	Fail
B	Supermini 1	2003-102	4.7	278	4.1	278	4.5	295	Pass
B	Supermini 1	78/2009	6.7	278	4.1	278	4.5	295	Fail
B	Supermini 2	78/2009	3.1	189	4.6	293	2.8	221	Pass
S	Small coupé	2003-102	4.1	284	4.0	271	4.4	257	Pass
S	Small coupé	78/2009	4.8	242	4.0	197	4.7	260	Pass

The test conditions (as defined in implementing Regulation (EC) No 631/2009 for the upper legform to bonnet leading edge test) vary according to the vehicle shape and bonnet leading edge height (see also Euro NCAP pedestrian testing protocol). The impact velocity, angle and energy are selected based on look-up charts with the bonnet leading edge height as the x-axis variable. Cars with a lower bonnet leading edge will be tested at a lower speed and energy than cars with a higher bonnet leading edge.

In Euro NCAP testing, one of the small coupés scored a maximum of six points in the bonnet leading edge area, whilst the other scored 4.4 for the bonnet leading edge tests (with a non-zero score for each test point – confirming that it also would have passed the monitoring test threshold for comparison). Both vehicles were front-engined.

As discussed by Hardy et al. (2007), a number of options are available to improve the upper legform test. The appetite for doing so may be influenced by the target population being injured in real world accidents, which is small. Nevertheless, consideration can be given to the feasibility of the options that would be quick to implement.

Options described by Hardy et al.:

- Keep the existing impactor, but revise the test condition look-up curves
- Keep the existing impactor, but revise the test conditions removing the need for look-up curves
- Revise the existing impactor to add rotation or a segmented mass
- Develop a new, biofidelic upper legform and pelvis impactor
- Add an upper body mass to the Flex-PLI (full legform impactor)
- Use a full dummy (via physical or simulation testing)

As research priorities, many of these options would have merits over the existing tests. However, the two which are close to implementation are modifications to the look-up curves or specifying test conditions without reference to the curves. These steps could be used to make the upper legform and pelvis test feasible in the interim before other options become suitably well developed for implementation in regulation:

1. Revising the look-up curves
    a. In their discussion of the upper legform and pelvis impactor test, Hardy et al. (2006) proposed the potential use of new look-up curves. These were based on pedestrian and vehicle model simulations (Neale et al., 2001) and incorporated several important changes with regard to the curves in the Regulation:
        i. Upper energy limit reduced from 700 to 500 J.
        ii. Angle of straight edge used to determine the bonnet leading edge reference line changed from 50° to the vertical to 40°.
        iii. Separate curves for vehicles with a low or high bumper
        iv. No test for vehicles with a required energy below 200 J.
        v. A minimum impactor mass of 9.5 kg and reduction of the impact velocity if the required energy cannot be met at the speed from the look-up curve.
    b. Furthermore, to aid feasibility Hardy et al. (2006) also proposed modifications to the assessment criteria, namely:
        i. Change the protection requirement targets with increased force and bending moment from 5 kN to 6.25 kN and 300 Nm and 375 Nm, respectively.
        ii. Simply changing the criteria in this way would allow 11 further vehicles from the list of monitoring test data results to meet the requirements (results in Table 3-3). Therefore whilst this may make a slight change to improve feasibility, both adjustment of the curves and criteria may have to be considered together to improve feasibility without the necessity for costly design changes to the bonnet leading edge region of vehicles.

Table 3-3: Upper legform to bonnet leading edge test results for vehicles meeting the proposed requirements of Hardy et al. (2006)

Segment	Class	Directive 2003-102 or Regulation 78/2009	Test 1		Test 2		Test 3		Result
			Sum of forces (kN)	Bending moment (Nm)	Sum of forces (kN)	Bending moment (Nm)	Sum of forces (kN)	Bending moment (Nm)	Pass/Fail
M	Large MPV	78/2009	5.9	359	5.4	253	5.7	289	Pass
M	Small MPV	78/2009	5.6	233	4.9	210	5.0	270	Pass
M	Small MPV	78/2009	5.5	363	4.6	302	5.7	364	Pass
F	Luxury	78/2009	2.0	315	1.7	283	1.6	216	Pass
D	Large family	2003-102	5.1	279	5.2	373	4.9	340	Pass
D	Large family	2003-102	5.5	289	5.8	224	3.8	206	Pass
C	Small family	2003-102	5.6	233	4.9	210	5.0	270	Pass
C	Small family	78/2009	5.4	324	6.0	333	6.0	211	Pass
C	Small family	78/2009	4.8	316	4.6	272	5.3	314	Pass
B	Supermini	2003-102	4.9	283	5.1	331	4.9	283	Pass
A	City car	2003-102	4.4	244	5.9	244	5.0	285	Pass

2. Revising the test conditions without reverting to the use of look-up curves.
    a. This approach was proposed by Snedeker et al. (2005). A procedure building on the femur assessment component has now been adopted by Euro NCAP in their pedestrian testing protocol, Version 8.0, in the 'Upper legform to WAD 775 mm tests'. Emphasis has now changed to try and assess both the bonnet leading edge as an injury causing region of a vehicle and to assess risk of injury to the femur and pelvis from a likely contact point on the vehicle. There is now a conceptual, if not practical, separation of these two aspects, which may help align the tests with the real world injury risk observations and expectations.
        i. The impact angle is perpendicular to a straight line passing through the internal bumper reference line and a point at a Wrap Around Distance (WAD) of 930 mm.
        ii. The impactor kinetic energy is based on ½.m.v^2. With a nominal femur mass of 7.4 kg and v = 11.1 cos (1.2 x the impact angle).
        iii. The test velocity is then reduced so that a minimum mass of 10.5 kg is used for the impactor without changing the impact energy. This is to accommodate the test without needing to replace the upper legform impactor from that already used in the regulation and Euro NCAP testing.
        iv. For the Euro NCAP pedestrian protection assessment, the latest protocol (Version 8.0) specifies higher performance limits of 285 Nm and 5.0 kN for the bending moments and sum of forces. The lower performance limits are 350 Nm and 6.0 kN, respectively. These lower limits are more stringent that those proposed by Hardy et al. (2006).
    b. The Euro NCAP implementation differs slightly from the theoretical proposal made by Snedeker et al. where there were two different tests,

split by the criterion of the Leading Edge Height being up to 900 mm or greater than 900 mm.

i. For vehicles with a leading edge height less than or equal to 900 mm they proposed testing with a 7.5 kg impactor mass and comparing the bending moments with the failure criterion of 320 Nm.
ii. For vehicles with a leading edge height greater than 900 mm they proposed testing with an 11.1 kg impactor and comparing the peak average force with the failure criterion of 10 kN.
iii. Just using these criteria and assessing the monitoring test data, then a further five cars only would have passed the tests (results in Table 3-4). However, three of the vehicles shown in Table 3-3 would not meet the lower bending moment limit.

Table 3-4: Existing upper legform to bonnet leading edge test results for vehicles meeting the proposed criteria of Snedeker et al. (2005)

Segment	Class	Directive 2003-102 or Regulation 78/2009	Test 1		Test 2		Test 3		Result
			Sum of forces (kN)	Bending moment (Nm)	Sum of forces (kN)	Bending moment (Nm)	Sum of forces (kN)	Bending moment (Nm)	Pass/Fail
M	Large MPV	78/2009	7.0	267	6.4	232	7.0	219	Pass
M	Small MPV	2003-102	5.5	250	8.4	229	6.3	179	Pass
J	Compact Utility Vehicle	2003-102	7.4	228	7.0	223	7.3	236	Pass
B	Supermini	78/2009	6.7	277	4.1	278	4.5	295	Pass
A	City car	78/2009	5.5	236	5.5	279	6.8	292	Pass

As the proposed changes to the test procedure include modifications to the impact conditions it is not possible to assess their feasibility on the basis of the results provided through the monitoring testing. In this regard it is suggested that further monitoring is carried out. However, as the existing monitoring has now ceased, consideration should be given to align any future monitoring with likely test conditions, if the upper leg and pelvis protection test (or tests) was ever to be made part of the mandatory type-approval requirements.

Information from Euro NCAP should be monitored in this regard to see if their application of the revised test changes the likely feasibility for regulatory application. This may offer an informal mechanism to monitor vehicle designs whilst the need for a regulatory upper legform test is kept under review.

3.2 Adult Headform to Windscreen

The adult headform to windscreen monitoring test results are different from the upper legform to bonnet leading edge tests in that far more cars would pass the comparison value in the Regulation. As stated, the results should be compared with the possible target of HPC 1,000 (HIC_{15}). Using this criterion, 124 of the 323 vehicles (38%) tested would have met the requirements. However, only 271 of the vehicles with monitoring test data had adult headform to windscreen results. Therefore, of the vehicles with test data, 46% would have met the requirements.

From the monitoring information provided it is not clear that the requirements are more or less difficult to meet for any specific class of car. The highest HPC value was 32,239 recorded in a test with a large family car, the second was 7,564 recorded in a test with a compact utility vehicle, and the third highest was 6,808 measured in a test with a small family car. The manufacturers of these models are quite different in the market to which they appeal predominantly; even so, it seems that high headform to windscreen HPC values affect each.

Also, unlike the upper legform to bonnet leading edge test, the high HPC values obtained in the adult headform to windscreen monitoring test match the real world experience; where we know that many head injuries are sustained through pedestrian head contact with the windscreen. This supports the notion that something should be done to improve safety in the windscreen area. The questions then follow, 'what can be done?' and 'is the possible target feasible for the other 50% of the car models?'

There seem to be three main responses that present themselves as countermeasures to this issue:

1. Change parameters of the windscreen design to reduce the severity of the head loading directly
    a. Factors that may affect windscreen 'stiffness' under impact are:
        i. Windscreen angle
        ii. The adhesive that bonds the windscreen to the car
        iii. The curved shape of the windscreen
        iv. The windscreen thickness
        v. The supplier
        vi. Within-batch and batch-to-batch windscreen production variation
        vii. The distance to the windscreen pillar
        viii. The distance to the dashboard
    b. It could be that through constraint of some of the factors causing variable results, a more consistent behaviour can be assured and that an adequate level of protection can be provided in a repeatable manner for all vehicles. If this constraint guarantees such a certain level of protection for a vulnerable road user head contact, it may surpass the need for any headform test for the central windscreen area.
    c. Therefore these factors could be investigated to provide advice on the best practice for pedestrian safety. However, setting requirements for windscreen angle and curvature would clearly have wide implications for vehicle design.

2. Provide improved passive protection around the periphery of the windscreen, including the potential use of deployable solutions.
    a. Conventional passive safety improvements can still be made around the dashboard area to reduce the severity of loading to the head after penetrating the windscreen.
    b. Also, the technology for deployable solutions, such as external airbags covering the A-pillars and windscreen scuttle is available. However, the suitability and robustness of existing designs needs further investigation before it can be considered for use among the whole car fleet.

3. Rely on AEBS to bring the safety improvements needed in this area.
    a. Avoiding the collision altogether is clearly the best way of improving safety and the potential collision avoidance and impact speed mitigation associated with such active safety systems is of substantial benefit (as quantified in the AsPeCCS Project; Edwards et al., 2014)

b. However, the effectiveness of AEBS depends upon the situation surrounding the potential collision and there are certain scenarios where the function cannot be expected to mitigate the severity of the head contact in a way that would prevent an injury from occurring. In these cases there would still be a benefit of having improved passive protection for a pedestrian or other vulnerable road user.

From the information reviewed alongside this project, it seems that there would be merit for the pedestrian casualty population for advances to be made with all three of these potential countermeasures.

The feasibility of providing vehicles with deployable passive safety systems or AEBS has been demonstrated. However, further improvements are required to make those solutions safe for all scenarios and robust in their operation. These should be encouraged and integrated approaches for assessing active and passive pedestrian protection have been developed already (e.g. within the AsPeCCS Project).

The feasibility of tuning the windscreen performance itself has not been demonstrated. Furthermore, the reliability of the monitoring test to determine pedestrian protection performance has also been called into question. There is scope here for further investigation.

However, in regard to the monitoring tests, the adult headform to windscreen test assesses a region where safety is critical to the outcome for a pedestrian in a collision with a car. The test data collated so far indicate that 46% of vehicles are capable of meeting the possible target of HPC 1,000 without any further modifications. It is recommended that work is undertaken to understand how these results are achieved, which would be beneficial for encouraging the same level of performance across the whole car fleet.

4 General Safety Study – Summary of Findings

4.1 General

There was considerable discussion in the stakeholder meeting regarding the bundling of safety systems and the effect of one safety system on the potential benefit that can be attributed to another safety system. For example:

- Intelligent Speed Adaptation or AEBS may affect the number of frontal collisions, and therefore the benefit that may accrue from improved frontal impact crashworthiness or improved restraint systems. In other words, it is important to avoid double counting benefits when multiple measures may affect (at least in part) common crash configurations.
- Lane Departure Warning may not be cost-beneficial on its own, but if Lane Keep Assist were mandated then most of the costs for LDW would have already been met and LDW may then be cost-beneficial.

For some, but not all, of the measures these issues were addressed in the draft reviews distributed prior to the stakeholder meeting; however, for other measures this was not possible from the information identified as part of this high-level review.

It should also be noted that the evidence reviews used publicly available cost-benefit information wherever possible, including available benefit:cost ratios, information on the cost of the technologies used, and valuations for casualty savings. All of these costs and values change over time, with technology costs typically reducing and casualty valuations typically increasing. This means that benefit:cost ratios based on older cost-benefit information may not be accurate for comparison with current values.

4.2 Active Safety

The detailed reviews for the potential active safety measures may be found in Annex 3 and the findings are summarised in Table 4-1. All of the active safety measures reviewed in this study were found to be feasible in terms of the technology required, and most systems are available on current production models either in Europe or in other jurisdictions. The primary exception to this is the cyclist detection part of the pedestrian/cyclist detection measure; pedestrian detection and warning or autonomous braking is available on production cars, but the stakeholders noted that reliable detection of cyclists is considered to be more difficult and is some way from being ready on a mass-production scale.

For many of the measures, the feasibility in terms of legislation is likely to require significant resources in terms of regulatory development. Although the systems exist, regulation-ready test procedures and performance requirements have not been developed and agreed. For many of the systems there may be ISO or other standards that define test procedures and/or require a certain minimum performance (see the bibliography in Section 7), but no evidence was identified that these have been assessed as suitable for application in legislation. Significant work may therefore be required to develop and/or validate suitable test procedures and performance requirements.

Based on the evidence reviewed, the following measures were considered to be likely to be cost-beneficial and could on that basis be taken into consideration:

- Enhanced AEB with collision mitigation
- Intelligent speed adaptation
- Lane keep assist

- Reversing detection and reversing camera systems
- Emergency brake light display

In addition, pedestrian/cyclist detection systems may become cost beneficial in the future as system costs come down, and ACC could be considered if enhanced AEB is mandated for cars, because most of the cost would be covered by the AEB system.

Furthermore, there was an indication in the evidence review that one lighting option – automatic main and dipped beam – may actually be disbeneficial; the number of accidents may be reduced, but the severity of the remaining collisions may increase. Consideration should be given to investigating this further with a view to establishing more robustly whether this type of lighting system should be allowed.

Traffic sign recognition had undemonstrated cost-benefit and stakeholders indicated that far reaching standardisation of signs across Europe may be required before this technology would become reliable. Similarly, stakeholders commented that maximum benefit from lane departure, lane change and lane keep assistance systems may require action on the EU level to improve the provision and maintenance of road markings.

Table 4-1: Summary of findings for active safety measures

Active Safety					
Code	**Measure**	**Feasible?**	**BCR**	**Legislate?**	**Recommendations/Notes**
AEB	Expansion and enhancement of AEB, BAS and LDW to avoid or mitigate collisions, including inter-urban, city and those with VRU	✓	~1	●	Greatest casualty benefit for AEBS is for M1 then N1 vehicles, although cost-benefit less clear than for N2/N3. System cost estimates suggest 'city safety' systems may be getting to the breakeven cost point
ISA	Speed limiters controlled by road speed limit (speed assist, intelligent speed adaptation)	✓	>1	●	BCR>1 for 6 Member States, for voluntary activation (switched on/off by the driver) and mandatory activation, and public acceptability of the systems considered to be growing. BCR higher for mandatory activation system, but both have positive BCR
LKA	Lane keeping system	✓	>1	●	Costs higher than LDW and similar to LCA, but benefits higher because higher expected effectiveness than LDW/LCA
REV	Reversing detection and reversing camera systems to prevent accidents involving children behind reversing cars	✓	>1	●	BCR>1 when including damage-only accident mitigation and regulatory requirements are being introduced in the US (mandated from May 2018), so the technology is likely to become commonplace and costs are likely to reduce further
EBD	Standard fitment of the emergency brake light display (i.e. rapidly blinking brake lamps) in case of hard braking	✓	>1	●	No formal BCR for EBD were identified, but costs likely to be very low and collision and injury benefits expected - therefore BCR may be >1
PCD	Pedestrian/cyclists detection systems	✓	<1	●	No BCR studies were identified and breakeven costs exceed current system costs. If other systems that share hardware with PCD systems are mandated and reliable system cost estimates can identified, this measure should be re-evaluated

Active Safety

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
NVIS	Night vision systems to detect obstacles and persons in unclear ambient lighting conditions	✓	<1	🟠	Issues with distraction with always-on systems; warning systems may be helpful, but the BCR is not yet clear
SURC	Surround camera systems, aiding the driver at visually obstructed intersections	✓	?	🟠	BCR not sufficiently well defined; better information needed on target population, system effectiveness and system costs
VIS	Better field of vision in the close surroundings of the vehicle (e.g. Japanese requirements)	✓	?	🟠	Benefits similar to reversing cameras, but likely to involve high design cost that could affect safety in other ways and may not be as effective at preventing accidents compared with alerting systems or well-positioned cameras
AFL	Fully automatic lighting and advanced adaptive front lighting combined	✓	?	🟠	US insurance data indicates high intensity lights and dynamic beam patterns reduce collisions and injuries, and that automatic high-beam assist reduces damage claims but greatly increases injury claims (suggesting that collisions are reduced, but those that occur are more severe). May want to consider legislating *against* high-beam assist
SML	Side marker lamps on passenger cars and vans to improve conspicuity	✓	>1?	🟠	Insufficient accident data to determine benefit and effectiveness, but implementation costs likely to be low. US study based on 1970s data may not apply to modern vehicles or to Europe. Specific study required.
TMP	Temperature sensors warning for unexpected icy road conditions	✓	?	🟠	No BCR information identified, but external temperature warning displays are already almost universally fitted. Requirements to standardise visual and audible warnings may be worth considering
ACC	Automatic cruise control	✓	<1	🔴	Do not consider on its own (not cost-beneficial and may have disbenefits in some situations). Consider if AEBS is mandated (much of the hardware cost would be borne by the AEBS)
LDW	Lane departure warning system	✓	<1 to >1	🔴	Insurance data suggests LDW not as effective as originally predicted, so BCR currently uncertain, although systems may not have been switched on
LCA	Lane change assist (incorporating blind spot detection systems)	✓	<1	🔴	Benefits may be more robust than for LDW, but system costs (based on retail price) currently too high for BCR>1
TSR	Traffic sign recognition	✓	?	🔴	No appropriate test procedures available from which to set legislative performance requirements and the cost-benefit is not clear (dependence on infrastructure). Recommend encouragement through other means
ICS	Integrated cleaning system (water comes from the wipers)	✓	?	🔴	Scale of benefits and costs are unknown, but benefits considered to be very low so BCR likely to be <1

4.3 Car Occupant and Pedestrian Safety

The detailed reviews for the potential car occupant and pedestrian safety measures may be found in Annex 4 and the findings are summarised in Table 4-2. Of the measures reviewed, only two were clearly feasible and cost-beneficial with the current technology capability and costs:

- Protection of far-side occupants in side impact collisions (M1 vehicles)
- Seat-belt reminders (M1, M2, M3, N1, N2 and N3 front seats; possible also other M1 seating positions on the basis of safety equality)

For several other measures cost information was either incomplete or out-of-date, but the study team considered that the measures were reasonably likely to be cost-beneficial, particularly if other complimentary measures are considered:

- Improved protection of seniors and small stature occupants through the adoption of advanced anthropometric test devices, which links with the application of advanced ATDs in a potential small overlap frontal impact test procedure
- Improved side impact protection, which links with potential measures on ejection mitigation and small overlap frontal impact testing

It is also recommended that some aspects of head-to-windscreen impact protection should be investigated further and that the mitigation of serious injuries to rear row occupants, which may include children on booster cushions, could be considered on an equality of protection basis.

For the third-party (non-OEM) replacement parts measure, no cost or benefit information was obtained. During discussion of this at the stakeholder meeting, no specific parts were identified as having a known and generic safety risk associated with them (though it is acknowledged that some research tests have shown safety degradation with certain aftermarket parts and/or their fitting). It was proposed that where a concern is raised, this could be addressed by setting specific performance requirements for that type of part (e.g. brake linings). This creates a level trading platform for all (OEM and non-OEM, etc.) parts suppliers. It was also mentioned that alternatively these specific parts, once identified, could be included in the currently empty Annex 13 of Framework Directive 2007/46/EC.

Table 4-2: Summary of findings for car occupant and pedestrian safety measures

Car Occupant and Pedestrian Safety					
Code	**Measure**	**Feasible?**	**BCR**	**Legislate?**	**Recommendations/Notes**
SFS	Protection of far-side occupants in side impact collisions	✓	>1	●	Likely to be cost-beneficial (spans 1, and cost estimate considered to be high) and already in production vehicles. Work would be required to define suitable test and assessment procedures

Car Occupant and Pedestrian Safety

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
SBR	Seat-belt reminder systems in front and rear passenger seating positions	✓	>1	●	Cost-beneficial for M1 driver and outboard passenger seat, M2 and M3 passengers, all seat positions for N1, N2, N3. Could consider legislation for M1 second and other row seats on basis of safety equality and being nearly cost effective
SEN	Improved protection of seniors and small stature occupants through the adoption of advanced anthropometric test devices	✓	?	●	No BCR due to lack of cost information. However, at least two different test severities would be required before significant benefit would be expected to accrue in the current (R94) and full-width test conditions. An advanced ATD would be necessary for small overlap (see crashworthiness/ small overlap frontal crashes 'FSO')
SIP	Side impact protection for occupants of all sizes and prevention of ejection (e.g. using full-size window airbags)	✓	<1	●	Costs likely to exceed benefits, but cost information not very reliable. Costs would also have to be re-evaluated if a small overlap test procedure was introduced because this may encourage improved side airbags for front seat occupants. Legislation could also be considered on the basis of providing equality of protection for all occupants, including rear seat occupants
RRR	Rear row occupants in rear impacts	?	?	●	No information on feasibility, costs or benefits was identified. However, some evidence that rear-row occupants have twice the fatality risk of front row occupants in a rear impact. Legislation could be considered on an equality of protection basis, but considerable further work would be required to demonstrate feasibility and cost-benefit. Rear occupant safety is currently assessed on vehicle system level (in some cases restraint system tests and in all cases interior fittings energy dissipation tests)
HED	Adult head to windscreen protection	✓	<1 to 1	●	BCR from 0.25 to 1, depending on real-world effectiveness of measures. There are indications that performance of the central area of the windscreen can be controlled better at negligible cost and this should be investigated further
3RD	Influence on safety of third-party (non-OEM) replacement parts on pedestrian protection	?	?	●	No cost or benefit information identified
ISO	Strength of ISOFIX connectors installed in vehicles to provide appropriate protection of heavier children	✓	?	●	No evidence of real-world injuries due to failure of ISOFIX connectors was identified; however CRS designs are changing and there is strong evidence that CRS load the anchorages to as much as 13 kN dynamically, compared to a static requirement in Reg.14 of 8 kN, and that loads may increase with some R.129 designs. Further work recommended to look at requirements if different materials for ISOFIX connectors are used in the future

Car Occupant and Pedestrian Safety

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
HOT	Raising alarm if small children are detected being abandoned in hot cars	?	?	●	It was not possible to predict reliably the benefit:cost ratio due to lack of EU-wide data on accidents and costs of systems, but likely BCR<1. There is evidence that the performance of current systems is unreliable, which affects feasibility and end-user acceptance (false alarms), and a number of manufacturers and developers have withdrawn potential systems due to liability concerns
PRE	Pre-crash seat-belt tensioners and occupant position adjustments in case of an inevitable impact	✓	?	●	Feasible technology (already on production vehicles), but not obvious how to encourage fitment and benefit:cost unknown. May be better encouraged through rewards in consumer information testing
BLE	Pedestrian upper leg and pelvis to bonnet leading edge	?	<1	●	Small numbers of pelvis and upper leg injuries caused by the bonnet leading edge of modern cars. Potential benefit for head, thorax and abdomen protection for children not yet quantified and should be further reviewed in depth, if considered. Adding other body regions and harmonisation with other tests could take the BCR>1; otherwise, BCR likely to be <1
REG	Influence of front registration plates (not present in type-approval testing) on pedestrian protection	?	0	●	No evidence of an injury risk identified and therefore no benefit predicted, while costs would be incurred

4.4 Crashworthiness, HGV Safety and Fuel Systems

The detailed reviews for the potential crashworthiness, HGV safety and fuel safety measures may be found in Annex 5 and the findings are summarised in Table 4-3. All but two of the measures were found to be technically feasible. The following measures were considered to be feasible and likely to be cost-beneficial for Europe:

- Improved HGV rear under-run guards for compatibility with M1 and N1 vehicles
- Removal of some exemptions to the requirements for side guards on HGVs (by improving the definition of those vehicles that are allowed an exemption)
- Safer HGV front-end design (for improved direct vision to improve VRU safety, self-protection of the driver and partner protection for collisions with other vehicles)
- Specific enhanced requirements for CNG vehicles in case of fire

Note that stakeholders indicated that consideration may also need to be given to improving the coverage of side guards. For this study the scope was to consider the current regulation only. However, the review and the casualty benefit numbers indicated that current side guard designs may not be effective in preventing all accidents where a vulnerable road user is run-over (allowing sufficient ground clearance for the VRU to pass underneath). It is conceivable that side guards could be improved in this respect, to cover more of the vehicle’s length and extend closer to the ground. Some stakeholders asked for a revision of the existing regulation to be considered in addition to the removal of exemptions from the requirement to fit lateral protection to HGVs.

Table 4-3: Summary of findings for crashworthiness, HGV safety and fuel system measures

Crashworthiness, HGV Safety and Fuel Systems

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
FCO	Compatibility with crash partners (incorporating HGV rear under-run)	✓	<1 (>1)	🟢	Insufficient benefit from testing for geometric alignment of M1 frontal energy absorbing structures; consideration could be given to a voluntary agreement for height of energy absorbing structures in a similar way as in the US. For HGV, improved rear under-run guard likely to have BCR>1
LAT	Lateral protection of trailers/trucks (removal of some exemptions)	✓	<1 to 1	🟢	Cost benefit likely to be less than 1 for vehicles that genuinely need either an exemption or adjustable side guards; however, the classification of these vehicles should be improved, which will reduce the number of vehicles receiving an exemption
DIM	Safer HGV front end design (enabled by changes to the weights and dimensions legislation)	✓	>1	🟢	Breakeven cost per vehicle €1,448–€4,889, so likely to be cost-beneficial. Further work needed to define suitable requirements, which will affect costs, so final BCR should be updated. Alternative active safety systems should also be investigated to ensure that the best benefit is delivered for a given cost
CNG	Specific enhanced requirement for CNG vehicles in case of fire (as proposed by the Dutch delegation in GRSG of UNECE)	✓	?	🟢	Recommend updates to regulation in line with hydrogen vehicle requirements and application of regulation to class I vehicles with CNG propulsion; requirements for emergency responder access to the engine compartment may also be considered. Cost-benefit for automatic fire extinguishers not clear; these have been encouraged as after-market equipment in some markets
FSO	Crashworthiness in small-overlap frontal crashes	✓	1?	🟠	Maximum benefit likely from NHTSA-style low overlap, for which there is less info available on likely EU benefits and particularly costs. Further work may be required
FFW	Crashworthiness in full-overlap frontal crashes to better assess occupant restraint systems	✓	1	🟠	Current proposal unlikely to lead to improved restraint systems, so minimal cost and minimal benefit. Further work needed in order to define requirements that would ensure improved restraint systems for a wider range of occupants in a wider range of collision severities
AFE	Comprehensive testing of fuel systems to avoid fires; possible inclusion of automatic fire extinguishers (LCV and HCV)	✓	?	🟠	Required by insurers for buses in some countries and has been effective; further work would be required on costs and benefits before legislation could be considered
RFT	Rear impact protection of the tank (e.g. US, Canadian and Japanese requirements)	?	?	🟠	Insufficient cost and benefit information identified. Fuel tanks are tested on component level (impacted with pendulum) and the fuel system installation is verified through EU legislation

Crashworthiness, HGV Safety and Fuel Systems

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
VEL	Increased crash speeds	✓	?	●	Higher speed test unlikely to change vehicle design, because vehicles already meet Euro NCAP; may affect some vehicles where the worst case model (tested in UN Regulations) is significantly different (e.g. much larger engine) than the most popular model (that is tested in Euro NCAP)
ROL	Roof strength testing to protect occupants in case of roll-over accidents	✓	?	●	Unlikely to be of sufficient cost-benefit. A number of vehicle types sold world-wide are already likely to meet US requirements
SUB	Requirements to ensure that occupants are always capable of escaping a vehicle in water	?	<1	●	Unlikely to be cost-beneficial, given the low occurrence of accidents in the EU

4.5 Driver Interface, Distraction and ITS

The detailed reviews for the potential driver interface, distraction and ITS measures may be found in Annex 6 and the findings are summarised in Table 4-4. It was found that the technical feasibility of vehicle/infotainment controls and distraction measures were not adequately demonstrated at the time of the review. Nevertheless, distraction is a significant and possibly increasing factor in road traffic accidents and further work is recommended to develop the evidence base and requirements that would be necessary to implement a technology-neutral measure to reduce driver distraction. The study identified that the technology exists to implement mobile phone interlocks; however, these would either block all signals within the car (and therefore block important functions such as mobile phone based satellite navigation systems that may have benefits such as reducing congestion and re-routing traffic away from the scene of accidents and penalise passengers in the vehicle) or require the voluntary installation and use of an application on the driver's phone. It is not clear how this could be applied in type approval legislation, but it could be encouraged in commercial fleets where the use of the technology can be made a condition of employment.

Based on the evidence reviewed, the following measures could be considered for further legislative development:

- Driver distraction and drowsiness recognition, noting that further work would be required to determine how to define and test the effectiveness of distraction and/or drowsiness monitoring systems
- Allowing the option for cameras to replace rear view mirrors, provided that adequate standards for the system (camera and screen) can be defined to ensure image quality at least equivalent to conventional mirrors in all lighting and weather conditions
- Alcohol interlocks
- Event data recorders

Regarding alcohol interlocks, the study focussed initially on the provision of a standard interface to ensure that it would continue to be possible to fit interlocks to future vehicles. At the stakeholder meeting, the manufacturers' representative from ACEA indicated that rather than a standard interface, it would be preferable for all manufacturers to provide authorised installers with standardised information on how an interlock system may be fitted to their vehicles, so as to reduce the potential for unintended exploitation of a standard interface.

Intelligent transport system measures were found to be feasible and many potential safety benefits have been proposed for vehicle-to-vehicle and vehicle-to-infrastructure communications. However, the costs and benefits remain unknown and the systems and test procedures were considered to be not sufficiently mature for application in type approval.

Table 4-4: Summary of findings for driver interface, distraction and intelligent transport systems measures

Driver Interface, Distraction and ITS

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
DDR	Driver distraction and drowsiness recognition	?	>1	●	BCR likely >1 for private cars and commercial vehicles, due to the large number of collisions involving distraction as a causative factor. However, further work required to determine how to define and test effectiveness of distraction/drowsiness monitoring systems and to define what action the system should take if inattention is detected
RVC	Cameras to replace all the rear view mirrors	✓	?	●	No BCR studies identified and the main benefit would be reduced fuel consumption. Legislation could be considered that would permit, rather than require, cameras to replace wing mirrors, provided that adequate standards for system (camera and screen) can be defined to ensure image quality at least equivalent to conventional mirrors in all lighting and weather conditions
ALC	Alcohol interlock devices to prevent drink driving	✓	?	●	Legislate to ensure that it remains possible to connect an alcohol interlock to the vehicle in the future (not for fitment of the interlock), e.g. via a standard interface
EDR	EDR acting as a possible psychological stimulant to safe driving (from DG MOVE study)	✓	>1	●	Real benefits identified, although difficult to monetise. However, most new European vehicles have EDR functionality (although currently not accessible in most), so most of the cost has already been spent. Recommend legislating to standardise specification for EDR and standardising technical protocols for access to the information (the latter most likely to be harmonised with US Part 563)
INF	Driver interface provisions and restrictions for on-board infotainment systems;	?	1	●	Currently handled by voluntary agreements and standards, which allows innovation but also non-standardised, non-intuitive controls that do not necessarily comply with the standards. Suggest development of tests to quantify compliance with the guidelines and continuous monitoring of effect on collision rates as systems become more commonplace

Driver Interface, Distraction and ITS

Code	Measure	Feasible?	BCR	Legislate?	Recommendations/Notes
DIS	Reducing driver distractions	?	1	🟠	BCR likely to be close to 1, but it is currently not clear how to legislate effectively to reduce distractions within the Type Approval system. Various standards committees are active on this topic and the situation should be monitored
MOB	Interlock to prevent the use of non 'hands free' mobile telephone systems while driving	✗	?	🟠	Technology exists to apply this voluntarily, e.g. for commercial fleets, where use of the technology can be a condition of employment; however, it is not clear how this could be implemented within Type Approval. If distraction and drowsiness recognition is implemented, specific requirements for mobile phones may become less important
SVC	Standardisation of uniform vehicle controls	?	?	🔴	Considered likely to have an effect on distraction, but no evidence for accidents being caused by variation in vehicle controls was identified, so not possible to estimate the target population or benefit
IOV	Improving the intuitive operation of vehicles	?	?	🔴	Considered likely to have an effect on distraction, but no evidence for accidents being caused by counter-intuitive vehicle controls was identified, so not possible to estimate the target population or benefit
C2C	Car-to-car communication	✓	?	🔴	US considering mandating in-vehicle systems so that cars can take advantage of developing car-to-car communication services but not mandating the services themselves. Systems and test procedures not sufficiently mature for type approval
C2I	Car-to-infrastructure communication	✓	?	🔴	US considering mandating in-vehicle systems so that cars can take advantage of developing car-to-infrastructure communication services but not mandating the services themselves. Systems and test procedures are not sufficiently mature for type approval
NAV	Standard accident avoidance functions in navigation systems; appropriateness of route data for vehicle type/dimensions	✓	?	🔴	There is a commercial market that appears to be working and it seems unlikely that market intervention would be warranted

5 Conclusions

This study has reviewed the evidence base regarding the feasibility, costs and benefits of over 50 safety measures for M, N and O category vehicles that could be considered for implementation in the General Safety or Pedestrian Safety Regulations (EC 661/2009 and EC 78/2009). Evidence gathering was undertaken by small teams of experts at TRL who reviewed available information obtained from the open literature. No new cost-benefit analyses were undertaken, but existing information and literature was used to provide a comprehensive insight concerning the potential for regulatory consideration of each identified measure. The evidence base and the draft recommendations arising from the review have been discussed with stakeholders during a process which included four-days of face-to-face consultation, with a further three weeks of consultation and evidence gathering after that. The reviews and recommendations have been updated where new evidence was provided during the consultation.

The outputs are indicative benefit:cost ratios that differentiate between those ratios that are very likely, moderately likely or very unlikely to provide a benefit consistent with the cost of implementation. Recommendations have been provided regarding the measures that have the most potential to be taken forward to improve vehicle safety in Europe.

For all of the recommended measures, further work would be required to define appropriate legislative test procedures and performance requirements for each measure, as well as to provide an impact assessment with final benefit:cost ratios that are specific to those procedures and requirements.

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ISO 15622:2010. Intelligent transport systems — Adaptive Cruise Control systems — Performance requirements and test procedures

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ISO 17361:2007. Intelligent transport systems — Lane departure warning systems — Performance requirements and test procedures

Annex 1 List of Potential Measures

Annex 1.1 Active Safety

Measure	Description
Automated emergency braking systems (AEBS)	Combine sensing of the environment ahead of the vehicle with the automatic activation of the brakes (without driver input) in order to mitigate or avoid an accident. The level of automatic braking varies, but may be up to full ABS braking capability. First generation AEBS are in production on a number of current vehicles at the top end of the market and are capable of automatically mitigating the severity of two-vehicle, front to rear shunt accidents (on straight roads and curves dependent on sensor line of sight and environment "clutter") as well as some collisions with fixed objects and motorcycles
Lane Departure Warning system (LDWS)	A lane departure warning (LDW) system is an in-vehicle system that provides a warning to the driver of an unintended lane departure. Warning only, no corrective action
Automatic Cruise Control (ACC)	In an extension to the speed management capability of conventional cruise control systems, Automatic or Adaptive Cruise Control (ACC) maintains a desired road speed if the roadway ahead is unobstructed and a constant time gap from a moving vehicle ahead
Lane Keeping Warning system (LKS)	Monitoring the position of the vehicle with respect to the lane boundary and applying a torque to the steering wheel, or pressure to the brakes, when a lane departure is about to occur. In current systems, the level of torque varies from one system to another. In some cases, the intervention is intended to suggest the corrective action to the driver, without altering the vehicle trajectory. In other cases, the intervention is sufficient to prevent the vehicle leaving the lane
Lane Change Assist (LCA)	Lane change assistance systems warn the driver when it is unsafe to change lanes. The system will not take any direct action to prevent a possible collision; hence the driver remains responsible for the safe operation of the vehicle. They function by monitoring the area around the vehicle during a lane change manoeuvre and issuing a warning if certain criteria are met. These criteria usually relate to the proximity of other vehicles in the driver's intended lane of travel
Automatic Lighting	The fully automatic switching on/off of dipped beam headlamps depending on ambient light level, in conjunction with DRLs and always-illuminated speedometers (which may confuse drivers, who subsequently forget to put on their dipped beam). Not automatic dip and main beam nor directional lighting
Advanced Front-lighting Systems (AFS)	An Advanced Front-lighting System (AFS) is a technology which varies the pattern of light produced by headlamps to maximise clarity of the roadway at night whilst minimising the glare posed to oncoming vehicles. AFSs are designed to provide drivers with a better field of view when driving at night

Measure	Description
Side marker lamps on passenger cars and vans to improve conspicuity	Dedicated lights on the sides of passenger cars/small vans that remain illuminated when the headlights are on to improve the lateral conspicuity of the vehicle
Emergency Brake Lights (EBL)	Triggered by the strength of brake activation the rear brake lights are illuminated in different ways to indicate emergency braking manoeuvres to the following vehicles; possibly also activated by stability control system
Intelligent Speed Adaptation (ISA)	Intelligent Speed Adaptation (ISA) describes a range of technologies which are designed to aid drivers in observing the appropriate speed for the road environment. Two levels of control were considered: advisory (alert the driver when their speed is too great) and voluntary (the driver chooses whether the system can restrict their vehicle speed and/or the speed it is restricted to). Mandatory systems (where the driver's speed selection is physically limited by an ISA system that cannot be switched off) were not considered
Ambient temperature sensors	Both sensors to warn of external temperatures and V2V/I2V communications to warn following traffic of ice (or fog, or accident etc.) were considered
Blind spot detection systems	Application to turning HGVs only
Pedestrian/cyclists detection systems	Pedestrian detection may employ video, laser, radar or infrared sensors to detect the presence of pedestrians/cyclists in the path or periphery of the vehicle. Systems can either warn the driver and/or apply AEBS (both to be considered)
Improved visibility from vehicles	Better driver visibility all around the driver in terms of reduced visual obstruction caused by size and position of vehicle structure. To include vehicles not already covered by R125 (i.e. M2, M3, N), e.g. Japanese requirement for additional mirror/camera on the front of SUVs
Traffic sign recognition	The system (normally via a camera and optical recognition) detects road signs and provides in-vehicle information to the driver
Night vision systems	Night vision systems are designed to increase detection performance of critical targets such as pedestrians, cyclists, animals, and other objects. They extend the visibility of objects during poor visibility conditions by projecting improved or higher contrast images using infrared (IR) cameras on a display
Junction camera system	Camera(s) on the side of the front of a vehicle provide an unobstructed view each side of vehicles at a junction
Reversing detection and reversing camera system	Camera (or sensor) on the rear of a car to alert drivers to pedestrians behind cars, in particular to prevent accidents involving children behind reversing cars
Integrated cleaning system	Cleaning water is emitted from the wiper blades rather than nozzles on the bonnet

Annex 1.2 Car Occupant and Pedestrian Safety

Measure	Description
Improved protection of seniors and small stature occupants through the adoption of advanced anthropometric test devices	In response to the potential for modifications to current safety requirements (e.g. R.94, R.95), upcoming requirements (e.g. Pole Side Impact, Full-Width frontal) and potential requirements (e.g. rear seat occupants in adult belt); safety measures, including the possibility of additional tests within each measure, to improve the safety of seniors and small stature occupants
Protection of far-side occupants in side impact collisions	In a side impact with both driver and front seat passenger (FSP) occupants, the struck-side occupant is protected by multiple airbags. However, the far-side occupant tends to slip out of the seat-belt and collide with the struck-side occupant, which may result in significant injuries to either occupant
Side impact protection for occupants of all sizes and prevention of ejection	Implementation of systems to protect the heads of occupants of all sizes and to prevent ejection of occupants as a result of a side impact crash (which would most likely mean the use of full-size side window airbags)
Rear impact protection requirements for rear seated occupants	Improvement of protection for occupants of rear-row seats in a rear impact, particularly focused on protection of occupants seated very close to the rear of the vehicle e.g. third row seats
Pre-crash seat-belt tensioners and occupant position adjustments	Improvement of occupant safety in case of an inevitable impact. Mandated measures could include pre-crash seat-belt pre-tensioning, adjustment of the seat position prior to the start of the collision (in both the occupant would be approximately stationary relative to the vehicle at the start of the collision), or dynamically moving the occupant just prior to and at the start of the collision
Seat-belt reminder systems	In front and rear passenger seating positions
Pedestrian upper leg and pelvis to bonnet leading edge and adult head to windscreen protection	When the legislation for pedestrian protection was implemented there were concerns from the automotive industry that: i) it was not feasible to meet the upper legform protection criteria proposed by EEVC Working Groups alongside that test, ii) the centre of the windscreen was 'safe' and not within the control of the vehicle manufacturer. As a result these tests were included for monitoring purposes only. Has sufficient progress been made to make these tests feasible for mandating?
Influence of front registration plates on pedestrian protection	The bumper test components of vehicle type approval are conducted without the front registration plates being present. However, when a vehicle is involved in an accident these will be in place. Therefore it is possible that the real world safety levels are different from those assessed at the time of type approval. Testing with the registration plates in place would remove this discrepancy but may offer very limited benefit and be subject to variations in plate design

Measure	Description
Influence on safety of third-party (non-OEM) replacement parts (e.g. bonnet, front bumper, wings) on pedestrian protection	For styling or accident repair purposes, aftermarket vehicle components can be purchased. These parts can be sourced from the original manufacturer or from a third party. Third party parts may not have been assessed for safety performance in the same way as the original parts and therefore safety could be degraded through the fitting of such parts. In principle it could be required for all automotive parts to have been assessed and certified to make sure that safety levels are maintained or will still meet type approval requirements. Alternatively, the fitting of third party parts that may affect pedestrian safety could be tracked and their effect monitored.
Strength of ISOFIX connectors installed in vehicles	To ensure appropriate protection of heavier children.
Safety of children in hot cars	Systems to raise the alarm or to cool the vehicle if the interior temperature exceeds a threshold and the presence of a child occupant is detected.

Annex 1.3 Crashworthiness, HGV Safety and Fuel Systems

Measure	Description
Crashworthiness in case of small-overlap frontal crashes	Car occupant protection for small overlap frontal crashes, i.e. those with less than 20 to 25% overlap and no direct loading of longitudinal rails.
Compatibility with crash partners	Better compatibility in crashes with other vehicles to minimise injuries in the accident overall. Includes compatibility with other cars (M1) and rear-under-run protection on HGVs and their trailers.
Increased offset-frontal crash test speed	Increased test speed in the current regulatory frontal impact test R.94 for cars (M1). Either increasing the speed of the current test or the addition of another test.
Crashworthiness in case of full-overlap frontal crashes	Car occupant protection for full overlap frontal crashes, i.e. those with more than about 80% overlap and with direct loading of both longitudinal rails, to better assess occupant restraint systems.
Roof strength testing to protect occupants in case of roll-over accidents	Static roof strength testing similar to FMVSS216 to ensure minimum roof strength to reduce roof crush in rollover accidents. Ejection mitigation testing similar to FMVSS226 to ensure side airbags offer help to prevent ejection is also included because it is closely related.
Vehicle submersion requirements to ensure that vehicle occupants are always capable of escaping a vehicle in water	Measures to ensure things such that electric windows can be opened when/if a vehicle rolls/falls into water to allow occupants to escape. For example, that central locking does not short-circuit or fail to disengage, and power windows remain operable and do not close automatically due to water immersion, etc. Equipment such as a hammer is not included, except devices that automatically trigger and shatter the windows.
HGV side guards	To consider the removal of some or all of the current exemptions for lateral protection side guards on trailers/trucks, which are designed to protect cyclists against over-run injuries.
Safer HGV front end design	Assuming that the weights and dimension of heavy goods vehicles will be changed for fuel efficiency reasons, are there measures that should be considered that make use of the additional cab length to improve cab safety. To include self-protection, partner (car) protection and improved direct vision for vulnerable road users.
Light and heavy duty fuel systems	Comprehensive testing of fuel systems to avoid vehicle fires and possible inclusion of automatic fire extinguishers
CNG fire requirements	Specific enhanced requirement for CNG vehicles in case of fire (as proposed by the Dutch delegation in GRSG of UNECE)
Rear impact protection of the fuel tank	Crash test requirements for the integrity of the fuel tank of M1 vehicles in a rear impact (e.g. US, Canadian and Japanese requirements)

Annex 1.4 Driver Interface, Distraction and Intelligent Transport Systems

Measure	Description
Standardisation of uniform vehicle controls	Standards exist for some aspects of vehicle control interfaces. However, with new ADAS functions emerging, manufacturers differ in the way in which they implement the new functions available to the driver. This measure relates to the standardisation of new vehicle controls to ensure that drivers moving from one vehicle to another have a consistent driving experience and reduce the likelihood of control misuse. Also considering the standard location of emergency buttons (horn, hazards) parking brake, gear shift patterns, indicator stalk/wiper stalk location, etc.
Improving the intuitive operation of vehicles	The way in which vehicles are driven is evolving. New active safety and comfort systems are changing the ways in which drivers interact with their vehicles. Additional vehicle functionality can bring additional complexity to the vehicle interface. Controls that are not intuitive to use are more likely to be misused resulting in a potential increase in collision risk or disused such that the driver fails to take advantage of the potential safety/comfort benefits that such systems may deliver. This measure would improve the intuitive operation of vehicle systems to minimise these risks and maximise the benefit of the systems. Considering the definition of performance requirements for intuitive vehicle operation encouraging industry standardisation. To explore the need and opportunities, closely linked to the point above
Driver interface provisions and restrictions for on-board infotainment systems	In-vehicle display, communication and computing technologies are advancing rapidly. There is the potential for drivers to access complex functionality through native vehicle systems and/or smartphone connectivity. This measure examines provisions and restrictions for on-board infotainment systems that may deliver this functionality
Reducing driver distractions	Driver distraction is the diversion of attention from activities critical for safe driving to a competing activity. Competing activities come in an increasing variety of forms and can be within the vehicle or external. Reducing distraction to improve drivers' attention to the activities required for safe driving should reduce collision risk
Driver distraction and drowsiness recognition	Sensor technology is advancing such that it is becoming possible for technology to provide a reasonably accurate estimate of driver alertness in relation to distraction or fatigue, with some vehicle manufacturers already offering systems that deliver warnings if they detect that the driver is showing signs of fatigue. This measure relates to the effectiveness of potential interventions for measuring driver distraction or drowsiness
Cameras to replace all the rear view mirrors	Rear view mirrors do not always offer an ideal rearward view for the driver. Cameras could be situated to ensure that drivers always have optimal rearward vision. This measure is the use of cameras and in-vehicle screens to provide the driver with rear view information in place of the typical driving and wing mirrors

Measure	Description
Alcohol interlock devices to prevent drink driving	Alcohol interlock devices require a vehicle operator to provide a breath sample and prevent the vehicle ignition from operating if the detected alcohol level is above a pre-defined threshold. This measure may reduce collision risk by restricting the opportunity for drivers to operate vehicles when under the influence of alcohol.
Interlock to prevent the use of non 'hands free' mobile telephone systems while driving	Ignition interlocks for mobile phones prevent a car from starting until the device is placed in a specific cradle. This cradle prevents the driver from manually interacting with the phone but Bluetooth connectivity enables some functions to be accessed 'hands-free'. This measure may reduce the level of driver distraction by limiting the opportunity for a driver to be distracted by manual interaction with a mobile communication device. For instance, a system that senses speech, GSM transmission activity, and use of controls, i.e. a smart system that can detect that the driver is texting, talking etc. while holding a phone
Crash event data recorders (EDR)	Crash event data recorders are devices that can record data about vehicle status and dynamic behaviour in the event of the detection of sudden, rapid acceleration (as would be expected in a collision). The presence of a data recorder supports drivers in providing objective information about the collision and may encourage better driving behaviour since drivers will be aware that unsafe driving practices may be recorded. EDR may enhance knowledge about accident causes and facilitate the development of safer vehicles
Car to Car communication (C2C)	Capability for vehicles to rapidly exchange digital messages to support a range of services/function for safety, efficiency and environmental benefits including, importantly, time critical messages to help avoid collisions or mitigate their effects. Called "connected car" in the US. Also V2V although here it is understood that the primary focus is passenger cars and light trucks
Car to Infrastructure speed and hazard warning (C2I)	C2I is a technology that can support many functions/services involving transfer of information from vehicles to the infrastructure (roadside) and from infrastructure to vehicle. Here only cars and light vans are considered as the relevant vehicles. Also, just two functions/services are considered - warning of hazards on the road ahead and warning of speed limits (which might be variable depending on traffic and weather conditions)
Enhanced Navigation Systems	Enhanced navigation functionality to a) dynamically route around accidents and congestion hot-spots, b) ensure routes are appropriate for the class of vehicle

Annex 2 Minutes of the GSR/PSR Stakeholder Consultation Meeting, Brussels 27-28 October 2014

Stakeholders were invited by the Commission to attend a two-day meeting in Brussels to discuss the reviews and recommendations for each of the more than 50 potential measures being considered in the study. Due to the large number of measures to be discussed, parallel sessions were held on each day as shown in the table below.

Day 1	Session 1	Session 2
Day 1 27 October 10:00 - 17:00	Active safety	Driver interface and distraction ITS
Day 2 28 October 09:30 - 16:00	Crashworthiness HGVs Fuels	Adult occupants Child occupants VRUs

For each measure, the TRL topic lead gave a brief presentation to:

Describe the measure

Indicate its feasibility

Report the Benefit:Cost ratio (BCR) evidence

Give the overall recommendation based on the available evidence

The following sections summarise the discussion in the stakeholder meeting for each of the measures.

Session 1 Day 1

Welcome from Peter Broertjes (European Commission)

Peter Broertjes explained the background to the review and asked if anyone thought that there were major items that should be included that have not been.

CLEPA noted that Tyre Pressure Monitoring System (TPMS) was not included at present. They commented that TPMS has both safety and CO_2 reduction benefits. It was discussed if both safety and CO_2 should be considered by EC and it was agreed that both should be considered, if not in this phase of work, then in a later phase. It was noted that DG CLIMA have recently completed a comprehensive study on TPMS (published one year ago). MAN noted that there are complications associated with applying TPMS for heavy vehicles.

Introduction

David Hynd (TRL) explained the format of the sessions and the way in which review results would be presented.

Annex 2.1 Active Safety

Annex 2.1.1 Introduction

Richard Cuerden (TRL) introduced the Active Safety session and the list of measures to be discussed.

CLEPA ask what factors are included in BCRs (e.g. is fuel economy included)? DH replied that it depends on the measure – we have used cost-benefit studies from the literature, so we have whatever the original authors have considered. This includes in some instances fuel economy, damage only accidents etc.

ETSC noted that they will distribute the reports received the week before the meeting to their experts and ask them to comment. They commented that BCR is very important, but questioned whether it should be the only way to prioritise measures. DH replied that technologies, costs and benefits will evolve and some will evolve very quickly for the measures considered. The commission is required to report periodically to the Parliament and Council regarding potential new measures, which will presumably include updated BCRs.

MAN asked if there are benefits for the manufacturer, or only costs. RC replied that typically the benefits are to society and that costs are ultimately paid by the consumer.

Annex 2.1.2 Adaptive Cruise Control

RC noted that the target population is a little inconsistent across the measures, because some studies are more recent and some are older, and the target population would be a different size at different times (because some casualty groups have been reducing with time).

CLEPA noted that ACC can also help avoid traffic jams. With 15-20% users then traffic jams can be avoided entirely. The Commission noted that it is important that additional potential benefits such as this are identified; even if they can't be accounted for in the BCR at this stage, they should be noted as a further aspect needs to be evaluated in the future.

UK DfT asked if it is the manufacturer cost or the consumer cost that is included, and commented that the consumer is the only one that puts money in to the system. DH replied that the information reviewed typically uses the cost to the manufacturer.

ACEA asked if the costs include maintenance? DH replied that this depends on the original benefit-cost study, but typically not. The stakeholders were asked whether maintenance costs should be included and, if so, how. No further comments were made.

Annex 2.1.3 AEB

CLEPA asked for clarification whether the AEB considered is one that operates at 'city safety' speeds, at highway speeds, and whether it includes pedestrian and cyclist detection. RC replied that the evidence identified primarily relates to 'city' speeds, where the evidence suggests most benefit can accrue.

KAMA asked if there was any consideration of measures that would be made obsolete? E.g. this measure could make head restraints obsolete. DH replied that it was not clear at what point one could relax head restraint requirements, but it would take a long time before the market penetration of AEB was sufficient and information about the effectiveness in real-world driving conditions was established with sufficient confidence. However, whiplash is one of the large cost savings for AEB so it is possible that this could be considered in the future and it will be noted in the report.

Annex 2.1.4 Pedestrian/Cyclist Detection

DH asked the stakeholders whether a pedestrian/cyclist detection system is the same cost as an AEB system or is an additional cost? CLEPA replied that more information is required from the sensors for VRU detection, so a more sophisticated system is required. However, if AEB systems are planned to achieve all detection then the additional cost is less significant.

TfL commented that TRL is doing work for TfL looking at the technologies which can be incorporated as they become available. They also asked why cyclists are not included in the summary for this measure. DH replied that less information was identified on the effectiveness for cyclists.

ECF commented that they consider that there is a need to separate between pedestrian and cyclist systems and to expand on cyclist detection in the report. They also recommended that the study should to include measures to prevent 'dooring' (whereby the door of a parked vehicle is opened into the path of a moving cyclist, causing a collision. DH asked the stakeholders whether the technologies for blind spot monitoring might be useful or applicable to warning of a cyclist approaching a parked from the rear. No comment was forthcoming.

T&E asked why was the AEB measure reviewed for automatic braking only, and the pedestrian/cyclist detection for automatic braking or warning - is safety of occupants only considered and not people outside the vehicle? The Commission replied that this is absolutely not the case - both VRU and occupants are considered in the current regulations and in the measures under review in the present study. Stakeholders were requested to provide additional ideas or proposals for other measures for VRU, i.e. what should be added over and above PSR and those potential measures listed in this study? T&E commented that driving in town is a luxury and asked how a luxury can be allowed to apply a risk to pedestrians and cyclists. RC replied that the number of measures for different road user types is not a reflection of the importance of that user. The VRU casualty population is very large, so even a system with modest effectiveness could be very worthwhile.

CLEPA asked if the measures is for cars only, or trucks etc. as well. RC replied that the review is for cars for the present study. TfL commented that the technologies would apply to larger vehicles as well. RC noted that he detection technologies would be very similar, but the technology and costs for doing something having sensed the person, e.g. automatically applying the brakes, could be quite different.

Annex 2.1.5 ISA

CLEPA commented that there may be legal issues that would not allow the car to control the speed of the vehicle. RC replied that the system would only limit the vehicle to the speed limit and that the driver can of course opt to go slower.

ETSC commented that it is important to clarify what sort of ISA is considered – just providing information, or assisting the driver to obey the speed limit. Assisting ISA gives an upward pressure on the accelerator when the speed limit is about to be exceeded; the driver can push through this, but has make an active decision to do so. ETSC noted that this is reckoned to be very effective. ETSC also commented that they don't recognise any legal issues – if the driver sees a sign that posts a limit lower than the one that the car has detected, they can always choose to go slower. The benefits considered should include environmental, fuel, congestion.

JAMA commented that ISA can only work well if road signs are placed well and standardised across Europe. ETSC replied that ISA with combined GPS and sign detection is probably the best type and could help with inconsistent or difficult to observe signs. Drivers seem to welcome this as a way of sticking to the speed limit and also avoiding fines.

Annex 2.1.6 Lane Departure Warning

RC noted that Ford analysed GIDAS data and identified that for many of the LDW systems the warning could have been too late for the driver to avoid the collision. DH noted that the studies reviewed tend to report that the effectiveness low, but the studies suspect that drivers typically switch the system off. Any quantification of this by stakeholders would be very useful.

FIA noted that the quality of road marking highly influences effectiveness, as does road conditions (rain etc.).

CLEPA noted that ESC has been mandatory in EU since 2007 and asked if the efficiency of this been incorporated in the effectiveness estimates. CLEPA also asked how VRU casualties are included. RC replied he accident and cost-benefit studies span the timescale for the mandatory provision of ESC, but generally don't factor ESC in. VRU casualties will include cars leaving the road and hitting VRUs.

Annex 2.1.7 Lane Change Assist (incorporating Blind Spot Detection)

UTAC asked whether powered two wheelers (PTW) were included in the target population. RC replied that this will vary from study to study, but that TRL will check.

ECF asked whether bundling of systems was considered in the study. DH replied that it was – for example, ACC is not cost-beneficial according to the evidence at this time, but it could be if AEB were mandated (which would bear much of the system cost).

CLEPA asked if bundling be highlighted in the report and whether the report will include effects on environment, congestion etc. – the study is targeted at the 'General Safety Regulation', which seems focused on safety issues. DH replied that bundling has been considered and that TRL will highlight opportunities for bundling systems in the final reports. RC replied non-direct safety benefits (environment, congestion) will be considered where the information is available. The Commission confirmed that it is not limited to looking at casualties and injuries, where information on other benefits is available.

UK DfT commented that in the UK, consumers are typically not buying optional safety systems, but are happy to have the systems where they are mandated. RC noted that we would need information from e.g. ACEA regarding adoption rates.

Annex 2.1.8 Lane Keep Assist

RC noted that there are systems optional on some vehicles that already go beyond this and will maintain speed and lane up to e.g. 30 km/h. This measure concerns systems that will only assist the driver in maintaining the lane.

T&E commented that there would need to be investment in the infrastructure in order for these systems to be effective (e.g. line marking), so mandating LKA would be asking for public investment in infrastructure only for certain road users.

JAMA commented that it would be necessary to regulate the road infrastructure before LKA systems could be mandated. RC noted that the effectiveness may well vary for different countries with different road types.

MAN asked if there is accident data on how effective these systems [LDW/LCA/LKA] are; they expressed the view that these are not safety systems because there are too many mis-functions – they are at best assistance systems. RC replied that TRL haven't identified literature that shows disbenefits for the driver as a result of using these systems and requested that MAN provide data to support their comment. DH asked MAN to clarify whether they were suggesting that the measure would be unsafe, or just unrelated to safety. MAN replied that the measure would be unsafe. RC asked MAN to provide evidence to the study team to support this. FIA commented that the on-going iMobility Challenge FP7 project is looking at this and will send the report to TRL. CLEPA noted that they published a report in 2011 on safety potential of LKA (and other systems), and found clear expected benefit (a what-if study). At the time there were not enough vehicles with the systems to get feedback from the accident data, and it is also very hard to distinguish between LDW, LCA and LKA in accident cases. CLEPA will distribute the report to TRL and noted that they agreed quite well with the RAG ratings.

Annex 2.1.9 Night Vision Systems

There were no comments or questions from the stakeholders regarding the proposed amber rating and lack of clear BCR information.

Annex 2.1.10 Traffic Sign Recognition

RC noted that there was a lack of information on the effectiveness of TSR (not including recognition of speed limit signs for ISA).

T&E asked what the range for the camera systems is, because this may affect environmental performance, e.g. system that can notify a red light which is 300 m distant allows the driver to coast to a halt rather than keep accelerating/maintaining constant speed for longer. RC replied that TRL have looked at signs, not signals. CLEPA noted that lighting-based speed limit signs should be included (e.g. variable speed limit signs), but traffic signals (stop lights) should not be included. This was agreed.

ANEC asked how TSR systems cope with different languages, e.g. in Germany a speed limit sign may have the suffix 'Monday to Friday'. CLEPA commented that this is a big challenge and that suppliers don't have a final solution at this time. The Commission noted that traffic signs are not harmonised across Europe, so there is a very complex situation for TSR systems. It was noted that it may be that this complexity makes these systems currently unsuitable for a proposal if it makes them unreliable.

MAN commented that people talk about automated driving in the future, which is related to this. The Commission noted that it may be imagined that for a certain level of automation, vehicles may need to rely on information from the environment – e.g. variable speed limit – and asked if we start with signs or with the technology. The report may need to recommend that other issues need to be resolved first, such as the signage and quality of signage. DG MOVE noted that there may be pre-conditions to this and other measures, such as requirements on quality and consistency of signage. RC asked how much signage will be needed in the future, when the vehicle knows where it is and what the conditions are; it is possible that we could recommend legislating for something that will be redundant in a short time.

Annex 2.1.11 Reverse Detection Systems

RC noted that most of the accident data identified relates to jurisdictions outside Europe, the exception being the UK, which supports the findings from elsewhere.

UK DfT asked how damage repair costs compare with injury costs, and whether the technology could be encouraged via insurance premiums, if the majority monetary value is from damage, which could be quicker than legislation.

PSA noted that the car parc is not the same in Europe as the US. They recommended that studies would be required for European vehicles. RC noted that European vehicles are covered in the report, but to let TRL know if this is not sufficiently covered.

The Commission asked whether the benefit would accrue from ultra-sonic sensors, rather than cameras. RC replied that it would not.

MAN asked for clarification about what was meant by the term 'candidate for legislation', i.e. is that mandatory legislation or optional legislation. It was noted that if there is a clear benefit, a measure should be mandatory; if not, it should not be legislated. Of course, optional fitment would still be allowed and be entirely up to the manufacturer. MAN commented that in Germany, there has to be a second person [a banksman] for certain manoeuvres. A camera cannot see as much as a banksman. RC: noted that the measure has been considered for cars only, and cars do not require a banksman.

KAMA asked if the information on damage-only collisions was from insurers. RC replied that it was.

NL asked if there was any consideration of standardisation of the system so that users are presented with consistent information. DH noted that this was being covered in another measure.

Annex 2.1.12 Junction Cameras / Intersection Assistance

It was clear from the discussion that the distinction between this and the following measure was not sufficiently clear in the draft report. The Commission noted that this measure comes from a requirement to perform due diligence. SUV's in Japan have small mirrors on the bonnet to show pedestrians and cyclists, and this is a mandatory requirement. Alternatively, manufacturers could fit camera systems. In the context of free trade agreements, there is discussion of harmonisation of requirements. So, in part, this measure is to identify whether this measure is relevant to Europe. Today is an opportunity to indicate a need or otherwise for this sort of measure. DH noted that the measure is analogous to the reversing camera measure, for vehicles with a high bonnet pulling forward from stationary.

TRL will differentiate the measures more clearly in the final report.

GDV noted that the infrastructure in Japan is quite different, and so a different solution may be relevant there. There are already fish-eye camera systems that could be used. The Commission noted that in Japan, cyclists use the footway and can be travelling relatively quickly, which may make pulling out more challenging.

Annex 2.1.13 Visibility from Vehicles

The Commission noted that this measure concerns visibility when pulling out at junctions. RC noted that heavy vehicle direct vision was considered in another measure.

ECF commented that they were surprised that there is not more information about collisions at junctions. RC replied that there is lots of information about the collisions, but that we have not identified evidence about how effective particular systems would be at mitigating these.

Annex 2.1.14 Advanced Front Lighting

T&E noted that it seems logical that people have more severe accidents if they have auto-dip beams; also is there potential for Xenon lights to dazzle other road users. DH noted that the finding was from a single source in a different market. UK DfT noted that they get approximately 3000 items of road safety communication information per year contributed by the public, a significant number regarding dazzling, including people with Xenon headlights being flashed because on-coming traffic thinks they haven't dipped. UK DfT will provide a summary on this to TRL. The NL noted that there is nothing in type-approval about 'luminance', one can now get the same amount of light out of a much smaller headlamp than used to be the case.

CLEPA asked whether TRL included information on Xenon headlamps provided in a report by Uni Berlin. DH replied that he would check. [Post meeting note: the measure concerns adaptive lighting and fully automatic lighting, and not Xenon lighting – although it was clear from the discussion that Xenon headlamps are an important issue and this will be noted in the report.]

MAN commented that advanced lighting is already regulated, but it is not mandatory. The Commission replied that advanced lighting options are allowed and regulated, but fitment is currently not mandatory. It was also noted that automatic levelling was discussed at GRE and this should be considered.

Annex 2.1.15 Side Marker Lamps

The Commission noted that side marker lamps are on every US market passenger car, but not on EU market passenger cars; this measure is about investigating whether this is something that should be harmonised or not. DH replied that, in summary, we did not identify any information for the EU – whether there are relevant collisions or whether side marker lamps are effective.

ECF asked about legislation of indicators on the side of vehicles. RC noted that side repeaters are legislated for cars. NL noted that side marker lamps are obligatory on trailers and GRE was investigating turning them into side repeaters (indicators). UK DfT noted that GRE agreed recently that side marker lamps can be used as indicators on trucks and that this will be reviewed at WP.29 in November. There will also be discussion about allowing separate side repeaters where there are technical issues in flashing the side marker lamps. MAN noted that side marker lamps are mandatory for heavy vehicles and from 2017 they must have a flashing light marking the vehicle length. The Commission noted that up to now, vehicles >6 m are not allowed to flash, but we need to look at the recent GRE decision. MAN commented that it is not easy to make a flashing side marker lamp from a standard side marker lamp on an existing vehicle type for technical reasons, but it is possible for a new vehicle type. [Post meeting note: the measure was defined for cars, as noted above, but the interest in repeaters for heavy vehicles will be noted in the report.]

The Commission noted that Volvo have equipped vehicles in Europe and asked if there evidence behind this. The NL noted that TNO did studies that led to the equipping on the S40/V40. Volvo agreed to provide the evidence from their vehicles. ETSC commented that this would be a very cheap and easy measure and therefore should be prioritised.

PSA commented that if the BCR is only based on US data, it is not sufficient to quote it for EU and recommended that EU data is required RC replied that this is part of the reason for the 'amber' rating.

Annex 2.1.16 Emergency Brake Light Display

CLEPA noted that this is already regulated 'if fitted' (under R.13). The Commission noted that R.48 also applies 'if fitted'. PSA commented that EBLD is very well regulated 'if fitted'; manufacturers have had systems on vehicles for many years and have never had a problem and have high customer acceptance.

UK DfT commented that they are uneasy about mandating EBLD – we have moved from brake lights, to high-level brake lights, plus fog lights etc. and didn't want to require more lamps. DH replied that the literature reviewed quantified a reduction in reaction time with EBLD, which would be expected to reduce the number of front-to-rear collisions. Not aware of evidence from accident data. The NL replied that EBLD does not use additional lamps, just makes better use of the existing lamps. Centre high-level brake lamp was only relevant to 5% or 8% of front-to-rear collisions, but was still sufficient to mandate.

KAMA recommended highlighting the link between this and other technologies that may achieve the same end – for instance AEB may achieve the same effect. MAN commented that the 'if fitted' regulation was to allow additional information for vehicles a large distance behind, which would be before activation of AEB.

Annex 2.1.17 Temperature Sensors

RC noted that temperature sensors are already fitted to almost all new cars; V2V communications may be the way to take a further step forward (although these may only warn once one accident has already occurred).

The Commission noted that not all cars are fitted – some budget cars don't have temperature sensors – but do they help or not? For instance, overpasses may freeze when the surrounding area is warmer. RC replied that no evidence was identified either way. More sophisticated systems that warn following vehicles may be worth considering as part of V2V or I2V, but no evidence was identified that mandating simple on-board sensors would be cost-beneficial.

No comments were received from the stakeholders.

Annex 2.1.18 Integrated Cleaning (windscreen cleaning jets integrated into the wiper)

There were no comments from the stakeholders.

Annex 2.1.19 Discussion

The Commission commented that the report should be the view of all stakeholders, and may need a technical annex with stakeholder feedback in it. DH replied that the minutes of the stakeholder meeting would be included as an appendix.

RC asked what do the attendees feel are the important measures, and what other measures may we have missed.

UK DfT that there were no measures specifically about power two wheelers; also, some manufacturers offer systems that are aimed at young drivers, such as the MyKey system. The Commission replied that the study is related to the GSR and PSR, which do not cover powered two wheelers – although some of the measures may have benefits for PTW, which is a priority road user group for the Commission. ETSC agreed that PTW must not be overlooked. ETSC strongly recommend ISA and AEB are prioritised as having the biggest casualty benefits.

TfL commented that it would be good to consider whether driver training should be updated to cope with new systems and whether driver re-training would be required for those who are already licenced.

JAMA commented that they have some concerns about the amount of US data used, because it is often not appropriate for the EU market.

UK DfT noted that consumer information testing such as SHARP and Euro NCAP have been important in driving improved safety and may do so more quickly than legislation. They noted that the UK was the only member state that voted against eCall. The UK is not against eCall at all; rather, most major manufacturers provide systems that are supported by UK emergency services and which perform better (and have been introduced faster) than is possible via legislation.

Session 1 Day 2

The welcome from the Commission and the introduction by TRL from Day 1 were repeated for the benefit of those who were not present on the first day.

Annex 2.2 Driver Interface, Distraction

Annex 2.2.1 Standardisation of Uniform Vehicle Controls

The presentation concluded that, although it may be feasible, there was currently insufficient evidence to recommend legislating for standardisation of vehicle controls on the basis of BCR.

Brief discussion of this topic centred around the view that care would need to be taken to ensure that any attempts to achieve standardisation of vehicle controls do not stifle innovation.

Annex 2.2.2 Improving the Intuitive Operation of Vehicles

The presentation concluded that, although it may be feasible, there was currently insufficient evidence to recommend legislating for improving the intuitive operation of vehicles on the basis of BCR.

As for standardisation of vehicle controls, the discussion of this topic reflected the view that legislation to improve the intuitiveness of vehicle controls may constrain innovation in interface design.

Annex 2.2.3 Driver Interface Provisions and Restrictions for On-board Infotainment Systems

The presentation described how there are a few available examples of systems that apply restrictions to information systems but evidence of BCR was limited. It was therefore concluded that legislation may be considered for this measure.

Brief discussion of this measure highlighted that it would need to take into consideration not just standard fit equipment but also aftermarket, consumer electronic devices. As a result, a regulation to address this issue could be difficult to define.

Annex 2.2.4 Reducing Driver Distractions

The presentation described how systems to reduce driver distraction are available and this can be achieved in a number of ways. However, with a wide range of potential distractions from inside and outside the vehicle, it was not clear how to legislate for this measure effectively. It was concluded that legislation may be considered for this measure.

Discussion of this measure confirmed that distraction was seen as a significant issue for road safety. There was also discussion around how distraction may be linked to other systems that might improve road safety – for example, applying a lane keeping assist system if the driver appears to be distracted.

Annex 2.2.5 Interlock to Prevent the Use of Non 'Hands-Free' Mobile Telephone Systems while Driving

The presentation described that there are commercially available systems that achieve this, but none as yet are specific for the driver – achieving this was seen as a non-trivial task. It was also highlighted that there is debate to whether hands free mobile phone use results in a genuine reduction in risk as compared to handheld use. With limited BCR evidence available, it was not clear that legislation in relation to this measure should be pursued.

The brief discussion that followed confirmed that the measure considered all voice activated smartphone functions. There was some agreement that hands free operation did not necessarily alleviate the risk associated with mobile phone use when driving. It was also agreed that although there may be significant benefit to road safety through the introduction of such a system there was limited BCR evidence to support any decision to legislate.

Annex 2.2.6 Driver Distraction and Drowsiness Recognition

The presentation described that systems are commercially available systems for drowsiness recognition and some are near-market for distraction recognition. Although there was limited evidence on the BCR of such a measure, the prevalence of these issues as contributory factors to road collisions lends itself toward legislating to encourage use of such systems.

The subsequent discussion indicated that, although distraction and drowsiness are significant issues on European roads, one must take into consideration the accuracy and effectiveness of the recognition systems in reducing the incidence of distraction and drowsiness before it can be concluded that such systems produce a genuine benefit. It was again reiterated that legislating for systems too early can limit innovation by system developers.

Annex 2.2.7 Cameras to Replace Rear View Mirrors

The presentation described that camera systems for rearward vision are being developed and that ISO standards are in development. As such, there is no BCR data available on which to base a decision to legislate in relation to the use of such systems. However, the benefits to vision and fuel efficiency and an awareness that manufacturers are working towards the wider implementation of camera systems suggests that further consideration of the measure is warranted.

Discussion of this measure highlighted the need to consider linkages to other measures – the introduction of cameras and screens for one purpose may enable other functionality in parallel. It was noted that a representative from the Dutch Government is chair of a working group on the use of camera systems for rearward vision, indicating that they are producing a report on these systems due for publication in April 2015. A representative from Volvo Trucks indicated that there are specific issues related to how a truck driver communicates with other road users using mirrors that may be lost through the introduction of camera based systems. It was highlighted that this measure is not available at present so there would need to be a period of evaluation before considering further legislation.

Annex 2.2.8 Alcohol Interlock Devices to Prevent Drink Driving

The presentation described that alcohol interlock systems have been in use in a number of countries for more than 40 years, gradually improving in accuracy and calibration stability. Recent studies have investigated the BCR of alcohol interlock usage in a range of different use cases, finding particularly positive BCR for drink-driving offender populations and commercial vehicle drivers.

After the formal presentation, a representative from ACEA delivered a presentation giving their perspective on the issue of alcohol interlocks and standardisation, suggesting that rather than a standard interface, it would be preferable for all manufacturers to provide authorised installers with standardised information on how an interlock system may be fitted to their vehicles.

An important topic of discussion was security – the introduction of the possibility to fit interlocks to vehicles may compromise security, opening a channel through which vehicle cyber-attacks may be instigated. ETSC agreed with the BCR results presented and offered to provide further supporting evidence from a Finnish study of alcohol interlock use.

Annex 2.3 Co-operative ITS

Annex 2.3.1 Introduction

Alan Stevens (TRL) began by providing an introduction to C-ITS which involved transmission and reception of data beyond an individual vehicle. He made the points that:

V2V and V2I communication paths provide a basis for many ITS services

These services can be “bundled” together in various ways

Architecture is important; the options don’t greatly affect benefits but affect costs

He noted that since the analysis was undertaken in March 2014, there have been developments that may have influence including results from European projects, FHWA notification of potential V2V legislation and the new European Commission’s C-ITS platform.

Annex 2.3.2 Enhanced Navigation

Little evidence of benefits beyond that commercially offered within dynamic route guidance could be found. Also, the benefits reported are more related to travel time savings (congestion, pollution) than safety.

As there is a thriving commercial after-market, requiring OEM fit would be considerably more expensive and for marginal additional benefit. Therefore, there is no basis to consider future mandating of measures.

There was no dissent to this view from the participants.

Annex 2.3.3 V2I

Two specific functions were considered under this topic:

Hazard on the road ahead

Speed limits (potentially variable depending on traffic, weather etc.)

In the TRL presentation, points made included:

Services need to be supported by good data

Deployment can be complex because of the number of Stakeholders involved (as, for example, the eCall situation)

There is potential for V2I services to provide safety enhancements but no mandating is suggested at this point

Data is awaited from field trials

A spokesperson from the Technical University of Madrid informed the meeting that the FOTSIS project is testing seven co-operative services in Portugal, Spain, Germany and Greece. Tests should finish in Jan 2015 and there will be a final event in March/April 2015. Initial results show increased awareness of conditions ahead and faster response to incidents.

In other discussions the importance of business models was noted and how services should be bundled together to be attractive to drivers. Bandwidth and security are also important issues.

Some participants offered to consult further with their Stakeholders and to forward comments. However, there was no dissent from the proposals made.

Annex 2.3.4 V2V

TRL presented a similar situation to the V2I case which showed considerable potential of the technology but no substantial field data. It was noted that the US have recently consulted on open standards for V2V passenger cars with a timetable for optional fitment in 2017 and potential mandating from 2020. The US approach would be to mandate the "platform" but not the services. The US study has also suggested costs and it was mentioned in discussion that costs for trucks would be greater than for cars.

Two key points for V2V implementation are:

Benefits from services depend on (virtually) all vehicles being equipped

The "base case" for identifying incremental benefits should be a vehicle equipped with on-board sensors and autonomous functions

On the basis of the current evidence, no mandating of V2V was suggested by TRL for Europe. There was no dissent to this view from the participants during the meeting.

Session 2 Day 1

Annex 2.4 Car Occupant and Pedestrian Safety

Annex 2.4.1 Children in Hot Cars

CV noted that approximately half of all fatal cases are when the parent intentionally leaves the child in the car – not intending harm, but not understanding the risk and how quickly hyperthermia can occur. Publicity about the issue may help. ETSC noted that many are when the child was sleeping and the parents didn't want to wake it. CV noted that the remainder includes children who had gained access to the vehicle (e.g. for play), and parents forgetting the child.

GM commented that they have been looking in to this subject for one year and we will provide more information to TRL following the meeting. There is no reliable technology available at the moment. NHTSA recommends not to rely on the technology, but to run public safety campaigns. GM recommended that it is far too early for standards; reliable technological solution may require multiple sensor technologies (sensor fusion; e.g. CO_2 levels, mass, vibration, temperature, etc.). In Germany it is illegal to leave your child in the car. Recommend EC looks at similar requirements and safety campaigns for the near term and rates this technology as ‘red’ (20-40 casualties per year in the EU, no technological solution ready yet). Recommend a WG to look at non-technical and technical solutions. Note that NHTSA say that with the current state of technology it is *dangerous* to rely on the technology.

T&E recommended keeping the measure as an amber priority, that member states gather data, and that the measure is re-evaluated in a few years.

GDV commented that for Germany, there is no knowledge of a problem – so seems much more appropriate to use non-technical measures.

Annex 2.4.2 Strength of ISOFIX Anchorages

BMW commented that the steel used is very strain rate dependent and can take much higher dynamic loads than static loads. BMW will send a reference to TRL. The NL noted that they have looked into this as well and there is a PhD from TU Eindhoven that supports this, so no longer concerned with this issue when the anchorages are metal and are content with the current legislation.

The Commission asked if anyone from the CRS manufacturers would like a higher mass rating for CRS and therefore may need stronger anchorages. UTAC replied that as Chair of the UN IG we have to take account of the limited strength of the anchorage. Other products could be provided if the strength was higher, for instance, ability to keep children rear-facing for longer.

CV asked where the 33 kg child plus CRS limit came from. UTAC replied that they thought it was from simple mechanical calculation, considering the strength of the anchorage and the acceleration of the vehicle.

KAMA cautioned that if there was a change in strength requirement we would have to consider the existing fleet, with anchorages of current strength, and how to prevent potential new, heavier seats being used with older vehicles.

GDV noted that they were not aware of any anchorage failures in Germany – all the fatalities they are aware of are due to misuse and similar. CV asked if GDV know of cases involving ISOFIX restraints. GDV replied they generally don’t know the restraint type – there are very few cases so they are unlikely to be picked up by in-depth studies and typically are observed in the media only.

CV asked if manufacturers are designing to (higher) US strength requirements. Volvo replied that they will check and send data to TRL. KAMA noted that the loading duration is very different in the US and the connector is different – so we must be careful to compare like-for-like when looking at US and EU data.

UTAC noted that if there has to be an update to R.14, there would have to be matching updates to R.44 and R.129.

Annex 2.4.3 Improved Protection of Seniors and Small Stature Occupants through the adoption of Advanced Anthropometric Test Devices

NL asked for clarification regarding what is the technology that will help seniors. DH replied that studies have indicated that there is a large group of seniors with serious injuries in frontal impacts, particularly at lower collision severity than regulation or Euro NCAP. Studies also show that chest compression is just as high at lower severity as at

Euro NCAP severity, indicating that the restraint system is too stiff, and stiffer than is necessary at lower severity. Therefore adaptive restraints are needed.

Autoliv commented that the review identifies the correct issues, although unfortunately cost information available. It would be good if this could be developed further for the UN Informal Group on Frontal Impact at Geneva. For advanced systems and tuning systems there is little or no component cost. There would be dossier costs and compliance testing costs.

ETSC noted that this will become more important in the future with the aging population and that they will consult with their experts regarding the cost information.

BMW asked if the measure is looking at rear seating positions, where load limiters may have consequences for CRS use. JC replied that in principal the restraint system improvements could benefit adult occupants in any seating position, but consideration of interaction with CRS would be necessary.

JC asked if it is necessary to use AEB sensing technology to characterise collision severity, or can it be done from the current in-crash vehicle sensing. Autoliv replied that an integration of passive and active safety is too early for legislation, but that suppliers could do more with the existing in-crash technology without adding component costs.

The Commission noted that there is work at Geneva to develop a new UN frontal impact regulation, but it won't apply in Europe unless it is adopted in the GSR. For that the Commission needs cost-benefit justification. We need to know from e.g. CLEPA, ACEA, JAMA etc. what are the costs that a regulation may impose on you.

Annex 2.4.4 Protection of Far-side Occupants in Side Impact Collisions

UTAC noted that Euro NCAP is planning to have a protocol on far-side occupant protection for 2018.

VDA asked which body regions are considered. JC replied that the initial focus of work was on the head, but testing with occupants in both seats shows benefits for the thorax as well.

NL commented that IHRA talked about harmonising a side impact test with the US (which did not happen), but also looked at far-side which as clearly a low-hanging fruit. However, NL would prefer to deal with this through Euro NCAP and would not be comfortable legislating.

ETSC said that they will provide some accident data on this. Their experts recommended that modified restraint systems and an airbag between the occupants should be prioritised.

DH asked whether the stakeholders were content with TRL's assumption that a 10-year-old cost for a seat-mounted airbag is an overestimate of current costs? KAMA replied that it would be necessary to define the test and performance requirements before a cost can be estimated. The Commission noted that the overall philosophy is to avoid mandating a technology by defining a performance requirement and allowing innovative solutions. Comment is very important and will be taken account of in a rule making process.

Annex 2.4.5 Full-size Window Airbags for Side Impact Protection of all Occupant Sizes and to Prevent Ejection

T&E commented that the cost information was considered unreliable, and asked why the fairly positive (amber) rating. JC replied that based on the (older) figures available, the BCR is less than one, but we consider the cost data to be well out of date and many cars already have suitable curtain side airbags.

NL commented that the measure should be re-phrased as head and ejection protection, not as a technology. This was agreed, although full-size airbags almost certainly the solution.

The Commission noted that the idea from the US is that full-size airbags mitigate ejection. EU has better belt-wearing rates, but rear seat occupants have lower rates. How would stakeholders feel if we applied a cost-reduction factor with time? At least until proven otherwise? There was no clear guidance from stakeholders.

UTAC indicated that a new regulation for pole side impact has been finalised, but it is not clear if the EC will adopt it. They noted that care is needed regarding the vehicle types – clearly less efficient for N1 than M1. Euro NCAP will apply a new oblique pole side impact which will stimulate head side airbag.

T&E noted that the technologies are first in high-end vehicles and costs for those will come down as it is applied to all vehicles. The Commission asked if T&E could provide any evidence of the trends on costs as a technology moves from niche, high-end vehicles to full market penetration. T&E agreed to try and provide this.

Autoliv commented that the concept of performance requirements are important for Autoliv and CLEPA. Need to talk about enhance side protection and ejection, and possibly consider ejection separately.

Annex 2.4.6 Pre-crash Seat-belt Tensioners and Occupant Position Adjustments in Case of an Inevitable Impact

UTAC noted that these systems are often combined with AEB and asked if there is information about movement of the occupants due to AEB. JC replied that the benefit comes from keeping the occupant in the ideal position despite pre-collision braking. There have been studies on the effect of braking in the lab or simulation, but not from field data.

NL commented that the benefit is also about minimising free-flight of the occupant prior to belt engagement, because early engagement with the belt gives a greater ride-down distance, and asked if this was considered in the review. JC noted that it is.

Surprised was expressed at the large range of consumer costs quoted. Is this for the same functionality of the system? JC replied that it is not, which is why the range is so big. This is typically a package cost and different manufacturers bundle different systems.

Annex 2.4.7 Seat-belt Reminder Systems in Front and Rear Passenger Seating Positions

VDA asked whether the M3 BCR is for the driver *and* the assistant seating positions. JC replied that it should be and TRL will check. NL noted that for M3, there can be a front seated guide or similar, who would play a role in vehicle evacuation. It is not just about saving them, but ensuring that they can help with evacuation.

ETSC welcomed the recommendation for front seats, and recommended also legislating for rear seats. They offered to provide casualty and seat-belt wearing rates for rear seats.

DH noted that this is not a technology, but a function, which was agreed.

Annex 2.4.8 Rear Row Occupants in Rear Impacts

VDA asked why rear seat occupants only in rear impacts; rear seat occupants may have a higher risk in other accident configurations. JC replied that the suggestion for the measure comes from the large risk ratio in this configuration – twice the fatality risk in rear row impacts cf. other rows in a rear impact.

ANEC noted that they tested rear seat strength of cars in 2002. Rear seat passengers could be injured or killed by luggage in the boot. The work was presented at UN ECE and they offered to distribute the report. Manufacturers have said that rear seat strength has been improved, but have not seen evidence of this. JC replied that this may be useful for additional benefits that could accrue from this measure. The Commission noted that testing for this mode is incorporated in R.17 and all new vehicles sold in EU must comply. The focus of the measure is rear seats that are very close to the rear of the vehicle, so have very little crush space. However, agree that frontal impacts should be considered for occupants in these seats.

KAMA commented that they felt that there was a risk that we may confuse fatality and whiplash mitigation. As for some comments yesterday, AEB may mitigate some of these collisions and rear-row seat-belt reminders may also address some injuries. They requested that these other measures are linked and see if this measure would still be a problem if the other measures are introduced.

VDA commented that at Geneva, Japan requested that all participants implement the rear impact fuel tank crash test, which would provide a test platform that could also be used for assessing the occupant safety. The Commission noted that the regulation is not currently mandatory in EU following the discussion in Geneva.

Annex 2.4.9 Pedestrian Upper Leg and Pelvis to Bonnet Leading Edge

BASt noted that the Euro NCAP test procedure has been finalised and will be implemented from 2015. It is no longer directly linked to the Snedeker research and will go away from assessing the BLE, rather the injured body region. Not many upper leg or pelvis injuries are caused in accident data. Also, headform impacts to the BLE will be performed as a monitoring test.

NL commented that the test was developed when car profiles were quite square and the BLE was relatively aggressive – pedestrians could be pinned on the BLE with a resulting long duration of loading at a single point on the leg. With new vehicle profiles, pedestrians tend to wrap around and don’t get focussed loading at this level.

KAMA asked if the measure is specifically related to the monitoring test and does the recommendation mean that the monitoring test will be deleted. The Commission noted that the monitoring test is no longer required from 24 February 2014. All approval authorities except Luxembourg have provided data and it is being assessed in the project. JC replied that the measure is related to the test and most cars do not meet the requirements. Therefore there is not good indication of feasibility.

BGS commented that having been involved in the development of the test procedures and testing vehicles, cars have improved greatly in terms of their measurements in these tests. Generally, every car manufacturer has vehicles that meet the monitoring requirements or Euro NCAP –not just due to explicit efforts to improve the pedestrian protection, but styling etc. However, if we lose the test, the progress to date could be lost. Agree that mandatory requirements are not justified, but we should not forget the issue and we should look for more relevant test procedures. There was a note in the report that a van scored zero, but it was not tested – BLE higher than 800 mm, so no requirement to test.

T&E asked if it is proposed that the test is not needed because injuries are now very rare. The Commission noted that the EC needs to check whether the relaxation of the monitoring test is appropriate and decide which direction to go in. We have heard today that even monitoring has been effective and it would be great if stakeholders could provide some information on trends. JC noted that in accident studies, few upper leg and pelvis injuries are attributed to the BLE; however, injuries are still observed in hospital data. We have a test procedure that is doing something, but we don’t properly understand the connection with the reduction in injuries.

T&E noted that this area of the vehicle is also important for protecting children, especially for vehicles with higher BLE. JC replied that we are not aware of specific studies regarding other injuries due to the BLE, but based on the BASt comment there is clearly a way to test safety – but possibly not information on the BCR for these.

T&E recommended some sort of sub-division or re-classification because drivers choose to drive as an optional activity, whereas pedestrians are exercising the default, natural decision. JC reiterated that TRL did not calculate the BCR, but rather used BCR in the literature; happy to have other information and include that in the report.

ETSC commented that 20% EU fatalities are pedestrians, but active systems such as AEB and ISA are likely to be of most benefit for these casualties and should be the priority. BMW agreed that these are more effective and the monitoring should be dropped. ETSC clarified that they do not have a position at this time on the monitoring test. VDA agreed that consideration of AEB etc. needs to be integrated in the report and recommendations.

NL asked if the monitoring results have been compared with the vehicles for which injuries have occurred. The Commission noted that most of the data was only provided to TRL in the last few weeks prior to the meeting, so has not been fully analysed. JC replied that the monitoring data has a number of test sites, but for the data that we have received we don't know which sites were used on each vehicle – therefore we cannot associate injuries with test results. Also, there are so few injury cases, that it would be difficult to rely on the results.

BASt commented that the BLE test was introduced because the BLE was identified as causing lots of leg injuries. Now the BLE causes few leg injuries, but it does cause other injuries and the monitoring test should be retained.

The Commission commented that it seems that pedestrian safety has more diverse views and requires more in-depth discussion compared with the potential GSR measures. TRL should highlight this in the report. DH noted that we don't know whether dropping the monitoring tests risks losing the good progress to date. NL commented that we also don't know the good progress is due to legislation or Euro NCAP. Also, the second phase of the legislation was softened due to the introduction of brake assist. Maybe monitoring is still useful.

ETSC recommended that accident avoidance technologies should be in addition to passive safety, not a replacement for them. JAMA disagreed; there are limits to mitigation by improved passive safety. The Commission noted that we still have weather, ice etc. that means that active systems can't necessarily avoid a collision, so passive measures still have a place.

T&E commented that we should strive for the best option that we can, which is a combination of approaches. Regarding cost-benefit, we don't have the casualty numbers partly because European infrastructure is so good. However, European vehicles are sold around the world, where upper leg and pelvis injuries could still be prevalent. Therefore we still have an obligation to make sure that advances in this regard are not compromised.

Autoliv noted that they have published widely on the effectiveness of passive, active and combined systems and will send documents to TRL. The calculations are based on real-life accidents, not theoretical situations.

Annex 2.4.10 Adult Head to Windscreen

The Commission noted that the legislation was not clear whether the intention was to test the glass area of the field of vision area. So some vehicles have been tested further from the A-pillars than other vehicles and the pass rate may not be fully reliable. This should be clarified in the report.

BASt asked if the fatal and serious injuries quoted in the report were from the field of vision or total glass area, and does it include A-pillar contacts. JC replied that they were from the windscreen, not taking account of the field of vision – i.e. the full glazing area – but will check the original publications and clarify this in the report.

BGS noted that an ACEA WG agreed to use the field of vision area and most technical services would have used this interpretation. The presentation noted that the middle area of the screen is 'safe' as shown in NCAP. However, this is untested and shown as 'green' by default. BGS and other laboratories have observed HIC values of over 1000 in the centre of the windscreen. JC noted that we don't have information in the monitoring results regarding the location of each test.

Autoliv commented that in accident data, fatalities tend to be at the periphery of the windscreen and non-fatal more distributed. JC replied that this is the case, but there are lots of serious injury contacts away from the periphery.

T&E commented that an increasing numbers of pedestrians and cyclists in cities may be expected to lead to an increase in casualties in these groups. We should aim to have zero fatalities. Also, car manufacturers noted that the performance of the windscreen is outside their control, but the evidence in the study is that performance varies by screen manufacturer. Presumably the car manufacturers can choose who they buy their screens from.

BGS commented that there was earlier discussion of the effect of AEB in taking energy out of the system, which might be assumed to lead to a reduction in head injury risk. However, BGS have seen that a certain energy is required to fracture the screen and that impacts at a lower speed can therefore result in a higher HIC.

VDA noted that the UN Informal Group on plastic glazing has finished its work and if WP.29 agrees on this, alternative windscreen materials may be introduced. The headform HPC tends to be higher with plastic screens (Gehring and Zander, 2011; Gehring and Zander, 2012[1]) and the whole-body kinematics could be worse with regard to injury potential.

DH commented that in previous discussions at Geneva it was indicated that the performance of the windscreen was outside the control of the manufacturer. Nevertheless 90% of vehicles meet the requirements. Also, there are indications in the literature that control of the orientation of the glass makes a significant difference – it would be almost no cost to control this and could make a worthwhile benefit. BMW replied that they had no comment directly on this, but there are also other legislative requirements for windscreens that may be in conflict. Also, the manufacturing process has some uncertainty – it is not an exact science, which leads to variability in performance of the end product.

Annex 2.4.11 Influence of Front Registration Plates

BASt asked if any back-to-back testing been performed with and without registration plates. JC replied that we have not identified any. The Commission noted that would be good if some test data was available, so please share information if you have it. This measure has been included not so much in the expectation that there is a problem, but rather to perform due diligence and check whether there is a problem. It is the one area in which member states require owners to modify their car and it is not certain that there is no effect on pedestrian safety as a result.

UTAC commented that the Commission could recommend that member states perform an energy absorption test on the registration plate, rather than requiring changes to the pedestrian requirements. It is possible that a particular design of registration plate can have a beneficial effect.

[1] **Gehring D-U and Zander O (2011).** Comparative tests with laminated safety glass panes and polycarbonate panes at the Federal Highway Research Institute (BASt). United Nations. IGPG-03-14. http://www.unece.org/trans/main/wp29/wp29wgs/wp29grsg/igpg_3.html [11 December 2014].

Gehring D-U and Zander O (2012). Comparative tests with laminated safety glass panes and polycarbonate panes at the Federal Highway Research Institute (BASt). United Nations. IGPG-05-07e. https://www2.unece.org/wiki/display/trans/IGPG+5th+session [11 December 2014].

GDV commented that we are very unlikely to be able to identify a need from accident data – it is almost impossible to attribute injury causation this precisely. Also not clear that the legform is biofidelic enough to tell the difference.

JAMA noted that several member states have requirements on size, fixation and location of registration plates, primarily to ensure visibility and not related to passive safety. The Commission asked if there are any conflicting requirements among the member states? JAMA replied that as far as they are aware, there are no conflicts; however harmonisation does simplify matters.

BMW commented that we had the EEVC legform for many years and we now are moving to FlexPLI. They suspect that the effect of the change of legform is greater than any effect of the number plate. Also suspect that car production tolerances outweigh any effect of the number plate. They recommended that there is no need to legislate on this issue, but if it is desired then harmonisation of registration plates would seem to be the preferred option.

There was little appetite among the stakeholders for legislating on this.

Annex 2.4.12 Influence on Pedestrian Safety of Third-party Parts

It was noted that third party parts may be fitted for repair or for tuning and customisation. JAMA commented that tuning parts are outside the scope of the Framework directive and GSR.

BGS noted that they have tested non-OEM replacement parts in the past and found parts with equal or worse performance than the OEM parts, but never better. Parts that alter the cosmetic/aesthetic appearance of the vehicle can also be detrimental. Have seen worse performance with tuning/customisation parts – for example the energy absorbing foam in the OEM part being completely absent in the customisation part. Reg 78/2009 requires something on frontal protection systems, but not ‘replacement’ or ‘tuning’ parts.

CLEPA commented that for parts with sensors it is very unlikely that the tuning of the combination of part and sensor is comparable in a third-party part to the OEM part. They asked if there is any information from accident data. JC replied that there was not. UK DfT noted that it should be possible to get vehicle and parts sales figures from manufacturers to get an idea of the possible scale of the problem. Can look at vehicle make and model in the GB national casualty statistics, including the age of the vehicle – and newer vehicles would be more likely to be repaired within the OEM dealer network. It should be possible to do this, but probably not within the timescale of the current study. NL agreed with the UK that the EC should take a pragmatic view here to reduce the cost burden in Europe.

The Commission asked whether if an insurer requires a repair (e.g. from minor parking damage) using the cheapest (probably non-OEM) part that may not meet safety requirements, does that create a non-level playing field for OEMs who have had to invest in that safety performance? NL noted that for replacement brake linings there is a regulatory performance requirement, but not for other parameters. UTAC commented that it is not just the part, but the installation – e.g. windscreen. Euro NCAP and Thatcham have looked at new car assessment and repaired part assessment and found little difference. If we have issues with specific parts, maybe e.g. airbags, these could be included in the currently empty Annex 13 Directive 2013/46**.**

Session 2 Day 2

Annex 2.5 Crashworthiness, HGV Safety and Fuel Systems

Annex 2.5.1 Crashworthiness in Small Overlap Frontal Crashes

ME asked if body in white (BIW) and restraints are the same in US and Europe for vehicles sold in both areas. This information would help determine if there will be benefits in Europe due to the implementation of assessment of cars in small overlap frontal crashes in the USA. CLEPA replied that restraints will be different in the US than in Europe; for example US side curtain airbags may extend over the A-pillar. The UK Aluminium Association commented that some cars are sold worldwide with the same BIW; however, lots of cars are only sold in the US or only sold in the EC. CLEPA noted that if manufacturers had responded quickly to the IIHS testing, perhaps the vehicle modifications were additions to structure/easy changes which might be neglected for the European market.

UK DfT noted that UK CCIS has shown differences between left hand and right hand drive vehicles. Small overlap is not the most common type of impact. UK DfT asked if improving crashworthiness performance for the low overlap situation have a negative effect on other more common frontal impacts. ME replied that modifications for improved performance in low overlap should mainly strengthen the occupant compartment, but not alter main rails and vehicle frontal stiffness much; so, likely that the disbenefits should, if any, be small. Also, extra area covered by the side curtain airbag likely to give benefit in other more common frontal impacts. However, this is an educated guess.

ETSC commented that the feedback from ETSC vehicle safety experts was that this measure was considered as one of the most important ones, particularly in some countries such as Sweden. ME replied that one paper in literature shows that fatals in low overlaps are a large problem in Sweden. However, in other countries, such as the UK, they are less of a problem (proportionally). With this type of variation there may not be an easy answer overall.

The Commission asked if the accident data was UK-biased. ME replied that the main data sources were German, French and GB data: Other data sources included Swedish data.

The Commission asked if the US situation encouraged by legislation or consumer testing. ME replied that the improvements in the US are currently driven by consumer testing (IIHS) – although NHTSA have performed research tests.

The Commission noted that the idea of the study to consider legislation by BCR, but also have to look at alternative measures for example Euro NCAP – If other colleagues would like to comment in writing that would be encouraged/ welcomed. ME noted that Euro NCAP are considering full overlap impacts, introduced very shortly, but small-overlap are not currently on the Euro NCAP roadmap.

Volvo recommended that the TRL report clarify the vehicle classes that may be affected by a measure to allow the report to be read and interpreted more easily – e.g. M1 for this measure.

Annex 2.5.2 Compatibility (incorporating HGV Rear Under-run)

UK DfT asked whether the Commission has more information on the latest proposals at GRSE. The UK recognises that for Germany it may be beneficial. However, for UK the DfT were unable to demonstrate that it would be worthwhile. The Commission noted that at GSRE the position of members states is split. However, the German proposal was refined at the last session (beginning of October) and is looking likely to be approved at the next session in April.

UK DfT noted that in car-car collisions, increasing the strength of the survival space mans you have to do more to optimise the restraints – females are less well catered for and the population is aging – have TRL taken into account how the changing population will affect the issues associated with improved compatibility – just be aware of these issues and be forward looking.

ETSC will ask their experts to consider the report in more detail and challenge them to review whether the red for car-to-car compatibility should be green. Improved HGV-to-car compatibility is a long standing recommendation by ETSC (lower ground clearance and higher test forces). ETSC will forward more information on HGV rear underrun.

CLCCR asked if we have accident data newer than 2008 because new technical prescription introduced 2010 (twice as strong) and therefore newer data is required to take changes from this into account. Also, if you increase the strength of the guard too much it will not deform as much and the car will have to absorb more of the impact energy – the bar will not deform and it will be catastrophic for the car. Volvo has produced a report that supports this comment. There is a report that was made about the German proposal and this will be shared (Volvo will forward the report). ME noted that no accident data later than 2008 was reviewed.

Stakeholders also noted that UN R.58 is applied differently across Europe regarding the proportion of derogations granted. This should be considered when analysis is undertaken – are the vehicles fully compliant with the most up to date Regulation?

Annex 2.5.3 Increased Crash Speeds

ETSC commented that they are concerned that increased speed could have disbenefits.

Annex 2.5.4 Full-overlap Frontal Crashes (Restraint Systems)

ETSC commented that they welcome this measure and emphasised that improved, adaptive seat belt technologies (pre-tensioners and load limiters) should be considered for rear passengers too. ME noted that only front seat occupants had been considered at this time.

Annex 2.5.5 Roof Strength Testing for Roll-over Accidents

UK/DfT noted that we have seen casualties decline in UK – is this likely to continue and what is the implication? TRL (Richard Cuerden) argued that rollover casualties may become a greater proportion of car occupant KSI as other crashes are prevented. However, arguably ESC benefits have been seen, so rollovers rates may plateaued. [Post meeting note: ME considers that this may not be the case because ESC equipped cars have not completely penetrated the vehicle fleet yet.

ME asked whether cars sold in US and Europe likely to have same roof strength and side airbags fitted. This information will help determine whether or not there will be fringe benefits for Europe arising from the implementation of FMVSS216a (increased roof crush strength) and FMVSS226 (Ejection mitigation – practically side airbags) in the USA. CLEPA/Autoliv noted that side airbags in Europe are different than US (confirmed airbag curtains are different in different regions) so might not be effective at preventing ejection in rollovers. ME concluded that BIW structures (i.e. roof strength) are likely to be the same for car models sold in USA and Europe, but restraint systems likely to be different. He therefore suggested that a third option for potential ways forward should be added to the report, namely implement FMVSS226 equivalent (and not FMVSS216a equivalent) in Europe.

ACEA commented that ESC systems should be considered in analysis as these could prevent many future crashes, in particular rollover ones.

Annex 2.5.6 Escape from Vehicle in Water

RDW indicated that this topic is an issue in the Netherlands, therefore disappointing that the conclusion is to not propose a regulation. Requirements for water resistance of electric components (e.g. window openers, central locking) could help reduce casualties.

UK DfT asked what are the marginal costs of protecting the electrics against water? The emergency hammer is such a low cost it should be required to carry one. There is also the link to side glazing – for example laminated or plastic glazing where the hammer would not be of benefit. But when talking about escape from a vehicle need to consider the fire situation too. There is the same potential for someone to be trapped in a fire – have these incidents been considered too and if so would they improve the CBR? ME replied that whilst doing the review, I did intend to include a recommendation that when considering other regulatory measures, any possible adverse effect on escape from a vehicle should be borne in mind. A particularly compelling example is laminated side glass for anti-theft measures which would be extremely difficult, if not impossible, for an occupant to break, to escape from a submerged vehicle. The report will be updated to emphasise this recommendation. In addition, consideration will be given to possible overlap for escape for other reasons, e.g. in the event of fire.

Annex 2.5.7 Lateral Protection of Trailers and Trucks

TRL (MS) specific questions for stakeholders:

- Costs of fitting side-guards?
- Number/proportion of vehicles that would be captured by different options of reducing exemptions?

ECF) asked whether under current regulations it is not required for the side guard to cover the full length of the vehicle. MS explained that for this study, the scope was to consider the current regulation and derogation only. However, the review and the resulting casualty benefit numbers highlighted that current side guard designs might not be very effective in preventing run-overs when HGV is turning. This might be because the ground clearance is large enough to miss VRUs lying on the ground.

T&E asked could side guards how be improved – given their low effectiveness – should the scope of the study be extended?

CLCCR noted that owners an buy lateral protection retrospectively and mount them to the vehicle. The situation in Europe is not harmonised: some vehicles have removable lateral protection, some other countries have derogation. A good first step would be to have a guideline that says which vehicles can and which cannot have a derogation.

ETSC commented that they believe that exemptions for off-road use should no longer be necessary. TfL study quoted (fatal files and cyclists).

T&E asked whether the study considered whether side curtains could also provide better aerodynamics. MS replied that the study focused on safety benefits.

The Commission noted a need to identify data on the rate of derogations/ exemptions for all countries in order to determine the size of the problem.

TfL noted that they would really welcome a removal of exemptions. TfL has a study looking at operating conditions – i.e. objective measures to decide whether a derogation should be applied. Regarding feasibility, all Cross Rail vehicles must have side guards and this has not caused any detrimental impact to operation.

UK DfT welcomed the proposal and is keen to see as many vehicles as possible fitted with side guards. UK DfT do not believe that using off-road classification (category G) as a criterion for exemption is appropriate as most vehicles (tippers) on the road could meet so these classification criteria and could therefore be exempted. It is important to establish the correct criteria to maximise the number of vehicles which are fitted with side guards. Volvo indicate that they will provide more information on the classification.

TRL (RC) reminded the stakeholders that TRL still needs information on the number of exempt vehicles in Europe and better cost information.

Annex 2.5.8 Safer HGV Front End Design

Volvo indicated that just allowing longer vehicles will not result in safety benefits automatically. Lane departure accidents and rear impacts are being considered in other measures. Active safety measures are key – just allowing longer vehicles will not equate to safety. 60% of the HGV occupants would have been saved if they had worn seat belts.

ETSC indicated that the review covers the major points and that ETSC would push this measure as a priority.

ECF welcomed the direct vision approach and asked if serious casualties could be included in the BCR as the numbers are substantial. MS replied that serious casualties were not included because numbers on involvement and in particular on potential effectiveness were not available in published material. TRL believes that substantial reductions would also be possible in lower injury severity groups.

TfL welcomed the comments and understands that just increasing the length of the vehicle will not in itself improve safety. But direct vision could be potentially achieved if vehicle length can be increased. TfL welcomed the study and indicated that they consider that it is a good summary of the topic.

T&E welcomed the study and the range of studies referenced, including the focus on VRUs in urban areas. Specifically on the direct vision requirements, it would perhaps make a comparison with active safety measures. The lead time for introducing active safety measures might be shorter than for extensive design changes which might allow reducing casualties in the meantime. T&E indicated the range of life-saving potential of improved direct vision is very large and asked how can we better reflect the range. T&E also asked if the increasing share of cycling across Europe could be included in the analysis (changing future and could this measure become more important)? They also asked whether 2012 is the most representative year to pick for vehicle registration numbers. MS replied that that quantitative data on the effectiveness of improved direct vision is required. The current lower end of casualty saving benefits (zero) is due purely to the fact that no published effectiveness numbers exist. TRL believes that the casualty saving effect will be considerably larger than zero. TRL will investigate fluctuation of vehicle registration numbers over years. Volvo indicated that they have some statistics on direct visibility and will circulate. Nevertheless, they indicated that active safety will be the real breakthrough in the future.

The Commission indicated the need to compare active systems and direct vision.

ACEA encouraged T&E and the Commission should consider the overall picture of active safety systems. TfL noted that low entry, high visibility cabs are available at the moment (e.g. refuse lorries). ECF noted the need to focus on both direct vision and active safety measures. Considering for example cars, it would not be the case that direct vision requirements would be dropped when additional active safety systems are introduced.

MS asked if there are concerns regarding the assumption that the costs for vehicle manufacturers of the measures discussed are almost exclusively one-off design costs (and not ongoing production costs). Volvo replied that the cost would be not be easy to estimate because it would affect the whole vehicle design, but will discuss it with colleagues in more detail. Cab redesign would affect weight distribution, entry and exit into the cab, and would be a large design project – at least this would be the case based on the Loughborough ideas, which have major consequences. Of course it can be looked at, for example, adding lower window to driver door for the cyclists and turning truck scenario.

T&E discussed timescales and costs, noting that if change is planned from day one of a new truck design process costs are much lower than introducing changes in two years. Also some current trucks are better than others with regards to direct vision.

The UK Aluminium Association commented that extra length provides greater benefits than just safety, for example more options for engine placement or space inside the cab. Volvo wondered whether stakeholders were making too big an assumption that a longer heavier vehicle will automatically be able to have better vision.

UK DfT noted that GRSP was considering the removal of all mirrors and replacing them with cameras which could be much better at directing drivers' attention to danger areas.

ACEA indicated that the winners were already picked; the Commission has already selected some areas. With respect to 963 (license and legislation) – how can we ensure a connection between the two? The Commission replied that the idea of this study is to make a report and propose a way forward for advances in safety – this measure is some way forward as other activities are happening. The primary objective is to save VRUs.

T&E noted that the Commission report will be sent to the European Council and Parliament and if they agree then the measures will be taken forward. Some measures, such as direct vision requirement, need to be introduced quickly. Could EC make proposals and speed this process up? The Commission replied that it is not certain that it would be quicker to go straight to Parliament with a proposal.

ECF asked what the time scale was for any measure on this topic. The Commission replied that next year will be the timeframe when a decision as to how to proceed will be made.

Annex 2.5.9 Fire Suppression Systems

The Swedish Transport Agency noted that they are responsible for the proposal for amendments to Regulation No. 107 (M2 and M3 vehicles) and need better information on the benefits. This is a measure that should be legislated and there are a few other member states that support this. The STA asked if there an alternative way to type-approve vehicles. The NL supported the proposal made by Sweden and would like to see some regulation to limit the risks of fire, in particular with regard to CNG vehicles.

Volvo indicated that they will provide comments after the meeting.

The Commission noted that there have been lengthy discussions in GSRG and that it would be helpful if the member states that sponsor this issue could provide the data so we can better assess the nature of the problem (number of fires etc.). Regarding type-approval issue, technical details are required to describe how the extinguisher will be fitted in the vehicle. It is understood that GRSG is close to general acceptance of this proposal.

Autoliv asked whether electric/ hybrid vehicles be taken into account. CV replied that for the present the focus is on conventional vehicles (including maybe some alternative fuel vehicles); electric vehicles have their own fire issues and mitigation strategies in legislation.

Annex 2.5.10 Specific Enhanced Requirements for CNG Vehicles

Clarification was requested regarding the scope of the measure, i.e. whether it covers CNG vehicles in general or just buses. CV replied that the background was buses, but this could be looked at for all vehicles. The NL recommended that it should be applied to M2 and M3 vehicles. NL could not comment on hydrogen other than to note that the upward direction of discharge was disputed.

The Commission noted that the problem with direction of discharge (upwards) could be relevant for M1 and N1, because the tank is encapsulated within the vehicle.

Annex 2.5.11 Rear Impact Protection of Fuel Tanks

There were no comments from stakeholders.

Annex 2.5.12 Discussion

The Commission noted that we have covered very many measures over two days. The focus was to get the views of stakeholders and the meeting has achieved that. We have noted that CO_2 effects should be included and that Tyre Pressure Monitoring Systems should be reviewed as a potential measure. Are there any other measures that should be considered?

T&E replied that it would seem that the more experienced a cyclist appears to be, the smaller the overtaking gap. Therefore there is a potential measure for an overtaking gap assist function for the protection of VRUs. Also, they commented that the main reason for taking a car in the UK rather than cycling is fear of a collision, and asked how that can be changed to the advantage of society and how can it be taken into account in BCR. For instance, the value of occupants and VRUs be biased deliberately so that the VRU protection measures look more favourable

GDV recommend that the report establishes the link to Euro NCAP and other consumer information testing which also influence vehicle design, and refers to their tests and planned tests. Also there is a big range of quality of proposed measure. Therefore recommend something more than just the BCR is used. DH replied that this may only be necessary for measures that are recommended to be taken forward. The Commission indicated a need some assessment of the importance of the different measures that could be considered now or in the future. We also need to decide what we do where we have insufficient BCR information.

Annex 3 Technologies and Unregulated Measures in the fields of Vehicle Occupant Safety and Protection of Vulnerable Road Users

Appendix A. Active Safety Measures

A.1 Adaptive Cruise Control (ACC)

An extension to the speed management capability of conventional cruise control systems, Adaptive Cruise Control (ACC) maintains a desired road speed if the roadway ahead is unobstructed and there is a constant time gap from a moving vehicle ahead.

A.1.1 Description of the Problem

Rear-end collisions comprise accidents where one car crashes into the rear end of another vehicle (car or other vehicle), driving in front at lower speed or being stationary. Rear-end collisions are a frequent type of accident on European roads.

The target population of safety systems aiming at mitigating rear-end collisions cannot be taken directly from accident databases of the whole European level, because the share of rear-end collisions from the overall casualty numbers is not documented in many countries. Additionally, apart from the accident type, in-depth data from accident reconstructions (e.g. pre-crash behaviours, collision speeds, etc.) is necessary to carry out assumptions of the proportion of rear-end accidents that could reasonably be expected to be influenced by an active safety system.

In-depth accident data shows that the proportion of casualties in rear-end collisions from the overall number of casualties is much higher on motorways than on rural or urban roads: For the UK, for example, the proportion of fatalities in rear-end collisions per road type is reported to be 11.0% for motorways, 1.6% for rural roads, and 2.2% for urban roads (Geissler et al., 2012). In-depth data from Germany and Sweden indicated a similar trend. However, overall front-to-rear accidents account for a relatively small proportion of the reported casualty population and are biased towards slight casualties. For example, research by the ASSESS project estimated that in Great Britain, reported casualties in front-to-rear accidents account for approximately 18% of all GB casualties: 1% of fatal, 3% of serious and 15% of slight casualties (McCarthy, 2012).

An ECORYS cost-benefit analysis from 2006 estimated the proportion of casualties in EU-25 that could potentially be influenced by ACC systems (target population) based on three previous studies as detailed in Table A-1 (COWI, 2006).

The ECORYS study does not give the estimated target population in total numbers. CARE data shows that in total across EU-27, 12,850 occupants of cars and taxis were fatally injured in 2012 (CARE, 2012). Applying the 4-6% from the table above, this would equate to a target population for ACC in passenger cars of between 514 and 771 fatalities per year.

Table A-1: Estimated EU-25 relative casualty target population for ACC systems in passenger cars (COWI, 2006)

	Relevant proportion from overall casualty numbers
Fatalities	4-6%
Severe casualties	13%
Slight casualties	13%

Grover et al. (2008) estimated European target populations for front-to-rear accidents as detailed in Table A-2. The numbers include all casualties from two-vehicle accidents on all road types where the front of a vehicle of the relevant category collides with the rear of any other vehicle excluding motorcycles.

Table A-2: Predicted annual EU-25 front-to-rear accident target populations for vehicle categories M1, N1, M2/M3 and N2/N3 (Grover et al., 2008)

	M1	N1	M2/M3	N2/N3
Fatalities	580-709	128-156	15-18	383-468
Severe casualties	10,189-12,453	1,369-1,674	406-496	1,915-2,340
Slight casualties	414,659-506,805	36,439-44,536	14,018-17,134	26,111-31,913

A euroFOT study from 2012 took the approach to scale up national in-depth accident data from Germany (GIDAS database), Sweden (STRADA) and United Kingdom (STATS19), to EU-27 level (casualty numbers from CARE) (Geissler et al., 2012). The study assessed ACC systems in combination with Forward Collision Warning systems (FCW), which provide a warning to the driver in case of an imminent collision. Table A-3 provides the estimated annual number of casualties that could potentially be influenced (prevented or mitigated) by ACC and FCW systems, which can be considered a sub-set of the casualty numbers for M1 vehicles in Table A-3.

Table A-3: Estimated annual EU-27 casualty target population for ACC and FCW systems in passenger cars (M1) (Geissler et al., 2012)

Road type	Motorway	Rural	Urban	Sum
Fatalities	162	124	60	345
Injured (severely and slightly)	12,433	19,194	27,582	59,209

A.1.2 Potential Mitigation Strategies

A proportion of rear-end collisions could be mitigated by an in-vehicle system that supports drivers to maintain a safe headway to vehicles in front by adapting the longitudinal speed. Such systems are called Autonomous Cruise Control (ACC), sometimes also Automatic or Advanced Cruise Control System. The driver selects a desired longitudinal speed which is automatically maintained by the vehicle in unobstructed traffic. When slower traffic is approached, the system decelerates autonomously so as to maintain a constant user-selectable temporal headway to the preceding vehicle and accelerates again when the lane is free. The driver remains in charge of lateral control of the vehicle, i.e. steering.

Apart from reducing the number of short time headways (Alkim et al., 2007), cited from (SWOV, 2010), the system has been reported also to reduce the maximum driving speeds (Bjørkli, 2003) and mean driving speed (Hoedemaeker, 1999), which is beneficial for traffic safety. Reported negative effects are increased lateral variability (Hoedemaeker and Brookhuis, 1998), which can potentially be mitigated by combining with a LDW system.

ACC is intended to be used on motorways and large carriageways, preferably in non-congested traffic, as negative safety effects have been reported in busy-traffic and small rural or urban roads (SWOV, 2010). However, some systems also provide assistance in heavily congested stop-and-go traffic by bringing the vehicle to a complete halt if necessary and, after a user input such as touching the accelerator, following the vehicle in front.

ACC systems are not designed to carry out emergency braking manoeuvres like AEBS, but only to apply the brakes to a level well below full deceleration. The driver remains mainly responsible for taking evasive actions in critical situations, although they might be alerted by their vehicle gradually decelerating. Also, the protective effect of ACC systems is only available at times when the system is active. ACC systems can however be combined with FCW systems, which provide a warning to the driver in case of an imminent collision and have a reported potential to reduce reaction times.

Potential future systems, so called Co-operative ACC systems (CACC), might be able to interact with other vehicles by exchanging information directly (V2V) or with the infrastructure (V2I). This would allow for closer following distances because the vehicle has a more complete picture of the traffic situation, or for an infrastructure-set target speed, which might be beneficial in terms of traffic throughput and fuel efficiency (Jones, 2013). CACC systems require a certain fleet penetration rate to be operable.

A.1.3 Feasibility

ACC systems are a proven technology that entered the market in the late-1990s and is currently available as an optional extra on many models (it is only standard on a handful of models from two manufacturers). The fitment rate is expected to be higher in higher segment vehicles.

The technology is most commonly based on single radar or multiple radar sensors mounted at the front of the vehicle. Multiple radar systems use a wide mid-range radar for an early detection of vehicles joining from adjacent lanes, and a long-range radar to detect range and speed of vehicles further ahead (ca. 100 to 170 m). Radar systems can be expected to work under different environmental conditions, e.g. dirt, darkness, rain and fog. Lidar- and laser-based systems are also being used, although laser systems might not perform as reliably in bad weather conditions or when following less reflective cars (e.g. dirty surface). Depending on the system design, the ACC function is available over the full speed range of the car (from 0 km/h to maximum speed) or only in a limited range, e.g. at elevated speeds as driven on motorways or rural roads.

Test procedures and sets of minimum requirements for ACC systems are available in ISO 15622 (latest version published in 2010). If required these might be investigated as a basis for type-approval regulations.

With regard to the acceptability of ACC systems to drivers, the Institute for Road Safety Research analysed two behavioural studies for their fact sheet on ACC and concluded that ACC was perceived as a useful, comfortable, and reliable system (SWOV, 2010). The system was experienced as being easy to use, although objective data indicated that approximately 400 km of driving with ACC were necessary to know, understand, and anticipate ACC reactions (Brouwer and Hoedemaeker, 2006).

CACC technology is not currently available on production cars and it is not known to TRL that any car manufacturer has plans to introduce this system in the near future. The technology has been demonstrated as being technically feasible; its success would depend on many factors outside the reach of a single manufacturer, such as fleet penetration rate, standardisation of communication protocols, and infrastructure upgrades for I2V communication (Jones, 2013). Noteworthy, past research projects with regard to co-operative vehicles are: SAFESPOT[2] and CVIS[3].

A.1.4 Costs

In 2006, a cost-benefit study carried out by a consortium led by ECORYS used a predicted system cost of €750 per car (manufacturers' cost) for ACC for the year 2010 (COWI, 2006). Considering the current market situation this cost estimate is too high in TRL's opinion. Manufacturer option data shows that the current average consumer price for ACC is approximately €1,700, but it should be noted that ACC is often only available as a package including a range of other related systems.

A more recent cost-benefit analysis from 2012 estimated the current system cost for a combined ACC and FCW system at €190 per car (Geissler et al., 2012). This number was derived by applying a fixed factor to the lower end prices for consumers. Taking into account economies of scale, under the assumption of mandatory fitment to any car, the cost was estimated at €112 per car. Cost figures were not given for ACC without FCW function; however both systems are based on the same hardware. It can therefore be assumed that the above numbers from the year 2012 give a reasonable indication of current system cost.

A.1.5 Benefits

ACC is advertised mainly as a comfort and convenience system but also has an impact on safety. Systems without FCW function perform their safety function only when they are activated, i.e. when the vehicle is in cruise control mode. A study from 2007 showed that ACC is mainly used on motorways in free flow conditions (≥ 90 km/h), less in dense traffic (70-90 km/h) and hardly at all in congested conditions (≤70 km/h) (Alkim et al., 2007), cited from (SWOV, 2010). Modern systems are capable of covering the full speed range of a car. It is not known whether this has an impact on the above observations or whether these are based mainly on behavioural factors.

Reported potential safety benefits of ACC are:

- Reduced frequency of rear end collisions, due to reduced driving speeds (Bjørkli, 2003), (Hoedemaeker, 1999), reduced frequency of very short headway (Alkim et al., 2007) and autonomous deceleration (not at full rate) when approaching slower traffic.
- Hypothetically reduced overall accident rates, due to reduced workload of the driver being relieved from the longitudinal control task. No studies were identified that quantified this effect. The possibility of a reduction in accident rates due to workload has to be regarded with caution, because very low driver workload can lead to a lack of alertness hence also be safety critical. The effect is expected to depend strongly on the traffic conditions under which ACC is used.

[2] http://www.safespot-eu.org/

[3] http://www.cvisproject.org/

Potential other benefits:

- Increased traffic throughput, due to increased string stability of the flow (reducing the propagation of disturbances upstream which might lead to flow breakdown) (Broqua, 1991). Future CACC systems might allow reduced headway and traffic flow optimised speed profiles (Jones, 2013).
- Fuel savings, due to smoother traffic flow (Bose and Ioannou, 2001), (Alkim et al., 2007)

Potential disbenefits:

- Hypothetically increased overall accident rates due to reduced driver workload. This is the potentially contradictory to the benefit of reduced accident rates. As discussed above, it presumably depends strongly on the traffic conditions under which ACC is used and has not been quantified in research.
- A hypothetically increased risk of crashing into stationary traffic more frequently is mentioned in (SWOV, 2010); however, no underlying research is cited.

The safety effects are assumed to depend strongly on the road types and traffic situation: From a literature review, the Institute for Road Safety Research (SWOV) concluded that ACC can have a positive impact on safety in non-congested motorway traffic, but if used in busy situations or rural/ urban roads the negative effects might be predominant (SWOV, 2010).

The casualty benefits for Europe were estimated in previous studies as follows:

In 2005, Abele et al. predicted the casualty reductions across EU-25 as indicated in Table A-4 (Abele et al., 2005). The numbers are not based on a potential mandatory fitment of ACC but rather on a normal uptake by the market. The authors estimated a small market diffusion rate of 3% in 2010 and 8% in 2020 although acknowledge that the share of the distance driven of the equipped vehicles is likely to be higher than average. The authors have taken into account that ACC the protective effect of ACC systems is only available at times when the system is active. TRL considers the values to be very high compared to the target population estimates discussed above.

Table A-4: Predicted annual casualty reductions across EU-25 due to ACC, assuming a low market penetration (Abele et al., 2005)

Year	2010	2020
Fatalities	213	332
Severe injuries	1,348	2,677
Slight injuries	3,346	6,654

A study carried out in 2006 predicted the casualty reduction across EU-25 as detailed in Table A-5 (COWI, 2006). The authors calculated the effects for a mandatory fitment scenario, which would increase fleet penetration from 1% in 2006 to 100% in 2025.

Table A-5: Predicted annual casualty reductions across EU-25 due to ACC, mandatory fitment scenario (COWI, 2006)

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

The predicted monetary benefits from these casualty savings are summarised in Table A-6. Other benefits were not monetised in this study.

Table A-6: Predicted overall (from 2007 to 2025) monetary benefits of ACC across EU-25; in million € (COWI, 2006)

Year	2010
Fatality monetary benefits	6,537 m€
Severe injuries monetary benefits	23,760 m€
Slight injuries monetary benefits	21,709 m€
Total of the above	52,007 m€

In the course of the euroFOT project in 2012, the potential impact of ACC combined with FCW systems was estimated as summarised in Table A-7 (separate numbers for ACC only were not calculated) (Geissler et al., 2012). Note that these most recent numbers are much lower than previous estimates. Compared to the ECORYS study from 2006, the predicted fatality reductions are about 10 times smaller, although FCW systems were included, two more countries were added, and a 100% fitment rate was assumed. TRL considers that the values predicted by the ECORYS study are overestimates that resulted from a brief overview study of a large number of safety systems. The numbers from euroFOT (Table A-7) can be considered to be more reliable predictions as they are more recent and resulted from an in-depth analysis of ACC and FCW systems based on in-depth accident data from Germany, Sweden and UK.

Table A-7: Predicted annual casualty reductions across EU-27 due to ACC combined with FCW for two market penetration scenarios; upper and lower boundary of estimates (Geissler et al., 2012)

Fleet fitment rate	10%	100%
Fatalities	6-12	42-88
Injuries (severe and slight)	762-1,290	5,610-9,555

Monetary benefits, taking into account safety benefits, effects on traffic flow, fuel and CO_2 emissions savings, were estimated by the authors to accrue to the numbers detailed in Table A-8.

Table A-8: Estimated annual EU-27 monetary benefits of ACC and FCW for two market penetration scenarios; upper and lower boundary of estimates; in million € (Geissler et al., 2012)

Fleet fitment rate	10%	100%
Safety benefit alone	62-109 m€	460-810 m€
Overall benefit (safety, traffic, fuel and emissions)	126-175 m€	830-1,194 m€

Assuming the European M1 vehicle fleet is approximately 242 million vehicles (EC, 2013), this implies a break-event cost, assuming a vehicle life of 12 years, for ACC (with FCW) of between €40 and €60.

A.1.6 Benefit-cost Ratio

The resulting estimated benefit-cost ratios from the aforementioned studies are summarised in Table A-9.

BCRs in two of the three studies are below 1, i.e. costs outweigh the benefits. The numbers stem from studies that were based on different assumptions and considering different sources of benefits (please note that the estimates by Geissler et al. are made for a combined ACC and FCW system and separate numbers for ACC are not given in the study). TRL consider that the earlier cost-benefit studies overestimate the effectiveness of ACC. This gives an indication that ACC is unlikely to be a cost-beneficial measure unless future unit prices reduce substantially. However, the ACC provides the first step of functionality of other systems that have greater safety benefits such as AEBS.

Table A-9: Benefit-cost ratio (BCR) of ACC predicted by the referenced studies

	Region	Benefits considered	Notes	Lower estimate BCR	Upper estimate BCR
(Abele et al., 2005)	EU-25	Safety, property and traffic	ACC only	0.9	1.2
(COWI, 2006)	EU-25	Safety and property	ACC only	0.2	0.7
(Geissler et al., 2012)	EU-27	Safety, property, traffic, fuel and emissions	ACC and FCW	0.51	0.74

A.1.7 References

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A.2 Advanced Emergency Braking System (AEBS)

AEBS combines sensing of the environment ahead of the vehicle with the automatic activation of the brakes (without driver input) in order to mitigate or avoid an accident. The level of automatic braking varies, but may be up to full ABS braking capability.

A.2.1 Description of the Problem

Front-to-rear accidents

Front-to-rear accidents account for a relatively small proportion of the reported casualty population and are biased towards slight casualties. For example, research by the ASSESS project estimated that in Great Britain, reported casualties in front-to-rear accidents account for approximately 18% of all GB casualties: 1% of fatal, 3% of serious and 15% of slight casualties (McCarthy et al., 2012). This situation is also considered to apply more generally to the European level.

Whiplash injury

While front-to-rear shunt accidents result in relatively few fatal and serious reported casualties, these types of accident account for the majority of whiplash injuries and a significant proportion of these may not appear in the casualty data because of the period between the accident and the onset of whiplash related symptoms.

Published insurance information in Great Britain indicates that there are approximately 570,000 whiplash claims per year[4] and according to Avery and Weekes (2009) about 70% of these claims arise from front-to-rear accidents. Thus, around 400,000 whiplash claims could potentially be influenced by AEBS annually. According to information cited by Avery and Weekes (2009) whiplash is responsible for 76% of bodily injury claims from road traffic accidents in Great Britain. If this percentage is applied to the slight casualties in Stats19, it provides a crude estimate of the number of whiplash injury cases that may have already been accounted for in Stats19. This means that a potential 376,533 whiplash cases may have not been considered by using the reported accident information contained in Stats19. These 'missing cases' amount to £5.5 billion (€6.93 billion)[5] per year (assuming DfT casualty values for slight casualties), or £1.5 billion assuming the average direct cost of whiplash: approximately £4,000 (€5,000)[4] per claim used by the UK insurance industry (ABI, 2008).

However, a large number of sources indicate that a significant percentage of whiplash claims may not be genuine, although the issue may more applicable to Great Britain than other European countries. Whiplash injury is a difficult injury to clinically prove or disprove and anecdotal evidence points toward an increase in the market for such claims. Research by the ABI Public Attitudes survey in 2002 reports that 50% of adults may exaggerate an insurance claim and Zurich insurance indicate that they are aware of

[4] http://www.abi.org.uk/Media/Releases/2012/04/THE_UKS_PAIN_IN_THE_NECK_CULTURE_MUST_END_SAYS_THE_ABI_.aspx

[5] Assuming GBP:Euro conversion of 1.26 (rate in June 2008)

staging of accidents and fraudulent whiplash claims being made[6]. Information from AXA Insurance indicates that just less than 40% of doctors believe that patients who come to them with whiplash injuries are fraudulent and that 7% of doctors have been offered money to refer patients with whiplash injuries[7]. This trend is in line with insurance data quoted by Avery and Weekes (2009) which indicates that the percentage of injury claims that are whiplash is 76% in the UK, compared with Norway (53%) and Germany (54%). Although there may be valid differences in the road environment (the number of roundabouts for example) and resulting accident types, these percentages reveal larger than expected differences.

Therefore, the true casualty benefit of AEBS systems is in excess of estimates made from national accident data because a large proportion of whiplash accidents may not be recorded, although some insurance information may overstate the whiplash benefit because a proportion of claims are not genuine.

A.2.2 Potential Mitigation Strategies

AEBS are fitted to some current vehicles and are capable of automatically mitigating the severity of two-vehicle, front-to-rear shunt accidents (on straight roads and curves dependent on sensor line of sight and environment "clutter") as well as some collisions with fixed objects and motorcycles. Second generation systems are also appearing (on high-end vehicles) and have improved functionality in curves, functionality at greater speeds, and incorporate the detection of pedestrians and improved detection of other objects. They are particularly applicable to situations in which the driver is distracted from the driving task.

There are essentially three AEBS groups aimed at different accident circumstances:

- Urban AEBS, which typically uses LIDAR sensors, is designed to function in low speed traffic and is primarily aimed at avoiding low-speed shunts and the associated vehicle damage costs and whiplash injury. An example system is the Volvo 'City Safety' fitted to some vehicles since 2010. Although the magnitude of the whiplash injury target population is large, the extent to which fraudulent insurance claims are clouding the picture is unknown. This is because national accident data under-reports whiplash injury because a large proportion of these accidents are not reported to the police. On the other hand, insurance claim data includes an unknown proportion of claims motivated by financial reward rather than genuine injury.
- 'Inter urban' AEBS which typically uses radar and camera is aimed at avoiding, or more likely, mitigating the severity of higher speed impacts. Currently, the functionality of these systems is limited to shunt accidents that are at higher speed than those mitigated by urban AEBS. Systems are capable of automatically mitigating the severity of two-vehicle, front-to-rear shunt accidents (on straight roads and curves, dependent on sensor line of sight and "environment clutter") as well as some collisions with fixed objects and motorcycles.
- Pedestrian AEBS use camera and radar/LIDAR data to detect pedestrians in critical situations and activate the brakes autonomously. As with urban systems, functionality is typically at low speeds because of the time required to detect the pedestrian and reduce the vehicle's velocity.

Second generation (and future) systems are likely to improve the detection capabilities (pedestrians, rigid objects etc.) and be able to react earlier in the event. However, in order to address head-on and side crashes, it is likely that vehicle-to-vehicle

[6]http://www.zurich.co.uk/NR/rdonlyres/4D99573F-59D1-4FA5-BB52-DC175814BC2D/0/Whathappensifyoususpectmotorclaimsfraud127747A02.pdf

[7]http://futureoftrials.com/claims-for-whiplash-compensation-are-fraudulent-argue-doctors

communication (rather than in-vehicle sensing) will be required. Vehicles with AEBS are also very likely to have Forward Collision Warning packaged as part of the same system as well as Brake Assist: a system that boosts the braking force when the driver initiates an emergency braking event. Since the collision warning can be provided earlier in the critical event than the brake activation, a proportion of any real-world benefit might actually result from the warning function coupled with the brake assist, rather than the autonomous brake function. This is validated by Hummel et al. (2011) who found that of the theoretical safety potential of AEB (avoidance of 19.6% of all accidents), 11.4% could be achieved by brake assist and 17.8% by a system with warning and brake assist.

Thus, there are a range of systems on passenger cars (M1 vehicles); some focus on low-speed accidents (addressing predominately damage-only and whiplash injury) and use full emergency braking in conjunction with short-range sensing (typically LIDAR; light detection and ranging). These systems are capable of avoiding some low-speed front-to -rear accidents entirely. Other systems aim to influence higher speed accidents and use a combination of longer-range sensors (typically multiple range radars or radar and LIDAR/camera sensors) to allow earlier detection and tracking of obstacles and critical situations.

Systems that aim to influence higher speed accidents may have different strategies. Earlier detection allows staged driver warnings (using combinations of audible, visual, and haptic signals) to be given and this in itself may allow the driver to take the appropriate action; steering may be the more effective action and this can be achieved later in time than the latest braking point at which the accident can be avoided. Earlier detection also allows some systems to apply a lower level of automatic braking before the accident becomes unavoidable. This acts as a further driver warning and allows some of the vehicle’s velocity to be reduced. If no driver input is detected, full emergency braking is activated. Some systems provide later warnings to reduce the risk of false alarms and apply only full emergency braking in critical situations.

For larger vehicles, for example buses and coaches (M2 and M3 vehicles) and goods vehicles (N2 and N3 vehicles) the manoeuvrability of these vehicles is inferior to M1 and N1 vehicles and extreme steering inputs are likely to create instability and induce rollover. For this reason, braking is the most effective mitigation action and AEBS on these vehicles typically provide warnings, followed by full emergency ABS braking.

A.2.3 Feasibility

AEBS are voluntary on M1 and N1 vehicles, although there fitment is incentivised via Euro NCAP. AEBS is fitted by 12 manufacturers in Europe, with six offering it as standard on at least one model. Volvo fit the system as standard to seven models. Fitment tends to be to vehicles at the higher end of the market. There has been strong support from the insurance industry for low-speed AEBS to avoid damage-only accidents and whiplash injuries. For M1 vehicles, AEBS are optional on approximately 20-50% of 2013 vehicle models depending on the type of AEB system. However, it is standard fitment on 90% of Volvo models, 49% of Mercedes models, 42% of Infiniti, 32% of Mazda models and 12% of Lexus models (Euro NCAP, 2013). Fitment rates to new vehicles are expected to rise in response to greater consumer awareness and acceptance of AEBS. Current system fitment in the fleet is unknown because of the large percentage of vehicles to which fitment is optional. For this reason, it is considered that current fitment in the fleet is still very low (probably below 3%).

Particular M1 fleets (such as taxis, hire cars etc.) have the potential to adopt AEBS and attain the benefits, although purchasing decisions probably exclude the more expensive options or packages of options.

Regulation (EU) No 347/2012 made the fitment of AEBS mandatory for new types of N2/N3 and M2/M3 vehicles in 2014, and this will become mandatory for new vehicles in 2015. Some N2/N3 and M2/M3 vehicles are excluded from the requirements. Fitment to goods vehicles should therefore increase rapidly as new vehicles penetrate into the fleet.

Some vehicle manufacturers have been fitting AEBS for some time; for example, Volvo offered all N2/N3 vehicles with AEBS in 2013 (Volvo, 2013).

Validated test procedures for M1 vehicles have been developed by several European projects and test procedures adopted by Euro NCAP based on the AEB and ASSESS projects could be used as a basis for future regulation.

A.2.4 Costs

M1 vehicles

Previous projects that have sought to define appropriate cost values often encounter difficulties isolating a single value, and often contend with markedly different system costs provided by stakeholders responding to any consultation. It is likely that this wide variation in cost estimates is due to differing assumptions, e.g. about functionality, development costs and production volumes, and also partly due to commercial interests, i.e. system suppliers may make optimistic assumptions to encourage wide-scale application, whereas vehicle manufacturers may be much more pessimistic to avoid added vehicle costs.

Consultation with industry more than six years ago found that total cost estimates for AEBS was between €1,000 and €6,000 (Grover, 2008). ACEA pointed out that specific costs (for then first-generation systems) were difficult to define because they depended on the specific technical requirements of the system, the system type (i.e. packaging with other related systems), and costs depend on the numbers of cars that the costs can be spread over. At this time, other stakeholders indicated values at or below the lower estimate provided by industry. In 2005, the eIMPACT project estimated the cost price (manufacturer cost before accounting for profit and tax) of a car AEBS to be between €180 and €650; a value more in line with information provided by other stakeholders and the lower ACEA estimate.

Over time (and since fitment rates have increased) it is reasonable to expect that system costs have reduced further. Current consumer costs for 'city safety' AEBS are as low as £200 (Ford, VW), although some manufacturers package this with other functions (e.g. Audi) where the option pack is £2,320 (but includes AEBS, ACC, Park assist and other functions). Previous studies such as eIMPACT also indicated that the price to the consumer may be approximately three times that of the manufacturer cost. Assuming this is the case for urban AEBS, the manufacturer cost for current vehicles may now be less than €100.

However, inter-urban AEBS and pedestrian AEBS is more complex, and therefore more costly. Mercedes-Benz package many systems together at a cost of £2,345, which include AEBS functions (including pedestrian AEBS), LKA, blind spot monitoring and cross-traffic assist (to react to crossing traffic at junctions).

Other vehicle types

Cost estimates for other vehicle types are much more difficult to locate, largely because of the lower penetration rate in other vehicles. However, the system hardware and functionality is similar to M1 vehicles and so the costs can be expected to be comparable to passenger cars. Previous benefit studies used a 'break-even' approach.

A.2.5 Benefits

System effectiveness and casualty benefit

The literature reveals wide variations in the effectiveness and casualty benefits because of the predictive nature of the estimates and the wide variety of assumptions made. For example, Sugimoto and Sauer (2005) estimate that automatic braking systems could prevent 38% of front-to-rear crashes in the U.S., and reduce the probability of fatality in rear-end crashes by 44%. McKeever (1998) estimated that the system could reduce fatal rear-end crashes in the U.S. by 48% and Kullgren et al. (2005) estimated a greater reduction of 57% of fatal rear crashes in the U.S.

Estimates from other countries also result in different values. For example, Mitsopoulos et al. (2002) estimate a reduction of 7% of rear-end crashes in Australia. Grover et al. (2007) estimated that the benefit of automatic braking systems on passenger cars in Europe could be the same as for trucks – reducing the severity of 25-75% of front-to-rear crashes in Europe, with these (admittedly wide) estimates compatible with US data. Hummel et al. (2011) found that of the real word safety potential of AEB was 13.9% of all accidents and that 2.2% of fatal, 9.4% of serious, and 35.7% of slight casualties could be avoided.

In terms of all crashes/casualties the eSafety Forum (2005) estimate that 3.1% of all crashes could be prevented. Furthermore, COWI (2006) estimated that such a system could reduce at least 8% of fatalities, 10% of serious injuries, and 10% of slight injuries in all types of accident in Europe. These figures demonstrate the wide variation in predictive estimates and the uncertainty regarding the actual real world effectiveness of the systems.

A predictive case-by-case analysis of 412 On-The-Spot (OTS) accident cases used engineering judgement combined with knowledge of test results from two current AEBS to determine whether AEBS would have influenced the outcome. It was found that approximately 30% (21%-38% for full range of estimate) of serious casualties in front-to-rear accidents could be avoided and 68% (58% to 77% for full range of estimate) of slight casualties could be avoided (McCarthy et al., 2012). There were no fatal accidents in the sample.

Combining these effectiveness estimates with the earlier target population estimates suggests that, if these are accurate, AEBS would be expected to bring about an overall reduction in casualties of approximately 11%; 1% (0.6%-1.1%) for serious casualties and 10% (9%-12%) for slight casualties.

Retrospective evidence from the US that indicates that AEBS (particularly the 'City Safety' systems) are more effective than these estimates suggest, perhaps because a proportion of accidents recorded in insurance claim data are not recorded in the reported road casualty data.

Warning-only systems

Recent insurance data from the US showed that Mercedes vehicles with collision warning and brake assist were involved in on average 3.1% fewer collisions (6.1% to 0%) compared with the same vehicles without the system (HLDI, 2012b). US insurance data for vehicles from two manufacturers (Mercedes and Volvo) suggest that systems that involve automatic braking are more effective than warning alone (HLDI, 2012c).

'City safety' systems

US insurance data shows that there is strong evidence that these systems are effective at reducing low-speed rear-end shunt accidents. For the Volvo XC60 fitted with City Safety, the collision frequency was 22% lower (95% confidence interval: 20-24%) compared with other mid-size luxury SUVs and 17% lower (95% confidence interval: 13-20%) compared with other Volvos (HLDI, 2011a). However in contrast to this strong evidence, collision frequencies for the similar XC70 (without city safe) were lower than that for the XC60; despite the fact the analysis controlled for other variables, and implies that some of the observed reduction might be associated with other differences between the treatment and control groups rather than being due to the fitment of the system.

More recent data confirms the effectiveness of 'city safety' systems, with collision frequencies 15% lower (Volvo XC60) and 9% lower (Volvo S60) than control vehicles (HLDI, 2012d). Frequency of bodily injury was also 33% lower (XC60; 95% confidence interval: 29% to 38%) and 18% lower (S60; 95% confidence interval: 4% to 30%), although injury benefits are probably limited to the prevention of whiplash injury. The same source shows that claim severities were also reduced by 10% (XC60; 95% confidence interval: 9% to 11%) and 13% (S60; 95% confidence interval: 11% to 15%) respectively.

Cars with 'city safety' might also have an AEBS system targeted at the avoidance or mitigation of more injurious accidents.

'Higher speed' AEBS

These systems are fitted in fewer numbers than the 'city safety' functions, although increasingly, the vehicle may have 'merged' systems using data from different sensors to address the full speed range of accidents. It is considered likely that the effectiveness for 'higher speed' AEBS is lower than for 'city safety' and probably more in the region of the predictive estimate of 11% of all casualties (McCarthy et al., 2012).

Initial retrospective data provides effectiveness values slightly lower than that predicted. For example, US insurance data shows that Mercedes cars fitted with Distronic Plus have on average 7.1% fewer claims (95% confidence interval: 12.8% to 1% fewer claims) than those not equipped with the system (HLDI, 2012b). This data also shows average reductions for property damage and injury claims, although the 95% confidence limits span zero meaning that with the data available, the true value may also be increased with system fitment. For Volvo vehicles, the trend is similar, although the magnitude of the collision reduction is smaller with an average 2.9% reduction, with 95% confidence interval of -13.8% to 9.3% (HLDI 2012a). Overall losses (including injuries) show on average much larger reductions (up to around 50%), but in all cases the confidence limits cross zero meaning that there could be a disbenefit if the data available thus far happened by chance to be biased in favour of accidents in which the system provided high benefits.

Systems that can function in head-on and side impacts will provide a great casualty benefit, but these might not be possible to detect without vehicle-to-vehicle communication or significantly improved car-based sensing performance. Similarly, systems that can reliably cope with objects off the road and pedestrians will also provide a significant increase in benefit.

Pedestrian AEBS

Pedestrian AEBS is fitted by two European manufacturers (Volvo and Lexus). Volvo fit the system as standard to at least seven models. It is known that Subaru also have a stereo camera pedestrian system on the market in Asia which not yet available in Europe, but has a real-world system performance superior to current radar/camera systems. The real-world effectiveness of these systems are not known although the systems are known to function well in low-speed test situations and are considered to have a significant casualty benefit likely to be greater in magnitude than to car-to-car accidents, because the vulnerable road user target population is biased towards fatal and severe injury.

Benefits – Other vehicle types

The benefits and fitment of AEBS to other vehicle types has been less well studied compared with passenger cars. However, one study by TRL considered all vehicle types and was the basis for the introduction of mandatory AEBS for N2/N3 and M2/M3 vehicles for new types from 2014 and new models from 2015.

This work highlighted that the types of accidents addressed are the same as for passenger cars. However, large vehicles tend to have a braking strategy of full autonomous braking (rather than partial or staged braking) because of steering responses being less likely to successfully avoid an accident.

The study predicted, based on the effectiveness found for passenger cars, that between 25% and 75% of front-to-rear accidents could be avoided (Grover et al., 2008). These predictions (for the EU) are presented in Figure A-1, below:

Accident and casualty type		Estimated total casualties (EU-25) 2005		Predicted reduction in casualty numbers (fatal/serious 25%/75%, slight injuries (0%/10%)		Cost per vehicle (€) sustainable for a benefit/cost ratio of 1	
		Upper	Lower	Upper	Lower	Upper	Lower
All casualties from two-vehicle accidents where the front of an M1 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	709	580	532	145		
	Serious	12,453	10,189	8,808	2,402		
	Slight	506,805	414,659	41,873	-2,402		
	M1 Total					**136**	**15**
All casualties from two-vehicle accidents where the front of an M2/M3 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	18	15	14	4		
	Serious	496	406	358	98		
	Slight	17,134	14,018	1,355	-98		
	M2/M3Total					**1,450**	**162**
All casualties from two-vehicle accidents where the front of an N1 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	156	128	117	32		
	Serious	1,674	1,369	1,138	310		
	Slight	44,536	36,439	3,315	-310		
	N1 Total					**144**	**20**
All casualties from two-vehicle accidents where the front of an N2/N3 vehicle collides with the rear of any other vehicle excluding motorcycles	Fatal	468	383	351	96		
	Serious	2,340	1,915	1,404	383		
	Slight	31,913	26,111	1,787	-383		
	N2/N3 Total					**1,343**	**286**

Figure A-1: Predicted front-to-rear accident target population, predicted casualty reduction (effectiveness) and estimated break-even value (Grover, 2008)

This shows that the predicted number of casualties for 'large vehicles' M2/M3 and N2/N3 is far lower than for passenger cars and vans, but the break-even values for large vehicles are much greater because the number of vehicles in these categories is lower and so the overall costs are significantly lower than M1 and N1 vehicles.

AEBS systems which can deal with a greater range of accident types (head-on and crossing accidents) and pedestrian accidents are predicted to have a significantly greater benefit because these accident types comprise a much greater number and proportion of fatal and serious injuries.

AEBS also has dual congestion benefits resulting from a reduction in severity and frequency of shunt-type accidents on major routes; this will have positive impacts on congestion on the road network. This is difficult to quantify accurately as the effect is very sensitive to the time and location of accidents.

Benefit:Cost Ratios

Most studies do not calculate BCRs and instead use a break-even approach because of the difficulty in identifying accurate costs and the differences in benefit and cost for different system types. However, Robinson et al. (2011) estimated a BCR for M1 cars of between 0.02 – 0.14 (0.02 – 0.15 for AEBS that can detect stationary vehicles). However, this estimate excluded large proportions of casualties that occurred in rain (where radar/lidar systems would still function), and excluded a large proportion of accidents that might not have had sufficient sightlines or time for the system to function (based on data from fatal accidents only). The BCR for low-speed systems (assuming whiplash is included) is considered to be closer to 1 than these estimates. For higher speed accidents, the costs of the system are probably above the break-even threshold, but the effectiveness of these systems is not well known.

As a summary, Intra-urban systems probably have a BCR close to 1. Regulatory action might not be justified at present, but a close watch should be kept on the market, particularly with respect to real-world effectiveness and system cost. For Inter-urban systems, the BCR is considered to be greater than 1 and this suggests the correct action is not to legislate at this time; however, this position has the caveat that this should be revisited if improved real-world effectiveness or lower system costs become available. EuroNCAP assessment of AEB (from 2014) is likely to increase voluntary fitment levels.

A.2.6 Summary and BCR (Benefit:Cost Ratio)

	M1	N1	M2/M3	N2/N3
System benefits	Greatest overall casualty benefit of all vehicle types. Front-to-rear accidents (first generation systems) were estimated as having the following EU benefits: Fatal 145-532, Serious 2,402-8,808, Slight -2,402-41,873 (Grover, 2008). Predictive estimates that AEBS would bring about an overall reduction in casualties of approximately 11% (based on reported casualties). Retrospective insurance data reveal between 10-20% fewer claims in US – these include whiplash accidents under-recorded in reported road accidents. Hummel et al. (2011) found that of the real word safety potential of AEB was 13.9% of all accidents and that 2.2% of fatal, 9.4% of serious, and 35.7% of slight casualties could be avoided.	See M1. Lower absolute benefits but lower number of N1 in fleet. Benefits expected to be similar to M1. Front-to-rear accidents (first generation systems) were estimated as having the following EU benefits: Fatal 32-117, Serious 310-1,158, Slight -310-3,315 (Grover, 2008).	Not as large as for M1, but smaller numbers of vehicles in fleet. Front-to-rear accidents (first generation systems) were estimated as having the following EU benefits: Fatal 4-14, Serious 98-358, Slight -98-1,355 (Grover, 2008).	Not as large as for M1, but smaller numbers of vehicles in fleet. Front-to-rear accidents (first generation systems) were estimated as having the following EU benefits: Fatal 96-351, Serious 383-1,404, Slight -383-1,787 (Grover, 2008).
System costs	Generally fitted as optional extra. 'City safety' AEBS offered for around £200 on some models (possibly €100 or less to the manufacturer) AEBS and pedestrian AEBS packaged with suite of other systems - £2,000 - £3,000 on some vehicles. Difficult to isolate AEBS cost from other systems.	Generally fitted as optional extra. Systems similar in cost to M1. Ford Transit Connect has optional 'City Safety' AEBS.	No information found on system costs.	No information found on system costs.

	M1	N1	M2/M3	N2/N3
BCR estimate/ info	Break even for first generation AEBS €15-€136 (Grover, 2008). Break-even of about €70. Systems with capability to address off highway objects and pedestrians (similar capability to more advanced current systems) break–even cost estimate of €151-€1,102.	First generation AEBS similar to M1 break-even cost €20-€144 (Grover, 2008).	First generation AEBS break-even cost €162-€1,450 (Grover, 2008).	First generation AEBS break-even cost €286-€1,343 (Grover, 2008).
Comment	Rewarded by Euro NCAP from 2014.	Rewarded by Euro NCAP from 2014.	Mandated from 2014/2015	Mandated from 2014/2015

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A.3 Intelligent Speed Adaptation (ISA)

Intelligent Speed Adaptation (ISA) describes a range of technologies which are designed to aid drivers in observing the appropriate speed for the road environment. Two levels of control were considered: advisory (alert the driver when their speed is too great) and voluntary (the driver chooses whether the system can restrict their vehicle speed and/or the speed it is restricted to). Mandatory systems (where the driver's speed selection is physically limited by an ISA system that cannot be switched off) were not considered.

A.3.1 Description of the Problem

This system is designed to address accidents in which speed in excess of the road speed limit was a contributory factor. Therefore, this system is independent of classification by impact type, and instead controls one of the main contributory factors present in many accidents – vehicle speed.

The link between excessive speed and increased severity/frequency of accidents has long been established (e.g. Finch et al., 1984; Taylor et al., 2000; Taylor et al. 2002). These studies broadly conclude, across all road types, that a 1 km/h decrease in mean speed would reduce the number of road collisions by 3%. As well as the having an influence on the frequency of collisions, speed also affects injury severity since collision energy is proportional to the square of velocity, and in an accident this means that the subsequent injury risk also increases more rapidly at greater speed.

As such, systems that warn the driver when the speed limit is exceeded, or prevent the driver from doing so, provide a very effective strategy for reducing accidents and injury severity. The magnitude of casualty savings depends on the type of ISA considered. Estimates vary between studies, however, Wilkie and Tate (2003) estimated that advisory systems offer the lowest accident savings (8.4%) and mandatory systems offer the greatest (30%); many studies find estimates are in broad agreement with these predictions.

Cost-benefit studies focus on passenger cars (M1 vehicles) but benefits are also expected for other vehicle types (N2/N3 and M2/M3 vehicles). No specific studies could be located for speed control on large vehicles, although of course commercial operations mean that N2/N3 vehicles are speed limited. This is not an ISA system because it is not linked to the prevailing speed limit, but this does mean that benefits for ISA at higher speeds will be lower than for M1 vehicles.

A.3.2 Potential Mitigation Strategies

Intelligent Speed Adaptation (ISA) describes a range of technologies that are designed to aid drivers in observing the appropriate speed for the road environment. ISA can achieve this through different degrees of control, the three main forms of which are

- Advisory - alert the driver to when their speed is too great;
- Voluntary - the driver chooses whether the system can restrict their vehicle speed and/or the speed it is restricted to; and
- Mandatory - the driver’s speed selection is physically limited by the ISA system.

The system alerts the driver with audio, visual, and/or haptic feedback when the speed exceeds the locally valid legal speed limit. The speed limit information is either received from transponders in speed limit signs (a ‘beacon system’), or from a digital road map, which requires reliable positioning information from GPS.

As the cost of technologies have decreased, GPS-based systems have emerged as the preferred solution, mostly due to their superior flexibility, the potential to integrate ISA into a package of wider "intelligent vehicle" technologies, and avoiding the need to set up a costly network of national beacons. However, GPS-based ISA systems need to surmount the difficulties faced by GPS in general, such as interference from weather conditions, the "urban canyon" effect (whereby the GPS signal can be lost between tall buildings in dense urban environments), and so forth.

Although ISA systems are discussed based on posted speed limits, there is the potential, either for a GPS map system or a local beacon system, to adjust the speed limit based on other factors (e.g. extreme weather conditions, temporary speed limits etc.). Deployment could also be targeted at: particular road types, at specific accident black spots, at particular times of day, or at particular driver groups (e.g. young drivers, commercial fleet drivers).

A.3.3 Feasibility

Many current vehicles are fitted with voluntary speed limiting systems which are can be set by the driver to ensure compliance with a particular speed threshold. However, the speed limiter is set by the driver and is not linked to any digital map of speed limit information.

It is clear that the implementation of a mandatory ISA system would require an accurate map of speed limits and would be likely to have a large effect on accident rates and offer real economic gains; however, such a system may find it difficult to achieve public acceptance. Some public surveys have highlighted a positive response: a MORI survey in the UK in 2002 found 70% of those questioned would support ISA in urban areas. Offering ISA as an option on new vehicles before gradually moving to a mandatory stage may help overcome this difficulty.

In terms of feasibility for current fleets, a study conducted for TfL suggested an ISA scheme could be implemented across its fleet within 24 months (Jamson et al., 2006). Several predictive studies claimed that the fitment of ISA could be increased. For example, a Swedish report speculated that at least 80% of vehicles could be equipped with ISA by 2020 (Vägverket, 2002). Furthermore, work completed for the DfT by Carsten and Tate (2005) proposed that by 2019 the use of ISA could be made mandatory and a strategy for achieving this was outlined.

Across Europe, between 60% and 75% of drivers who have tried out ISA technologies said they would like to have the system in their own cars (Peltola and Tapio 2004). Furthermore, Almqvist and Nygard (1997) found that 73% of drivers reported being more positive towards ISA after using it than before. Other examples of positive feedback on ISA come from Sweden, where more than 10,000 people have tested ISA, one in three test drivers would have been prepared to buy the so-called 'active accelerator' ISA, and one in two would have been ready to pay for a sound warning system (Vägverket, 2002). The technology cost of ISA is considered to have reduced since this time, so the proportion of the public willing to pay may now be greater.

A.3.4 Costs

Jamson et al. (2006) estimated even the most expensive ISA system would have a cost of no more than £1,000 per unit. More comprehensive studies by Carsten and Tate (2005) predicted that the 2010 cost for an ISA system would be in the range £293 to £372 (approximately €350 to €450). Other 'one-off' costs were also described for establishing the ISA mapping system: £8 million for a 'fixed speed limit system', £12 million for a 'variable speed limit system' and £43 million for a system that would allow dynamic changes to the speed limits. Further annual costs were identified as £2.25 million and £1 per vehicle for a fixed or variable system and £4.54 million plus £5 per vehicle for a dynamic system (Carsten and Tate, 2005).

A.3.5 Benefits

The main benefits of ISA are reduced speeds, which result in fewer accidents and reduce the injury risk for those that do occur.

Reagan et al. (2013) found that drivers of ISA-equipped vehicles spent more time during a field test of 50 participants travelling at 70 mile/h (113 km/h) or lower (54.8%) compared to the control group (48.8%). This effect leads to fewer (and less severe accidents). Many studies have found that the presence of ISA had positive effects on accidents and injuries:

- Carston and Tate (2005) found that "...a simple mandatory system, with which it would be impossible for vehicles to exceed the speed limit, would save 20% of injury accidents and 37% of fatal accidents. A more complex version of the mandatory system, including a capability to respond to current network and weather conditions, would result in a reduction of 36% in injury accidents and 59% in fatal accidents." These estimates were made by combining research from a number of European countries. The predicted percentage decreases in accidents imply savings of over €20 Billion per annum in the EU28.
- Biding and Lind (2002) reported that in a trial of several thousand vehicles in Sweden, mean speed, standard deviation of speed, and speed violations were reduced.
- Based on data from the UK, Lai et al. (2012) predicted that mandatory ISA would reduce number of fatal accidents by 30% and serious accidents 25%. Both mandatory and voluntary ISA were predicted to reduce CO2 emissions by 5.8% and 3.4% respectively on roads with speed limit of 70 mile/h (113 km/h).
- The SafeCAR project in Australia predicted on the basis of data collected from 23 drivers (15 equipped, 8 control) travelling at least 16,500 miles (26,400 km) that there could be 20% fewer road injuries in urban areas (Regan et al., 2006).
- Data from field tests in the UK involving 79 drivers over a six-month period showed that a voluntary ISA system reduced driving speed by about 5% (Lai and Carsten, 2008). The authors estimated that this system has the potential to reduce the number of fatalities by 2.1-10.7%, fatal accidents by 1.7% - 8.7%, and serious injury accidents by 0.7-3.6% depending on the expected market penetration between 13-65% in 2016 and the quality of implementation.
- Wilkie and Tate (2003) used UK data to predict accident reductions ranging from 8.4% for an advisory-based system, to 30.2% for a mandatory system. These authors also found that a local ISA system with a 15km radius would have 84% of the effectiveness of a national ISA system. Assuming that beacon based ISA systems would have to be introduced region-by-region, this report investigated what safety improvements could be achieved by the use of local systems.

Other benefits come from the more efficient control on the throttle which, at higher speeds, leads to improved fuel economy and fewer CO2 emissions and other tailpipe emissions. For example:

- Mandatory ISA was found to reduce CO2 emissions by an average of 6% on motorways by using instrumented vehicles to predict the vehicle emission levels. On other roads the effect was found to be very small and in some cases may result in increased emissions on urban roads with low speed limits (Carslaw et al., 2009).
- Advisory ISA reduces fuel consumption 14% based on a small field trial of 26 vehicles in Sweden and this was achieved by reducing the distance driven above the speed limit which reduced from 25% to 14% (Andersson, 2009).
- Broekx et al. (2006) found a significant reduction in Nitrogen Oxide and Hydrocarbon emissions in 80 km/h zones when an ISA system was active.

Several studies found that advisory ISA systems were overridden more frequently in urban areas. An eight-week field trial of 44 drivers showed a trend for a voluntary system to be overridden in urban settings. On 20 mile/h roads, ISA was overridden for 13% of distance travelled, while on the 30 mile/h roads and 40 mile/h roads the ISA was overridden for 8% of the distance travelled. It was also shown that the ISA system was overridden more often by male and young drivers than other drivers (Saint Pierre and Ehrlich, 2008). This suggests that mandatory systems might be more effective for young drivers and Young et al. (2010) found evidence in a simulator study involving 30 drivers that inexperienced drivers benefited more from ISA systems.

As well as the predicted benefits from ISA from reducing accidents and injuries ISA also has the potential to reduce costs associated with traditional police enforcement of speed limits and could replace costly physical measures currently used to obtain speed compliance (for example, speed cameras and motorway policing).

No specific ISA benefit studies were located for large vehicles (N2/N3 and M2/M3 vehicles). However, a study on the effectiveness of Directive 2002/85/EC (the Speed Limitation Directive) found a positive impact on safety; accident reductions of 9% for fatal accidents on motorways with HCVs involved, 4% of serious injuries, and 3% of injury accidents were estimated (Transport and Mobility Leuven, 2013).

A.3.6 Benefit:Cost Ratio

A cost-benefit analysis of ISA was performed by Carsten and Tate (2005) which produced ratios of 7.9 to 15.4 depending on the type of ISA system considered; mandatory ISA yield the greatest benefit to cost ratios, or to quote "…i.e. the payback for the system could be up to 15 times the cost of implementing and running it."

Other studies have also found benefit to cost ratios in excess of one and consistently show that the benefits substantially outweigh the costs of ISA implementation. The benefit-to-cost ratios for mandatory ISA predicted for six EU countries range from 2:1 to 4.8:1, taken into account a period of 45 years from 2005 to 2050. However, this depends strongly on the implementation scenario (Carsten, 2005). For example, the range of Benefit:Cost ratios for mandatory ISA for scenarios in which the fitment of ISA is left to the market and one in which ISA is actively encouraged was estimated by as follows:

Table A-10: Estimated BCRs for mandatory ISA in two different implementation scenarios (Carsten, 2005)

Country	BCR "Market scenario"	BCR "authority scenario"
Belgium	3.5:1	4.8:1
Great Britain	3.1:1	4.2:1
France	2.4:1	3.5:1
Netherlands	2.6:1	4.1:1
Spain	2:1	2.8:1
Sweden	2.5:1	3.5:1

The current situation is similar to that in 2005 in terms of ISA implementation, so the potential benefits are likely to be of a similar size. However, as the cost of technology reduces, and more cars are equipped with navigation systems as standard, the costs of ISA implementation are considered by TRL to have reduced over time. This has the effect that the estimates made by Carsten (2005) and Carsten and Tate (2005) may underestimate the benefit to cost ratio.

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A.4 Lane Departure Warning System (LDWS)

A lane departure warning system (LDWS) is an in-vehicle system that provides a warning to the driver of an unintended lane departure.

A.4.1 Description of the Problem

Lane departure accidents

These comprise accidents in which a vehicle leaves the lane unintentionally. This is usually because of driver distraction or fatigue and can result in a range of accident configurations:

- Head-on collisions - vehicle leaves its lane unintentionally and collides head-on with oncoming vehicle. These accidents are most likely to occur on single carriageway roads.
- Leaving roadway collisions –vehicle drifts out of the travel lane. These accidents are often single vehicle (can include pedestrians) and may involve impacts with roadside furniture. Other vehicles may be involved, however, because they have been required to react to the initial lane departure event.
- Side-swipe collisions – when the vehicle of interest unintentionally leaves the lane in which they are travelling on a road with multiple lanes, the side of the vehicle of interest could collide with the side of a vehicle that is travelling in an adjacent lane. There is also a possibility of an impact between the front of one vehicle and the rear of the other.

Visvikis et al. (2008) defined target populations based on the three main lane-departure warning accident types and used national data from Great Britain and Germany to estimate the percentage of casualties in each accident type. These target populations were validated by comparing accidents at the national level with in-depth data, with upper and lower ranges defined based on the ability of the national data to correctly identify lane departure relevant accidents. This yielded the following EU27 casualty estimates for the LDWS target population and shows that the main casualty target populations are for passenger cars:

Table A-11: EU27 LDWS target population based on GB/German national and in-depth data (Visvikis et al., 2008)

Equipped vehicle type	Casualty severity	Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	903	5,949	67	612	64	620	1,034	7,181
	Serious	5,773	31,539	1,026	7,530	249	3,197	7,048	42,266
	Slight	21,867	64,838	7,028	19,549	459	1,361	29,354	85,748
M2/M3	Fatal	7	189	0	7	0	5	7	201
	Serious	51	1,045	0	21	0	0	51	1,066
	Slight	338	1,000	27	82	8	23	373	1,105
N2/N3	Fatal	23	111	0	65	0	5	23	181
	Serious	135	615	19	213	3	315	157	1,143
	Slight	404	1,413	184	693	9	42	597	2,148

Identifying the proportion of these accident types for which LDWS is an effective countermeasure is difficult because identification of unintended lane departures within these accident types is difficult to identify in the accident data.

Abele et al. (2005) estimated the LDWS target population as 25% of serious and slight casualties and 50% of fatal casualties and then applied estimates for the percentage of these accidents avoided or mitigated. However, this approach did not take into account that not all of the accidents had a causation for which LDWS could provide a benefit.

A.4.2 Potential Mitigation Strategies

A system that monitors the lateral position of the vehicle within the lane boundaries and issues a warning to the driver in the case that lateral deviations take the vehicle towards or over the lane boundary. The system functions only if warning threshold criteria are met. These criteria may include vehicle speed, rate of departure and time to lane crossing. A LDW system will not take any automatic action to prevent lane departure; the safe operation of the vehicle remains the responsibility of the driver at all times.

A.4.3 Feasibility

There are a range of systems currently on the market. The majority of systems use a forward-looking video camera mounted behind the windscreen. Other systems use infrared sensors or laser scanning technologies. The current systems utilise a range of different types of warning: visual, audible or haptic, or a combination of these. Audible warnings include the use of a "rumble strip" noise and haptic warnings include vibrating steering wheels or seats. The systems are only active above a certain speed. The trigger speeds identified range from 56 to 80km/h for passenger cars and 60 to 80km/h for HGVs and coaches, and are often specified by the OEM rather than the Tier 1 supplier.

LDWS is currently fitted to higher specification cars and increasingly on more mainstream models. Abele et al. (2005) estimated that 0.6% of the European fleet would be equipped in 2010, increasing to 7% by 2020. However, they assumed that the exposure of equipped vehicles was likely to be proportionally greater and equated a 3% of market fitment to approximately 6% of vehicle kilometres. COWI (2006) reported e- safety working group estimates of fleet penetration between 0-5% for 2005, 5-20% for 2010 and 20-50% for 2020. These predictive estimates have proved high, as LDWS is today still largely an optional feature.

Lane support systems rely to a large extent on the presence of road markings, although some systems are capable of detecting road edges without lane markings. However, in the majority of cases, performance (and subsequent benefits) will be negatively affected by missing, worn or obstructed line markings. Road markings are already required on European roads (although the types of marking differ between countries). If regulated, systems should be able to detect any road line marking system and the benefits attainable could be affected by levels of maintenance of the road lines within each country.

A.4.4 Costs

M1 vehicles

Unit price for LDW was estimated to be approximately €300 in 2010, reducing to €200 by 2020 (Abele et al., 2005). A survey of cars in 2009 found that the consumer cost of the system to the consumer ranged between £305 and £500 (€366 to €600) (Robinson et al., 2011)

LDWS are generally optional systems and are typically packaged with other related systems. For example, Ford offer lane departure warning packaged with LKA, Traffic sign recognition, Driver Alert and Auto High Beam for £550 (approximately €660). Other manufacturers offer LDWS as part of a more advanced lane keeping system. For example, Audi offer LDW functionality as part of Lane Assist (which also includes LKA) for £400 (approximately €480). These are all consumer costs and therefore subject to mark-ups. It is also reasonable to assume that if such systems (which are currently only available on a very small number of vehicles) were mandated, the production costs would tend to be somewhat lower than the current situation through economies of scale and product innovation.

The packaging of systems and the uncertainty of relating consumer costs to manufacturer costs make it difficult to isolate the true cost of the LDWS system. Robinson et al. (2011) used a range of £100-£300 per vehicle as an estimate of manufacturer cost and this remains a reasonable estimate for the cost, bearing in mind that the cost to the consumer is likely to be approximately three times greater than the cost to the manufacturer.

Other vehicle types

Little information is available on LDWS for other vehicle types. The author considers that the costs are similar to that for M1 vehicles.

A.4.5 Benefits

System effectiveness and casualty benefit

The effectiveness of a LDWS is dependent on a number of factors, not least the accident type, the type of warning signal and driver response, and the performance of the sensing system. Visvikis et al. (2008) reviewed a range of studies that had defined LDWS effectiveness values, including the main predictive studies by Abele et al. (2005) and COWI (2006). More recent US research included a predictive study (Jermakian, 2010) and a small-scale field operational trial (Nodine, 2010).

The research evidence for this system shows a wide range of effectiveness. Taking into account environmental conditions and lane marking condition, US estimates for effectiveness were 10% of M1 lane departure accidents and 30% reduction in heavy goods vehicle lane departures (Pomerleau et al., 1999). More recent, Field Operational Test (FOT) data from a very small sample of specific M1 vehicles in the Netherlands found a 20% reduction in lane departure events (Alkim et al., 2007). Other authors such as Abele et al. (2005) estimated that lane departure warning systems had the potential to avoid 25% of head-on impacts, 25% of impacts where the vehicle left the carriageway, and 60% of side-swipe impacts in Europe. COWI et al. (2006) estimated that up to 25% (15%-35%) of all road traffic accidents in Europe could be avoided by fitting lane departure warning systems and 15% of accidents mitigated.

However, the number of accidents influenced by LDW systems is considered by the present author to have been overestimated by published sources, since the system will only provide a benefit in accidents where there was an unintended lane departure. Both COWI (2006) and Abele et al. (2005) selected target population on accident type, not on the causation of accidents within a particular accident type. For example, a head-on collision might have been primarily due to excessive speed or an intentional action such as an overtaking manoeuvre, rather than an unintentional action as a result of fatigue or inattention. Furthermore, effectiveness is influenced by whether a warning would have been heeded, or would have allowed sufficient time for the driver to take avoiding or mitigating actions. In many (or even most) unintended departures, the warning which can be provided up to 0.3 m after lane crossing (ISO 17361:2007) may not elicit a driver response that leads to accident avoidance or mitigation, especially when it is considered that the reaction time of a distracted/tired driver is likely to be more than 1 or 2 seconds.

Vivikis et al. (2008) produced ranges for LDWS effectiveness by vehicle type and accident type (these types being listed in Section C.4.1.1). These ranges were as follows:

Table A-12: Predicted LDWS effectiveness ranges by accident type (A, B, C: head-on, lane departures, side swipes) and vehicle type (Visvikis et al., 2008)

	Target population A			Target population B			Target population C		
	M1/N1	M2/M3	N2/N3	M1/N1	M2/M3	N2/N3	M1/N1	M2/M3	N2/N3
Fatal	16%-48%			16%	48%	48%	16%-48%		
Serious	12%-36%			12%	36%	36%	12%-36%		
Slight	7%-20%			7%	20%	20%	7%-20%		

Jermakian (2010) identified the three basic accident scenarios relevant to LDWS and systematically excluded cases from each that would likely not be relevant, e.g. because of road defects, loss of control, avoidance manoeuvres, low speed, snow on the road way, etc. Those left, and thus potentially relevant to LDWS fitment, were split into those where the car was not speeding, which were defined as definitely relevant to LDWS, and those where the car was speeding, which were defined as possibly relevant. The analyses were further split into fatal crashes, non-fatal injury crashes and all crashes. Effectiveness ranges were deduced for each target scenario and for both fatal and non-fatal injury accidents as follows:

Table A-13: Effectiveness ranges by impact scenario (Jermakian, 2010)

Scenario	Fatalities	Non-fatal injuries
A – Head-on	35-41%	24-31%
B – Leaving roadway	7-10%	17-31%
C – Side-swipe	30-39%	27-33%

Nodine (2010) presented a summary of the results of field operational trials on 16 prototype cars, shared by 108 drivers travelling a total of 219,000 miles. Each driver had the car for 40 days, the first 12 of which without LDWS fitted and the remaining 28 days with the system in-use. The results showed a 21% decrease in unintended lane excursions for all drivers. The following estimates for system effectiveness were made:

Table A-14: Effectiveness by impact scenario (from Nodine, 2010)

Scenario	All crashes
A – Head-on	7%
B – Leaving roadway	23%
C – Side-swipe	40%

These estimates exhibited some differences and the ranges used (the minimum and maximum values from each) were broadly comparable with the effectiveness values used by Visvikis et al.

Hummel et al. (2011) found that of the word real safety potential of LDW was 2.2% of car accidents and that 2.2% of fatal, 9.4% of serious, and 35.7% of slight casualties could be avoided.

However, in contrast to these largely predictive estimates, recent insurance data from the US shows that lane departure warning systems (from Buick and Mercedes in this case) appeared to be associated with, on average, increased claim rates and costs when compared to unequipped control vehicles. However, the increases were not statistically significant (HLDI, 2012) and spanned a large range, from decreased to increased claim rates. This suggests that LDWS are not realising the expected reduction in accidents or casualties, although the analysis may have been limited by the relatively small data size, the lack of clear lane markings on rural roads and/or and the fact that the driver may have switched the system off to avoid repeated departure warnings. Volvo vehicles with lane departure warning had lower claim frequencies compared with Volvos without the feature, but LDW vehicles were also equipped with AEBS and HLDI observed that this is probably more likely to be responsible for the observed benefit. It is likely that functional advancement of the system to retain the vehicle in the lane (i.e. Lane Keeping Assistant) would realise a greater proportion of the predicted casualty benefits.

There was no evidence that suggested problems with driver acceptability, although all systems can be switched off by the driver to avoid false warnings; this is one of the problems with using insurance data as it is not clear whether the system was actually switched on at the time of the accident. The effectiveness of the system depends on clear warnings and unwanted warnings may encourage the system to be deactivated, thus meaning that any benefit of the system is not realised.

Further research regarding quantification of the real world effectiveness of LDW system in situations where the system is switched on, most likely to be achieved from field operational trials is required to determine its relative priority as an active system and the appropriate policy action.

Despite the large range in predicted casualty benefits, the main benefit-cost ratios from the two European studies were between 1.7 and 2.1. Abele et al. (2005) and COWI (2006) combined the casualty benefits with benefits arising from reduced congestion and environmental benefits, although the values attributed to these were small when compared to casualty values.

Benefits – Other vehicle types

The target population in terms of accident types that can be addressed by LDWS is identical to that for M1 vehicles (see Section C.4.1.1). European estimates for the annual casualty savings (assuming 100% fleet fitment) are presented in Table A-11. These show that the annual casualty benefit for large vehicles is significantly lower than for passenger cars.

Effectiveness – Other vehicle types

System effectiveness estimates for other vehicle types are less frequent in the literature than M1 vehicles. Studies in the US indicate that predictive effectiveness for trucks is approximately 30% reduction in heavy goods vehicle lane departures (Pomerleau et al., 1999). Visvikis et al. (2008) found a wide range of predicted estimates; these are presented in Table A-12 and were very similar to M1 vehicles. For lane departures, the available information indicated greater effectiveness for N2/3 category vehicles (based on US data); effectiveness for M2/M3 vehicles was assumed, in the absence of more specific data, to be similar to N2/3.

Estimated casualty benefits

The casualty benefits for Europe were estimated by Visvikis et al. (2008) as follows:

Table A-15: Estimated casualty benefit of fitting LDW system.

Equipped vehicle type	Casualty severity	Estimated benefit – number of casualties							
		Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	144	2,856	11	294	10	298	166	3,447
	Serious	693	12,249	123	3,391	30	1,468	846	17,108
	Slight	1,531	15,232	492	6,718	32	359	2,055	22,309
M2/M3	Fatal	1	91	0	3	0	3	1	96
	Serious	6	399	0	9	0	0	6	408
	Slight	24	222	2	27	1	6	26	255
N2/N3	Fatal	4	53	0	31	0	3	4	87
	Serious	16	233	2	88	0	147	19	468
	Slight	28	300	13	181	1	9	42	490

A.4.6 Summary and BCR (Benefit:Cost Ratio)

	M1	N1	M2/M3	N2/N3
Benefits	Potentially large benefits predicted, but levels of reduction not seen in US claims data. This may suggest that predictive methods overestimate the benefit of LDWS.	See M1	See M1	See M1
Costs	System costs for LDWS difficult to isolate from other systems as often packaged. Consumer costs in 2009 were between €366 to €600.	See M1	See M1	See M1
BCR	1.7-2.1 predicted by European studies. TRL research predicted BCR of 0.13 to 4.18 (Visvikis et al., 2008) and 0.25-2.12 (Robinson et al., 2011) Data from US insurance data suggests that BCR may be towards the lower end of this range, although system may not have been switched on.	BCR of 0.13 to 4.18 (Visvikis et al., 2008) and 0.25-2.12 (Robinson et al., 2011). Data from US insurance data suggests that BCR may be towards the lower end of this range.	BCR of 0.47 to 23.47 (Visvikis et al., 2008).	BCR of 0.18 to 6.56 (Visvikis et al., 2008).

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A.5 Lane Change Assistance (LCA)

Lane change assistance (or alert) systems warn the driver when it is unsafe to change lanes. The system will not take any direct action to prevent a possible collision; hence the driver remains responsible for the safe operation of the vehicle.

A.5.1 Description of the Problem

Lane change accidents

These comprise accidents that occur as a result of a lane change manoeuvre, usually because the vehicle changing lanes has failed to detect another vehicle occupying or approaching in the adjacent lane.

Visvikis et al. (2008) used GB data to identify accidents in the LCA target population. This sample was verified and adjusted by comparing accidents in the high-level, in-depth data with a sub-set of in-depth cases in the On-The-Spot (OTS) database. This process allowed the target population to be estimated for Great Britain. This methodology was also applied to German national data (with verification from in-depth GIDAS data) and the results scaled up to the European level.

This yielded the following EU27 casualty estimates for the LCA target population and shows that the main casualty target populations are for passenger cars (see Table A-16):

Table A-16: Target population for LCA

Equipped vehicle type	Casualty severity	Estimated benefit – number of casualties							
		Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	0	52	11	189	45	230	56	471
	Serious	199	2,196	146	1,323	711	3,877	1,056	7,396
	Slight	3,472	15,424	5,242	23,982	5,629	20,638	14,343	60,044
M2/M3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	11	0	15	0	51	0	77
	Slight	90	393	86	419	98	399	274	1,211
N2/N3	Fatal	0	23	0	45	11	114	11	182
	Serious	0	11	99	788	25	568	124	1,367
	Slight	84	489	2,518	14,895	163	648	2,765	16,032

A.5.2 Potential Mitigation Strategies

LCA is a system which monitors the area around the vehicle during a lane change manoeuvre and issues a warning if certain criteria are met. These criteria usually relate to the proximity of other vehicles in the driver's intended lane of travel. The system will not take any direct action to prevent a possible collision; hence the driver remains responsible for the safe operation of the vehicle. Highly capable systems will warn the driver when another vehicle is adjacent to theirs and when another vehicle is approaching from the rear. However, less capable systems may provide warnings when there is a vehicle already in the lane adjacent to the car: blind-spot warning systems.

Most lane change assistance systems are based around radar sensors to detect the presence of other vehicles, although camera, infra-red and ultra-sonic sensors may also be used. Two-stage warnings are usually recommended in the literature: the first stage is reserved for cautionary warnings where there is a low likelihood of a collision. The second stage is a separate warning where there is a high likelihood of an imminent collision. Visual, audio or haptic warnings may be issued; however, visual warnings are recommended for low priority information only because they depend on the driver looking at the warning display. In contrast, auditory warnings and haptic warnings can attract the driver's attention irrespective of where they are looking and are therefore suitable for warning of imminent collisions. There are no standards on the type of feedback given and this may lead to inconsistencies between vehicles.

Most of the research on lane change collisions was carried out in the United States, where lane change collisions account for around 5% of all Police-reported crashes using the General Estimates System (Svenson et al., 2005). Comparable statistics for Europe are not currently available, but a similar situation could exist. While this would represent a relatively small proportion of the overall crash population, lane change assistance systems are available as an option on a range of current vehicles, and the blind-spot warning functionality (i.e. when a vehicle is already in the blind-spot, rather than approaching from the rear) requires fewer sensors.

In the absence of data from the real world, researchers often make assumptions about the potential effectiveness of these systems. These assumptions are usually derived from the observation that the majority of lane change collisions occur because the driver failed to see another vehicle in the adjacent lane. Since a lane change assistance system will warn drivers of the presence of other vehicles, it is considered that the system will reduce the frequency of these collisions.

Very few field tests and simulator studies in which a lane change assistance system was fitted to a test vehicle have been reported in the literature. Nevertheless, it would appear that there are no adverse effects on lane change frequency, mirror usage or over-the shoulder glances. Some studies observed that there was anecdotal evidence that lane change assistance systems improve driving, either to prevent warnings, or because drivers' awareness of safety during lane change manoeuvres was improved.

A.5.3 Feasibility

The market penetration of LCA systems is currently very low, although it is offered as an option on a range of vehicles. The Road Map Working Group of the eSafety Forum (eSafety, 2005) estimated that if no extra measures were made to accelerate the fitment of these systems, the level of deployment would rise to between 5% and 20% by 2010 and to between 50% and 80% by 2020. However, more pessimistic figures were proposed by Abele et al. (2005), who estimated that just 0.6% of vehicles would be equipped by 2010 with this percentage increasing to 7% by 2020.

At the present time, few vehicles on the road are equipped with lane change assistance and it is only offered as an option by several manufacturers (e.g. Audi, Citroen, Ford, Porsche). It is considered that the current fleet fitment is very low, and probably lower than 1%.

A.5.4 Costs

M1 vehicles

Abele et al. (2005) predicted that the unit cost of a combined lane departure warning and lane change assistance system would be €300 in 2010 and €200 each in 2020.

Visvikis et al. (2008) reported that Blind spot monitoring systems cost around £450 (€576) to the consumer in Europe and $200-$395 (€127-€250) in North America. Current systems are packaged with other lane departure warning or lane keeping systems and consequently the cost of LCA is difficult to disaggregate from the system package cost. For example, Audi offer LCA functionality as part of Lane Assist (which also includes LDW and LKA) for £400 (approximately €480).

Other vehicle types

Little information is available on Lane Change Assistance for other vehicle types. It is considered that the costs are similar to that for M1 vehicles in the absence of any specific information.

A.5.5 Benefits

M1/N1 System effectiveness and casualty benefit

None of the literature reviewed contained LCA system effectiveness values by vehicle type and lane change accident type. The main situation described as relevant to LCA systems are 'side collisions', although the LCA will only be effective in a specific group of these accidents. Visvikis et al. (2008) determined effectiveness ranges of 15%-60% for 'side swipe' collisions (considered the most important group for LCA) and broad ranges of 0%-60% for all other LCA accident types in the target population because of the limited and highly variable information on the effectiveness of systems of this these types of accident. A review of LCA effectiveness failed to identify any more recent studies that would allow further refinement of these effectiveness estimates.

Hummel et al. (2011) estimated that real world accident reduction to be 1.4% of all accidents (based on German insurance data) and could reduce 1.6% of fatal, 1.2% of serious and 3% of slight casualties.

US insurance data from one model indicates that LCA (blind spot detection) resulted in increased frequency of claims (1.3% collision; 95% confidence interval from -1.9% to 4.6%) but reduced frequency of bodily injury liability (-6.2%; 95% confidence interval from -21% to 11.4%), when compared to control vehicles, although these figures were not statistically significant (HLDI 2012a). Results from another model showed virtually no effect on collision frequency (-0.1%; 95% confidence interval -12.4% to 13.8%) or bodily injury liability (-3.6%; 95% confidence interval -50.8% to 54.4%) compared to control vehicles (HLDI 2012b). These results were non-significant and show that there is no clear demonstrated effect to date.

Benefits – Other vehicle types

The target population in terms of accident types that can be addressed by LCA is identical to that for M1 vehicles (see Section C.4.1.1). European estimates for the annual casualty savings (assuming 100% fleet fitment) are presented in Table A-17. These show that the annual casualty benefit for large vehicles is significantly lower than for passenger cars.

Effectiveness – Other vehicle types

No data was identified on the effectiveness of LCA for other vehicle types.

Estimated casualty benefits

Estimates made by Mazda reported by Euro NCAP (n.d.) indicate that about 4% of accidents could be affected by LCA (5% of accidents involve vehicles travelling in the same direction and 80% of these involve a lane change). This is relevant for the main 'side swipe' accident type in the target population.

Visvikis et al. (2008) used GB data to identify accidents in the LCA target population. This sample was verified and adjusted by comparing accidents in the high level, in-depth data with a sub-set of in-depth cases in the On-The-Spot (OTS) database. This process allowed the target population to be estimated for Great Britain. This methodology was also applied to German national data (with verification from in-depth GIDAS data) and the results scaled up to the European level.

This yielded the following EU-27 casualty estimates for the LCA target population and shows that the main casualty target populations are for passenger cars (see Table A-17)

Table A-17: Estimated casualty benefit of fitting LCA system

Equipped vehicle type	Casualty severity	Estimated benefit – number of casualties							
		Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	0	31	2	113	1	138	3	283
	Serious	15	1,318	13	794	14	2,326	42	4,438
	Slight	207	9,254	322	14,389	88	12,383	618	36,026
M2/M3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	7	0	9	0	31	0	46
	Slight	6	236	7	251	3	239	16	727
N2/N3	Fatal	0	14	0	27	0	69	0	109
	Serious	0	7	14	473	0	341	14	820
	Slight	12	294	365	8,937	4	389	380	9,619

C.5.6 Summary and BCR (Benefit:Cost Ratio)

	M1	N1	M2/M3	N2/N3
Benefits (predictive target population, effectiveness)	Visvikis et al. (2008) estimated up to 283 fatal, 4,438 serious and 36,026 slight per annum in EU. Hummel et al. (2011) estimated that real world accident reduction to be 1.4% of all accidents (based on German insurance data) and could reduce 1.6% of fatal, 1.2% of serious, and 3% of slight casualties.		Visvikis et al. (2008) estimated up to 46 serious and 727 slight per annum in EU.	Visvikis et al. (2008) estimated up to 109 fatal, 820 serious and 9,619 slight per annum in EU.
Costs	OEM system costs are unavailable. Consumer costs are difficult to disaggregate from other packaged systems (some of which share hardware etc.). Packaged systems that include LCA are options in range €480-660.	Costs for N1 are assumed to be similar to M1.	Visvikis et al. (2008) reported that Blind spot monitoring systems for M1 cost around £450 (€576) to the consumer in Europe. The same cost was assumed for other vehicle types.	Visvikis et al. (2008) reported that Blind spot monitoring systems for M1 cost around £450 (€576) to the consumer in Europe. The same cost was assumed for other vehicle types.
BCR	BCR of 0 to 0.15 (Visvikis et al., 2008)		BCR of 0.02 to 2.51 (Visvikis et al., 2008).	BCR of 0 to 0.62 (Visvikis et al., 2008).

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A.6 Lane Keeping Assistance (LKA)

LKA monitors the position of the vehicle with respect to the lane boundary and applies a torque to the steering wheel, or pressure to the brakes, when a lane departure is about to occur.

A.6.1 Description of the Problem

Lane departure accidents

These comprise accidents in which a vehicle leaves the lane unintentionally. This is usually because of driver distraction or fatigue and can result in a range of accident configurations:

- Head-on collisions - vehicle leaves its lane unintentionally and collides head-on with oncoming vehicle. These accidents are most likely to occur on single carriageway roads.
- Leaving roadway collisions –vehicle drifts out of the travel lane. These accidents are often single vehicle (can include pedestrians) and may involve impacts with roadside furniture. Other vehicles may be involved, however, because they have been required to react to the initial lane departure event.
- Side-swipe collisions – when the vehicle of interest unintentionally leaves the lane in which they are travelling on a road with multiple lanes, the side of the vehicle of interest could collide with the side of a vehicle that is travelling in an adjacent lane. There is also a possibility of an impact between the front of one vehicle and the rear of the other.

Visvikis et al. (2008) defined target populations based on the three main lane-departure warning accident types and used national data from Great Britain and Germany to estimate the percentage of casualties in each accident type. These target populations were validated by comparing accidents at the national level with in-depth data, with upper and lower ranges defined based on the ability of the national data to correctly identify lane departure relevant accidents. This yielded the following EU27 casualty estimates for the LDWS target population (which is identical to the target population for LKA) and shows that the main casualty target populations are for passenger cars:

Table A-18: EU27 LDWS/LKA target population based on GB/German national and in-depth data (Visvikis et al., 2008)

Equipped vehicle type	Casualty severity	Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	903	5,949	67	612	64	620	1,034	7,181
	Serious	5,773	31,539	1,026	7,530	249	3,197	7,048	42,266
	Slight	21,867	64,838	7,028	19,549	459	1,361	29,354	85,748
M2/M3	Fatal	7	189	0	7	0	5	7	201
	Serious	51	1,045	0	21	0	0	51	1,066
	Slight	338	1,000	27	82	8	23	373	1,105
N2/N3	Fatal	23	111	0	65	0	5	23	181
	Serious	135	615	19	213	3	315	157	1,143
	Slight	404	1,413	184	693	9	42	597	2,148

Identifying the proportion of these accident types for which LKA is an effective countermeasure is difficult because identification of unintended lane departures within these accident types is difficult to identify in the accident data.

Abele et al. (2005) estimated the LDWS target population as 25% of serious and slight casualties and 50% of fatal casualties and then applied estimates for the percentage of these accidents avoided or mitigated. However, this approach did not take into account that not all of the accidents had a causation for which LKA could provide a benefit.

A.6.2 Potential Mitigation Strategies

Lane keeping assistance systems help the driver to stay in their lane and are an advancement of functionality from lane departure warning systems. They function at speeds typically from 65 km/h by monitoring the position of the vehicle with respect to the lane boundary (typically via a camera mounted behind the windscreen sited behind the rear view mirror) and applying a torque to the steering wheel or pressure to the brakes when a lane departure is about to occur. The level of torque varies from system to system. In some cases, the intervention is intended to suggest the corrective action to the driver, without altering the vehicle trajectory. In other cases, the intervention is sufficient to prevent the vehicle leaving the lane. If a deliberate steering input is detected that might be associated with an intended lane departure, or if the indicators are activated, the system deactivates. For some systems, LKA deactivates if no driver steering input is detected over a period of time so that the driver cannot drive using relying on the system to maintain the vehicle in the lane.

LKA systems can typically be switched on and off by the driver and the system retains the last status at the start of the subsequent journey. Therefore, if the driver switches it off, then no benefit is realised. The camera system is used to detect the road boundary markings and so in some circumstances detection can be impaired, for example, in conditions of very low contrast (e.g. driving into glare), or where the road markings are worn or covered by dirt, debris or snow. The camera is sited in a location within the windscreen swept area in order to keep the sensor view unobstructed, but performance of the system is dependent on windscreen condition.

A.6.3 Feasibility

The market penetration of lane change assistance systems is currently low because very few vehicles are equipped with lane keeping assistance and when it is offered it is as an optional extra. However, systems are offered currently by many of the major manufacturers: e.g. Audi, BMW, Ford, Toyota, VW, Skoda, Honda, Lexus etc. but the actual uptake of the optional extras is unknown, but is assumed to be low because the optional packages that contain this feature are expensive.

A.6.4 Costs

M1/N1 vehicles

LKA are generally optional systems and are typically packaged with other related systems. For example, Ford offer LKA packaged with LDW, Traffic sign recognition, Driver Alert and Auto High Beam for £550 (approximately €660) as a cost to the consumer. Other manufacturers offer lane departure warning functionality as part of a more advanced lane keeping system. For example, Audi offer LDW functionality as part of Lane Assist (which also includes LKA) for £400 (approximately €480) cost to the consumer.

Other vehicle types

Little information is available on LKA for other vehicle types. It may be the case that LKA is even less common on M2/M3 and N2/N3 because LKA requires electronic power-assisted steering to provide the torque inputs which is less often present on large vehicles.

A.6.5 Benefits

System effectiveness and casualty benefit

Since LKA systems act to maintain the vehicle in the lane, they provide an improvement to LDWS which only warn of the lane departure, and may not provide the warning until the point of line crossing, or even just after (the threshold in the ISO standard is within 0.3m of line crossing) at which point, with the required reaction time of the driver, it may be impossible to avoid the accident.

Lane support systems rely to a large extent on the presence of road markings, although some systems are capable of detecting road edges without lane markings. However, in the majority of cases, performance (and subsequent benefits) will be negatively affected by missing, worn or obstructed line markings. Road markings are already required on European roads (although the types of marking differ between countries). If regulated, systems should be able to detect any road line marking system and the benefits attainable could be affected by levels of maintenance of the road lines within each country.

As part of the EuroNCAP rewards, car manufacturers predicted that LKA systems could be effective in approximately 50% of all lane departure accidents that result in fatal or serious injury. This effectiveness is comparable with the upper effectiveness estimates made by TRL for LDW/LCA systems (Visvikis et al., 2008). This equates to over 3,500 EU fatalities and over 17,000 serious casualties per annum in the European Union.

Retrospective insurance data from US shows some evidence for increased average claim rates for some equipped vehicles, although the 95% confidence intervals for collision frequency and property damage spans zero (HDLI, 2012). Bodily injury liability shows marginal deceases (-2.8%) but the confidence intervals were very wide (-56.7% to 118.3%) (HLDI, 2012). For this data, whether the driver had switched the LKA off is unknown, so the benefit might be accurate or considerably underestimated.

Drivers' acceptance of lane keeping assistance could be a barrier to implementation (or continued activation) of these systems while they remain an optional feature. Driver's acceptance in the long term is likely to be influenced by their perception of the benefits to their safety.

A.6.6 Other vehicle types (N1, N2, N3, M2, M3)

For other vehicle types, the system functionality and target populations are the same as passenger cars. Fitment of LKA is much lower on other vehicle types, although it is an option on some N1 vehicles (e.g. Ford Transit). The effectiveness of the system is expected to be comparable for these vehicle types and may even be greater for N2, N3 vehicles where the driver may undertake more long journeys on main roads.

Estimated casualty benefits

The effectiveness of LKA is considered to be greater than LDW because the system takes action to prevent the departure event, providing of course it is active and the speed of the vehicle means the system is active. Therefore, the casualty benefit of LKA is likely to be towards the upper range of the estimate made for LDWS. Visvikis et al. (2008) estimated the annual casualty benefits for LDWS in Europe as follows:

Table A-19: Estimated casualty benefit of fitting LDW system

Equipped vehicle type	Casualty severity	Estimated benefit – number of casualties							
		Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	144	2,856	11	294	10	298	166	3,447
	Serious	693	12,249	123	3,391	30	1,468	846	17,108
	Slight	1,531	15,232	492	6,718	32	359	2,055	22,309
M2/M3	Fatal	1	91	0	3	0	3	1	96
	Serious	6	399	0	9	0	0	6	408
	Slight	24	222	2	27	1	6	26	255
N2/N3	Fatal	4	53	0	31	0	3	4	87
	Serious	16	233	2	88	0	147	19	468
	Slight	28	300	13	181	1	9	42	490

EuroNCAP is planning to assess LKA systems from 2016 and this action might be expected to result in an increase in voluntary fitment.

A.6.7 Summary and BCR (Benefit:Cost Ratio)

	M1	N1	M2/M3	N2/N3
Benefits (predictive target population, effectiveness)	OEMs predict up to 5,000 fatalities and 40,000 serious casualties per annum in EU. Visvikis et al. (2008) estimated up to 3,447 fatal, 17,108 serious and 22,309 slight per annum in EU.		Visvikis et al. (2008) estimated up to 96 fatal, 408 serious and 255 slight per annum in EU.	Visvikis et al. (2008) estimated up to 87 fatal, 468 serious and 490 slight per annum in EU
Costs	OEM system costs are unavailable. Consumer costs are difficult to disaggregate from other packaged systems (some of which share hardware etc.). Packaged systems that include LKA are offered as an option for €480-€660.			
BCR	1.7-2.1 predicted by European studies (COWI and Abele et al.) TRL research predicted BCR of 0.13 to 4.18. Greater effectiveness of LKA (compared to LDW) may result in BCR being towards upper range of estimate.	TRL research predicted BCR of 0.13 to 4.18. Greater effectiveness of LKA (compared to LDW) may result in BCR being towards upper range of estimate	TRL research predicted BCR of 0.47 to 23.47. Greater effectiveness of LKA (compared to LDW) may result in BCR being towards upper range of estimate	TRL research predicted BCR of 0.18 to 6.56. Greater effectiveness of LKA (compared to LDW) may result in BCR being towards upper range of estimate

A.6.8 References

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A.7 Pedestrian/Cyclist Detection

Sensing to detect the presence of pedestrians/cyclists in the path or periphery of the vehicle that can be used to provide a warning signal and/or can be linked to automatic braking functionality.

A.7.1 Description of the Problem

Pedestrians comprise over 21% of EU27 fatalities and in 2011 there were over 6,500 pedestrian fatalities in Europe (EC, 2013). In the same period, there were over 2,000 cyclist fatalities, comprising over 8% of all EU27 fatalities (EC, 2013). The majority of pedestrian and cyclist casualties occur in urban areas and over 80% result from collisions with motor vehicles (cars, lorries, and buses).

In urban areas, one of the major accident types for these road users, especially for cyclists, are accidents with N2/N3 vehicles where there is a conflict during a turning manoeuvre. Statistics from London (GB) show that over 50% of cyclists killed or seriously injured occurred when an HGV was turning or changing lanes with the vulnerable road user on its nearside (TfL, 2014). This mechanism is encouraged because a driver intending to carry out a turn manoeuvre typically positions the vehicle so as to allow sufficient room to carry out the turn. This creates a more inviting gap for Vulnerable Road Users and encourages cyclists to travel up the inside of the vehicle. For pedestrian accidents however, the pattern is different, with just over 20% of fatal or seriously injured vulnerable road users associated with turning or changing lanes and the majority of fatal or serious casualties occurring where the HGV was 'going ahead other'.

There are several issues here: firstly, an N2/N3 vehicle may have direct and indirect visibility blind spots, meaning that, especially in waiting traffic, a cyclist may encroach very close to the side of the vehicle unseen prior to a turning manoeuvre. Vulnerable road users may also walk across, or position themselves directly in front of an N2/N3 vehicle when it is stationary, either to cross the road, or wait for the traffic to move again. Secondly, the driver may not have detected the vulnerable road user arriving alongside in close proximity because of the large information burden from the complex urban environment and/or because of lack of attention or distraction. Although N2/N3 vehicles are now equipped with six mirrors to the 2007/38/EC directive, including wide angle, close proximity nearside and front mirrors, the successful detection of a vulnerable road user is dependent on these mirrors being correctly adjusted and on the driver using them correctly.

For car accidents, the majority of accidents also occur in urban areas; the typical impact speeds are around 48 km/h and often occur near crossings or cycle lanes because the risk of interactions between traffic and vulnerable road users is increased at these locations. Studies consistently show that the vast majority of accidents involve a pedestrian moving perpendicular to the path that of the vehicle (e.g. Wisch et al., 2013, Moxey et al., 2005). The pedestrian target population for Europe has been identified as follows:

Table A-20: Total pedestrian casualties by severity for EU27 excluding Bulgaria and Lithuania average per year 2008-2010 (Edwards et al., 2013)

Casualty severity	2008	2009	2010	2008-10 average
Fatal	7,653	6,640	6,016	6,770
Injured (serious & slight)	163,748	156,072	149,788	156,536
Serious	42,590	39,393	37,005	39,663
Slight	121,158	116,679	112,783	116,873
Total	171,401	162,712	155,804	163,306

A.7.2 Potential Mitigation Strategies

Pedestrian and cyclist casualties could be prevented or mitigated by:

- Improvements with respect to the separation of vulnerable road users from traffic and the visibility and signage of such facilities to road users (e.g. improved crossings and cycle lanes).
- Safety systems that scan the key areas around sides and in front of large vehicles and provide driver alerts to warn the driver of the presence of vulnerable road users.
- Improvements in visibility (both direct and indirect) or sensing technologies on large vehicles aimed at addressing cyclist casualties that occur on the nearside of the vehicle during a low-speed turning manoeuvres or in front of the vehicle cab for N2/N3 vehicles.
- An in-vehicle pedestrian/cyclist detection system that uses exterior sensing (infra-red, camera, radar etc.) to detect, characterise and track vulnerable road users in relation to the vehicle. This functionality can be used to provide the driver with a warning and/or can be linked to AEBS so that the accident can be avoided or mitigated.

A.7.3 Feasibility

Pedestrian detection and night vision systems are currently fitted by approximately 5% of manufacturers: BMW, Mercedes-Benz, and Audi. These systems typically use infra-red sensing which may be linked with other data, for example radar and camera data to detect and track pedestrians. These systems are offered as optional systems. Volvo currently offers a pedestrian AEBS on the Volvo V40, S60, V60, XC60, V70, XC70 and S80 models (system was launched in May 2013); some current AEBS systems may detect cyclists, but they are not specifically designed to do so.

The functionality of warning and automatic braking could be linked to other systems that may already be on the vehicle, such as FCW or AEBS. In this respect, adding pedestrian functionality to an AEBS system is another step in the development of this system type but requires additional sensors (the Volvo system uses radar and camera) and additional processing of the sensed information. Therefore, the costs of pedestrian systems are greater than that of standard AEBS.

Two test procedures for pedestrian AEBS have been developed by the European AsPeCSS project (www.aspecss-project.eu) and may be used in the future by Euro NCAP. It should be noted that if either methodology is adopted by Euro NCAP, further work would be required (e.g. by other research initiatives or the Euro NCAP Primary safety group) to develop and verify the detailed aspects of the procedure and rating system.

Encouragement of such systems using consumer information schemes may be an effective way of increasing system fitment, but it is not clear how effective this will be at improving standard (as opposed to optional) fitment, especially due to the high system costs.

For large vehicles, warning systems (for example ultrasonic or camera detection systems) are available as retrofit systems and are currently fitted to some commercial fleets.

A.7.4 Costs

Current costs (to the consumer) for pedestrian detection/night vision average over €2,400.

A.7.5 Benefits

Edwards et al. (2013) reported on benefits of three car pedestrian systems (with AEBS functionality) from research carried out by the European Aspecss consortium:

- Current generation AEB pedestrian systems 2013+.
    - This system is representative of current systems.
- Second generation AEB pedestrian systems 2018+
    - This system is representative of a future system with performance estimated using expected improvements in system component performance such as sensor performance and brake ramp.
- Reference limit AEB pedestrian system 2023+
    - This system is representative of a system that has the greatest performance technically feasible.

This analysis (based on in-depth data from GB and Germany) found that current AEB systems could reduce fatal pedestrian casualties by 2.9-6.2%, serious casualties by 4.2-4.4% and slight casualties by 2.2-4.4% (Edwards et al. 2013). An analysis by Hummel et al. (2011), predicted more optimistic casualty reductions of 21% for fatal, 15% for serious, and 44.5% for slight casualties in accidents involving cars and pedestrians.

Edwards et al. predicted improved benefits for second-generation systems and these estimates were scaled to EU27 level and are presented in the following tables.

Table A-21: Estimated GB pedestrian casualty reductions for current and future AEB Systems (Edwards et al., 2013)

System (Baseline calculation)	Benefit compared to 'no AEB system'				
	Fatal	Serious	Slight	Avoided	Value £(m)
Current generation 2013+	31 (6.2%)	234 (4.2%)	463 (2.2%)	728	£119
	(13-61)	(97-441)	(107-873)	(218-1,375)	(£49-£229)
Second generation 2018+	69 (14.1%)	495 (8.8%)	747 (3.6%)	1,311	£255
	(31-102)	(224-766)	(319-1,550)	(574-2,418)	(£115-£394)
Reference limit 2023+	98 (19.9%)	762 (13.6%)	1,532 (7.3%)	2,392	£385

System	Benefit compared to 'no AEB system'				
	(45-123)	(341-981)	(634-2,513)	(1,019-3,616)	(£172-£501)

Table A-22: Estimated German pedestrian casualty reductions for current and future AEB Systems (Edwards et al., 2013)

System (Baseline calculation)	Benefit compared to 'no AEB system'				
	Fatal	Serious	Slight	Avoided	Value £(m)
Current generation 2013+	17 (2.9%)	374 (4.6%)	1,034 (4.4%)	1,424	€63
	(7-36)	(137-792)	(331-2,381)	(474-3,208)	(€24-€135)
Second generation 2018+	39 (6.7%)	788 (9.7%)	2,006 (8.6%)	2,833	€136
	(16-60)	(310-1,271)	(681-3,191)	(1,006-4,522)	(€54-€218)
Reference limit 2023+	57 (9.9%)	1,281 (15.8%)	3,455 (14.8%)	4,792	€216
	(23-73)	(497-1,673)	(1,250-4,598)	(1,771-6,344)	(€85-€282)

Table A-23: Estimated annual benefit of pedestrian AEB system for EU27 excluding Bulgaria and Lithuania (estimated by scaling GB and German benefit estimates) (Edwards et al., 2013)

Pedestrian AEB system	Monetary value (€ Billion, i.e. €*109)					
	GB			Germany		
	Pessimistic	Nominal	Optimistic	Pessimistic	Nominal	Optimistic
Current generation 2013+	€ 0.46	€ 1.09	€ 2.11	€ 0.31	€ 0.82	€ 1.77
Second generation 2018+	€ 1.07	€ 2.38	€ 3.61	€ 0.70	€ 1.78	€ 2.84
Reference limit 2023+	€ 1.59	€ 3.51	€ 4.50	€ 1.10	€ 2.81	€ 3.66

Benefits for other vehicle types have not been well studied and require further analysis, but pedestrian and cyclist collisions with larger vehicles tend to be associated with low speed manoeuvres and so more specific, targeted solutions may be more appropriate (e.g. presence sensors, improved direct/indirect visibility).

It is unknown how well current systems (either pedestrian or standard AEBS systems) detect cyclists.

A.7.6 Benefit:Cost Ratio

The 'central estimate' of the most recent and most detailed research on the topic predicted annual EU27 benefits for current pedestrian AEB systems from about €1 billion to about €3 billion. This assumed all cars had AEB systems with a similar performance to current systems.

No detailed cost benefit studies on pedestrian AEBS were identified in this study and the break-even cost for benefits of this order of magnitude are well above the current system costs, even though the available cost information is for consumer costs (not OEM cost).

The benefit-to-cost ratio (based on the currently available cost data) is considered to be less than 1, although the magnitude of the absolute casualty benefit is very high. Pedestrian AEBS systems may share hardware and software with other systems (e.g. AEBS) and therefore the additional cost of pedestrian AEBS may not be as great as current figures. Hardware costs are expected to reduce over time. Further research is required to identify the manufacturer cost estimates for system fitment so that an accurate assessment can be made on the true benefit-to-cost ratio to realise the potentially very large casualty savings.

It is recommended that the costs and real-world effectiveness of pedestrian AEBS are monitored, along with the (standard) fitment rate resulting from Euro NCAP assessment and the subsequent effect on system cost.

No information on benefit-to-cost ratio was found for N2/N3 detection systems. However, it seems likely that the cost of simple detection systems (e.g. ultrasonic sensors) would be low. Cost associated with integrating the system into the vehicle and ensuring the warning is delivered effectively would be greater. Systems that use camera detection are likely to be more expensive, but no data was found on the relative benefits of these systems other than statements that these are very effective.

A.7.7 References

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A.8 Traffic Sign Recognition (TSR)

Systems that inform the driver via an in-vehicle display about applicable traffic signs such as speed limits, restrictions, and warnings.

A.8.1 Description of the Problem

Traffic signs setting out speed limits, restrictions (e.g. overtaking ban, stop, no-entry) and warnings (e.g. sharp bend) assist drivers in manoeuvring safely in road traffic. High workload or sensory overload can lead to individual traffic signs being disregarded unintentionally (because they are either not detected or detected but forgotten) or intentionally, both of which can result in a safety hazard. The main accident causes with a potential relation to neglected traffic signs might be excess speed, overtaking in no-overtaking zones and wrong-w7ay driving.

Exceeding the applicable speed limit can be an important contributory factor to road accidents of almost any typology. Details can be found in Section C.3.1 and, in the interest of space, are not repeated here in full. It is estimated that typically 40% to 60% of EU drivers exceed the speed limit (DaCoTA, 2012). Excess speed has been assumed in the past to be at least a contributory factor to circa 30% of fatal crashes (TRB, 1998), which leads to the crude casualty estimate given in Table A-24. However, excess speed does not necessarily mean a posted speed limit has been exceeded, but can also refer to speed not being adapted to adverse environmental conditions.

Table A-24: Estimate of EU-27 car occupant fatalities in connection with excess speed (at least contributory factor)

	Total number of EU-27 car casualties	Percentage in connection with excess speed	EU-27 casualties in connection with excess speed
Killed	12,850 (CARE, 2012)	30% (TRB, 1998)	3,855
Injured (slightly or severely)	913,297 (Geissler et al., 2012)	unknown	unknown

Overtaking in no-overtaking zones might be a second accident cause related to neglecting traffic signs, although the available data on this topic is very scarce. The casualty numbers of accidents where at least one car was involved in an overtaking manoeuvre for the UK are detailed in Table A-25.

Table A-25: UK car occupant casualties in overtaking manoeuvres in 2009 (RoSPA, 2009)

	Total number of UK car casualties	Percentage involved in overtaking	UK casualties involved in overtaking
Killed	1,432	5.6%	80
Seriously injured	11,535	4.2%	484
Slightly injured	148,466	2.6%	3,853

Unfortunately, this data is not available on a European level. If the percentage across Europe was identical to the UK, numbers as detailed in Table A-26 could be derived for EU-27. Please note that these numbers can only be regarded as a crude estimate and that not all of the accidents from the original data occurred in no-overtaking zones (the proportion is not known).

Table A-26: Estimate of EU-27 car occupant casualties in overtaking manoeuvres

	Total number of EU-27 car casualties	Estimated percentage involved in overtaking	Estimated EU-27 casualties involved in overtaking
Killed	12,850 (CARE, 2012)	5.6%	718
Injured (slightly or severely)	913,297 (Geissler et al., 2012)	2.7%	24,756

Statistics on casualties caused by wrong-way driving are not collected in many European countries, which makes it impossible even to estimate a specific number. The frequency of wrong-way driving is considered low compared to other offences. The consequences of resulting collisions, however, are often severe because of the high closing speeds involved in head-on collisions on dual carriageways or motorways (SWOV, 2009). Gerlach and Seipel estimate that about 0.2% of all injury accidents on German motorways (i.e. about 35 to 40 accident each year) are caused by wrong-way driving (Gerlach and Seipel, 2012). The numbers can be expected to vary considerably across countries due to differences in the road infrastructure, such as different layout and markings of motorway slip roads or toll booths on motorway exit roads preventing motorists from mistakenly entering in some countries (e.g. France and Italy). The numbers from Germany can therefore not be transferred to other countries. An unknown proportion of wrong-way driving offences are committed deliberately by people seeking excitement or as a method of committing suicide.

The TRACE EU project produced an estimate of the overall target population for TSR systems in passenger cars, i.e. the maximum proportion of casualties that could be prevented by a system that is fitted to 100% of cars and effective in 100% of relevant cases (Pappas et al., 2008). To determine the target population the data were filtered for accidents which were either attributed to disregarding a stop or give-way sign, or were caused by exceeding a posted speed limits. The numbers were based on an analysis of in-depth accident data from the GIDAS database, hence apply to German traffic conditions. If the percentage across Europe was identical to Germany, numbers as detailed in Table A-27 could be assumed for EU-27. Note that these numbers can only be regarded as a crude estimate and include, for example, all accidents that have been caused by exceeding a posted speed limit, but no accidents due to ignoring an overtaking ban or wrong-way driving. These numbers are considered very high by the present author.

Table A-27: Maximum target population for TSR based on (Pappas et al., 2008); please note the broad base assumptions discussed in the text

	Total number of EU-27 car casualties	Relative casualty target population for TSR	Estimated EU-27 casualty target population for TSR
Fatally or severely injured	unknown	5.82% (Pappas et al., 2008)	unknown
All injured (slightly, severely or fatally)	926,147 (CARE, 2012), (Geissler et al., 2012)	10.54% (Pappas et al., 2008)	97,616

A.8.2 Potential Mitigation Strategies

In-vehicle systems capable of detecting and recognizing road signs are commonly referred to as Traffic Sign Recognition (TSR) or road sign detection/ recognition systems. The systems detect and identify traffic signs placed alongside the road or on overhead gantries. Modern systems are capable of detecting not only speed limit signs but also other restrictions and warnings, such as overtaking bans, stop signs, no-entry signs and general hazard warnings. Most commonly, the traffic signs are displayed to the driver in the dashboard or heads-up display until limits are changed or restrictions lifted. Apart from just displaying the identified traffic sign to the driver, additional strategies are conceivable which can be expected to influence the effectiveness in improving safety:

- Issue a warning if a limit or restriction is disregarded (e.g. ISA systems); or
- Use the information to adapt the warning and intervention strategies of other safety systems (Pappas et al., 2008).

TSR systems rely on an in-vehicle camera and image recognition technologies to detect and identify traffic signs. Infrastructure changes are not required for TSR systems, although a range of different traffic signs need to be recognised by the system in different countries. The systems might be coupled with information about the specific road environment stored in the navigation system.

With the aim to reduce the frequency of exceeding speed limits, TSR systems are often combined with Intelligent Speed Adaptation (ISA) systems, i.e. are not only indicating the applicable speed limit but also putting it into relation to the speed currently driven (for these systems please refer to Section C.3.1). ISA systems, in their least intrusive implementation, issue a visual and/ or audible warning to the driver when the applicable speed limit is being exceeded; more intrusive implementations limit the maximum vehicle speed.

By displaying overtaking bans permanently to the driver, signs which have not been detected or forgotten might be brought to the driver’s attention and hence a reduction of the frequency of overtaking in no-overtaking zones and associated accidents might be expected.

Similarly, wrong-way driving, for example when entering motorways, might be mitigated to a certain extent by displaying no-entry signs to the driver and bringing wrong-way driving to their attention by issuing a warning if these signs are passed.

A.8.3 Feasibility

TSR systems are already offered in production cars to end users. The first systems were introduced in 2008 in higher segment cars. Since then, systems have become available as optional extras on many models across almost all vehicle segments, even compact cars. Many tier one suppliers were identified during this study offering TSR solutions to OEMs.

The systems on the market are based on front-facing cameras mounted behind the windscreen. Image recognition software detects and recognises traffic signs from the footage of the road scene in front of the vehicle. Several systems also rely on a database of speed limits and other restrictions stored in the map data of the navigation system and only use the optical road side recognition to correct errors in the database or to cover temporary restrictions, e.g. during road works. The recognised signs are displayed to the driver, most commonly within the multifunctional dashboard display or in a head-up display if present.

Modern systems are capable of detecting speed limits signs, no-overtaking signs, do not enter signs and some other restrictions (Daimler, 2014). Some systems are advertised to work with different traffic sign designs across the whole of Europe and to work even at high speeds of up to 250 km/h (Mobileye, 2011).

The reliability of TSR systems is considered high enough by manufacturers to offer them in production vehicles to their customers and is usually advertised as being 'high'. No published quantitative data could be identified to specify the reliability, in particular under difficult conditions. Anecdotal evidence found on the internet and the fact that improving the reliability of TSR systems is still a frequently covered topic in the research community give an indication that improvements are still possible and necessary to increase user acceptance (Schram et al., 2013). There are no principal technical reasons that should prevent these improvements from being made in the near future.

Standardised test procedures and sets of requirements that could be potential sources for legislation are scarce. UN Regulation No. 89 on speed limitation devices only covers manually adjustable devices and does not deal with traffic sign recognition (UNECE, 2011). Euro NCAP included speed assist systems in their assessment protocol in 2009 (please note that Euro NCAP only deals with speed limits, i.e. no other hazard signs). The least intrusive form of these systems is simply providing information regarding the current speed limit, which can be based on roadside recognition of traffic signs or map data coupled with the navigation system. Requirements regarding this 'Speed Limit Information Function' are defined in the Section 4.4 of the Assessment Protocol Safety Assist (Euro NCAP, 2013); a test procedure is defined in Section 4 of the corresponding test protocol (Euro NCAP, 2012).

The requirements are basic rules regarding the display and design of speed limit information to the driver (e.g. has to be in direct field of view of the driver). The test procedure appears to be a test of the system's functionality rather than its accuracy and cannot be considered suitable as a performance requirement for legislation. It consists of a test drive exceeding 100 km on public roads (not further defined) in manual and cruise control mode and noting any major discrepancies (not further specified) between sign posted and indicated speed limit. Different traffic sign designs across European countries are not tested. Warning requirements shall be checked during the test drive in areas "where it allows safe driving". Note that this test appears to require exceeding the speed limit on public roads unless a long stretch of closed public road with current signs in normal condition is available.

Schram et al. (2013), who were involved in designing the test protocol, suggest in their paper that this form of testing has problems attached to it but had to be chosen considering financial limitations. Vehicle-in-the-loop tests could be investigated and might be an affordable option in the future to perform more extensive tests (Schram, et al., 2013).

The public acceptability of TSR systems can be expected to be very high. Studies researching the more intrusive ISA systems have found that these would be accepted by approximately 60-75% of drivers (DaCoTA, 2012). Although no studies could be identified looking into the TSR function separately it seems reasonable to expect that the acceptance of this less intrusive measure would be even higher. The reliability and accuracy of the system is expected to influence the attitude of driver’s towards it.

A.8.4 Costs

The exact level of current manufacturer costs of TSR systems is unknown and consumer costs are often reported for packages including several systems sharing parts of the required sensors. For example, Ford offer lane departure warning packaged with LKA, Traffic Sign Recognition, Driver Alert and Auto High Beam for £550 (approximately €660). To get from consumer costs to an estimate of manufacturer costs a common approach suggested by FESTA (Malone et al., 2008) is to apply a factor of 1/3. Considering the costs of the other systems offered in the package, current manufacturer costs for TSR systems can be expected to be below €200. In case of mandatory fitment, economies of scale and accelerated innovation could be expected to reduce prices further.

A.8.5 Benefits

Only very limited research into the effectiveness of TSR systems could be identified. The TRACE EU research project did not provide quantitative results apart from an estimate of the potentially affected target population (see Section C.8). The researchers commented, however, that the expected effectiveness is low since drivers were usually well aware of traffic signs (Pappas et al., 2008). This general statement can be called into question based on research by Möri et al., which found that 42% of speed limit signs are only partially and 28% not at all recognized (Möri and Abdel-Halim, 1981).

Isogai et al. performed a driving simulator study with 24 participants to analyse the effect of TSR on speed keeping behaviour (Isogai et al., 2009). TSR was found to change the speed keeping behaviour of drivers, although only in situations where they were unsure about the correct speed limit. The researchers did not quantify the magnitude or significance of these results. Note that the simulated system did not provide a warning when the speed limit was exceeded.

Apart from this study, potential reductions in speeding were mainly investigated in combination with an ISA function, because the systems are usually offered in combination. The effectiveness of ISA systems is discussed separately in Section A.3. The effectiveness of the less intrusive TSR systems can be expected to be lower. The potential target population, however, is larger because violations such as overtaking under overtaking-ban or wrong-way driving are also addressed.

A.8.6 Benefit:Cost Ratio

Due to the lack of research findings on the quantitative effectiveness of TSR systems (without ISA function) a benefit-to-cost ratio cannot be estimated by TRL. It is expected to be somewhat lower than ISA systems (Section A.3) because the cost of both systems is expected to be similar (using the same hardware), but the effectiveness of TSR in reducing speeding is expected to be smaller.

TSR systems offer certain possibilities for technology sharing: Apart from ISA systems, the required front-facing windscreen camera might be shared with LDW or LKA systems. There might also be a certain potential for sensor sharing with camera-based AEB systems, which require higher resolution cameras. Map data from satellite navigation systems can support the road side recognition of traffic signs to determine the applicable speed limit or other restrictions. Head-up displays, if available, can be used to display traffic sings to the drivers.

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Annex 3.1 Night Vision Systems

Night vision systems are designed to prevent accidents by increasing the detection performance of critical objects such as pedestrians, cyclists, animals, vehicles, and other objects in night, low light or low visibility conditions (i.e. fog).

Annex 3.1.1 Description of the Problem

Poor visibility is estimated to be a factor in 42% of all traffic collision (OECD, 2003), whilst 1.4% of fatal accidents happened in foggy or mist weather conditions in EU19 in 2006 (SafetyNet, 2008).

Annex 3.1.2 Potential Mitigation Strategies

Night vision systems are designed to prevent accidents by increasing the detection performance of critical objects such as pedestrians, cyclists, animals, vehicles, and other objects in night, low light or low visibility conditions (i.e. fog).

The systems use these data sources to either display the data to the driver, for them to decide what action to take, or intelligently analyse the data and warn the driver of a potential collision. If linked to an AEB system, braking or manoeuvres could be activated automatically even in low light conditions; however this functionality will be covered in the section on AEB systems.

Night vision systems are already available in vehicles (as an optional extra). In general, only infrared is commonly considered night vision, however, other detection systems that can detection objects in low light will also be considered.

Current night vision systems are based on; Infrared (which can be further subdivided into near- and far- infrared: NIR or FIR respectively), Radar, or Lidar. Multiple systems can be fitted to a vehicle.

The different sensors have varying capabilities; the MOSARIM project[8] under the European Commission Seventh Framework Programme detailed the Performance indicators, environmental influences, electromagnetic influences and other concerns such as eye safety, for a range on sensing technologies and sub types. The results of this study are presented below (Figure A-2 to A-5):

[8] https://assrv1.haw-aw.de/mosarim/index.php/sensing-technologies

Key: = good performance = fair performance = bad performance

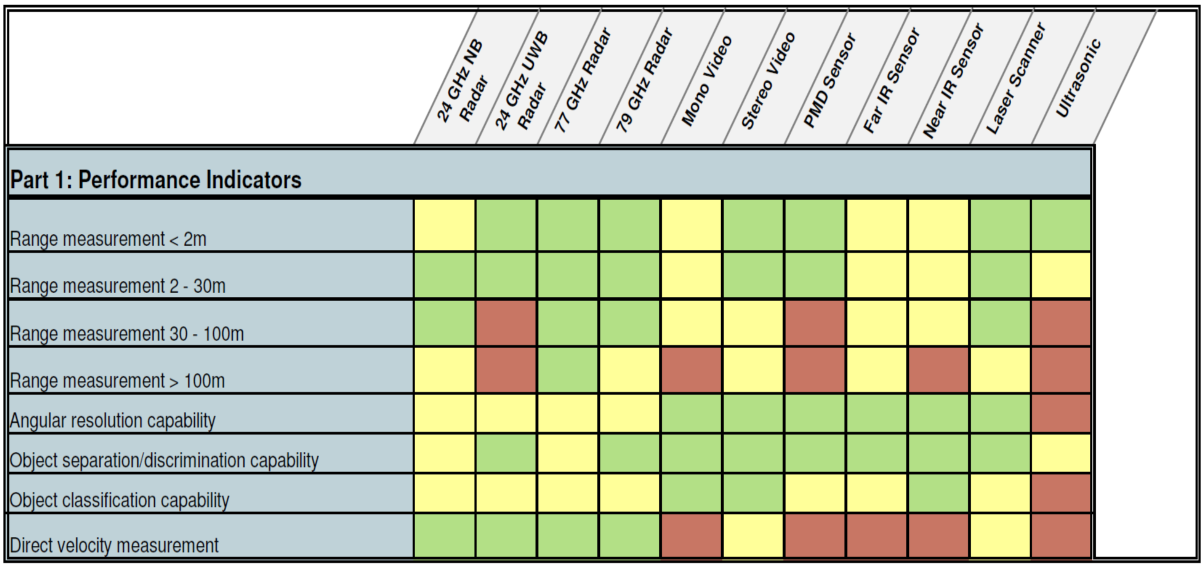

Figure A-2: Sensor technical comparison: performance indicators (MOSARIM Consortium, 2012)

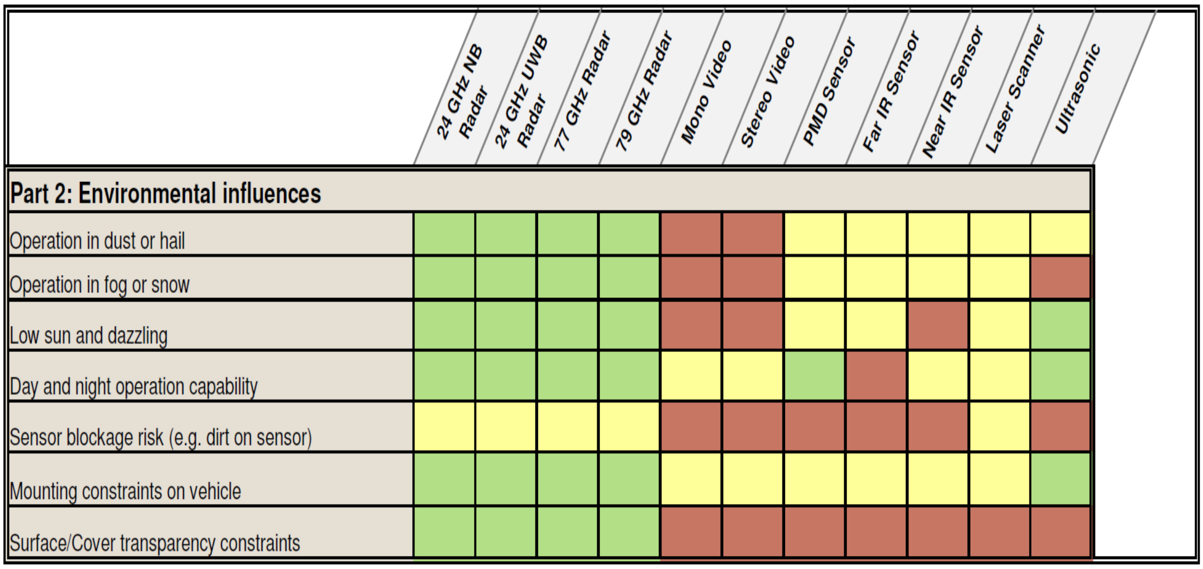

Figure A-3: Sensor technical comparison: Environmental influences (MOSARIM Consortium, 2012)

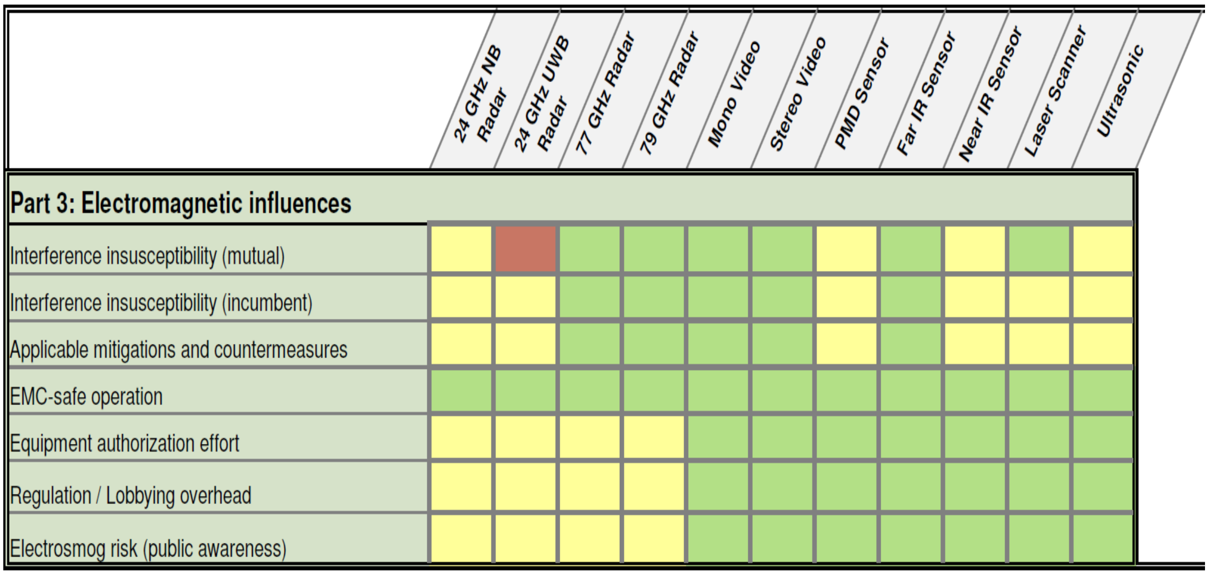

Figure A-4: Sensor technical comparison: Electromagnetic influences (MOSARIM Consortium, 2012)

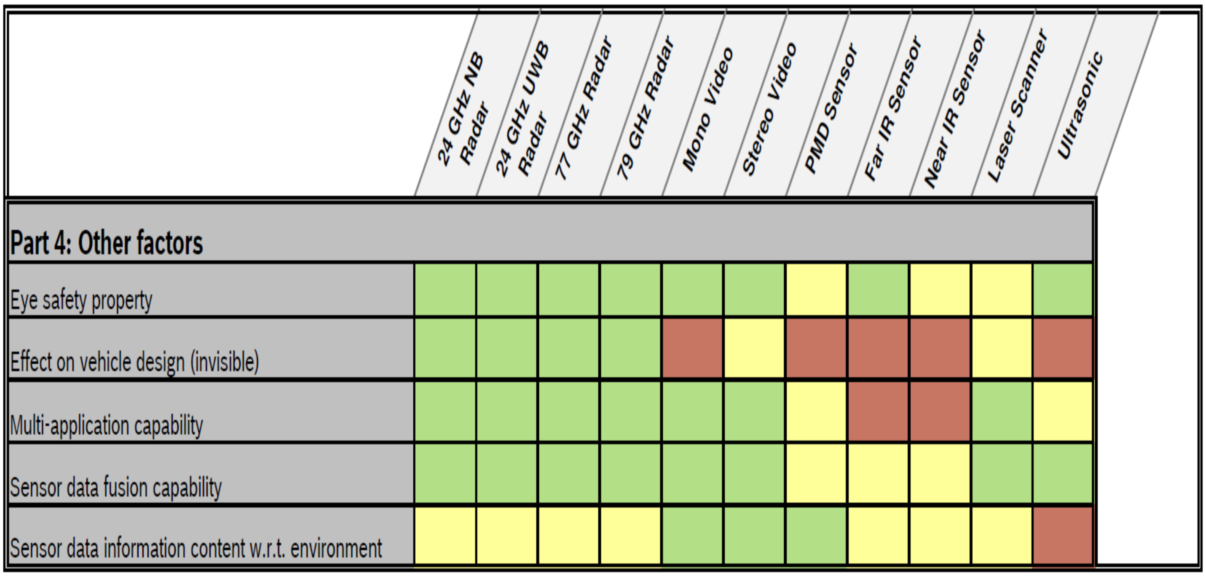

Figure A-5: Sensor technical comparison: Other factors (MOSARIM Consortium, 2012)

Below is a further explanation of these technologies and their suitability for this use.

Infrared

Infrared consists of a wide range of electromagnetic frequencies higher than visible light. The light closest to visible is termed Near-infrared (NIR) and acts very much like it. Far infrared however is a far higher frequency and is closer to microwaves on the spectrum, having its heat transfer characteristics (Tsimhoni and Green, 2002). These are also sometimes referred to as active or passive systems respectively, due to the need for lights (Grossman, 2007).

FIR systems act as passive sensors of thermal radiation emitted by objects. The image is determined by the relative differences in thermal radiation caused by different temperature and/or thermal conductivity of objects. The images it produces can be displayed in different shades of grey, the warmer the object, the more energy it emits and the more visible it is, or colour, usually cold objects are represented as blue and rising through the spectrum to red or white for the hottest items. By seeing the changes in temperature certain objects can be identified, therefore general ambient temperatures relative to the object and the sensitivity and resolution of the sensor are key factors in its ability to function.

The far infrared sensor has a larger spatial coverage than the near infrared sensor, and is not affected so much by glare from headlights.

A FIR supplier states a thermal sensitivity of 0.15 - 0.06 °C (Contral, 2014), however, Transport Canada (2013) cites a failing of some systems being that they are unable to detect or present a heat contrast of 10 °C, which is needed to detect people or animals. FIR cameras fail the detection of pedestrians in hot or sunny weather, namely, when pedestrians are not warmer than the background (Bertozzi et al., 2009). That said, FIR cameras are more suited than daylight ones for detecting pedestrians in cold, night or low-illumination conditions. Moreover, FIR images generally show less-noisy details, easing the initial steps of an automate detection process (Bertozzi et al., 2009). When the FIR image is displayed, it looks less familiar to the untrained eye so are better suited to intelligent night vision systems.

The use of near-infrared systems requires active infrared headlights, i.e. they don’t rely on natural ambient IR light or light emitted by warm objects. A NIR camera captures the light bouncing back from IR-reflective surfaces. IR light defuses less through the air so shadows and contrast are more distinct. The camera output is a monochromatic image, which is comparable to the real-world scene produced by high-beam headlights (Mahlke et al., 2007). These cameras share the same technology as normal monochromatic digital cameras, just with changes to their filtering and post processing. These systems are affected by the glare from other lights, such as other vehicles with active IR systems.

Radar

Standing for Radio detection and ranging, Radar emits pulses of microwaves and receiving the reflections, measuring the time interval and intensity it is possible to build-up a picture to identify objects and predict a collision.

The frequency, pulse form, polarization, processing of the signal, and type of antenna used determine what objects the Radar can observe. Radar can be designed to avoid detecting water and so rain, snow, etc. can be made transparent. Radar can travel through other objects, while partially detecting them, this can be used to build a plan view of the target area, seeing though vehicles and obstructions. Radar systems used in vehicles typically has a range of ~50-150m (Goroncy and Sterbak, 2005). A key consideration for radar is the radio frequencies permitted for use and their possible interference with other communication transmissions, systems using in cars generally use 77 or 24 GHz (Goroncy and Sterbak, 2005).

The data output by radar is difficult to translate for the untrained eye, therefore for vehicles recognition software is used. This can look for any objects in the path, or specifically identify people or animals. Another characteristic of radar which is interesting to note in the application for collision mitigation is the ability to detect movement away from or towards the radar using the Doppler effect, however when the object is moving perpendicular to the radar, such as when a person is crossing a road, there is no effect. For detecting objects crossing a vehicles path the refresh rate is a key factor. At least two passes, outputting two images, are required to identify whether an object is moving, and so may enter the path of the vehicle.

Lidar/laser scanner

Lidar takes its name from Light and Radar (LiDAR-UK, 2011). It uses a laser and detector, and measures the time to return to build a 3D map of objects. Lidar can work with many light frequencies, however near infrared is preferred for vehicle use as it is non-visible, so doesn't cause glare and distract other road users.

Often, the system is fitted within the bumper or grille, this allows accurate distance measurement from the car to objects in front (LiDAR-UK, 2011). Lidar can have a range of ~150m (Goroncy and Sterbak, 2005) and some systems even ~250m (Simion, et al., 2007).

Lidar functions during the day or night, however a strong sunlight reflection off a highly reflective target may "saturate" a receiver, producing an invalid or less accurate reading (Simion et al., 2007). Also the sun in open air in foggy weather can result in the detection of false targets. Temperature however, has no effect on the systems. Dust and vapour can also weaken readings as they scatter the laser beam and the signal returning from the target. Fog can appear as several different moving targets. Due to these issues, Simion et al. stated that the system would benefit from an intelligent pattern recognition system.

In addition to the scanning laser lidar, there is a system called a Time-of-flight (ToF) camera or PMD (Photonic Mixer Device) sensor. This system, in connection with a pulsing light source, is able to measure the distance of an object at the same time as capturing the image. These devices can function very fast (~160 fps) which is a benefit to AEB systems where rate of change and therefore movement can be used in identification. They currently have a low resolution comparable to CMOS cameras used in vehicles currently. Depending on the system, they can have a range of ~60m, however the MOSARIM (2012) states a range of up to ~30m; this is likely due to the balance of field of view and the low resolutions currently available, which will have a major effect when the system can be used for detection.

Ultrasonic

Ultrasound can also be used for systems to see their surroundings in dark conditions; however, a drawback of using ultrasound in air is the limitation of range and data update due to high attenuation and low speed of sound (Langer and Thorpe, 1992). Therefore, these sensors are used for short range detection such as parking. The output of such a system can be a beep, the higher the frequency representing a shorter distance, or lights, where they get brighter or a greater number illuminate to represent approaching close to an object.

Output to driver

With these systems the output can be used in multiple ways. In the original types and most systems available pre 2008, the video is output to the driver onto a screen for them to decipher. In more modern systems the video is analysed, key items are identified, and these items are brought to the attention of the driver only when necessary by highlighting the item on the video, emitting warning sounds, warning lights, bringing the display to fore (i.e. turning a screen on, overriding the Satnav or overriding an instrument panel display), and/or feeding this information into an AEB system.

Night vision images can be projected onto different displays: a head-down display (HDD) taking the place of the conventional head unit in the centre console or the instrument panel, a head-up display (HUD) integrated into the dashboard in front of the driver, or using the windscreen for projection (Gish and Staplin, 1995).

Augmented reality can be used, by projecting the camera's view onto the windscreen, augmenting the driver’s normal view. This can provide the improved view to the driver, without dividing the driver’s attention away from the road ahead (Borroz, 2010). Aligning the augmenting image with the real external view requires tracking of the drivers eyes, this can be problematic, failing due to; glasses, eye shape, eye colour, eye lashes etc. therefore, unless this can be perfected the system could cause more distraction.

A.8.8 Feasibility

Technical feasibility

A disadvantage of simply displaying these images without processing is that they may lead to higher demands on visual and mental resources because drivers have to search for relevant information on the display and compare it with the outside. Since this may negatively affect traffic safety (Rumar, 2002). Therefore, developments have since focussed on intelligent, automatic image processing. These so-called "intelligent night vision systems" detect and identify relevant objects such as pedestrians. Event-related warnings can subsequently be generated as optical or acoustical signals to shift the driver's attention to the object identified. This prevents the driver from completely focusing on the system instead of looking through the windshield (Gayko and Tsuji, 2006; Mahlke et al., 2007).

A.8.9 Costs

Penetration and introduction

A number of companies are currently offering night vision systems: Cadillac since 2000 (General Motors, 2000) (ceasing in 2004), Toyota-Lexus since 2003, Honda since 2004, Mercedes-Benz and BMW since the end of 2005 and Audi since 2010. Night vision systems are currently mostly fitted to executive style higher specification cars. However, this technology is now moving from into their medium-to-high end vehicle types, although still as an optional extra.

An intelligent night vision system was developed by Autoliv in 2008 (Autoliv, 2013) as did other tier 1 suppliers and vehicle OEMs. Of the vehicles identified which have been introduced after this date, all have an intelligent system.

Overall, current night vision systems are costly (see Table A-28). Economies of scale could potentially reduce the costs of far-infrared cameras, but most other components are already in large-scale production.

Although sensor technology does not require further development; image processing is an ongoing science. In addition, work on the integration of these systems into vehicles to be the most beneficial and appropriate to both safety and the driving experience, is still being investigated by manufacturers.

Manufacturing costs were not obtained. However, the consumer costs for vehicle options and aftermarket systems can be found. To obtain an estimate of manufacturer costs from the cost of the option to the consumer, a common approach suggested by FESTA (Malone et al., 2008) is to apply a factor of 1/3 to the consumer cost. All subsequent values in this section are presented with this estimated manufacturer cost with any currency conversion applied[9] along with the original figure in brackets.

Mercedes offers a Night vision system based on near-infrared for €950 (£2,250). While hi-resolution near infrared security cameras are approximately ~€55 (£130), however it is no known whether these would be suitable for the automotive environment.

Audi's far infrared system is €650 (£1,535). While a retro fit far-infrared camera to be mounted behind the radiator grill costs €660 ($2,495) (ThermalVideo, n.d.).

The same supplier offers the system including a large centre console mounted display for €855 ($3,245), subtracting the camera cost above gives €195 for a display. While Mercedes S class can have an optional HUD for €516 (£1,230).

[9] Conversion rates of £→€ = 0.8, $→€ = 1.3

Table A-28: IR: Costs overall

Estimated costs	Cost range	Details
Likely fitment costs (estimated manufacturer costs)	High	Far-infrared €650 €660
	High-low	Near-infrared €950 €55
	Note the cost difference between far and near infrared seem counter intuitive, it is likely that Mercedes' mark-up is higher.	
Any infrastructure costs?	None	No
Any exploitation costs?	None	No
Legislation costs	Low	Regulation: No regulation exists Type approval: For type approval/design standard; likely to require a dark room with heat and IR reflective sources Performance testing: EuroNCAP is implementing an on track AEB type test; this could include low light conditions in the future.
Result	Medium	€55-950

Technology sharing

The technology has the potential of sharing technology with most car systems that use an external camera, a driver viewable video display, and driver warning systems (vibration, lights, buzzers). In addition, the intelligent night vision systems can connect to, or be part of, various automatic driving systems such as AEB.

The Adose FP7 project[10] looked at multiple sensing elements and their pre-processing hardware to create multiple detection related systems. Figure A-6 below shows some of the systems used in the project and their operational ranges, these included: Far Infrared cameras, CMOS imagers (standard digital cameras use this technology), 3D packaging technologies, ranging techniques, bio-inspired silicon retina sensors, harmonic microwave radar and tags.

[10] ADOSE FP7 project. January 2008. http://www.adose-eu.org/

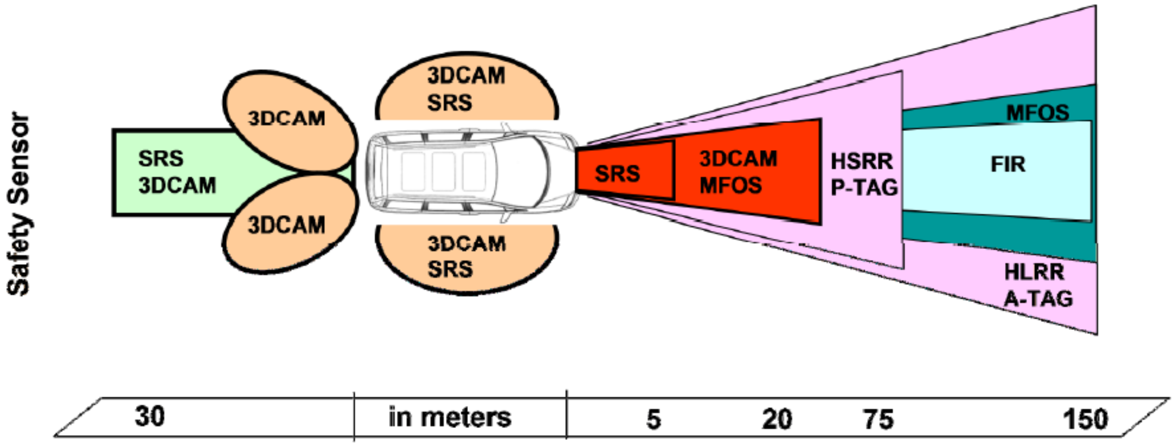

Figure A-6: Night vision: Technology application and field of vision on vehicles (Pallaro, 2011)

Key:

MFOS	Multifunctional optical sensor
3DCAM	3D Range Camera
SRS	Silicon Retina Stereo Sensor
HSRR P-TAG	Harmonic Short-Range Radar for Passive Tags
HLRR A-TAG	Harmonic Long-Range Radar for Active Tags
FIR	Far Infrared Camera

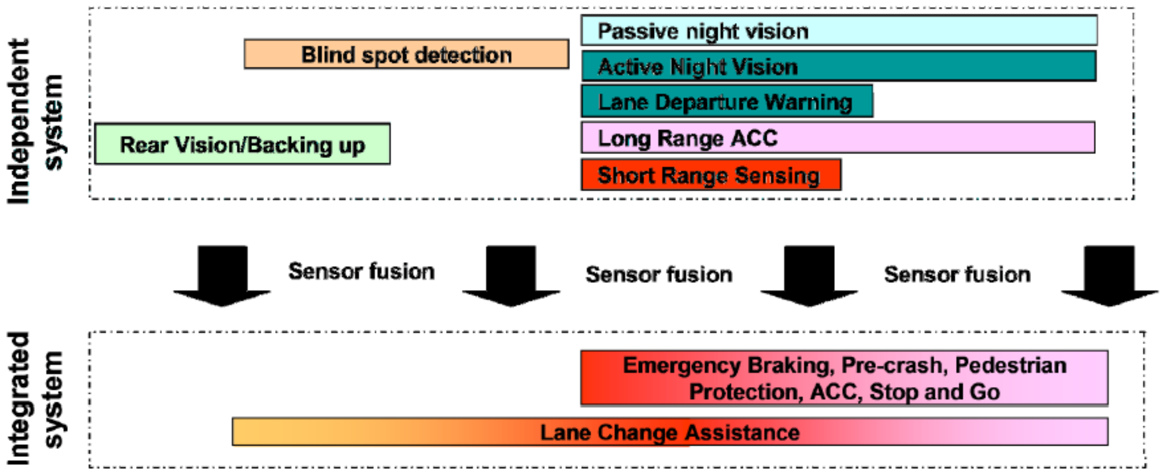

Figure A-7: Night vision: Technology sharing through sensor fusion (Pallaro, 2011)

Figure A-7 shows how these systems and technologies can be fused to provide the data required for multiple active safety systems, allowing further technology sharing and therefore cost reduction for a given benefit.

Table A-29: Night vision: Technology sharing

	Outcome	Notes
Technology		All of these forward looking sensor technologies can also be used as inputs for the following technologies to varying degrees: ACC (active cruise control), AEB (automatic breaking system), LDW (lane departure warning), Road Surface Scanning, Predictive Powertrain Control (Terwin et al., 2004) for M3 and N3 vehicles.
Camera	Yes	
Near IR	Yes	
Far IR	Yes	
Radar	Yes	
Lidar	Yes	
Sonar	Yes	
Headlights	No	Near IR requires additional IR lights
Display	Yes	Sat-Nav, Head unit, instrument panel
Analysis	Yes	ACC, AEB, LDW
Warnings	Yes	Sound system, LDW (vibration), instrument panel

Note, for near infrared systems where active lighting is required, the natural IR output of the headlights is not sufficient (especially for current low energy headlight systems), independent IR lights are required however they have the possibility of being aimed higher-up, providing a longer distance view, as they do not cause glare to other drivers (however they may to other IR cameras).

In addition, Lidar is also being incorporated into a development called Pre-Scan which scans the road surface and adjusts the individual suspension at each wheel to improve ride comfort (LiDAR-UK, 2011) or used in Predictive Powertrain Control (Terwin et al., 2004), where gear changing and engine power is adjusted to the upcoming road features, improving fuel economy and performance.

Overall the support systems; computer, IR lights, standard displays, wiring, warning lights, vibration and/or buzzers will or have reduced significantly in cost with increased use and standardisation. Small HUD systems are already widespread while large scale, or laser based full windscreen HUD systems are in advanced stages of development

Near infrared sensors are close to the cost of normal cameras, the difference being changes to the lens filters and calibration and so can potentially be very low cost, however frame rates, quality and resolution increases demanded for this purpose can increase that cost. Far-infrared sensors are a high cost option, but may be preferable for some situations.

A.8.10 Benefits

Improved vision in low visibility situations would be especially useful for regular night drivers (taxis and emergency vehicles), for older drivers who have difficulty seeing at night and who are sensitive to glare, and in regions will largely unlit roads and extended dark periods (northern Europe).

Sullivan et al. (2007) compared target detection when driving either with or without night vision systems. Results showed that the night vision system increased target detection distance for both young and old drivers, with noticeably more benefit for younger drivers. Cadillac's "Night Vision" system increases the viewing distance of the user from 90 metres with standard headlights, to up to 450 metres (Lawrence et al., 2004).

In a simulator study, Hollnagel and Kallhamer (2003) have shown that drivers using a night vision system gained time to assess the situation and choose an appropriate response, which was seen in terms of better control of braking and swerving. It was concluded that night vision systems lead to a significant improvement in the drivers' anticipatory control, and hence has considerable safety potential. It should be noted that drivers have been found to compensate for the improved vision by increasing their speeds (Tsimhoni & Green, 2002), this could be considered a potential disbenefit unless it can be defined at the appropriate response for the driving conditions.

Estimates of the approximate reductions in accidents expected with night vision systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum (2005). It was expected that 25% of vulnerable road user crashes occurring in low visibility would be affected, leading to a 17.5% reduction in these crashes, equating to a 0.1% reduction in all crashes.

In a study by Tsimhoni et al. (2005) they concluded that detection distances with NIR with no automatic warning were substantially inferior to FIR under similar conditions. Furthermore based on their experiment, detection accuracy with NIR without automatic warning degraded so much (by the need to do the steering task) that subjects missed 22% of pedestrians. However, NIR systems may be enhanced to improve pedestrian detection, such an improvement was found in their simulated automatic visual warning. This result reinforce that conclusions from a previous experiment.

Automatic pedestrian warning, in the form of highlighting pedestrians on the night vision display, is generally helpful in increasing detection distances and accuracy. However, warnings might not be effective if they do not appear far enough in advance of the pedestrian. Interestingly within their study some subjects detected the pedestrians later with the warning system than they did without the warning.

Regarding disbenefits, one of the possible risks of introducing night vision systems in vehicles is that they will increase the workload imposed on drivers. Automatic warnings have the potential of reducing workload by reducing the need to constantly sample the display. However in experiments by Tsimhoni et al. (2005), automatic warnings did not significantly reduce perceived workload, subjects continued to frequently view the display (~3 s).

The benefits from having a night vision image needs to be balanced with the needs for the driver observing the forward and peripheral areas "The poor visibility causes people to concentrate their attention directly ahead in order to see where they are going. This decreases the probability of seeing with the peripheral field, so that, for example, it would be harder to see a car or pedestrian approaching from the side." (Green, 2013)

The extent of road safety impact of night vision will rely on how drivers will adapt their behaviour to the increased visibility conditions.

A.8.11 Summary

If, and to what extent night vision will filter down to more mainstream models will depend on its usability, acceptability, and effects on road safety. The benefits of current systems, as well as possible negative consequences in terms of driver distraction and risk homeostasis are largely unknown. Overall there is not a consensus that night vision systems are a benefit, therefore it is not possible to calculate a cost benefit ratio.

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A.9 Reversing Detection Systems

Systems that increase the view or warn drivers of people behind reversing vehicles. Particularly vulnerable are short, crouching and slow moving people, especially children and the elderly.

A.9.1 Description of the Problem

Paine et al. (2001) cite increasing concern about accidents involving young children being run over by slow moving vehicles, particularly in private driveways. In these circumstances, there is a possibility that young children are too short to be seen, and so detections systems could be employed to warn the driver of children (and obstacles or vehicles) in the path of the reversing vehicle.

Figure A-8: Illustration of the blind zone behind vehicle

Studies have been performed in Australia and the US regarding the issue (termed "Backover"). In the US there were 183 fatalities, and 6,700 to 7,419 injuries (A significant proportion being minor) annually caused by reversing (NHTSA, 2006). In Australia, New South Wales, 17 children were killed between January 1996 and June 1999, (4.8 annually), with a significant proportion being 2-4 year olds (toddlers). According to a study by NHTSA in developing a FMVSS based on FARS, NASS-GES, and NiTS data for the USA (NHTSA, 2014):

- Crashes when reversing result in 410 fatalities and 42,000 injuries annually
- Of these, those involving a vehicle striking a non-occupant of the vehicle contribute to an estimated 267 fatalities and ~15,000 injuries annually
- Of these, vehicles with a GVWR (Gross vehicle weight rating) of under 10,000 pounds [~4.5t] account for an estimated 210 fatalities and 15,000 injuries annually[11]

Roberts et al. (1993) performed a study of all non-traffic child pedestrian deaths and injuries resulting in hospitalisation over a five year period in New Zealand. There were

[11] Note: the USA has a population of ~300 million, there are ~250 million vehicles, ~3 trillion miles driven per year. Sources: US Census Bureau. International Road Federation. Bureau of Transportation Statistics, National Transportation Statistics. US Department of Transportation, Federal Highway Administration., Federal Highway Administration, Highway Statistics. EC Eurostat Transportation Statistics.

eight deaths (0.77/100,000 children per year) and 91 hospital admissions (8.7/100,000 children per year) in the Auckland region (population ~1.1m in 1993) over a 5 year period. 87% of the non-traffic pedestrian injury deaths and 93% of the injuries occurred in residential driveways, most often involving a child run over by a reversing vehicle.

Due to the predominance of international studies, data from Great Britain was examined to see if the issue existed within the EU. Table A-30 shows the numbers of casualties by injury type and age group, while Table A-31 shows this as a proportion of all pedestrian injury accidents (with the same vehicle types and years).

Table A-30: Stats 19 data on pedestrian casualties hit by reversing vehicle in single vehicle accident in Great Britain. M1-3/N1-3 vehicles. Averaged over 4 years (2009-2012)

Casualty Age	Casualty injury			
	Killed	Seriously injured	Slightly injured	Total
0-5	0.8	10.8	64.5	76.0
6-10	0.5	6.5	57.5	64.5
11-15	-	5.0	68.5	73.5
16-20	-	9.5	91.5	101.0
21+	15.0	248.3	1,293.5	1,556.8
unknown	-	4.0	32.5	36.5
Total	16.3	284.0	1,608.0	1,908.3

Table A-31: Stats 19 data on proportion of pedestrian casualties hit by reversing vehicle in single vehicle accidents in relation to all pedestrian casualties in Great Britain. M1-3/N1-3 vehicles. Averaged over 4 years (2009-2012)

Casualty Age	Casualty injury			
	Killed	Seriously injured	Slightly injured	Total
0-5	10.0%	3.7%	6.3%	5.8%
6-10	7.4%	1.4%	3.3%	2.9%
11-15	-	0.6%	2.2%	1.9%
16-20	-	1.9%	4.1%	3.6%
21+	4.1%	8.2%	12.3%	11.2%
unknown	-	5.5%	6.8%	6.7%
Total	3.8%	5.5%	8.4%	7.7%

From this data it can be seen that injuries and fatalities to pedestrians caused by reversing vehicles do occur in Great Britain, and that a large proportion of those killed are young children.

In relation to reversing aids it is important to understand the nature of the collision, and therefore whether a given mitigation technology is appropriate. This can be done by an analysis of the contributory factors (CF) recorded in the national statistics[12], which in these cases shows that: 'Failed to look properly' is the most common contributory factor recorded in the single vehicle reversed and hit a pedestrian collisions and also the most commonly recorded contributory factor in all collisions (with these vehicle types – see Table A-32).

Table A-32: The top ten most common contributory factors pedestrian casualties hit by reversing vehicle in single vehicle accidents

contributory Factor		Number of Accidents	% of reversing single vehicle & pedestrian accidents	% of all accidents which have this factor
405	Driver failed to look properly	754.5	41%	28%
802	Pedestrian failed to look properly	447.8	24%	9%
803	Pedestrian failed to judge vehicle's path or speed	211.0	12%	3%
710	Vision effected by vehicle blind spot	203.8	11%	1%
403	Poor turn or manoeuvre	193.0	11%	9%
602	Careless, reckless or in a hurry	138.5	8%	12%
808	Pedestrian careless, reckless or in a hurry	79.8	4%	4%
406	Failed to judge vehicle's path or speed	67.8	4%	16%
801	Pedestrian crossing road masked by stationary or parked vehicle	58.5	3%	2%
806	Pedestrian impaired by alcohol	53.3	3%	2%
	Total	2,208		

[12] CF (contributory factors) are only recorded where a police officer attended the scene. There were 7,329 collisions in the CF analysis and 7,633 in the overall count, which also includes 304 collisions not attended by the police for the four year period.

However, 'Failed to look properly' was recorded in 41% of the collisions of interest compared with being recorded in 28% of all collisions. "Pedestrian failed to look properly" was the second most commonly recorded contributory factor in the collisions of interest, whereas this was the 6th most commonly recorded factor for all collisions.

These data relate to reported casualties. Fildes et al. (2014) point out that national data alone is insufficient to account for the scale of the problem and recommend that data is required for settings outside that required by official accident data (i.e. hospital data).

A.9.2 Potential Mitigation Strategies

Solutions to aid in the detection of people and objects behind vehicles can be improvements to the driver's view or warning systems:

- Warning systems include: ultrasound, rear view cameras with intelligent object recognition, and sensors used in AEB systems such as radar and lidar.
- Assistance aids can be; improved minimum requirements for rear vision, cameras linked to an in-car screen, mirrors, and Fresnel lenses.

Requirements for Rear Vision

Read (2012) stated that; "The major cause of back over accidents is the blind spot immediately behind a vehicle. Ironically, this has become a bigger problem over the years, as auto designers have enlarged vehicles, raised beltlines, and reduced the size of windows to improve vehicle [occupant] safety." Read cites that the number of child fatalities in reversing accidents increased by 88% between mid-1990s and mid-2000s.

Paine (2001) found that there was a scarcity of information about the rearward field of view from motor vehicles and methods of improving this view. They devised a test method, which included reversing speed and reaction time as a factor. They tested 61 vehicles and obtained 2 key results:

- The reversing speed in km/h should be no more than twice the detection distance in metres [in order to react and stop in time]; and
- With a simulated toddler (a cylinder 600 mm in height), for the vehicle that afforded the greatest view the cylinder was only visible when at least 3 metres from the rear of the vehicle. For a popular large car it was only visible when 19 metres away.

The study also concluded that the issue was not constrained to large 4-wheel drive vehicles.

Sonar/Ultrasonic

Sonar technology functions in all visibility conditions; however, ultrasound has a limited range in air (Langer and Thorpe, 1992). Therefore, these sensors are used for short range and low speed detection such as parking. The output of such a system can be a beep, the higher the frequency representing a shorter distance, or lights, where they get brighter or greater to represent approaching an object.

The drawbacks of such systems are that they can only indicate that something is within range, not identify what the object is. Therefore, a driver may not take the warning to mean a child, but just that it's getting close to where they intend to reverse. In addition, it is possible to be out of range if between the multiple sensors needed to cover the rear of the vehicle.

Lidar/Radar

Radar (Radio detection and ranging) emits pulses of microwaves and receives the reflections. By measuring the time interval and intensity of the reflections it is possible to use the strength of the return signals (which are dependent on the size and density of the object they reflect off) to provide information on the object location and some information about the type of object, although radar is not a very sensitive discriminator between objects.

Lidar (which takes its name from Light and Radar) uses a laser and detector measuring the time to return to locate and range objects (in the case of single beam systems) or to build a 3D map of objects in the case of scanning systems (LiDAR-UK, 2011). Lidar can work with many light frequencies; however, near infrared is preferred for vehicle use because it is non-visible and therefore does not cause glare and distraction to other road users.

Mirrors

Internal mirrors suffer some of the same problems as viewing directly because the view afforded is restricted by the body of the vehicle. External mirrors can be fitted to give the driver the required view; however, they distort the image, the image is small, especially on long vehicles, and the mirror blocks the view rearward for normal driving. The mirror may also need adjustment for each user of the vehicle and seating position.

C.10.2.5 Fresnel Lenses

A lens fitted to the rear window can be used to expand the viewing angle below and around the body of the vehicle. It also does not restrict the view rearward for normal driving, but it does distort it.

One key drawback is that although the view is expanded and improved the view is still not complete, with the area close to the vehicle not visible. Also, as with mirrors, the length of the vehicle and restrictions on the size so as not to impede normal use of the rear window means that the image is small, possibly making interpretation of the image difficult.

Camera

Cameras can be fitted at one or multiple points at the rear of the vehicle. These can show an image of the area directly behind the vehicle for the driver to use while reversing.

Read (2014) states that IIHS studies have found rear-view cameras are better than sensors (such as radar) at identifying objects in a vehicle's path (IIHS, 2014). In a test with 21 vehicles, the blind zone was reduced by 90%. This was reduced further by a small degree when both cameras and radar were used.

In a further study on driver behaviour involving 111 drivers all using the same vehicle, rear-view cameras outperformed sensors by a significant margin. Interestingly using both technologies reduced performance, the authors hypothesising that the radar systems "gave drivers a false sense of security, so they paid less attention to the camera display".

The report goes on to clarify that "Rear-view cameras didn't prevent all collisions, even when properly used. When the stationary object was in the shade, for example, nearly every driver who looked at the display still hit it. In the real world, weather and lighting conditions would likely affect the usefulness of cameras."

One major disadvantage of camera systems is that they rely on the driver using the information effectively; in a trial situation, subjects might pay a greater degree of attention to the screen during the reversing manoeuvre than they might otherwise do.

As noted by the US NPRM (Notice of Proposed Rulemaking), a further disadvantage of the more complex electronic systems is the required start up time. The majority of accidents of concern are likely to happen just after the vehicle is started, with the driver beginning to drive before the various safety systems have become active.

A.9.3 Feasibility

Technical Feasibility

Of the systems detailed above ultrasound sonar, radar, mirrors, Fresnel lenses and cameras all exist on the market. Rear pointing Lidar based systems were not identified.

These systems are often marketed as parking aids or parking sensors, rather than pedestrian safety. For day-to-day use when parking they can help to reduce the likelihood of damage to the vehicle.

Enforcement Feasibility

Test procedures to require improved rear visibility have been developed in the US. It will become mandatory for vehicles under 4.5t manufactured after May 2018, including buses and trucks, to have a minimum rearward visibility.

Due to the increased occurrence of off-road reversing accidents (Read, 2012), the Cameron Gulbransen Kids Transportation Safety Act of 2007 (Public Law 110–189, 110th Congress) was enacted. As well as other child-related safety provisions, it required states to increase the rearward visibility of vehicles and for NHTSA to collect data on the issue. The rule at this stage did not specify a preferred technology. NHTSA delayed the release of a final rule multiple times (Nelson, 2014); some sources stated that this was to assess technologies in development such as higher resolution versions of radar.

On the 31st March 2014 the final rule was released. 49 CFR Part 571, Docket No. NHTSA 2010-0162, states that field of view must be expanded for all vehicles below ~4.5t (10,000 lbs.). The ruling stipulates that this includes passenger cars, trucks, multipurpose passenger vehicles, buses, and low-speed vehicles (as defined in 49 CFR Part 571.3: vehicle speed of ~32-40 km/h or 20-25 mile/h).

The required view as shown in Figure A-9 is a zone ~3 by 6 meters (10 by 20 feet) directly behind the vehicle. Previously passenger vehicles only required a rear view mirror to provide a view from 61 meters to the horizon (FMVSS No. 111). The ruling stipulates that this old requirement has not changed; one being a requirement for rearward vision for driving, while the new requirement is for reversing.

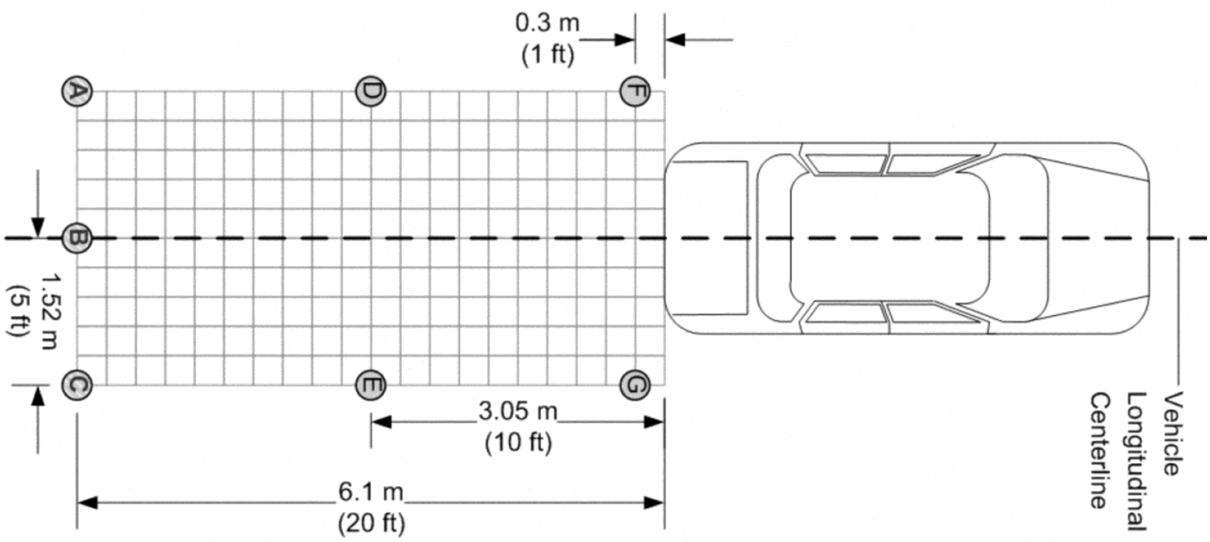

Figure A-9: countermeasure performance test area illustration and required test object locations

The US ruling states that cameras meeting the regulatory requirements (e.g., rear view video systems) consistently outperform other rear visibility systems (e.g., sensors-only or mirror systems) due to a variety of technical and driver-use limitations in those other systems. It goes on to say that:

"Rear visibility systems meeting the requirements of today's rule are the only systems that can meet the need for safety specified by Congress in the K.T. Safety Act (the backover crash risk) because the other systems afford little or no measureable safety benefit."

Encouragement Feasibility

A first step to encouraging reversing detection systems via Euro NCAP is feasible. The award 'Euro NCAP advanced' aims to encourage the development of any safety system and could be used as a route to encourage the fitment.

Annex 3.1.3 Costs

Once source indicated that a rear-view camera system can add around $160 - $200 to the price of a new vehicle. However, this is likely to include a significant proportion of mark-up and many of the technologies in a system can be shared. (Read, 2012)

In the study for the FMVSS, NHTSA states that the cost will be between $132 and $142 per vehicle to fit a system to meet the requirements put forward. However, for vehicles already equipped with a suitable display the cost is estimated to be $43 to $45 (NHTSA, 2014).

NHTSA (2014) also state in their study that the costs they found differ from those of the NPRM (Notice of Proposed Rulemaking), which reported that for each vehicle a complete system is $159 and $203 or $58 for those already fitted with a suitable screen. The difference is due to the reduction in cost as manufacturers gain experience, and commercial reasons such as reduced costs with increased production (NHTSA's sources: Advocates, American Academy of Pediatrics, Sony and Magna). Table A-33 lists some of the areas where technology sharing is possible.

Table A-33: Reverse detection: Technology sharing

Technology		Notes
Camera		May already be fitted for reverse parking assistance, or replacing the rear view mirror in some vehicles. The viewing angle, resolution and refresh rate needs may be different.
Sonar	Ultrasound transducers	May already be fitted for reverse parking assistance
Radar	LDW, AEB, blind spot detection, pre-collision warning	Rear pointing radar is used to mitigate the harm to passengers from a rear end collision (Daimler, 2012). Lane departure warning and blind spot detection can also use side-pointing radar. The radar likely used in these systems is for detecting closing speed and distance information, but not object recognition.
Display	Sat-Nav, Head unit, instrument panel	The resolution and refresh rate needs may be different
Analysis	ACC, AEB, LDW	These systems analyses sensor and camera data to identify objects and issues warning or take control of the vehicle if necessary
Warnings	Sound system, LDW (vibration), instrument panel	
Braking	ESC, AEB	

Vehicle Categories

The technologies detailed are compatible with all vehicle categories. High-end M1 vehicles are more likely to already have suitable displays. Larger categories of vehicles (M/N2-3) may require greater resolution detectors, wider field of view and/or larger numbers of sensors.

A.9.4 Benefits

There are many beneficial areas for this concept.

- Mitigation of pedestrian injuries and deaths
- Mitigation of damage to the vehicle, surrounding vehicles and other objects while parking and reversing
- The same technology can give benefits for:
    - Mitigating rear end collisions of injuries from them
    - Mitigating lane change collisions
- These savings could all cascade into reduced insurance costs

Parking damage has a much higher occurrence, so may have a comparable if not greater benefit.

A.9.5 Summary and BCR (Benefit:Cost Ratio)

Although the US study specifies a camera system, a performance requirement (which is non-technology specific) would be preferable. Alternatively, a minimum viewable area and quality of view could be defined. An assessment of national statistics in Europe would be required to take into account the situations causing the majority of casualties. For an assessment method to be developed the distance between the pedestrian and vehicle before reversing started may be needed as would the driving direction (i.e. turning); this is highly unlikely to be recorded with a statistical significance in any of the main accident databases.

It should be noted that NHTSA originally took the same view (Public Law 110–189, 110th Congress), but concluded that the only option currently able to fulfil all requirements was a rear view camera including specific requirements on luminance of the screen, image size, image response time, and system start up time etc.

Estimate BCR (Benefit:Cost Ratio)

Given the statistics readily available, the calculation has only been performed for M1 category vehicles. A specific study for this measure is required to obtain more accurate information for Europe.

Multiplying the casualty numbers per year from Table A-30 (4, 71 and 402 for fatal, serious and slight respectively), by a rough estimate of the DfT's injury costs to society (£1,703,822, £191,462, £14,760 for fatal, serious and slight respectively) (DfT, 2013) provides a cost of £26m per year, this calculation could be improved as a study by Mayr et al. (2001) has looked at the types of injuries from these collisions leading to more accurate cost estimates. Dividing this by the average number of M1 cars sold in the UK per year (2.26m in 2013, Society of Motor Manufacturers and Traders (SMMT)), this produces a value of ~£12 per car. In comparison, by taking even the fitment values from the study in the US of £25 to £122 (rate of 0.6 £/$) (NHTSA, 2014) it can be seen that the benefit-to-cost ratio (for GB) would not be positive: 12:25 – 12:122. It is considered likely that the GB situation is comparable to Europe. However, as noted by Fildes et al. (2014) the scale of the problem may not be adequately described by official statistics.

However, an article by Breakeryard.com (Alvaro, 2012) states that "figures from Accident Exchange, there are nearly 200,000 reversing accidents annually in the UK, equivalent to more than 500 each day and with an average repair cost of £2,123. This means that UK motorists spend a combined £409 million every year to cover the cost of damage caused by accidents involving someone reversing their car". This gives a cost of ~£180 per car, even taking into account that a proportion of these vehicles will already be equipped with parking sensors. Performing the same calculation, but with a combination of reversing damage and pedestrian casualties, generates a cost per vehicle of approximately £193, which is more comparable to the fitment costs from NHTSA and gives positive BCRs of 193:25 – 193:122 for the UK.

Assuming that the UK figures are representative for the rest of Europe, in terms of safety alone, the BCR has been estimated as being less than one, although the casualties associated with these accidents (i.e. children) mean a case for preventative systems could be made even if the BCR was lower than one. Furthermore, most new vehicles already have reversing parking sensors so the costs of making fitment mandatory might now be much lower. Further study is required to determine whether this measure is beneficial on safety grounds alone. This evidence suggests that it is beneficial in terms of casualty and accident costs.

For systems with reversing cameras, NHTSA in the US indicates that the benefits of a camera system with a screen on the driver's dashboard are sufficient to warrant mandating this approach. However, due to differences in vehicle size between Europe and US, it is not clear whether this is the case in Europe. There are defined performance requirements for the screen covering luminance, image size, image response time etc. One of the drawbacks noted in the NPRM is that there is an initialisation time between engine ignition that may mean that images are not immediately available; precisely at the time that the information is required by the driver.

A.9.6 References

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A.10 Junction Cameras

Surround camera systems, aiding the driver at visually obstructed intersections.

A.10.1 Description of the Problem

Accidents within 20 m of a junctions account for over 60% of accidents in Great Britain (DfT, 2013). A proportion of these occur as a result of interactions between two vehicles entering/leaving different roads at the junction, of which many accidents have a causation factor of "looked but did not see." In a small proportion of these, the main contributory factor was the visibility from the junction or poor use of the available visual cues, leading the driver to have insufficient information on which to judge the safety of moving off from the junction. The precise percentage of accidents is unknown because in-depth accident reconstruction is required to determine the accident contributory factors and, in many cases, more than one contributory factor may apply.

A.10.2 Potential Mitigation Strategies

- Camera system at the front of the vehicle to allow the driver to view approaching traffic from left or right before pulling out from a junction.
- Forward-looking sensing system to warn drivers of crossing (or emerging) traffic would address this accident type, but is addressed by fitting a system to the 'other vehicle' in the accident, rather than the vehicle pulling away from the junction.

A.10.3 Feasibility

Junction cameras could be fitted at the front of the vehicle and used by the driver as additional visibility aids at junctions. This has the potential to prevent some accidents because the improved visibility means that a better decision about whether or not to pull out from the junction can be made. However, it may not reduce the severity for accidents which the driver decides to pull out and is then in conflict with an unseen vehicle.

Some inter-urban AEBS systems may be able to react to and mitigate crossing accidents, especially in the coming years as sensing technologies improve. However, the sightlines and time that the vehicle is in the sensor view, as well as the speed of the bullet vehicle, are factors in whether the crossing vehicle could be detected by the system. While these may reduce the severity, if sensor sightlines are restricted (as may be the case in a significant number of accidents) avoiding the accident entirely may be very challenging.

Technical requirements would be required for the clarity and size of the camera screen image to ensure that appropriate visual information can be supplied to the driver.

A.10.4 Costs

Costs are unknown. Junction camera systems are in development for motorcycles (BMW) and for some cars, but are not yet available on the market.

Inter-urban AEBS is available on some vehicles and second-generation systems that have some capability in identifying crossing vehicles have been demonstrated but no systematic testing has been carried out to date for this collision type. For example, AEB tests developed for Euro NCAP are all front-to-rear configurations.

A.10.5 Benefits

Benefits cannot be quantified because the percentage of the target population that might benefit from the system has not been well studied. Furthermore, the camera system does not prevent the driver from entering a dangerous situation and only provides information on which the driver bases a decision.

A.10.6 Benefit:Cost Ratio

Benefit-to-cost ratio not calculated because both aspects are not sufficiently known. It is considered by TRL that the benefit-to-cost ratio is likely to be less than 1, but more research is required to identify the target population more accurately and research to define appropriate manufacturer system costs.

A.10.7 References

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A.11 Visibility from Vehicles

Better driver visibility in close proximity to the vehicle to reduce visual obstruction caused by the size and position of vehicle structure.

A.11.1 Description of the Problem

Depending on the size of the vehicle, there may be difficulties in viewing (either directly or indirectly) some areas close to the vehicle on the nearside of the vehicle. Visibility in these areas may be important in situations where the vehicle is manoeuvring at low speeds or driving in crowded, narrow streets and, for some vehicles, when they are performing turning manoeuvres.

Japan has requirements for areas in close proximity to the vehicle that differ from those in Europe. All vehicles, except motor cycles with or without sidecars, mini-sized motor vehicles with caterpillar tracks and sleds, large-sized special motor vehicles, small-sized special motor vehicles and trailers, must comply with Article 44 of the Ministry of Transport Ordinance No.67 (MTO, 1951). The requirements specified are that a cylinder 1 m in height must be visible when placed in an area 0.3 m from the vehicle along the passenger side and front of the vehicle (Attachment 81 – MTO, n.d.). To meet this requirement, at the front offside of the vehicle (forward of the wing mirror), some vehicles have an additional mirror to provide a view down the passenger side of the vehicle.

In Europe, UN Regulation 46 (Indirect visibility) prescribes requirements for indirect visibility (UNECE, n.d. a). For M1 and N1 vehicles, this mandates an external mirror that provides a field of vision such that the driver can see at least a 4 m wide flat, horizontal portion of the road which is bounded by a plane parallel to the median longitudinal vertical plane passing through the outermost point of the vehicle on the passenger's side, and which extends from 20 m behind the driver's ocular points to the horizon. In addition, the mirror must allow visibility of the road over a width of 1 m, which is bounded by a plane parallel to the median longitudinal vertical plane and passing through the outermost point of the vehicle starting from a point 4 m behind the vertical plane passing through the driver's ocular points. Therefore, an external mirror meeting these requirements will enable an area in close proximity to the vehicle to be visible despite not containing specific requirements for these regions.

Regulation 46 also specifies that N2/3 vehicles are fitted with a close proximity mirror (Class V mirror) at least on the passenger side. The purpose of this mirror is to provide the driver with a view of the area directly adjacent to the passenger side of the vehicle's cab so that the driver is aware of other vehicles in this area when changing lanes and is aware of pedestrians, cyclists and motorcyclists when turning at junctions or manoeuvring the vehicle. Latest amendments to Regulation 46 that became mandatory for new types of N2 in June 2014 and will be mandatory for all new N2 vehicles from June 2015 have requirements that increase the area of the field of vision by 2 m forward from the vehicle and 2.5 m to the side of the vehicle.

EC Directive 77/649/EEC (as last amended by 90/630/EEC) and UN Regulation 125 (UNECE, n.d. b) provides the requirements for direct visibility for M1 vehicles. Amendments to Regulation 125 that come into force in 2015 are that a 1.2 m tall cylindrical object (300 mm in diameter) must be detectable when positioned 2 m from the vehicle at any lateral location 0.4 m from the driver's side and 0.6 m from the passenger's side of the vehicle.

A.11.2 Potential Mitigation Strategies

Improvements to direct visibility

Vehicle structure improvements so that pedestrians and vulnerable road users can be detected directly when they are in close proximity to the passenger side and front of the vehicle.

Japanese-style mirrors mounted on the side of the vehicle front

Addition of mirror on the front of the vehicle to provide improved indirect visibility of areas close to the side of the vehicle such that 1 m target can be seen when within 0.3 m of the front and passenger side of the vehicle (Japanese requirements).

Camera systems

Camera systems to provide the visibility of the areas close to the vehicle, with the image displayed to the driver on the dashboard.

A.11.3 Feasibility

Direct visibility from M1 and N1 vehicles

Improvements to the direct visibility from vehicles have been shown to be possible and several models in Japan have altered the direct visibility to meet the technical requirements. These include changing the vehicle design to facilitate lower sightlines from the driver’s eye point to the side of the vehicle. Other solutions include transparent areas or sections to allow improved direct visibility of areas close to the side of the vehicle.

Indirect visibility

This could be improved by improving the indirect visibility both in front and to the side of the vehicle. However, this is already covered by existing legislation in Europe and the issue remains because the driver may not utilise the indirect vision, or not use it at the correct time to avoid an accident. Sensing systems to detect vulnerable road users in front and at the side of the vehicle are another potential solution.

Camera systems

Camera systems provide the driver with a view of the area close to the vehicle and are permitted by the Japanese regulation in lieu of indirect visibility.

A.11.4 Costs

Direct visibility

Direct visibility changes are likely to be more expensive. No specific costs were obtained although examples from Japan indicate that if integrated into the design cycle are not cost prohibitive.

Indirect visibility

Mirrors are generally low cost; no costs were obtained for the fitment of additional mirrors similar to those fitted to some Japanese vehicles. Depending on their size and position on the vehicle structure, these could also influence direct visibility.

Camera systems

Visvikis et al. (2008) reported that Blind spot monitoring systems cost around £450 (€576) to the consumer in Europe and $200-$395 (€127-€250) in North America. Current systems are packaged with other systems. For example, Audi offer LCA functionality as part of Lane Assist (which also includes LDW and LKA) for £400 (approximately €480). It is likely that some functionality of camera systems could be shared.

A.11.5 Benefits

No studies were located that considered the additional benefits of providing solutions that meet the Japanese requirements compared to that for European regulatory requirements.

A.11.6 Benefit:Cost Ratio

There is insufficient information on the benefits available to enable a benefit-to-cost ratio to be estimated. Furthermore, the solutions have differing costs and these are in themselves, largely unknown.

Based on the information available, TRL consider that the visibility requirements for European vehicles are well specified for all vehicles, with measures for N2/3 vehicles for indirect visibility (mandatory close proximity mirrors on at least the passenger side) and M1/N1 vehicles (direct visibility within 2 m). TRL consider that the additional benefits brought about by requiring visibility of a 1 m object 0.3 m from the vehicle side and front will not outweigh the costs associated with achieving this requirement. Indeed, since European requirements for indirect vision are made on the ground plane, work would need to be done to understand how different the Japanese technical requirements are from the close proximity visibility attained from compliance with European requirements.

A.11.7 References

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Annex 3.2 Advanced Front Lighting (AFS)

Technology that varies the pattern of light produced by headlamps to maximise road clarity at night whilst minimising the glare posed to oncoming vehicles. AFSs are designed to provide drivers with a better field of view when driving at night.

Annex 3.2.1 Description of the Problem

Night-time accidents

Accidents at night are significantly overrepresented in accident statistics; therefore, any improvement in visibility represents a significant opportunity to reduce fatalities. For example, analysis of UK accident data by Ward et al. (2005) showed that 40% of fatal and serious injuries occur during the period 19:00 and 08:00, despite only a quarter of car journeys being between these times. Similarly, in Germany the accident risk at night is three times greater: 28% of injury accidents and 42% of fatal accidents occur at night, despite 20% of the distance travelled being at night (BASt, 1988).

There a range of lighting technologies available; light sources such as Xenon or LED have been shown to provide increased detection distances at night compared to Halogen sources: e.g. Zydek et al. (n.d.), Baum and Geißler (2009). An examination of German night-time accidents using GIDAS data showed that fitment of Xenon lights could avoid around 16% of these accidents (Schöttler et al., 2010)

Jermakian (2011) considered that accidents relevant to AFS are front-to-rear, single-vehicle, or sideswipe same direction crashes that occurred on curves in darkness or twilight. In the US, it was estimated that these accident types account for 4% of front-to-rear, single-vehicle, and sideswipe same direction crashes (Jermakian, 2011).

AFSs are designed to provide drivers with a better field of view when driving at night; static, front-facing headlights offer the same performance in curves, on motorways and in urban environments, despite the different illumination pattern requirements for these environments. AFS offers optimal carriageway illumination patterns depending on a variety of driving parameters (steering angle, speed, activation of indicators, etc). From these inputs a series of algorithms predict the vehicle's road environment and adjust the performance of the headlamps accordingly. Future systems will incorporate GPS information to select illumination patterns based on a prediction of road conditions (the need for which has been demonstrated empirically; drivers prefer lighting angles to be changed in advance of a corner, rather than in response to steering inputs when in the corner).

Different AFSs produce similar lighting patterns across a range of driving environments, these environments that typically include: curves, motorways, adverse weather, overhead traffic signs, country roads, and towns. These lighting patterns have been investigated across a range of studies that examined drivers' preferences for headlamp swivel angle and light pattern distributions. A large European project funded by the EUREKA inter-governmental initiative attempted to reach a consensus as to which lighting patterns were most appropriate in various environments and these standards seem to have be adopted by the majority of manufacturers.

A.11.8 Potential Mitigation Strategies

A technology that varies the pattern of light produced by headlamps to maximise road clarity at night whilst minimising the glare posed to oncoming vehicles. The pattern chosen depends on the type of road the vehicle is on and (in some cases) weather conditions.

This system can be complemented by improvements in the light source used (e.g. Xenon rather than Halogen bulbs), which have shown to provide improvements in visibility, but also may have effects on other driver's due to glare. However, Zydek et al. (n.d.) present information on high intensity discharge high beam lights that significantly increase detection distances compared with dipped HID (32m; 36%).

A.11.9 Feasibility

One way to reduce accident rates at night would be to improve drivers' field of view by introducing a superior vehicle lighting technology, such as AFS. Annual potential reductions in fatal and non-fatal accidents in the USA have been estimated at over 2,500 (IIHS, 2008). In order to make more reliable estimates of the reduction in accident rates, data must be gathered from actual AFS trials.

Furthermore, AFS is being adopted by an increasing number of motor manufacturers either as standard equipment or as an optional extra. This includes systems such as:

- Swivelling lights
- Automatic levelling systems - offer stable distribution of light unaffected by the vehicle's pitch which can help prevent glare to oncoming vehicles e.g.
    - static levelling e.g. luggage weighs down the back of the car
    - dynamic levelling e.g. vehicle position changes going over a bump, accelerating or driving up a slope
- Adaptive / advanced front lighting systems
    - Glare Free High Beam Headlamp (GFHB) / Adaptive Driving Beam (ADB)
    - Automatic beam switching

Research on reflector posts, raised pavement markers, and other roadway markings on curves in the US has reported that drivers sometimes increase their speeds when visibility is improved (Kahlburg, 1993) and this could offset the potential benefits of AFS.

A.11.10 Costs

Several manufacturers fit AFS as standard to some models; for example Lexus, BMW, Honda etc. When AFS is available as an optional extra, AFS is typically packaged with other systems such as bi-xenon headlights, beam levelling etc. AFS is standard equipment on some, mainly high-end makes or higher specification models. For Intelligent Adaptive Forward Lighting (AFL) incorporating bi-xenon headlights with dynamic beam levelling, high beam assist and high-pressure headlight washers, the package is £890 on some Vauxhall/Opel models and standard on higher models in the range.

In terms of HID (Xenon), Baum and Geißler (2009) estimated system costs at €236.75 for two Xenon lamps, a washing system, and a levelling system. It is not clear whether this is OEM or consumer cost, what information the estimate is based on, or whether this level of cost is accurate in the current market.

A.11.11 Benefits

Data from the USA suggests roughly 1 in 40 pedestrian fatalities (2.5%) could be prevented annually by improvements to vehicle headlights. Jermakian (2011) estimated that approximately 2.3% of US crashes (142,000 of 6 million crashes) could be prevented with AFS. While the reductions in fatalities from AFS are yet to be comprehensively estimated in Europe, AFSs are being offered by an increasing number of major motor manufactures, typically on high to mid-range vehicles. The systems are supplied by several suppliers, including Valeo, Hella, and Automotive Lighting.

Baum and Geißler (2009) predicted (in an assessment of Xenon lights) that there are 1,084,924 relevant accidents in the EU27 annually, resulting in 35,869 fatalities, 275,457 serious and 1,171,178 slight casualties. These authors present an effectiveness of Xenon lights of 60%, although no evidence for this is provided, and state that this only applies to rural roads.

US Insurance claim data from HDLI (2012) for one car make shows that High Intensity Discharge headlights (typically Xenon) reduced property damage liability by 5.5% compared to non-equipped (Halogen) vehicles (95% confidence interval: -7.2% to -3.7%). There is also strong evidence that the severity of the accidents were reduced since frequency of all injury claim measures (bodily injury liability, medical payments and personal injury protection) showed reductions between -4.5% to -9.7%. These measures relate to different types of insurance coverage available in the US.

Similarly, systems which alter the beam pattern with the upcoming curve, reduced property damage liability claims by an estimated 4.7% (-7.7% to -1.6%). There was also strong evidence that injuries were significantly reduced; bodily injury liability reduced 9.9% (-17.3% to -1.7%) and medical payments 14.0% (-21.7 to -5.5%), suggesting that crashes involving equipped vehicles were less severe.

Adaptive high beam assist, which activates full beam to utilise the extra lighting available and dips the beam automatically to avoid glare to oncoming cars, showed 5.9% reduction in property damage liability (-16.7% to 6.2%), but a large increase in bodily injury liability of 32.6% (-13.3% to 102.9%) and personal injury protection (12.9%). This suggests that while the frequency of accidents shows a small reduction, the severity of those accidents might be increased (although note that the confidence limits span one in most cases). One possible explanation for this is that the greater beam throw of the high bean encouraged drivers to travel at greater speeds that they would otherwise do, therefore allowing less reaction time should an unexpected event occur. This is in line with previous findings that drivers were found to compensate for the improved vision by increasing their speed, which in some circumstances even led to increased accident risk (Kahlburg, 1993).

Studies such as Zydek et al. indicate that HID high beams can create similar levels of discomfort glare than standard HID, showing that improved detection distances without increases in glare are possible for HID "glare-fee" systems. However, information from the DfT suggests that "many thousands" of complaints are received each year about glare from standard HID light sources.

A.11.12 Benefit cost ratio

No BCR studies were located for AFS. For HID light sources, Baum and Geißler (2009) estimated that the BCR for EU27 at 3.6 (€15,159.3 million annual benefit / €4,268.8 million annual cost). However, the effectiveness values used were not robustly justified and could have been overestimated. The effect of this might at least be partially offset by the reductions in cost from the time of this study.

A.11.13 References

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A.12 Side Marker Lamps

Dedicated lights on the side of passenger cars/small vans that remain illuminated when the headlights are on to improve the lateral conspicuity of the vehicle

A.12.1 Description of the Problem

The accident type that this solution addresses is accidents that occur between collision partners on perpendicular trajectories at night, where the lack of lighting on the side of the vehicles make it difficult to detect the vehicle, leading to an accident.

In the United States, the fitment of side marker lamps has been compulsory since January 1, 1968, when Federal Motor Vehicle Safety Standard 108 that regulates the lamps, reflectors and associated equipment for cars, trucks, trailers, buses, multi-purpose passenger vehicles and motorcycles required side marker lamps. FMVSS 108 required side marker lamps for vehicles wider than 80 inches (large trucks and buses) and from 1969, for the other vehicles.

In Europe, the fitment of side marker lamps is not compulsory for M1 and N1 vehicles under 6 m in length, but EC Regulation 48 specifies the location of the lights should they be fitted and also prescribes limits of 45 degrees geometric visibility (from the longitudinal plane) for headlights and tail lights which means that the light source itself is not visible from the side. Regulation 91 specifies fitment of side marker lamps to all vehicles over 6 m in length is however compulsory; there are requirements for the height and location of fitment.

A.12.2 Potential Mitigation Strategies

Fitment of lights on the side of the vehicle provides improved lateral conspicuity for vehicles approaching on perpendicular courses. Other strategies, which have to a large extent already been embraced by more modern car design, is to provide fundamental vehicle designs that are less 'box-shaped' although limits exist on the geometric visibility of the lights such that they cannot be directly seen from angles greater than 45 degrees from a longitudinal plane through the light source.

A.12.3 Feasibility

Side marker lamps are very feasible as they are equipped to US vehicles and are also permitted in Europe, provided they comply with the positional and other requirements specified by EC Regulation 48.

A.12.4 Costs

Information from the US shows that the costs were (at 1982 prices) reported to be $21 per vehicle for lifetime of the vehicle (Kahane, 1983); this included components for the initial price increase ($16.76), increased fuel consumption due to increased weight ($2), increased fuel consumption due to increased power demand ($2.19), cost of replacement bulbs ($0.27).

Costs are now likely to be very much lower than this value and although the initial cost would remain the largest component, increases in fuel consumption are likely to be considerably lower. Furthermore, the addition of side marker lights would be relatively cheap to implement, especially as all European vehicles have regulated side turn signals that could also act as a side marker lamp when the headlights are activated (Sivak and

Flannagan, 1994), meaning that the main cost component for the fitment of the light itself has already been spent.

A.12.5 Benefits

Kahane (1983) estimated that side marker lamps reduced the number of night-time angle collisions by 16%, from 661,000 assuming no vehicles were equipped, to 555,000 if all vehicles had side marker lamps. It was also reported that the accident reduction was statistically significant, with confidence bounds of between 10% and 22% percent. It is not clear how applicable this finding is to Europe because the road configurations (as well as other factors) are likely to differ.

The US analysis also concluded that the fitment of side marker lamps did not affect fatal collisions with confidence intervals of -25% to 13% (Kahane, 1983). It was speculated that this was because the efficacy of side marker lamps in fatal accidents was at least 75% lower than non-fatal accidents because the side marker lamps were detected too late for the drivers to take the appropriate braking or avoiding action.

It appears questionable, however, whether these findings (based on data from the 1970s) would be confirmed in studies using more recent crash data. For instance, as Rice (2010) points out, side-marker lamps were introduced in the US as a result of vehicle design changes taking place in the 1960s which made the headlights less visible from the side.

Therefore, the degree to which these findings can be transferred to the current situation and to Europe is unclear. In night-time accidents the headlights of the respective vehicles are considered likely to facilitate detection of vehicles, even in situations where two vehicles are approaching perpendicular to each other. In addition to the headlight design and positioning meaning that they are visible from right angles, the average performance of headlamps has increased considerably since the 1970s (sealed beam headlamps were used at the time) to support the detection of obstacles, including vehicles seen from the side, earlier. It is therefore expected that the real-world effectiveness of side-marker lamps in modern cars is considerably smaller than found by Kahane (1983).

A.12.6 Summary and BCR (Benefit:Cost Ratio)

The original decision to regulate the fitment of side marker lamps in the US was supported by a cost benefit study based on statistical analyses of data from North Carolina, Texas and Fatal Accident Reporting System data, a study of traveling speeds in fatal angle collisions, and cost analyses of production lamp assemblies. This found, at the time of the assessment (in 1983) that:

- Side marker lamps have significantly reduced the number of night-time collisions and were estimated to prevent 106,000 accidents, 93,000 non-fatal injuries and $347 million in property damage each year.
- Side marker lamps have not had an effect on fatal accidents.
- Side marker lamps add $21 (in 1982 dollars) to the lifetime cost of owning and operating motor vehicle.

Insufficient European accident data exists to determine the frequency of night-time collisions relevant to side marker lamps. A specific study on these accidents is required to investigate using relevant and recent data whether regulation is warranted. Specific data from the US is old, and result that fatal accidents are unaffected by side marker lamps is contradictory to the findings that accidents of this type are reduced by around 16%.

However, installation costs of side marker lamps (although no up-to-date figures have been obtained) are likely to be low and functionality could be integrated with the side turn signal. In this case, small benefits might still mean that the measure was cost beneficial. A specific study is required to determine the effectiveness and cost benefit of side marker lamps in Europe.

A.12.7 References

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A.13 Emergency Brake Light Display (EBLD)

Standard fitment of the emergency brake light display (i.e. rapidly blinking brake lamps) to raise awareness of following traffic in case of hard braking, possibly also linked to anti-lock braking or stability control activation in case of slippery road surfaces.

A.13.1 Description of the Problem

This system is designed to address front-to-rear accidents. This system is primarily effective on motorways and dual carriageways and provides better quality information to following drivers so that rear shunt accidents can be avoided or mitigated.

The rationale behind EBLD is to decrease the time required to detect an emergency brake by the following driver, thereby avoiding or mitigating the effect of rear-end collisions. A road user who is temporarily not looking at the road, for instance when inspecting in-vehicle equipment, will notice through peripheral vision a flashing or a more intense brake light more readily than the activation of 'normal' braking lights.

Li et al. (2014) found that flashing brake system and flashing hazard system reduced drivers' brake response times by 0.14-0.62 seconds and 0.03-0.95 seconds respectively when compared to standard brake lights. Berg et al. (2007) compared individuals' reaction times to a flashing LED light (20Hz) and a continuous LED light and showed the flashing light to be more effective. These findings are in line with previous research showing flashing lights to have more attention attracting properties than continuous lights, especially when they appear in the periphery of the visual field as might be the case for a partially distracted or inattentive driver (Gail et al., 2001).

A.13.2 Potential Mitigation Strategies

To use the visual information in the brake light activation to quickly alert following drivers when a leading vehicle is braking harshly, for example under conditions in which fast-moving traffic unexpectedly comes to a sudden halt. Triggered by the strength of brake activation the rear brake lights are illuminated in different ways to indicate emergency braking manoeuvres to the following vehicles. Some EBLD systems illuminate the brake lights with greater intensity and larger illuminated area, whereas others employ a strategy of rapidly flashing brake lights. The stronger the braking, the bigger is the illuminated area or the greater the frequency of flashing lights. Studies consistently find that the most effective signal is provided by flashing the brake lights and that the frequency is important and most effective at 4Hz (GRE, 2003).

A.13.3 Feasibility

This system is currently fitted to higher specification cars. For example, EBLD using enlarged brake light areas (marketed as "brake force displays" rather than EBLD) has been standard equipment for the BMW 7 Series, X5, Z4 and 3 Series Coupe and Cabriolet since 2008. Furthermore, EBLD using flashing brake lights are standard equipment in the Mercedes S, SL, and CL-Class. EBLD can expected to filter down to more mainstream models considering the high prevalence of rear-end collisions.

Manufacturers show differing strategies for EBLD: Mercedes vehicles flash the stop lamps, while vehicles from the Volkswagen Group of manufacturers (VW, Audi, SEAT and Skoda) flash the hazard lights to indicate emergency braking. Some studies have shown that flashing the amber hazard lights are a more effective emergency signal; Li at al. found a 0.11s (10%) improvement in brake response time for flashing hazard lights compared with flashing red brake lights. In the past, flashing the hazard lights while the vehicle was in motion was not permitted, but because even in these jurisdictions the use of manually activated signal to warn following drivers is commonly used and well understood, it is now allowed.

Flashing EBLD equipped with incandescent lamps have been found to be ineffective at reducing braking responses due to the slow rise times of incandescent lamps (Alferdinck, 2004). Thus, for best performance, EBLD requires LED lights because this source provides a fast response. Since more and more cars are increasingly equipped with LED lights, the uptake of EBLD can be expected to grow in the future and the benefits of EBLD could be realised more easily.

The scale of the aftermarket (retrofitted flashing EBLD) is currently unknown. However, EBLD systems based on larger illuminated areas and light intensity are unfeasible for retrofit onto older vehicle models employing filament or incandescent light bulbs.

UN Regulation 48 (UNECE, 2013) contains specification for the lamps providing the optional EBLD to flash at 4Hz (+/- 1Hz) for LED and 4Hz (+0Hz/-1Hz) for incandescent sources when a passenger car decelerates at greater than 6 ms-2 or a truck or bus decelerates at greater than 4 ms-2.

A.13.4 Costs

EBLD is fitted as standard on some vehicles, but costs were not forthcoming for optional fitment. However, with the available information, it seems likely that the system cost is relatively small because a signal could be used by the light system from ABS or ESC activation.

A.13.5 Benefits

The EBLD system using flashing brake lights as developed by Mercedes-Benz has been shown to reduce drivers' braking reaction time by up to 0.2 seconds (NHTSA, 2005). For a car travelling at 80 kilometres per hour, for example, this effectively results in a 4.4 metre reduction in the braking distance.

On the basis of data on German traffic accidents, EBLD has been estimated to affect 25% of rear-end crashes in moving traffic and 15% in stationary traffic resulting in a 14% reduction in these crashes. These estimates were based on the assumption of an EBLD penetration rate of 70% of the German passenger vehicle fleet (Gail et al., 2001).

A.13.6 Benefit:Cost Ratio

No formal assessments of EBLD were located. The available evidence suggests that the effectiveness of EBLD is greater for LED light sources and that these are effective in some situations at providing better information to following drivers. The cost benefit ratio is unknown and this would require a more detailed study to gain an accurate estimate of the effectiveness of the EBLD and in costs of the current system. This means that the benefit to cost ratio is considered to be in the region of 1, or perhaps slightly greater, even if the overall benefits may be relatively small.

A.13.7 References

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A.14 Temperature Sensors

Temperature sensors that provide a warning to the driver of unexpected icy road conditions.

A.14.1 Description of the Problem

The issue that temperature sensors would address are accidents caused by reduced friction between the road surface and the tyre because of ice on the road. Controlling the vehicle becomes more difficult in these conditions because the threshold at which the vehicle loses grip with the road surface is reduced. If a driver is aware of the conditions, they can adapt their driving style to reduce the risk of loss of control.

In Great Britain, 2.6% of all accidents occurred when the road surface condition was recorded as 'snow or ice'. For fatal accidents, this percentage was 2.2%, serious accidents 2.3% and slight accidents 2.7% (DfT, 2013). For a proportion of these accidents, the road surface will be obviously covered in snow and/or ice. It is likely that a sensor that warned of unexpected "black ice" would apply only to a proportion of the target population identified above.

A.14.2 Potential Mitigation Strategies

Sensing system that alerts the driver when the external temperature reduces to near freezing, therefore warning the driver of the possibility of ice formation on the road surface.

A.14.3 Feasibility

Almost all modern cars have an external temperature reading on the dashboard despite it not being mandatory. Most models have at least a visual warning signal when the external temperature reduces to 4°C and many a further warning at 0°C. These types of temperature readings have been equipped in vehicles for a number of years.

A.14.4 Costs

Costs are unknown, but the inclusion of the required sensing and display is already included as standard fitment.

A.14.5 Benefits

Benefits cannot be quantified because the vast majority of the fleet already have these sensors and displays and therefore the benefits have been realised. Further benefits may be possible using car to car or infrastructure to car communication to relay temperature information, but no studies have been carried out to assess the benefits. Furthermore, the driver would still remain responsible for any changes in driving behaviour in response to the warning.

A.14.6 Benefit:Cost Ratio

Benefit to cost-ratio-not calculated because the appropriate systems are already fitted. Improving the signal to include requirements for audible warnings would improve the system effectiveness.

A.14.7 References

DfT (2013). Reported Road Casualties in Great Britain: 2012 Annual Report. Department for Transport, London.

A.15 Integrated Cleaning System

System for which the screen wash is projected from nozzles on the windscreen wipers as opposed to from nozzles positioned in front of the windscreen

A.15.1 Description of the Problem

Poor visibility through the windscreen swept area while windscreen washer fluid is projected onto the windscreen. A traditional windscreen cleaning cycle takes up to 11 seconds (Fraunhöfer Institute, n.d.), during which time, the quality of the driver's direct vision can be impaired. However, TRL consider that the safety risk is small for several reasons. While water and cleaning fluid on the windscreen might temporally affect the quality of vision, key hazards are still visible. Furthermore, drivers generally choose to clean the windscreen at a time which it is safest to do so. For these reasons, and the fact that no accident causation has been identified in relation to the conventional windscreen wipers, TRL consider the issue addressed by this measure to be of minor safety relevance.

There is no data available on the number of accidents that occur in these circumstances and for this reason, the target population cannot be accurately estimated. TRL consider that it is negligible in number.

A.15.2 Potential Mitigation Strategies

- Instead of windscreen washer fluid being of being sprayed in jets from nozzles beneath the windscreen, washer fluid is projected directly from the wiper in synchronization with its position in the wiping cycle.
- Ensure the condition of the wiper blades is appropriate; this is already an item in (PTI) Periodic Technical Inspection.

A.15.3 Feasibility

Daimler (in partnership with Valeo) launched an integrated windscreen wiper system in 2012 (Automotive Engineer, 2012). This system comprises over 30 heated water jets (to avoid freezing) and delivers water just in front of the blade (in both directions) so that the windscreen fluid is projected exactly where it is needed for effective cleaning.

It is known that some other vehicles also have nozzles on the wiper (e.g. Jaguar) but these are lower density than the Daimler system.

A.15.4 Costs

System costs are unknown.

A.15.5 Benefits

An integrated cleaning system means that the quality of the driver's vision remains better than it would with conventional wipers. The Fraunhöfer Institute demonstrated a reduction of the driver's reaction time when using the system compared to conventional wiper. At 50Km/h, this equated to a reduced braking distance of 4m (Fraunhöfer Institute, undated). In some circumstances, this could reduce pedestrian injury or occupant injury risks in general. However, TRL considers that the real world benefit of such a system is low.

A.15.6 Indirect benefits

Possibly reduced congestion resulting from fewer accidents, although these are believed to be negligible.

A.15.7 Benefit:Cost Ratio

Benefit-to-cost ratio is unknown. Scale of benefits and costs also unknown. Benefits are considered to be very low because the driver can still view hazards while using conventional windscreen wipers, and to date, no significant safety concerns have been raised in relation to the use of conventional windscreen wipers.

TRL's view is that the benefit to cost ratio for this system is below one, although the costs for the system are also likely to be low.

A.15.8 References

Automotive Engineer (2012). Daimler claims a world-first in windscreen wiper technology. March 2012. http://ae-plus.com/technology/daimler-claims-a-world-first-in-windscreen-wiper-technology.

Fraunhöfer Institute (n.d.).

Annex 4 Car Occupant and Pedestrian Safety

Appendix B. Car Occupants and Pedestrians

B.1 Improved protection of seniors and small stature occupants through the adoption of advanced anthropometric test devices

Potential for modifications to current (e.g. R.94, R.95), upcoming (e.g. pole side impact, full-width frontal) and potential (e.g. rear seat occupants in adult belt) occupant protection safety requirements, including the possibility of additional tests within each measure, to improve the safety of seniors and small stature occupants.

B.1.1 Description of the Problem

Currently the frontal impact safety of cars sold in Europe is regulated by the performance requirements of UN Regulation 94. Performance limits are set for the front seat occupants (anthropometric test devices / crash test dummies) in a full‐scale test where the car is driven into a wall with a deformable element facing at 56 km/h. By setting limits for the occupant loading, the structural performance of the car and the effectiveness of the occupant restraint system is assessed. As a result of this test and also the implementation of the Euro NCAP frontal impact test (similar to that of Regulation 94, but carried out with at a slightly higher impact speed of 64 km/h), advances have been seen in maintenance of the occupant compartment integrity during such an impact. Occupant safety has also improved through the use and refinement of airbags and other restraint system components. In the last 25 years the safety systems in cars including the seat-belt, the airbag and the provision of a stable occupant compartment have helped save thousands of lives in road traffic accidents (Sandner and Unger, 2011). However, the requirements placed on the safety systems mean that there are now complex restraint systems balancing seat-belt pretensioning, limiting the force through the belt and contribution from the airbag situated in stiff occupant compartments. The stiffness of the vehicle has been increasing in order to prevent intrusion into the occupant space. The consequence is that safety improvements reduce dangerous intrusions and excursion of the occupant and the remaining injury challenges relate to the deceleration levels and forces from the restraint system in a crash. This is particularly the case for occupants who are less able to tolerate high loads as well as others, according to their stature or age. For instance, women, small and elderly people have a higher risk of injury than mid sized, male, young people.

Shorter occupants have been identified as being at increased risk of injury compared with average size males in dummy tests (Summers et al., 2001; Smith and Couper, 2006) and numerical modelling studies (Ridella et al., 2005; Happee et al., 1998), but the evidence from accident studies was less conclusive (Carroll, 2009; Frampton et al., 2005). This may be due to the relatively low recording rate of occupant height in some studies, or to the presence of strong confounding factors such as age. Furthermore, female front seat passengers were identified as a relatively high risk group, which may also be influenced by size and age considerations.

Fatality risk is higher for females than males of the same age where they are more susceptible to neck and abdominal injuries and, at lower crash severity levels, highly susceptible to arm and leg fractures; mainly due to their small stature causing them to be out-of-position compared with the optimal design position for the vehicle's safety equipment during an impact.

Older occupants are more susceptible to thoracic injuries especially rib fractures and sternum fractures. This is true in all impact types (frontal, side and rear; Hong et al., 2013). Older occupants have much higher injury and fatality risk in vehicle collisions than young adults; starting at 21 years old, for each year older an individual gets, their injury risk will grow by at least 3%. Older occupants have reduced bone strength and fracture tolerance compared with younger occupants.

National accident databases provide a breakdown of car occupant fatalities by impact type. Based on the UK and France data, it is found that approximately 60% of fatal and serious car occupant casualties occur in frontal impacts (Richards et al., 2010). If this is assumed to be representative for Europe, it can be calculated that in 2010 there were about 17,000 car occupant fatalities and 108,000 seriously injured car occupants in frontal impacts in Europe; which indicates that car frontal impacts are still a major problem.

However, not all injured occupants are correctly restrained with a seat-belt and some casualties are injured in impact types where intrusion is the dominant cause of loading, rather than the restraint system. A large proportion of fatalities will be associated with levels of intrusion into the occupant compartment of 10 cm or greater. Therefore, it could be expected that restraint system changes would be of most benefit in lower severity accident cases, particularly those in which the occupant was seriously injured, rather than killed. This is supported by the fact that the highest proportion of injuries sustained by MAIS 2 or MAIS 3+ surviving car drivers in frontal impacts with cars or light goods vehicles are restraint system induced injuries to the thorax.

About 40% of the serious casualties in frontal impacts and 30% of those killed are female. With regard to older occupants, more than 10% of seriously injured casualties and 20% of the fatally injured casualties are 66 years old or older.

Therefore the target population for restraint system induced changes would be 10% of fatalities and 30 to 50% of serious injuries, depending on the precise injuries being addressed. For female occupants this could be 3% of all frontal impact fatalities and 12 to 20% of seriously injured casualties. For older occupants, it could be 2% of fatalities and 3 to 5% of those seriously injured.

Annex 4.1.1 Potential Mitigation Strategies

Several sizes of anthropometric test dummies are used to test safety restraints in an attempt to represent the diversity of the population. The Hybrid III frontal impact crash test dummy used in Regulation 94 was designed to represent the 50th percentile mid sized male person. Additionally, 5th percentile female and 95th percentile male Hybrid III dummies exist and are readily available. The Hybrid III 5th percentile female is regulated by the Code of Federal Regulations (CFR), Title 49, Part 572 Subpart O. The 95th percentile is not included in Part 572, but has been evaluated for use in the Federal Motor Vehicle Safety Standards (Shaw et al., 2007) and has been used widely in automotive and military research for many years.

With regard to restraint system adaptations, a variety of solutions exist already for the detection of and tuning for occupants of different sizes:

In 1999 Tailorable Occupant Protection System (TOPS) was being developed by BSRS Restraint Systems. The system tailors the airbag and seat-belt functions based on the occupants' data (including their weight and proximity to the airbag when seated) and severity of the collision. The occupant data will be used in the smart airbag system to suppress or adjust the power of the airbag deployment to meet the needs of the individual occupant.

Siemens have developed a new seat frame integrated occupant Weight Classification System (WCS) which is used in TOPS. The Siemens WCS employs four strain-gauge force sensors which are located within or beneath the occupant's seat and positioned in its four corners. The sensors are connected to an Electronic Control Unit (ECU) which processes their signals; the "real" weight of the occupant can be determined from the weight measured and its position in the seat. The WCS can also account for the portion of the occupant's weight which is transferred to the vehicle floor through the legs.

The WCS will classify the occupant using the real weight into one of four weight classes:

- "Empty"
- "Child class", based on the weight of an average six-year old child
- "Small adult" class, based on the 5th percentile female, and
- "Large adult" class, based on the 50th percentile male

The WCS works in conjunction with a seat position sensor which detects where the seat is positioned along its track relative to the airbag module. The occupant's position to the airbag can be accurately determined by the seat position input combined with the occupant's weight distribution (centre of gravity) in the seat, and is then classified into one of three position zones (red, yellow, green).

- Red zone – will suppress the deployment of the airbag
- Yellow zone - will likely require a depowered or staged airbag deployment
- Green zone – will allow for full airbag deployment

For older occupants, there is a need to reduce the severity of loading. The effectiveness of different load limiting levels is reported by Trosseille and Labrousse (2010). It is expected that implementation of load limiters with a lower force limit than is generally the case with the existing fleet, would represent an improvement in protection for thoraces of occupants. Unfortunately, as was shown by those authors, the Hybrid III dummy, when used in the Euro NCAP frontal impact test procedure, is not able to determine a different risk of injury with different load limiting forces. This suggests that to drive widespread adoption of load limiters with a lower force limit, a new dummy torso is required. As such, this may constitute a benefit that can be brought about if Euro NCAP were to test with the new dummy torso.

Whilst not without issues (Shaw et al., 2013), the THOR presents an option for a dummy with improved biofidelity and a more sensitive dummy torso than the Hybrid III (Parent et al., 2013).

Annex 4.1.2 Feasibility

The most common components in frontal impact restraint systems are seat-belts, driver steering wheel or passenger airbags, belt pretensioners and belt load limiters. These may sometimes be supplemented by systems such as knee airbags, anti-submarining airbags in the seat base, and buckle clamps (which prevent load being transferred between the lap and shoulder sections of the seat belt). Some vehicles also include steering columns that can move forward to give the driver more space, enabling the driver to be decelerated more gently over a longer distance.

Driver steering wheel and front seat passenger airbags may be single-stage or dual-stage. The latter allows the airbag control system to deploy the airbag in a more or less vigorous manner and is typically used to give a lower airbag inflation force if an out-of-position occupant is detected. In addition, more precise control of airbag volume and inflation force can be used to tune the airbag for different occupant sizes and positions. This may be implemented via a range of techniques such as:

- Variable geometry tethers within the airbag (which may be achieved by allowing additional tether payout or by cutting the tethers)
- Variable venting (which may be achieved within the airbag by linking the vents to the tethers, or by rotatable venting modules within the housing)

Richert et al. (2007) show a DaimlerChysler concept for a 'Continuously Adaptive Restraint' airbag that has: continuously variable shape and volume appropriate to each seat position; increased mass flow for faster airbag inflation and therefore earlier coupling with the occupant; and variable venting to adapt the airbag damping characteristics to ensure that all of the available deceleration space is used to stop the occupant in a smoother fashion. In simulations, large reductions in head accelerations were observed for 5th percentile female, 50th and 95th percentile male occupants, with modest reductions in chest defection for the larger occupants, at a US-NCAP collision severity. Further work was considered to be necessary to validate hardware samples of the system.

Seat-belt pretensioning may also be achieved in a variety of ways, typically actuated by pyrotechnic systems. Pretensioning may be applied to the shoulder belt and/or lap belt. Typical systems tension at the shoulder belt and outboard (or both) lap belt anchorages, but some systems tension both parts of the belt via the buckle stalk. These systems help to ensure that the belted occupant is 'in-position' prior to airbag inflation, maximise the available ride-down distance for the occupant, and help to reduce the risk of submarining.

Load limiters are typically used to control the maximum force in the shoulder belt in order to reduce the risk of shoulder and thorax injuries from the belt loads. Again, many load limiting options are available, in terms of both the load limit that is set and the technology that is used to achieve it. Load limiters in modern vehicles typically give a maximum belt force of 5-6 kN, and may be set as low as 4 kN. The load limit may also be adjustable and various mechanical systems are available to give a pre-programmed load limit that varies with belt payout, or a load limit that can be varied in response to the collision severity (Sieffert and Wech, 2007).

Occupant sensing has been used in production vehicles for many years, with various levels of sophistication. For instance, (Chan, 2000) notes that relatively simple sensors in the seat base have been used to determine seat occupancy and estimate occupant fore-aft position since the mid-1990s. Occupant weight may be estimated with load sensing bolts between the seat base frame and the seat rail used for fore-aft adjustment of seat position (Bosch, 2007). The relative load on the forward and rearward seat bolts (or similar systems) may also be used to estimate whether the occupant is leaning forward or backward in the seat.

Occupant position can be estimated from the seat fore-aft position assessed by sensors on the seat rail. In combination with a shoulder belt pretensioner, this can be used to estimate the occupant position relative to the steering wheel or dashboard in the early part of a collision. Occupant position can also be determined with more sophisticated sensors based on cameras or other non-contact sensor technologies. This information could be used, for example, to determine the most appropriate airbag volume for a particular occupant. IIHS reported that occupant weight and position sensors have been common in US-fleet vehicles since the introduction of the 'advanced airbag' rule into FMVSS 208 in 2003.

Schramm et al., (2006) (VW) and Rölleke & Köhler (2001) (Bosch) both note that the collision severity can be determined from the crash sensors and associated control algorithms. Indeed, Rölleke & Köhler show a wide range of first and second-stage airbag deployment options for different crash types (e.g. full-width rigid wall, pole, offset deformable, and truck under-ride) and collision severities (from 15-64 km/h). They note that the severity would typically be determined using a combination of an intrusion sensor and a centralised acceleration sensor.

Hynd et al. (2011) defined a 'smart' restraint system, based on components which are already available to the market, as comprising:

- Occupant sensor, e.g.
    - Seat fore-aft position sensor
    - Occupant weight sensor
- Variable airbag volume
    - e.g. by tethers and/or venting
- Variable shoulder belt load limit
    - Depending on crash pulse
- Standard pre-tensioners and seat-belt.

Hynd et al. note that a number of vehicles already contain some or all of these components, and the degree to which they are available may be dependent on the market in which the vehicle is sold. It is considered, therefore, that such a restraint system can be considered 'near-to-market' and therefore suitable for consideration as a solution to improved front seat occupant safety diversity, which may be encouraged by possible updated legislative requirements.

Digges et al. (2013) describe how injury risk functions used in the US NCAP could be adjusted so that they provided a closer link to the rates of injury for older occupants as seen in the accident data. They comment that this adjustment would produce added incentives for safety designs that more correctly prioritise the reduction of injuries most harmful to older occupants.

It should be noted that in an ideal implementation, improving restraint system performance to protect the thorax and offer greater protection for older occupants should also be of benefit for younger occupants. However, this will not be the case if it conflicts with existing safety provision, for instance protection against excursion in high severity incidents. Therefore, rather than simply changing the restraint system requirements it would be important to ensure that the improvement is additional. This may require the implementation of adaptive restraint systems which take account of impact severity.

In summary, it seems that restraint system performance could be tuned to improve the situation for another size of occupant using existing technology. Some improvements to protect older occupants could also be made, for instance through the implementation of lower seat belt load limits. However, there is no test requirement present yet to encourage this. In the future smart restraint systems could be used, given that the necessary technology is already near-to-market.

Annex 4.1.3 Costs

The costs for provision of a restraint system tuned to offer improved protection for small or older occupants are not known. The costs are likely to consist of the following elements:

- Development of an appropriate solution
- Piece costs for the restraint system components and vehicle hardware
- In-house validation testing by the vehicle manufacturer and final tuning
- Any additional test costs through new requirements for vehicle type approval
    - For instance, generation of technical dossier to demonstrate performance to a Technical Service
    - Alternatively, provision of a body-in-white for sled testing with different sizes of occupants and seating positions

Annex 4.1.4 Benefits

Carroll et al. (2010) found that a more sensitive dummy thorax that is capable of supporting a drive towards advanced restraint systems could offer protection for the torso providing a potential benefit of up to £33 million (€41 million) based on a willingness to pay. A new injury risk function to represent ages of the occupant population having a lower tolerance to torso loading was also cited as being beneficial if protection is improved for older occupants. Depending on the overlap with improvements brought about through the use of a new dummy torso, Carroll et al reported that this could lead to an estimated benefit of as much as £30 million (€37 million) (willingness to pay). This figure considers only mid-sized occupants as the dummy thorax was (and is) only available as the mid-sized option.

The influence of using a dummy that represents occupants who are either smaller or larger than the mid-sized male was also investigated by Carroll et al. They noted difficulties with this measure because of small accident data sample sizes and a lack of reporting of stature and mass of casualties in those data. However, their initial indications suggest that the use of a larger than average size dummy could lead to the greatest benefit, of up to £154 million (€190 million) (willingness to pay).

In contrast, based on a case-by-case study, Hynd et al. (2012) estimated that for two options to change the dummy size in Regulation 94, then even optimistically it was estimated that there would be an overall disbenefit for drivers, and pessimistically this disbenefit was greater. Although it was estimated that the front seat passenger groups would fare better than drivers if the dummy was changed to a 5th percentile female, the predicted optimistic benefit was still very small and there was the possibility of an overall increase in the number of fatal and serious casualties. There was a similar split between drivers and front seat passengers if the injury criteria in the chest region were to be changed to protect older occupants. A disbenefit was estimated for drivers, while there was a possibility of an overall benefit for front seat passengers. These findings may sound surprising, in that making a test more stringent could decrease safety. This comes from the possibility that tuning to make the restraint system 'softer' in a single impact condition could create a decrease in safety in more severe crashes. To avoid this, and generate a substantial benefit, Hynd et al. comment that a smart restraint system would be needed and this could only be required in another test condition was added as well as Regulation 94. We now know that a full-width frontal impact test has been proposed.

If a new test procedure was to be added to the frontal impact requirements, Carroll et al. (2010) noted that one which helps to provide safety for accidents that occur at speeds lower than the current offset frontal impact tests appears to offer the greatest maximum estimate of benefit. This benefit could be as much as £247 million (€305 million) on a willingness to pay basis. However, the data from France suggested that low speed impacts were less important in the causation of torso injuries (of at least moderate severity) than the CCIS data from Great Britain.

A full-width test such as has been proposed by the Informal Working Group on Frontal Impact was estimated to offer benefit in the range from £0 to £105 million (€130 million). Carroll et al. suggested that this benefit could be enhanced by setting the test speed to account for accidents which occur at a lower severity than the current offset procedures, with the use of the new dummy hardware, and a torso injury criterion which protects older occupants. This could extend the benefit to beyond £300 million (€370 million), each year for the EU-28 countries, based on the in-depth data from Great Britain.

Similar approaches could be used to assess the benefits for rear seat occupants as well as front seat occupants, or for those in other classes of vehicle or impact types. However, existing benefit estimates on these topics were not obvious in the literature.

Annex 4.1.5 Benefit:Cost Ratio

Without cost information, no benefit-to-cost ratio can be produced. However, given the benefit analyses carried out to date, some comment can be given on the likelihood of benefit coming from measures to improve restraint system performance for small or older occupants.

With the introduction of a full-width frontal impact test procedure in European legislation, there is scope for requiring advancements in the provision of restraint system safety. Using a small female in the front seat passenger position can simulate an 'at risk' occupant group.

Reducing pass/fail thresholds to improve performance for older occupants should benefit all occupants. However, it is possible to require too much protection in this manner, where safety is degraded for all occupants at higher severity levels. Therefore at least two different test severities are needed to encourage smart (adaptation) functions to be built into restraint systems. Until this happens the benefit will be marginal and limited fundamentally by the need to avoid the creation of disbenefit.

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B.2 Protection of far-side occupants in side impact collisions

In a side impact with both driver and front seat passenger (FSP) occupants, the struck-side occupant is protected by multiple airbags. However, the far-side occupant tends to slip out of the seat-belt and collide with the struck-side occupant. This often results in head-to-head contact and head/shoulder/chest-to-chest contact and concomitant injuries.

B.2.1 Description of the Problem

Despite the introduction of countermeasures to protect occupants on the struck-side of the vehicle during a side impact event, from contacts with the intruding structure or an external object, it remains possible for occupants to be severely injured through contacts with adjacent occupants within the same vehicle.

Monash University research (Fildes et al., 2010) states that: "Real-life crash analysis indicates that occupants on the struck side of the vehicle may also be injured by contact with an adjacent occupant in the same seating row. The injury consequences of occupant-to-occupant impacts can be severe, and sometimes fatal." Additionally, there is evidence that the traditional three-point seat-belt does not prevent an occupant moving out of their seat when there is a far-side impact, potentially leading to a number of serious injuries, including head, spinal and abdominal injuries.

In far-side impacts, occupants are flung either into the other seat or another occupant, if present, which can cause harm to both occupants. In the US, nearly 29% of fatalities for belted front occupants in side-impact non-rollover crashes are caused by far side impacts, according the to the National Highway Traffic Safety Administration.

The U.S. data used by Digges et al. (2009) showed that about 43% of the MAIS 3+ injuries in side crashes and rollovers occur in far-side crashes. Also, more than half of the MAIS 3+ injuries in rollover are in far-side rolls.

B.2.2 Potential Mitigation Strategies

There are a range of systems that could protect far-side occupants in the case of side impact collisions. Two of these have been researched in detail: altered three-point seat-belts and side support airbags (also known as mid-mount and front centre airbags).

Research undertaken by Monash University (in collaboration with George Washington University, GM-Holden, Autoliv Research, Medical College Wisconsin, Virginia Tech, William Lehman Centre, Human Impact Engineering and Ford) looks in detail at the injuries caused to far side occupants in side impacts. They have looked at injuries using countermeasures compared with a baseline with no countermeasures, and a variety of speeds and impact types were considered. It was found that altered three-point (and four-point) belts and side support airbags performed best, but that other existing systems, like belt pre-tensioners, also provide additional restraint from injurious contacts (kinematic effects noted by Kent et al., 2013).

General Motors (GM) has taken the research from Monash University, which their Australian subsidiary GM Holden was involved in, and worked with supplier Takata to design a front centre airbag, now available on three vehicle models. The airbag deploys from the side of the drivers chair and positions itself between the driver and front passenger (if there is one), acting as a cushioning element between the occupants. It is predicted to be able to reduce injuries and fatalities in driver-passenger collisions, rollover crashes and for single drivers where the far side is hit. It weighs about 1.1 kg and takes 26 milliseconds to inflate, or slightly longer than an outboard airbag.

No research was identified regarding such systems for anything other than M1 vehicles.

B.2.3 Feasibility

There are currently no requirements to fit far-side impact protection systems in vehicles, and tests like the side impact protocols in Euro NCAP do not have a test that covers this scenario. However, the Euro NCAP 2020 Roadmap includes updates to the side impact test suite to include far side occupant protection for driver and front passenger, with a protocol developed by 2017, ready for adoption in 2018 (Euro NCAP, 2014). Also, as a countermeasure, GM has recently introduced a front centre side airbag in three of their top range crossover SUVs.

Digges et al. (2009), suggest that:

- Either the THOR or the WorldSID dummy would be satisfactory test devices for assessing far-side protection with minor modifications such as changing the location of the chest instrumentation (citing Pintar et al., 2007).
- Injury criteria and risk functions for use with WorldSID in far-side crashes have been documented
- There is now a sufficient technology base so that far-side protection can be evaluated and rated by consumer information tests.
    - Noting that crash tests have shown that the presence of a far-side dummy has no influence on the near-side dummy's measurement of injuries from the near-side contact (Newland et al., 2008).

GM have installed front centre side airbags in three of their Crossover SUVs (all prices are for basic models):

- Buick Enclave – has a suggested retail price of $39,270 (in 2013)
- Chevrolet Traverse – has a suggested retail price of $30,340 (in 2013)
- GMC Acadia – has a suggested retail price of $34,485 (in 2013)

This clearly demonstrates the feasibility of implementing suitable restraints in production vehicles.

B.2.4 Costs

No costs have been identified in the existing research.

However, front centre airbags are very similar to head/thorax side airbags, for which more is known about cost. The 'Safety Is Not An Option' report states that Ford installed a head/thorax side impact airbag as an optional safety feature in the Ford Focus in 2004. The 'per vehicle' retail price of side curtain airbags was $350, but the cost for installation was actually $200. This value is in 2004 prices, and doesn't include the costs of research into the far side impacts and development of the airbag.

To add a single airbag module, $200 seems like a high cost, given that no additional sensing is likely to be required. Vehicle recall information from the U.S. suggests that a figure of $90 to $100 may be more appropriate for a single airbag unit, including the fitment costs. However, whilst a lower unit price than $200 is anticipated, definitive costs for a centre side impact airbag are yet to be obtained.

In 2013, GM delivered over 245,000 of the Enclave, Traverse and Acadia, suggesting they will have spent nearly $49,360,000 installing the front centre airbags. Assuming that there are about 230 million vehicles in the fleet in Europe (ANFAC, 2013), then at $200 per unit, the cost of equipping the fleet would be $46 billion. This might be expected to accrue at the rate of about 12 million new registrations each year, which would be $2.4 billion per year or about €1.8 billion.

B.2.5 Benefits

The benefits of using countermeasures to prevent far-side occupant injuries are quite clear in all tests – the number of fatalities will reduce and there are serious injury reduction opportunities (57% estimated in Monash Universities report) for improved belts and side support air bags. Additionally, side support airbags were shown to be effective in preventing interaction injuries, which cause a number of fatalities.

However, possible injuries caused by the countermeasures were disregarded. These were, however, investigated by Thomas and Scott (2013). They reported that, as part of the development of the GM and Takata technology, several out-of-position and arm interaction test conditions were evaluated. Some of these positions were based on existing out-of-position test procedures, while others were developed independently. The front centre airbag demonstrated performance that met IARV (Injury Assessment Reference Value) goals for such tests.

Older occupants appear to be over-represented in far-side crashes, and are also more likely to sustain serious injuries. Additionally, older drivers appear to be involved in a higher number of vehicle-to-vehicle crashes at junctions than younger drivers, who are more likely to hit poles or trees. As vehicle-to-vehicle side impact crashes occur more frequently than pole or tree impacts, the benefits of countermeasures for far-side occupant injuries are much higher for older occupants.

The overall injury reduction for each countermeasure depended on the change in speed and type of impact, but varied from 18%-57% for serious injuries.

A report by Bostrom et al. (2008) states that: "On an annual basis over 250,000 belted, front seat occupants are exposed to far side impact. Over 2,200 of these occupants are seriously injured. An estimated 456 occupants are fatally injured each year in the U.S.". Additionally, it found that 18% of the fatalities occurred for the lateral delta-v below 30 kph and 48% occurred for a lateral delta-v below 50 kph. From this, it theorised that countermeasures could prevent 136 (out of the 456) fatalities in the USA annually. Using the Road Safety Annual Report 2013, an estimate for changing an accident from fatal to injury could be $920,000 (2000 prices), providing an estimated saving of $125 million annually.

Additionally front centre airbags, the only system currently in use, have been shown to provide a clear advance in restraint performance – they can reduce the total torso excursion by 45% - while no sacrifice needs to be made towards passenger comfort.

In Europe, there are about 28,000 road fatalities each year. Almost 50% or these are car occupants (European Commission, 2013). Of the approximate 14,000 car occupant fatalities occurring each year, up to 40% may occur in side impact accidents and the balance of struck-side to far-side occupants is 60:40 (Thomas et al., 2009). Therefore, it can be expected that there are, approximately, 2,240 far-side car occupant fatalities occurring due to side impact events in Europe each year. Each fatality may be assigned a cost of €1,564,503, which leads to a benefit of €1.33 million, if mitigated to result in a serious injury outcome for that casualty. Therefore the potential to save up to 30% of the far-side impact fatalities would realise a maximum benefit of €900 million each year in Europe.

Additionally, in Europe, there are about 180,000 seriously injured road casualties each year. A smaller proportion of surviving road casualties are car occupants than those killed: around 40% (European Road Safety Observatory, 2013). Of the approximate 72,000 seriously injured car occupants, about 25% are likely to occur in side impact accidents and the balance of struck-side to far-side occupants is more like 55:45 (Thomas et al., 2009). Therefore, it can be expected that there are, approximately, 8,100 far-side car occupant seriously injured casualties occurring due to side impact events in Europe each year. Each serious injury may be assigned a cost of €231,278, which leads to a benefit of €215 thousand, if mitigated to result in a slight injury outcome for that casualty. Therefore the potential to save up to 18 to 57% of the far-side impact serious injuries would realise a benefit of €311 to €986 million each year in Europe.

B.2.6 Benefit-to-Cost Ratio

The benefit will depend on the speed of the vehicles involved in the collision and the type of impact, but varies from 18%-57% serious injury reduction. This is more effective for older occupants, who are more likely to be involved, and more likely to be seriously injured. In Europe it could be possible that up to 670 fatalities and up to 4,600 seriously injured casualties may be prevented annually, with a value of €1.2 to €1.9 billion.

Component cost with installation is thought to be around $200; probably less than this. Based on $200, and delivery figures, the annual cost in Europe to equip each new car, each year, would be about €1.8 billion.

Based on these figures, the benefit-to-cost ratio would be up to the range of 0.6 to 1.1. However, it should be noted that implementation of far-side protection requirements in the side impact suite of Euro NCAP testing would potentially affect both the benefit and cost associated with this measure. Therefore, consideration should be given to the effect of legislation in this context and how regulatory and consumer information programmes could operate together to minimise the cost and maximise the benefit of far-side occupant protection.

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B.3 Side impact protection for occupants of all sizes and prevention of ejection

Implementation of systems to protect the heads of occupants of all sizes and to prevent ejection of occupants as a result of a side impact crash (which would most likely mean the use of full-size side window airbags)

B.3.1 Description of the Problem

The UN Regulation 95 mobile deformable barrier side impact test and equivalent, or similar, procedures around the world have encouraged side impact protection improvements. Though not essential, most vehicle manufacturers have responded to this test and the prevailing safety need by fitting side impact airbags to protect the occupant. The conventional bag used for this protection is mounted in the seat back to inflate in a crash and provide separation between the intruding structure and the thorax of the occupant.

Some protection for the head can be offered in this way. However, to protect the head robustly from partial ejection from the vehicle or to isolate it from intruding structures a dedicated curtain airbag covering the window aperture can be used.

In Europe vehicle crash safety is not only driven by Regulation but it is also driven by consumer rating programmes, i.e. Euro NCAP, and manufacturers' in-house requirements. Because of this, there is considerable variation in the side impact safety performance levels of vehicles in the fleet: from those that just meet the Regulation 95 requirements to those that exceed them substantially and achieve a high score in Euro NCAP.

This variation can be described with three safety performance levels (Edwards et al., 2010):

- Just Regulation 95 compliant
    - The vehicle is designed to meet the Regulation 95 requirements just. This vehicle would score minimal points in Euro NCAP and most likely not be fitted with a thorax airbag.
- Typical (baseline)
    - This vehicle would score about 13 points in a Euro NCAP side impact test rated to the 2008 protocol and be fitted with a thorax airbag, but not fitted with an airbag for head protection.
- State-of-the-Art
    - This category was defined as the performance of a state-of-the-art vehicle. This vehicle would score close to 18 points (maximum) in a Euro NCAP side impact test rated to the 2008 protocol and be fitted with a thorax airbag and a curtain airbag for head protection.

Chauvel (2012) estimated that there were 52 barrier test-like side impacts causing a severe injury or fatality in France each year for each million M1 vehicles registered. This number was 19 for N1 vehicles. However, a smaller number of pole-like side impacts occurred causing severe or fatal injuries. For these impacts there were 16 injuries for each million M1 vehicles and 3 injuries for each million N1 vehicles registered. Multiplying these numbers by the total number of vehicles in use in Europe (around 230 million according to ANFAC, 2013) suggests that the target population would be 15,640 occupants killed or seriously injured (KSI) in M1 side impacts and 5,060 KSI in N1 side impacts. Of these, 3,680 and 690 would involve pole-like impact partners for M1 and N1 vehicles respectively.

Pole side impacts are considered important in this context as a full-size window airbag is likely to be a critical countermeasure in preventing an occupant from being KSI.

As a comparison, 30% of all passenger car accidents and 25% of all commercial vehicle accidents are side impacts (OICA, 2012). Although only 1.6% of all car accidents and 0.5-0.9% of all commercial vehicle accidents are side impacts with a tree, in Germany. Assuming that about 40% of all road users KSI are car occupants, then there are about 85,000 KSI car occupants in Europe each year. On this basis and using the OICA percentage, then it should be expected that at least 1,275 of these will have been involved in a pole-like side impact. This is a smaller estimate than from the French data.

Another countermeasure ("Rollover – crashworthiness") considers the target population for rollover accidents in Europe. Within this population it is suggested that there could be 267 fatalities due to rollovers without a significant other impact or ejection and 446 fatalities in rollover accidents where the occupant was partially or completely ejected from the vehicle. It should be noted that the regulatory impact assessment for ejection mitigation measures supporting the implementation of FMVSS No. 226 had stated that window curtain and thorax airbags with a rollover sensor were effective countermeasures in preventing these fatal injuries from occurring.

Therefore full-sized window curtains could contribute both to reducing the burden of injury from side impacts and rollovers.

B.3.2 Potential Mitigation Strategies

A draft UN Regulation has been prepared regarding the approval of vehicles with regard to their pole side impact performance. This will be used to enforce a minimum level of performance in the provision of head protection airbags for vehicle occupants represented by the test dummy in the crash test.

As it stands, the dummy to be used is the WorldSID 50M (the 50th percentile male version of the WorldSID).

In addition to the draft Regulation, a pole side impact test has been included as an option for vehicles with a head protection airbag in the Euro NCAP side impact procedures since 2009. This uses the ES-2 side impact dummy, also a representation of the 50th percentile male anthropometry, although this will change to the WorldSID 50M in the revisions to the protocol expected in January 2015.

As such, there is already an incentive to provide protection for the mid-size male and this will become mandatory upon implementation of the pole side impact regulation.

It can be noted that the WorldSID and ES-2 dummies have different seating position procedures. As a result of these differences the initial positions of WorldSID 50M and ES 2 dummies in cars can be different. For instance, Edwards et al. (2011) determined that in a small family car, the head to roof measurement was 74 mm for the ES-2 compared to 119 mm for WorldSID 50M. That is, the WorldSID head was 45 mm lower.

Furthermore, in the Euro NCAP Oblique pole side impact test protocol, Version 7.0, to be introduced from January 2015 there is an assessment of the coverage of side airbag head protection. This is evaluated by considering the inflated airbag position with respect to the nominal head centre of gravity for the dummy allowing a head protection device zone around that point, when projected laterally onto the airbag. This zone extends down and forward from the 5th female seating and head position and upwards and rearwards of the 95th male seating and head position. Where a vehicle does not offer sufficient protection to cover this zone, a penalty of -4 points shall be applied to the overall pole side impact score. Any vehicle that does not provide a head protection device covering the front and rear seat positions on both sides of the vehicle will also attract this modifier.

An EEVC WG13/21 subgroup was formed towards the end of 2008 with Terms of Reference (ToR) to perform an analysis to estimate the likely societal benefits and associated costs for the following potential options for the modification of Regulation 95 (Edwards et al., 2010):

- Option A – Baseline - To do nothing and allow current measures to propagate throughout the vehicle fleet, taking account of additional safety benefits derived from vehicles complying with Euro NCAP (Do nothing option).
- Option B – Amend the existing Regulation 95 with a new barrier face, test conditions and assessment criteria (AE-MDB option).
- Option C – Adopt a pole test, to complement the existing Regulation 95 (Pole test option).
- Option D – Adopt a head impact test procedure, to complement the existing Regulation (Interior Headform or FMH test option).
- Option E – Combination of Option B and Option C
- Option F – Combination of Option B, C and D.

It was assumed that the pole test regulation would effectively require the vehicle to be fitted with a countermeasure, such as a curtain airbag, which gives protection for head strike against objects anywhere between the A and C pillars, such as the cant rail and B pillar, in a range of impacts and not just car-to-pole accidents. A countermeasure such as a thorax head airbag which did not offer protection for head strike over all of this area would not fulfil this requirement. However, it was noted that to enforce the fitment of this type of countermeasure the regulation would need to include measures, in addition to the pole test, to assess if adequate protection is provided for areas between the A and C pillars that are not in alignment with the pole.

Whilst there is the assumption that the pole test introduces the need to fit a head protecting airbag for a 50th percentile male front seat occupant. It does not guarantee protection for smaller occupants (as the curtain need not extend down to that level) or for rear seat occupants (as the test does not include a dummy in the rear seats and is aligned to load the front seated occupant principally).

There has been talk within child safety fora about the potential need to extend head protection in the rear seats of vehicles to cover the expected height of an older child sitting on a booster cushion. The precise height at which it might be expected that a child restraint system no longer offers substantial head protection seems to be contentious. However, it is generally agreed that in a state-of-the-art vehicle head protection should extend far enough to account for the sitting height of the 5th percentile female – assuming that this does not interfere with the fitment of child restraint systems in that seating position.

B.3.3 Feasibility

Fitment rates for window curtains were not obtained for this project. However, there is an expectation that most new vehicles will provide curtain airbags for the front seat position at least (i.e. between the A and B pillars). A quick review of the 11 latest vehicles tested by Euro NCAP indicated that all of them (except the Berlingo) had a window curtain in the front and seven of the eleven also included the same protection for the rear seat occupants (coverage from A to C pillar), despite there being no formal incentive to do so, yet.

Therefore, there seems no barrier to the provision of a suitable countermeasure for the tests, setting aside the usual constraints of cost and increased mass.

However, without results from the updated Euro NCAP pole impact protocol, there is no quantitative information available as to how well the implemented curtains protect smaller occupants. Edwards et al. (2011) observed that in a Euro NCAP 5 star small family car, the WorldSID 5F (5th percentile small female) rear passenger kinematics showed that the head curtain airbag did not protect the dummy's head during the impact. Despite initial contact with the lower part of the airbag, the dummy's head was not prevented from contacting the door.

Eung-Seo et al. (2011) reported on nine design factors have a major effect on the ejection mitigation performance of curtain airbags, with regard to FMVSS 226. One of these is the overlap between the airbag and the 'beltline' of the vehicle. They propose that an overlap of 50 mm is required between the inflated cushion and the door trim. It is assumed that such a design would also offer good coverage of head protection for even small occupants in a side impact.

Costs

As mentioned, there is considerable variation in the side impact safety performance levels of vehicles in the fleet from those that just meet the Regulation 95 requirements to those that exceed them substantially and achieve a high score in Euro NCAP. Therefore, the measures and associated costs required to upgrade these different vehicles to meet safety levels dictated by the proposed regulatory change options will vary.

For the EEVC WG13/21 subgroup analysis, the costs to upgrade a vehicle to meet the proposed regulatory option B to E requirements were estimated for vehicles having a range of safety performance levels by a group of European car manufacturers co-ordinated by ACEA and the WG13 German industry advisor. These costs were scaled using passenger car registration data to estimate costs for the UK, Germany and the EU. The average costs estimated per car for the UK depending on its safety performance level ('Just Regulation 95 compliant', 'Typical (baseline) Euro NCAP 13 point', 'State of the Art Euro NCAP 18 point') were as shown in Table B-1.

Table B-1: Costs per passenger car to meet the requirements for the various options given the three levels of existing performance (Edwards et al., 2010)

Option	Just R95	Baseline	State-of-the-Art
B (AE-MDB test)	€355	€264	€116
C (Pole test)	€386	€297	€121
D (FMH test)		€70	
E (AE-MDB test and pole test)	€505	€402	€222

Some members of the subgroup thought that the costs estimated were too high. For Option C (Pole test) they were up to nearly double those estimated by NHTSA in a Regulatory Impact Assessment to add an oblique pole test to FMVSS214. However, it should be noted that the NHTSA only included part costs and assumed that other costs, such as those for structural changes, padding and packaging, would be subsumed in ongoing vehicle redesign costs whereas the EEVC WG13/21 subgroup study included these costs and also other costs such as after-market costs. This should at account for part of the difference between the costs but is unlikely to account for all of the difference.

Associated weight increases to upgrade the vehicle were also calculated by the EEVC WG13/21 subgroup for vehicles with 'typical (baseline)' safety performance levels.

No cost information was available for a geometric evaluation of the area covered by the curtain airbags in a side impact, as encouraged via Euro NCAP.

B.3.4 Benefits

The benefits were estimated for the UK by the EEVC WG13/21 subgroup for each of the proposed regulatory options A to E in terms of lives and serious injuries saved. These benefits were transformed into a monetary value using the values published by the UK Department for Transport in Road Casualties GB 2007.

For Option A (do nothing) it was estimated that 72 lives would be saved per year (5% of car occupant fatalities) and 285 serious injuries (2% of car occupant serious injuries). This was equated to a monetary value of £166 million. Using recent casualty prevention costs, mitigating the severity of these injuries would lead to a monetary benefit of €156 million. This value indicates that there is still much benefit to be gained from allowing current safety measures, i.e. Regulation 95 and Euro NCAP, to propagate throughout the vehicle fleet. Here it should be noted that the pole side impact GTR and Euro NCAP head protection device zone initiatives had not reached the position that they have now.

For Options B to E and Option B* the following benefits over and above those for Option A were estimated, as shown in Table B-2:

Table B-2: Benefit and estimated monetary valuation of adopting the various side impact protection options (Edwards et al., 2010)

Option	Benefit (fatalities)	Benefit (serious injuries)	Monetary value
Option B (AE-MDB test)	28 lives (2%)	88 serious injuries (0.7%)	£61 million
Option C (Pole test)	75 lives (5%)	230 serious injuries (2%)	£162 million
Option D (FMH test)	1 life (0.07%)	49 serious injuries (0.4%)	£9 million
Option E (AE-MDB & pole tests)	75 lives (5%)	230 serious injuries (2%)	£162 million
Option B*(AE-MDB test at higher speed)	51 lives (4%)	115 serious injuries (1%)	£103 million

() expressed as a percentage of all car occupant fatalities / serious injuries.

The results show that from the options proposed, Option C (the pole test) and Option E (AE-MDB and pole tests) offer the greatest additional benefit. The reason that the pole test alone was predicted to give as much benefit as the combination of the pole and AE MDB tests was that for the protection of the front seat occupant (in the majority of cases the driver) it was assumed that the pole test would introduce all the countermeasures that an AE-MDB test would. For the rear seated occupant it was assumed that the AE MDB test would introduce additional countermeasures compared to the pole test for head and thorax protection. However, because the number of rear seated occupants in the data sample was small, the effect of this was not seen in the predicted benefit.

It should be noted that the benefits for the pole test were calculated based on the assumption that the regulation would require the vehicle to be fitted with a countermeasure, such as a curtain airbag, which gives protection for head strike against objects anywhere between the A and C pillars, such as the cant rail and B pillar, in a range of impacts and not just car-to-pole accidents. A countermeasure such as a thorax head airbag which did not offer protection for head strike over all of this area would not fulfil this requirement.

A precise benefit analysis could not be performed for Germany at the time of the EEVC WG13/21 subgroup report because there were only a small number (428) of MAIS 2+ casualties in new cars (registered 2000+) in the GIDAS database.

No formal benefit estimate was found describing the different potential usefulness of different airbag coverage. Therefore, it is difficult to provide information on the proportion of the WG13/21 subgroup estimates which would not be realised due to ineffectual coverage.

B.3.5 Benefit:Cost Ratio

Costs and benefits analysis

A costs and benefits comparison was performed by the EEVC WG13/21 subgroup for the UK only (see Table B-3).

Table B-3: Cost-to-benefit ratio of adopting the various side impact protection options (Edwards et al., 2010)

	Cost:Benefit ratio			
	Benefit	Just R95	Baseline	State-of-the-Art
Option B (AE-MDB test)	€67M	12:1	9:1	4:1
Option C (Pole test)	€178M	5:1	4:1	1.6:1
Option D (FMH test)	€10M		17:1	
Option E (AE-MDB and pole tests)	€178M	7:1	5:1	3:1

It is seen that Option C (Pole test) gives both the highest benefit and the best (lowest) cost-to-benefit ratio with a range from 5:1 to 1.6:1 depending on the safety performance level of the car.

It is also seen, for all Options and for all vehicle safety performance levels, that the costs were greater than the monetary value of the benefits, i.e. the net benefits are negative. However, this may not actually be the case because of the biases and uncertainties in the benefit and cost analyses. Hence, it was recommended by that subgroup that the absolute value of the cost-benefit ratio is not considered. Instead, that a comparison of the ratios for the proposed options is made to help determine the most cost effective way forward.

Adding the benefit from KSI occupants that are ejected or partially ejected in rollover accidents may decrease the cost-to-benefit ratio. This is considered in the crashworthiness measure for rollover countermeasures. In that section, a target population of 446 fatalities was estimated. However, no estimate of effectiveness is available for the behaviour of full-size window airbags in preventing or mitigating the severity of these injuries.

A study of French data was considered alongside the UN GRSP Informal Group on Pole Side Impact (Chauvel, 2012). It was considered for this study that the potential benefit would be different for ESC equipped vehicles, compared with the current fleet. Taking the values produced assuming ESC is fitted, the Cost:Benefit ratio for M1 vehicles was between 5.2:1 and 6.2:1 in France. The equivalent numbers for N1 vehicles were a minimum of 17.3:1 and a maximum of 20.8:1. The break-even costs required for M1 and N1 vehicles, respectively, of providing curtain airbags and improved structural features were €66 and €20.

B.3.6 References

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B.4 Pre-crash seat-belt tensioners and occupant position adjustments in case of an inevitable impact

Mandated measures could include pre-crash seat-belt pre-tensioning, adjustment of the seat position prior to the start of the collision (in both the occupant would be approximately stationary relative to the vehicle at the start of the collision), or dynamically moving the occupant just prior to and at the start of the collision (as in the Mercedes system). Front impact only? Would one mandate this, or simply have enhanced frontal impact requirements that are difficult to meet without introducing this?

B.4.1 Description of the Problem

Regulatory and consumer information crash tests necessarily specify a particular standard seated position for the occupants prior to the test. Knowing this, specification, vehicle manufacturers will use this during the design and validation phases when introducing a new vehicle, seat or restraint system. However, in the real world driving situation, occupants can adopt a wide variety of positions. Some of this variation will come from their size, some from their seating position preference and some from the particular functions they are undertaking at the time (e.g. looking to the side, or adjusting the radio station, etc.). Also, emergency manoeuvres such as hard braking and swerving often made before a collision will lead to out-of-position occupants. Therefore if the restraint system has been optimised for a specific combination of seat and occupant position, there could be scope for improvements with respect to other positions observable in everyday driving and immediate pre-crash positions. Seat-belts and air bags cannot work as effectively for out-of-position occupants.

By tensioning the seat-belt early in a crash event, it is possible to restrain the pelvis of an occupant through coupling with the seat base or anchorages and ensure that the thorax couples with the restraint system early in the collision event. This pre-tensioning of the seat belt is widely used in modern cars. However, there may be scope for extending the options for pretensioning if the function could take account of the phase when an impact has been detected and judged to be either likely or inevitable.

B.4.2 Potential Mitigation Strategies

A pre-crash system prepares the vehicle’s safety features before a likely impact to provide the best possible protection to the occupants within the vehicle. A system may use reversible pre-crash seat-belt tensioners to automatically tense an occupant’s seat belt before an inevitable crash by retracting some of the webbing. This aims to restrain the occupant firmly into the seat to reduce the amount the occupant is thrown forward during a moderate or severe frontal crash.

A system has also been developed that adjusts the timing of the pre-crash tensioner such that the occupant is moving rearwards relative to the vehicle at the start of the crash. This is intended to reduce the maximum forward change of velocity of the occupant, reducing the energy that must be absorbed by the restraint system and thereby reducing the injury risk.

In addition, the seat could be moved rearwards, either before the crash to provide a greater space between the occupant and forward vehicle structures such as the steering wheel, or timed to enhance the rearward occupant motion mentioned above.

B.4.3 Feasibility

A variety of vehicle manufacturers offer an extra added safety feature to their vehicles at a relatively small price to the consumer. Sensors within the vehicle will determine whether the vehicle is in a spin or the driver is performing emergency manoeuvres. The vehicle will apply the brakes in stages whilst tightening the front seat-belts using seat-belt pretensioners; holding the occupant securely in his/hers seat in the correct position. If a collision is avoided, the seat-belts are reversible and will loosen off and all other safety features will go back to normal.

Vehicles with the appropriate safety packages available (typically more expensive than the above systems) use sensors to scan ahead and will sense when a collision is likely to happen. The vehicle will take the precautions needed to prepare for impact and secure the occupants in the optimal position.

Mercedes Benz first introduced a 'Pre-Safe' system on the S Class in 2002 (Merz et al., 2013). Pre-Safe is now available on 40 models from Mercedes Benz at an optional added cost. At speeds above 30 km/h it will monitor the dynamic state of the vehicle (speed, rotation, etc.) and the driver's inputs to steering, accelerating and braking to determine whether or not emergency actions are taken.

If the system deems a collision is imminent it will:

- Take the slack out of the seat-belt using pretensioners; and
- Optimise the occupant's seating position, including adjustment of the front head restraints.

If there is sufficient vehicle rotation and a roll-over or side impact is considered likely, the system will:

- Close all windows and the sunroof to prevent foreign objects from entering the car;
- Inflate supporting bolsters in seat cushions and backrests in both front seats;
- Move the passenger seat longitudinal adjustment and backrest and cushion angle to favourable positions.

An additional feature to Pre-Safe on the newest 2014 S Class is the Pre-Safe Impulse system, which will move the driver and passenger towards the centre of the vehicle if an impending lateral collision is sensed. Air chambers in the side bolsters of the seat backrests are inflated giving the occupant a nudge in the ribs, enough to move them up to 50 mm out of the danger zone, whilst also accelerating the seated occupant in the direction they will later take during the impact. In a frontal impact more use is made of seat-belt pretensioners facilitating earlier coupling of the occupant with the restraint system and hence both lower chest and pelvis loading.

If a collision doesn't occur, the Pre-Safe process is reversible, the seat-belts will release again and the system will return back to normal. However, Pre-Safe Impulse is not reversible as the current power level of the reversible belt pretensioner does not suffice for moving occupants in the event of a crash.

Volkswagen uses a similar technology as the Pre-Safe system which is called 'Proactive Occupant Protection'. It will detect when an emergency manoeuvre is being made and prepares the vehicle and occupant restraint systems in advance of an imminent collision. The system will receive continuous feedback from the braking, stability control and 'Front Assist' ambient traffic monitoring system using sensors to detect any critical situations which have the potential of a possible accident. If these systems detect a critical manoeuvre (e.g. skidding), at speeds above 30 km/h, the Proactive Occupant Protection will remove slack from the front seat-belts using electrical pretensioners to prevent the occupants from moving to an unsafe position in their seat and will close any open windows and the sunroof to just a small opening. This will allow the head and side airbags to offer the best possible support to the occupant. However, this system is only enabled at speeds over 30 km/h. If no collision occurs, the pretensioners return to their nominal starting position and the windows return to their original position.

Audi and Skoda, which are owned by the Volkswagen Group, use the same pre-crash technology used in the VW Proactive Occupant Protection. The system analyses information from the ESP sensors used in the braking and stability control systems. Audi’s “Pre-sense basic” system is in many of the larger Audi model series and Skoda’s “Crew protect assist” is used in a small number of models.

Available on the Lexus GS Premier model as an added extra at an additional cost to the consumer, is a Pre-crash safety system with driver monitoring and lane keeping assist. It uses millimetre-wave radar and an on-board computer to analyse the road ahead and calculate possible collision risks. At a high risk of a collision the driver will be alerted by audible and visual warnings and the brake pressure will be increased. In a situation where a collision is unavoidable, the brakes will be applied automatically and the seat belts will be tightened ready for an inevitable impact.

Lexus has similar safety features as selected models in the Toyota range. Toyota has named it as a “Pre-collision system” which also includes “Pre-collision intelligent headrests”. This uses a sensor built into the head restraint and will detect the head position. When a low-speed rear collision is determined to be unavoidable, the head restraints will shift forward to help mitigate the risk of a whiplash injury to the occupant.

Nissan and Infiniti use a “Predictive Forward Collision Warning” system to detect potential risks ahead of the vehicle. It uses sensors to analyse the relative velocity and distance to a vehicle directly ahead as well as the vehicle travelling in front of the preceding one. If the system detects a potential risk ahead it will show a signal on the display warning the driver to decrease their speed in addition to an audible warning and will also tighten the seat-belt holding the occupant securely in the correct position in their seat.

Honda uses a “Collision Mitigation Brake System” which is a radar-based autonomous emergency braking system. It will detect moving and stationary vehicles up to 100 metres ahead when the vehicle is travelling above 15 km/h.

The system will go through a three-stage process if it detects an obstacle:

1. Approximately three seconds before impact, the driver will be alerted by visual and audible warnings
2. The second stage, when the system senses that a collision is still likely, will automatically start to apply the brakes and give three sharp tugs on the seat-belt.
3. When the collision is unavoidable, the system will tighten the front seat occupants’ seat-belts using reversible tensioners and apply a high level of braking force. This can be supplemented by the driver braking to the car’s maximum.

The collision mitigation brake system is reversible: if the accident is avoided, it will loosen the seat-belts and the warnings will stop.

Volvo state that, “To be properly restrained and positioned in the event of a crash is essential.” The Volvo electrical reversible belt retractor (ERR) as fitted to the new XC90 will tighten the seat-belts before a likely collision and will reset them automatically after activation when the dangerous event is over. The system works in different scenarios including frontal collisions, rear collisions, harsh braking, running into a ditch or over rough terrain.

Rates of fitment of pre-crash safety systems have in general seen a modest increase over the last year but overall, a large amount of car models do not offer crash avoidance and pre-crash systems in any of their models. Although there is currently no mandatory requirement in place for pre-crash systems in vehicles, rewards from NCAP are given to car manufacturers recognising their safety technology and used to incentivise manufacturers to accelerate standard fitment to their model range, and encourage others to pursue higher safety standards.

Since 2010, Euro NCAP have been rewarding car manufacturers who make available safety technologies in their vehicles and can demonstrate a safety benefit to the consumers and society from using these safety systems. This reward system incentivises car manufacturers to accelerate the standard fitment of this safety equipment and make them more transparent to the car buyer.

Euro NCAP have rewarded the following relevant systems:

- 2010 Mercedes-Benzes Pre-Safe
- 2010 Mercedes-Benz Pre-Safe Brake
- 2010 Honda Collision Mitigation Brake System
- 2012 VW Proactive Occupant Protection
- 2012 Audi Pre-Sense Basic
- 2013 Skoda Crew Protect Assist

Euro NCAP will analyse a number of features associated with the technology:

- Innovation
- Safety potential
- Accident and injury causation
- Target requirement
- Procedures and criteria
- Expected benefit and side effects and
- Real world experience

However, they do not yet have a formal test protocol to verify the claims presented within the technical dossier supporting the system.

To summarise, there are a number of systems on the market from different car manufacturers and each year the technology is improving and fitment increasing, so a pre-crash system which can include seat-belt pretensioners is definitely feasible. However, there does not yet seem to be a valid way of assessing the effectiveness of these systems and hence encouraging their fitment.

B.4.4 Costs

Most Mercedes-Benz models either supply the Pre-safe system as standard with their vehicles or as an optional extra at a cost. The A Class from £20,045 offers the Pre-Safe with buckle mounted belt tensioners for £340 extra. For the C Class (from £26,855), Pre-Safe comes as standard. On the Mercedes S Class short wheel base, from £62,090, it also comes as standard whereas as the long wheel base, from £65,090, has the extra option for intelligent rear seat-belt package with Pre-Safe for £1,230.

Volkswagen price their Proactive Occupant Protection package as an additional fitment to the vehicle at a cost of £135 to the consumer on their Golf range (Golf S, Golf BlueMotion). However the Golf SE, the Proactive Occupant Protection package comes fitted as standard at the vehicle cost of £19,480.

The same system on the Audi (Pre-sense basic) is priced at an extra cost of £260 on the A6 series from £30,995.

Skoda's Crew Protect Assist is available as an added extra of £120 on the Octavia Hatch S which retails from £16,310.

Optional safety equipment is often available only when combined with other safety features as part as a package. On the Toyota Land Cruiser Invincible starting from £52,495 it costs the consumer £1,360 to add their Safety Pack which includes Pre-crash safety, lane keeping assist and adaptive cruise control. Whereas on their Avensis Excel which costs from £27,505, the same safety pack will cost £1,500 extra.

The Lexus Pre-crash safety with adaptive cruise control package available as an optional extra on the GS 450H Premier from £51,495 will cost £3,350.

Infiniti offers a Safety shield package which includes Predictive forward collision warning system for an extra £2,080 on the Infiniti Q50 Premium 2.2D 6MT from prices of £30,350.

From the above we get a maximum breakdown retail price for pre-crash pretensioning systems. However to provide the consumer with an idea of what components are used in the system, below is a breakdown of the components used and their prices (indicative).

Many of the larger car manufacturers use pre-crash systems which need a millimetre-wave radar (used in adaptive cruise control) to sense vehicles ahead to determine the likelihood of a collision. Based on the information given by the radar and the range of sensors; they will relay information to the system’s ECU where it will determine the required output from the brakes, driver warning features and retractable seat-belt pretensioners (either electric or motorised) to secure the occupant. Many of the components used in these systems are commonly used in cars for basic safety (e.g, seat-belt pretensioners and sensors used in forward collision warning and brake assist systems, etc).

A breakdown of the Honda Collision Mitigation Brake system (CMS):

- Millimetre-wave radar
  Will detect vehicles within a range of 100 metres ahead, in a 16° arc.
- Sensors
  The system uses a range of sensors to determine driving conditions such as yaw rate, the steering angle, wheel speed and brake pressure.
- CMS Electronic Control Unit (ECU)
  Based on information obtained from the radar such as the distance to the vehicle ahead and relative speed and the anticipated vehicle path determined by the information from the sensors; the ECU will calculate the likelihood of a collision and will warn the driver and in some cases will activate the braking function. The ECu will exchange information as required with the E-Pretensioner, the Variable Signal Analyser (VSA) and the Meter Unit.
- VSA-ECU Integrated Hydraulic Unit
  Receives information from the various sensors and sends the information to the CMS ECU and other control units. Based on instructions from the CMS ECU it will control the brake hydraulic unit to activate the brakes.
- E-Pretensioner ECU
  Will send instructions based on braking instruction signals from the CMS ECU and electrically controlled brake assist signals to the motorised E-Pretensioner to retract the seat-belt.
- E-Pretensioner
  Based on instructions from the E-Pretensioner ECU, the E-Pretensioner will retract the seat-belt using an internal motor. It is used in combination with conventional pretensioners.
- Meter Unit
  The meter unit receives signals from the CMS ECU, and warns the driver of potential danger using an audio alarm and visual warning.

CMS and E-Pretensioner System Overview:

- Steering angle sensor: £20.00 - £80.00
- Warning display
- Millimetre-wave radar: (Honda collision mitigation brake system radar: £995.00)
- Miniature onboard VSA-ECU: (VSA: £145.00 - £275.00)
- CMS switch
- Active wheel sensor: (£60.00-£225.00)
- CMS ECU: (Honda ECU ranging from £50.00-£80.00)
- E-Pretensioner: from £10.00
- E-Pretensioner ECU: (Acura E-Pretensioner control unit assembly from £40.00)
- Yaw Rate sensor: £40.00-£290.00

Prices vary with car manufacturers, but pre-crash systems are usually included in a safety package as an optional added extra ranging from £120 to £3,350 or come as standard fitment on higher priced cars and specifications.

However, components bought separately (millimetre-wave radar costing £995 alone) would cost the consumer around £1,500 for a basic pre-crash system at a minimum price. If the vehicle is already fitted with systems such as adaptive cruise control and brake assist then the vehicle will already have the sensors and radar components available which will bring down the costs significantly. The main component needed would be the E-pretensioner ECU which will instruct the seat-belt pretensioners to tighten, securing the occupant in an optimum position.

As such the precise cost varies with model, specification and price. It is dependent on component costs, pre-crash systems available and car manufacturer. Assuming a basic system price of £1,500 or €1,800 then costs for the European fleet can be considered. There are about 12 million new registrations each year in Europe (ANFAC, 2013). Therefore the cost of equipping these vehicles with pre-crash seat-belt pretensioners would be approximately, €22 billion each year.

B.4.5 Benefits

Pre-crash occupant position systems are expected to increase the likelihood that the restraint systems will be capable of working optimally as they were designed to in the impact phase. This will prevent the injury risk increasing due to the pre-crash braking or loss of control from emergency manoeuvres such as hard braking and swerving.

"The potential occurrence of effects like bag slap or a contact to the instrument panel can be reduced if the occupant remains closer to the nominal seating position, as this is the reference position the restraint system can show its best protection effectiveness." (Mages et al., 2011).

The Volkswagen system used on the VW golf and some Audi and Skoda models only functions at vehicle speeds above 30 km/h. This would therefore limit the range of collisions in which such systems could offer a benefit, though it is expected that relatively few (less than 25%) frontal impacts resulting in a serious or fatal injury would occur at speeds lower than 30 km/h (Edwards et al., 2009). In all other frontal impact accidents, pre-crash pretensioning should be of some benefit, although from the information reviewed it is not known how much.

Research from the ASSESS Project showed some reduction in injury metrics with a pre-pretensioning system (Infantes et al., 2013). The same behaviour was observed in modelling, full-width testing and offset deformable barrier frontal impacts. Small improvements were noticed in most measures though some small increases in criteria were also found when using the pre-crash pre-tensioning. However, with pre-crash braking there was a risk that the driver would move forward into a position where an undesirable interaction with the deploying airbag was evident. This adverse issue with pre-crash braking was mitigated by the pre-pretensioning of the seat belt. Hence Infantes et al. conclude that, the effect of the pre-pretensioner seemed to have a positive effect in reducing the occupants' injuries. However, the sensitivity of the passive safety tools currently on-the-market is not high enough to reliably quantify this benefit.

There has been no past literature found on pre-crash systems used on N1 vehicles. Presumably seat-belt pretensioners in pre-crash systems are less effective as vehicle mass goes up and available braking acceleration goes down.

B.4.6 Benefit:Cost Ratio

The absence of benefit information means that no benefit:cost ratio can be provided.

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B.5 Seat-belt Reminders (SBR)

A system that detects the presence of occupants on front and rear seating positions and monitors their belt status. In order to encourage seat belt use, an audible and/ or visual warning is issued if occupants are not wearing a seat belt.

B.5.1 Description of the Problem

It is widely recognised that the seat-belt is one of the most important and effective secondary safety features for vehicle categories M and N. A range of retrospective studies have consistently demonstrated a significant reduction in casualties of all severities for belted occupants compared to those not wearing a seat belt (Elvik and Vaa, 2009). The seat belt provides a proven and effective way to reduce the risk of injury by arresting the occupant in a controlled manner and is also necessary to allow the airbag to be fully effective as a supplemental restraint system. Occupants in the rear seating positions also benefit from being restrained by seat belts. The protection benefits rear seat occupants and those in the front seating positions because the seat belt prevents injurious interactions between rear seat passengers who would otherwise be thrown forward in an accident.

Despite this proven protective potential, seat belt wearing rates in the European Union (EU) differ markedly between countries: on front seats of M1 vehicles, for example, between 69% and 99% (IRTAD, 2013), (WHO, 2009). Recent calculations by TRL, based on the latest available data for each country (2008-2013), show that the average on-road seat belt wearing rates in M1 vehicles across EU-28 are approximately 90% on front seats and 70% on rear seats (TRL, 2014).

The available data on seat belt wearing rates in other vehicle categories than passenger cars (M2, M3, N1, N2 and N3) is limited. In order to make reasonable assumptions of wearing rates for the other countries, TRL considers it the best approach to assume a relationship between rates in passenger cars and commercial vehicles. This would mean assuming wearing rates in commercial vehicles to be at a generally lower level, but to be relatively higher in countries with high wearing rates in passenger cars. Based on data from Austria, Germany, Sweden and the United Kingdom, the wearing rates for N category vehicles were estimated to lie between 40% and 81% on a per country basis for EU-28. For M2 and M3 vehicles, the driver wearing rate was assumed to be the same as M1 drivers; for passengers the wearing rate was assumed to be 50% of M1 rear seat passengers.

The belt wearing rates in casualty statistics differ from these numbers, due to the general protective effect of seat belts (i.e. some people wearing a seat belt are not or not as severely injured when involved in accidents) and a correlation of risk taking behaviour with both increased involvement in accidents, and reduced seat belt wearing. A Swedish study found that only 5% of HGV occupants fatally injured in traffic accidents were wearing a seat belt, (Trafikverket, 2010) cited after (Volvo Trucks, 2013). 50% of Swedish unbelted HGV fatalities could have be saved had they been wearing a seat belt (Strandroth, 2009).

The target population for this measure is the number of unbelted casualties in the European Union (EU-28) and therefore, the group of current casualties that could benefit from the protection provided by a seat belt if its use was successfully encouraged. A correct estimation of the target population is an important input for the impact assessment. However, determining whether or not an occupant wore a seat belt in an accident is generally poorly recorded in accident data. Subsequently, a method was developed that did not allocate belt use to casualties and instead used measures of seat belt effectiveness and belt wearing rates to estimate the proportion of the casualty population that could be influenced (see section D.5.5). With this approach, the input to the calculation from the casualty data uses only absolute numbers recorded in the CARE database

B.5.2 Potential Mitigation Strategies

Seat Belt Reminders (SBR) are devices that detect the presence of an occupant and the belt buckle status and give an audible and/or visual warning if occupants are not wearing a seat belt. Different specifications regarding the warning strategy are available. These are mainly UN Regulation 16, Section 8.4 and the Euro NCAP assessment protocol (Euro NCAP, 2013). System designs can meet both specifications simultaneously. SBRs have the proven potential to increase the seat belt wearing rate (and thereby reduce casualty rates) by issuing warnings (Williams et al., 2002), (Ferguson et al., 2007), (Lie et al., 2007), (Freedman et al., 2009).

SBR systems consist of, in principle, the following components:

- A sensor in the belt buckle, to determine the belt wearing status;
- an occupant detection sensor, to determine if occupants are present;
- a control unit;
- tell-tale and chime to warn the occupants as required in UN R16 and Euro NCAP; and
- wiring.

The occupant detection sensor is not necessary for the driver's seat, as this can be assumed to always be occupied. Advanced occupancy sensors are available that are capable of discriminating between objects, children and adults. Occupancy detection is also omitted frequently in rear seats, because Euro NCAP does not require it to be awarded extra points (it is recommended, however). The control unit is usually integrated in the airbag control unit which makes a separate housing unnecessary. A dedicated tell-tale displaying the belt status will increasingly be replaced by information displayed in the general on-board display.

B.5.3 Feasibility

Technical Feasibility

SBR systems are offered as optional or standard equipment in many passenger cars (M1) and also some N category vehicles. For the driver's seat in M1 vehicles SBRs are a mandatory requirement for all new vehicle sold since 1st November 2014. Fitment for passenger and rear sets in M1 vehicles has been increasing over the last years, in response to reward provided by Euro NCAP. Unlike in some other countries with NCAP initiatives, it is possible to achieve a five star rating without SBRs. However, the reward is such that SBRs are an effective way to improve the Euro NCAP rating. In 2013, 95% of tested car models were equipped with passenger seat SBR and 77% with rear seat SBRs.

Regarding other vehicle categories (M2, M3, N1, N2 and N3), no information on fitment rates with SBRs could be identified. It is known that Volvo Trucks fits SBRs as standard for driver's seats in their vehicles. The situation for other manufacturers is unknown.

There are no technological barriers preventing implementation in all vehicle categories. For the passenger seats in buses and coaches (M2, M3) some adaptations of the existing systems would be required, not least regarding the warning strategy for passengers leaving their seat during journeys. TRL would consider an implementation in the near future possible without serious technological problems.

Enforcement Feasibility

UN Regulation 16[13], Section 8.4 requires at least the driver's seat to be equipped with a SBR for the type approval of M1 vehicles. It requires a system design that issues a first level warning for at least 4 seconds when the vehicle is stationary and the ignition is switched on, and a second level signal for at least 30 seconds when the vehicle is moving above a certain speed, has covered a certain distance or the engine has been running for a certain time. At the second level, the system has to present an audible and a visual warning. The visual warning may be continuous or intermittent and has to be readily visible and recognisable in the daylight. The audible warning may also be continuous or intermittent and shall be easily recognized. The SBR may allow short term deactivation by the driver and long term deactivation to be performed with garage equipment.

The Euro NCAP assessment protocol (Euro NCAP, 2013) awards vehicles with up to three extra points for SBRs (one point for each of driver's seat, passenger's seat or all rear seats) if the system meets certain criteria. Seat occupancy detection is required for the passenger's seat only. The driver's seat can be expected to always be occupied. For the rear seats occupancy detection is recommended, but does not currently influence the rating. From 2017, rear seat occupancy detection will become part of the SBR protocol and will contribute to the rating.

For front seats, Euro NCAP requires a "final signal", which has to be audio-visual and must be presented at the latest 60 seconds after the engine start, after 500 metres of vehicle travel or speeds above 25 km/h. The final signal must last for a minimum of 90 seconds and consist of a loud and clear audible and a visual signal. This leaves room for variation because it is, for example, not necessary to present the signal for 90 seconds continuously but gaps of up to 25 seconds are permissible. The start of the final signal may be delayed if the car provides an "initial signal" shortly after vehicle start that consists of an audible and/or visual signal. The initial signal may be followed by an "intermediate signal". If a change in belt status occurs at speeds above 25 km/h, i.e. a belt gets unbuckled, an immediate audible signal must be presented.

For rear seats, Euro NCAP requires a "start signal", which may be visual only and starts within 5 seconds of engine start or forward travel at speeds higher than 10 km/h. This may be delayed by 10 seconds if occupancy detection is present. The duration of the signal must be at least 30 seconds. If a change in belt status occurs at speeds above 25 km/h, i.e. a belt gets unbuckled, then an immediate audible signal must be given.

Acceptability

Stakeholder input suggested that mandatory fitment for N category vehicles (driver seat) and M1 (front passenger seat) appear acceptable to vehicle manufacturers. Vehicle manufacturers would strongly oppose requirements for M1 rear seat SBRs with occupancy detection. Belt status-only systems, which can be implemented at a reduced cost, were suggested as an alternative. The level of acceptance of mandatory fitment for M2/M3 category vehicles is unknown.

Acceptance of SBRs by the vehicle users appears to depend widely on the level of intrusiveness of the specific implementation. Warning strategies found in production cars since the early introduction of SBRs reached from a simple warning lamp to an engine interlock that would not allow starting the engine without being buckled. The criteria set out by Euro NCAP are considered as being of medium intrusiveness so as to strike a balance between providing enough motivation to the occupants but also not producing a negative attitude towards the system. Most SBRs in current European M1 vehicles follow this specification. Road users who have medical reasons not to wear a seat belt can have the system permanently deactivated at a dealership (not possible for all systems). The systems are sometimes being circumvented by hardcore non-users by putting a spare buckle into the latch or by sitting on the buckled belt.

[13] http://www.unece.org/trans/main/wp29/wp29regs1-20.html

B.5.4 Costs

The costs of SBR systems comprise the cost of the required components and the development cost (design, engineering and testing). The component costs are summarised in Table B-4. Large economies of scale for cannot be expected because the technology is already widespread. For M1 driver seats SBRs are already a mandatory requirement which is why no cost figure is given (see Section D.5.3.1). The costs for front seating positions include an occupant detection sensor, belt buckle sensor and wiring. The costs for M1 rear seat position include a buckle sensor and wiring to each seat. For M2 and M3 vehicles, where the additional cost of wiring many passenger seats and also integrating the associated tell-tale for many seats is considered likely to result in increased costs.

Table B-4: Estimated component cost of an SBR system per seating position (McCarthy and Seidl, 2014)

Vehicle category	M1		M2 & M3		N1		N2 & N3	
Seating position	Front seat passenger	Rear seat passenger	Driver	Passenger (incl. assistant seating position)	Driver	Passenger	Driver	Passenger
Component cost	€6	€4	€6	Unknown, increased	€6	€6	€6	€6

Some of the components required for SBRs might be shared with other safety systems, such as the occupant detection sensors (for advanced restraint systems), the belt buckle sensor (for airbag deployment strategy), or the dedicated tell-tale displaying the belt status (might be replaced by information displayed in the general on-board display that is used for information from a range of safety technologies).

TRL considers most vehicle manufacturers (at least for M1 and most in N category vehicles) already have reasonable experience, with SBR systems for all seating positions offered at least as option, and therefore have already developed a system. For M2 and M3 vehicles it is less clear what the development costs for the system would be and whether any manufacturers have already made this investment. It is therefore likely that for M2 and M3 vehicles the costs may be greater than the estimates made for M1 vehicles.

No additional infrastructure is necessary for SBR systems. The cost of legislation is expected to be very low, because legal text for the driver's seat of M1 vehicles exists in UN Regulation 16. Furthermore, the Euro NCAP test protocol (Euro NCAP, 2013) sets out well established and generally accepted requirements.

Annex 4.1.6 Benefits

SBR systems issue visual and/or audible warnings if vehicle occupants do not wear a seat belt. This has the potential to increase seat belt use amongst temporary non-users considerably. The measure as such works on all road types and on all seating positions, but only benefits otherwise unbelted occupants. The distribution of unbelted occupants varies by road-type and seating position. Also, road users who are more likely to be involved in an accident are at the same time less likely to be influenced by a SBR. This effect, called selective recruitment, reduces the protective effect of SBRs and was taken into account for producing the benefit numbers cited below.

The effectiveness of SBR in motivating belt use was analysed in several on-road observational studies. The most extensive one was conducted by Lie et al. and showed that the number of unbelted drivers was approximately 80% lower (in vehicles with EuroNCAP compliant SBRs compared to no SBR), independent of the wearing rate without SBR (Lie et al., 2007). The study comprised a sample of 11,160 drivers of M1 vehicles in seven EU countries. The authors limited the observations to roads in built-up areas and claim in the discussion, that while the wearing rates on non-built-up roads are generally higher, the wearing rate with SBR would probably not be lower. In an NHTSA report on the effectiveness of different types of SBRs, Freedman et al. found that the increase in belt wearing rates for front seat passengers was similar to the increase for drivers (Freedman et al., 2009). No on-road observational studies could be identified regarding the effectiveness of SBRs in rear seats; a study in a simulated environment indicates that rear seat SBRs are effective in motivating seat belt use and that the most effective implementation used both visual and auditory signals (Akamatsu et al., 2012). In this study, TRL assumed a generally lower effectiveness compared to front seat SBRs, because many models are not equipped with occupancy detection and only provide a rather short visual signal, which is less intrusive than audio-visual signals (and an audible signal if buckle status changes during journey).

The data regarding drivers of other vehicle categories (N1, N2, N3, M2 and M3) is fairly limited and no studies could be identified regarding passengers in these vehicles. TRL assumes that the overall effectiveness compared to passenger cars is lower, as the proportion of hard core non-users, i.e. those who actively refuse to wear a seat belt, is likely to be higher amongst drivers of commercial vehicles. This assumption was supported in stakeholder interviews. In initial studies with limited groups of participants different implementations, such as increased accelerator pedal back force when the driver is unbuckled, were found to be more effective (van Houten et al., 2010; van Houten et al., 2011).

A recent study conducted by TRL (McCarthy and Seidl, 2014) analysed the benefits of mandatory introduction of SBR systems for different vehicle categories in EU-28 from 2015 and identified potential casualty savings as detailed in Table B-5. The monetised value of these casualty savings was estimated as given in Table B-6.

Table B-5: Estimated number of EU-28 casualties that would be influenced by mandatory SBR (total numbers for the 11 year period of 2015 to 2025; mid-estimate). 'Influenced' means that, for example, a fatality could remain seriously, slightly or not injured (McCarthy and Seidl, 2014)

Vehicle category	M1		M2 & M3		N1		N2 & N3	
Seating position	Front seat passenger	Rear seat passenger	Driver	Passenger (incl. assistant seating position)	Driver	Passenger	Driver	Passenger
EU28 Fatal	27	13	1	68	29	8	33	12
EU28 Serious	336	189	7	1,018	98	57	141	56
EU28 Slight	700	768	117	2,696	295	119	926	353

Table B-6: Monetised value for EU-28 casualties influenced by mandatory SBR (total numbers for the 11 year period of 2015 to 2025; mid-estimate) (McCarthy and Seidl, 2014)

Vehicle category	M1		M2 & M3		N1		N2 & N3	
Seating position	Front seat passenger	Rear seat passenger	Driver	Passenger (incl. assistant seating position)	Driver	Passenger	Driver	Passenger
EU-28 Monetised value (Million €)	M€ 117	M€ 68	M€ 4	M€ 337	M€ 65	M€ 24	M€ 88	M€ 33

B.5.5 Benefit:Cost Ratio

The TRL study calculated break-even costs to get a view on the cost-effectiveness of mandatory fitment from 2015 (Table B-7). These figures represent the system cost below which the benefits would outweigh the costs.

Fitment costs (see Section D.5.4) are comparable with, or lower than the break-even estimates, with the exception of M1 rear seat passenger systems. This suggests that regulatory action is likely to be cost-effective for M1 front seat positions and all M2 & M3 and N1, N2 & N3 vehicles (McCarthy and Seidl, 2014). Note that the front assistant seating position in M3 vehicles was not analysed separately, hence cannot be separated from the figures relating to other passengers. It should be considered that the person usually seated at this position is likely to have an important role in evacuating the vehicle.

With regard to category N vehicles, anecdotal evidence from literature and stakeholder input suggests that current implementations of SBRs might not be able to increase the belt wearing rates to the desired levels close to 100% among occupants of commercial vehicles. A lack of evidence and research into this problem and potential solutions became apparent during the course of the present review.

Table B-7: Break-even costs per vehicle and per seat for EU28 casualties influenced by mandatory SBR (Mid estimate: 2015-2025) (McCarthy and Seidl, 2014)

Vehicle category	M1		M2 & M3		N1		N2 & N3	
Seating position	Front seat passenger	Rear seat passenger	Driver	Passenger (incl. assistant seating position)	Driver	Passenger	Driver	Passenger
EU 28 Break-even value (€) per vehicle	€ 8	€ 1	€ 31	€ 692	€ 31	€ 12	€ 22	€ 5

Vehicle category	M1		M2 & M3		N1		N2 & N3	
EU 28 Break-even value (€) per seat	€ 8	<€ 1	€ 31	€ 2314	€ 31	<€ 12	€ 22	<€ 5

B.5.6 References

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[14] Assuming average number of seats is 30

B.6 Pedestrian upper leg and pelvis to bonnet leading edge protection

When the legislation for pedestrian protection was implemented there were concerns from the automotive industry that: i) the upper legform protection criteria proposed by EEVC Working Groups for use in that test were not feasible, ii) the centre of the windscreen was 'safe' and not within the control of the vehicle manufacturer. As a result these tests were included for monitoring purposes only. This measure considers whether there has been sufficient technological progress since their original implementation to make these tests feasible for mandating now.

B.6.1 Description of the Problem

In 2003, the European Union agreed a European Directive 2003/102/EC that requires car manufacturers to provide pedestrian protection in vehicles of the type covered by the scope of the Directive (principally passenger cars). The EC Directive consists of three principal test procedures each using different sub-system impactors to represent the main phases of a car-to-pedestrian impact. The three impactor types are:

- A legform impactor representing the adult lower limb to measure lateral knee-joint shear displacement and bending angle, and tibia acceleration, caused by the contact with the bumper.
- An upper legform impactor representing the adult upper leg and pelvis to record bending moments and forces caused by the contact with the bonnet leading edge.
- Child and adult headform impactors to measure head accelerations caused by contact with the bonnet top.

When the legislation for pedestrian protection was implemented there were concerns from the automotive industry that:

- The upper legform protection criteria proposed by EEVC (European Enhanced Vehicle-safety Committee) Working Groups for use in that test were not feasible,
- The centre of the windscreen was 'safe' and not within the control of the vehicle manufacturer.

As a result, these tests were included for monitoring purposes only. It is now reasonable to ask if sufficient progress has been made so as to make these tests sufficiently feasible that performance requirements can now be mandated.

This topic covers the upper leg and pelvis to bonnet leading edge (BLE) monitoring tests. However, it should be noted that some of the comments regarding Autonomous Emergency Braking Systems (AEBS) made in conjunction with the head impact test may be relevant for the legform as well as the other headform pedestrian protection tests.

The upper legform to BLE test was developed on the basis of accident data and reconstruction tests involving vehicles that generally had much squarer profiles than the more rounded profiles of current car designs. Since then, a number of accident studies have reported a considerable reduction in the injuries caused by the BLE of cars of modern design. For instance, Lubbe et al. (2011) cite data from the German In-Depth Accident Study (GIDAS). Given that the EEVC WG17 upper legform to BLE test fails most current cars, effectively predicting high injury risks, this seems inconsistent with the accident data (JARI, 2004).

The upper legform impactor and the BLE test have been criticised for their lack of biofidelity (Snedeker et al., 2003). The current test was described by JARI (2004) as possessing serious problems in terms of the impact energy, the test tool in relation to biofidelity and the injury acceptance levels. However, it has not been demonstrated whether poor biofidelity is the cause of the high predictions of injury risk.

In spite of this, pelvis, hip and femur injuries are still seen in Hospital Admission data (Cookson et al., 2011). They are particularly prevalent amongst the older pedestrians and primary injuries to the hip and thigh were associated with the longest mean and median duration of stay in hospital. However, it is not necessarily the case that these injuries are a result of contacts which could be addressed by the upper leg and pelvis test procedure (e.g. they could result from the pedestrian hitting the ground rather than the vehicle contact).

The study by Fredriksson et al. (2010) used data from the German In-Depth Accident Study (GIDAS) for pedestrians impacted by the front of a passenger car or van between 1998 and 2008. From a total of 1,030 cases, 155 were severely injured (AIS3+) pedestrians with a known injury source. Five percent of these (2-10%, 95% CI) had at least one severe injury attributed to 'leg to bonnet front edge' contacts. In this study the body region 'leg' included the pelvis.

The ACEA Task Force – Pedestrian reported to the Euro NCAP Pedestrian Working Group with updated accident research related to the BLE test. This was also based on GIDAS data and included pedestrian accidents from 1999 to 2011; M1 cars, SUVs and also vans minibuses and pickups; having a contact of the vehicle front with the pedestrian and leading to an injury severity which is known. Of the pedestrians meeting the selection criteria (279), only 22 had a pelvis or upper leg injury at the AIS 2+ level, and of these only 2 received their injury from a vehicle travelling up to 40 km/h and with a contact within the upper legform test area. Therefore it seems that the pelvis and upper leg test could affect the outcome for around 9% of pedestrians with pelvis and upper leg injuries and less than 1% of the total pedestrian population (as selected).

The EU Transport Pocketbook (European Commission, 2013) reports that between 2009 and 2011 there were, on average, 1,140,494 reported injuries from road traffic accidents in the EU27 per annum. Using the 2.5% to 3.5% range derived from in-depth studies, the numbers of (reported) pedestrian casualties arising from impacts with car fronts are estimated to be between 28,512 and 39,917 per annum (Carroll et al., 2014). These authors used the AIS levels associated with the in-depth cases to give an approximate indication as to whether the pedestrian would have been killed, seriously injured or slightly injured. It should be noted that this method of assigning severity level may not be accurate. However, based on these inferences and estimated number of casualties, about six percent (1,611 to 2,256) would be fatal and 50 % (14,256 to 19,959) would be serious.

Using the ACEA proportions and applying them to the anticipated annual number of serious pedestrian casualties, then the target population for the upper legform and pelvis test is 102 to 143 serious injuries per year in EU-27 (and would be slightly greater for EU-28).

B.6.2 Potential Mitigation Strategies

Beyond the initial contact between a car and a pedestrian, usually to the leg, other interactions with the vehicle are complex. The next segment of a pedestrian's body to contact the vehicle may be the upper leg and pelvis and the component test provided within the pedestrian protection protocols is used to assess the injurious nature of this interaction. The severity of the contact with the bonnet leading edge will depend on the initial impact speed between the vehicle and pedestrian, the angle of contact between the body and vehicle, the effective mass of the body part struck, anthropometry of the pedestrian and the shape of the vehicle. To try and incorporate this complexity within the prescribed test conditions, the current procedure uses three look-up graphs to determine appropriate test velocity, energy and impact angle for the particular vehicle shape being assessed. The risk of injury to the pedestrian is assessed through the femur bending moment and the total force measured by the impactor.

The properties and solutions needed to provide pedestrian protection in the area of the BLE are:

- Sufficient crush depth
  - Whilst there may be sufficient depth before immovable objects such as the engine are struck, most current cars have other features in the BLE area which limit the available crush depth, e.g.
    - Headlamps
    - Upper cross member including the bonnet lock and upper fixing for the cooling pack
- Appropriate deformation stiffness
  - Traditional angular bonnet leading edges (with a small radius of curvature) are likely to have a high stiffness for the BLE test
  - A more curved shape on the front edge would avoid localised stiff areas around the BLE it may also improve force distribution during the impact event
  - With close underlying support from the upper cross member, again the stiffness may be too high

B.6.3 Feasibility

Due to the difficulties associated with providing appropriate crush properties and pedestrian protection solutions in the BLE region, manufacturers have said that the EEVC upper leg and pelvis test procedure is unfeasible (Lawrence et al., 2004). This is supported through the knowledge that there is a conflict between the ability to reduce stiffness and provide crush depth against the need for structural rigidity for bonnet retention at high speeds and headlamp performance and the associated mass of lamp units and rigidity of their mountings, etc.

To assess whether the BLE test has changed in feasibility since the introduction of the pedestrian protection legislation, the upper legform to BLE test is required for monitoring purposes as a part of the type approval process.

It is not expected that since this test was adopted for monitoring purposes that there have been any fundamental design changes for cars which now make this test feasible. Nevertheless, with developments in composite materials there may be scope for tuning some of the stiffness in the BLE region. Also, for new vehicles with alternative powertrains, such as electric vehicles, there may not be the same design pressures to have hard immoveable parts within the engine bay. This may also offer some scope for improved pedestrian protection around the BLE. However, for the majority of cars produced today, there has not been a step change in design which would now ensure the upper leg and pelvis test is feasible. It is expected that the results from the monitoring tests support this assertion.

A study by TRL (Hardy et al., 2007) undertook to review research pertinent to protection of pedestrians and other vulnerable road users. From this review recommendations were made as to how the Regulations might be updated in the future and what additional work was needed to achieve this. With regard to the bonnet leading edge test, the TRL study concluded the following:

- A number of accident studies have reported a considerable reduction in the injuries caused by the bonnet leading edges of cars of modern design.
- Studies have also reported that the EEVC WG17 upper legform to bonnet leading edge test fails most current cars, effectively predicting high injury risks that are inconsistent with the accident data for recent car designs.
- The upper legform impactor and the bonnet leading edge test have been criticised by experts for their lack of biofidelity. However, it has not been demonstrated whether poor biofidelity is the cause of the high predictions of injury risk.

The study recommended that a new or revised bonnet leading edge test should be developed for legislative use and that accident data should be used to determine the scope of vehicles that should be tested and to ensure that vehicles that don’t cause real world injuries are not failed by the test. Several options were considered in the study –

including: modifying the current upper legform impactor and the bonnet leading edge test procedure, or developing a completely new impactor – however the point was made that the issue of acceptability must be taken into account due to the difficulties and high costs of any option, and that the relevant working groups must be involved in development.

A check of the latest test results published on the Euro NCAP internet site revealed varying levels of protection in the BLE area. Of the 16 vehicles considered, six scored no points for the upper legform testing. It should be noted that the Euro NCAP procedure currently uses the same impact conditions as Commission Regulation (EC) No 631/2009. A test score of 0 would indicate that none of the test sites passed the criteria for the sum of the impact forces to not exceed 5.0 kN and the bending moment to not exceed 300 Nm. These are also the same criteria as specified in Regulation (EC) No 78/2009.

A further nine of the vehicles had upper legform scores in the range from 0.4 to 5.2 points. This indicates that at least one of the test sites would have a bending moment less than 380 Nm and a sum of forces less than 6 kN. In addition, there was one vehicle which scored the maximum six out of six points for the upper legform testing. This was the Maserati Ghibli. Scoring the maximum for the BLE tests indicates that all test sites passed the thresholds in Regulation 78/2009.

The one van in the latest test results from Euro NCAP scored no points for upper leg and pelvis protection because this test was not undertaken. The upper legform tests are not required if, "the calculated impact energy would be 200 J or less, nor if the height of the Bonnet Leading Edge Reference Line… is, at all points, greater or equal to 835 mm vertically above the ground at the vehicle's normal ride attitude." (Euro NCAP, 2012)

B.6.4 Costs

Proposals were made previously for changes to the upper legform impact energies and to the acceptance criteria. However, it has not been demonstrated that these would be adequate to bring the test results into line with data from accidents involving recent car designs.

A number of concepts for a replacement impactor and bonnet leading edge test procedure have been identified and the advantages and disadvantages of each have been discussed previously (Hardy et al., 2007).

The option involving the least change to the current test would be to review the test parameters and acceptance criteria, while retaining the current upper legform impactor. Updated look-up curves for determining the impact conditions for the upper legform test were proposed by Hardy et al. (2006) based on improved modelling work and incorporating a lower energy cap of 500 J to improve feasibility.

However, changes to the test parameters and acceptance criteria may still not be adequate to bring the test results into line with data from accidents involving recent car designs, as the impactor has an inherent lack of biofidelity in certain respects. Also, a test procedure that retains the current impactor may obtain limited support from experts.

In spite of this, Euro NCAP is planning to change their test procedure to align with research and use modified conditions and assessment thresholds similar to those proposed by Snedeker et al. (2005). This proposal assessed femur injury risk for vehicles with a leading edge height not greater than 900 mm. The proposal also suggested using a 7.5 kg impactor with a failure criterion of the average bending moment exceeding 320 Nm. For vehicles with a leading edge above 900 mm, the proposal assessed pelvis injury risk. For this purpose an impactor mass of 11.1 kg is proposed together with the criterion for peak average force to be no greater than 10 kN. With this method of assessing only one criterion for tests above or below the 900 mm leading edge height, it would be useful to check that the switch between injury mechanisms is reflected in the real world accident data. It should be noted that the requirement for a 7.5 kg impactor would preclude the use of the existing legform which has a minimum mass of 9.5 kg.

Euro NCAP has adopted a procedure similar to this which permits the use of the existing upper legform tool (at 10.5 kg) adjusting the impact speed to provide an equivalent energy (Euro NCAP, 2014a). This may make an improvement to the Snedeker et al. procedure as the 7.5 kg mass assumes no effective mass contribution from the lower leg or from the pelvis, which is likely to be overly simplistic for contacts with a duration long enough for coupling of mass between these anatomical segments. Another conceptual change is the move away from testing the BLE specifically, instead the test is conducted at a WAD (wrap-around distance) of 775 mm and assesses the potential for any structures in that region to cause an injury to the upper leg and pelvis (Zander, 2014).

It should be noted that for any of the proposals for a change in the methodology, it is likely that research would be necessary to prove that the alteration has resulted in a feasible test. This research would have an associated cost. In addition costs would be incurred by manufacturers in responding to the change. In the case of the Euro NCAP protocol, Lubbe et al. (2011) has already shown that the Snedeker et al. (2005) proposal may be associated with an impactor force decrease of 0.26 kN and a reduction in the bending moment of 60 Nm, which could aid feasibility, particularly if the revised injury limits are taken into account too. However, these are only small proportions of the limits for force and bending moment.

The change in the method used by Euro NCAP may also facilitate testing with vans or “heavy vehicles” (heavier van-based eight or nine seater vehicles derived from commercial vehicles with a mass of between 2.5 and 3.5 tonnes) which would otherwise be exempt due to the height of the bonnet leading edge.

One example of an alternative test tool which could be used for assessing the upper leg and pelvis with bonnet leading edge interaction would be the addition of an upper body mass to the Flex-PLI. The feasibility of adding an upper body mass to the Flex-PLI has already been investigated by Zander et al. (2009). Subsequently, Zander et al. (2011) used tests with the Flex-GT attached to a Hybrid II dummy to show that the addition of the upper body mass introduces the possibility of femur injury assessment in lateral vehicle-to-pedestrian accidents. Recently, there has also been a Japanese proposal to ISO for an activity on modifying the Flex-PLI to add an upper body mass.

The vehicle component cost estimates made for the European Commission by Hardy et al. (2006) assumed zero cost would be apportioned by passenger car manufacturers during the design process for the bonnet leading edge as that test was already being considered for monitoring purposes only. However, two years earlier, Lawrence et al. (2004) had included costs for providing pedestrian protection in the BLE area. The assumed costs were derived on the basis of proposed modifications required to make a typical car from each segment meet the requirements with respect to upper leg and pelvis protection. The modifications were then described to an engineering firm who provided a cost per piece and for tooling. These costs were multiplied for the number of car types in each segment (tooling) and the number of cars in each segment (per piece) and summed to provide an overall European cost. It should be noted that the costs per vehicle were given as a total for all pedestrian protection measures, not just the BLE modifications. However, comparing the changes from the costs with upper leg protection and the costs without upper leg protection can provide this number. In total, removing the BLE protection reduced the European costs (for the 2006 fleet and Euro value) by almost €34,400,000.

Using a cost value derived from the previous studies is subject to certain assumptions and, hence, limitations. For instance:

1. The original estimates were robust
2. The types of modification and associated cost assumptions are the same for modern cars as for cars from that time
3. Those modifications are still necessary given the monitoring and Euro NCAP testing.
4. The numbers of models per segment, numbers of cars per segment and total number of cars hasn’t changed
5. Inflation and fluctuations in currency exchanges are not included

No information was found with respect to the costs for providing BLE pedestrian protection for other classes of M and N category vehicles.

B.6.5 Benefits

It has been observed that the height of the BLE may influence the incidence of upper leg and pelvis injuries, with those injuries becoming more of an issue for vehicles which have a higher bonnet leading edge (BLE) than small passenger vehicles (Roudsari et al., 2007). Based on U.S. accident data, these authors noted that the leading causes of injury for an adult pedestrian with light-truck vehicle crashes were the ground for head (39%) and upper extremity (37%) injuries and the hood edge (BLE) for thorax (48%) and abdomen (56%) injuries. This suggests that for sport utility vehicles, like the U.S. light trucks, the bonnet leading edge could be important when considering pedestrian thoracic and abdominal injury risk. These body regions have typically not been included in the accident analyses when considering the injuries caused by the BLE in European studies. However, it could be important to include them assuming that countermeasures made to improve the safety of the BLE for the pedestrian pelvis and upper leg might also be useful for the thorax and abdomen. It is suggested that if it could be shown that the BLE test is capable of driving improvements in this region which could reduce thoracic and abdominal injury risk, then the accident data should be reviewed to see such injuries attributable to the BLE could be mitigated in the future.

As Euro NCAP moves away from testing the BLE to testing a particular WAD, the potential arises for there to be an untested region between the top of that assessed in the upper legform test and the lower boundary of that assessed with a headform impact. This region would lie between a WAD of 930 mm (WAD 775 at the centre of the upper legform impactor plus half the legform's height) and WAD 1000 mm (at which point the child headform tests start). This region matches the 50th percentile stature of children 3 to 4 years old (Zander, 2014). To monitor the potential for a BLE in this untested area to cause injuries to body regions other than the upper leg and pelvis, it has been proposed to introduce a headform test to the BLE under certain circumstances. As from 2015 onwards, this test will be conducted for Euro NCAP for monitoring purposes only (Euro NCAP, 2014b). However, whilst not included in the pedestrian protection score, the results are to be published on the Euro NCAP website alongside the other pedestrian test results.

In the absence of appropriate injury risk estimates from an accepted test method, it is difficult to predict the effectiveness of legislating pedestrian protection in the bonnet leading edge region. However, a concern has been raised by stakeholders that if there was no upper legform test to the BLE area any more, this area will become stiffer and harder and will cause more injuries in future. This may be exacerbated because of new SUV designs with high bumpers and leading edges and because of the increasing number of sensors and associated components (e.g. for forward-looking object detection systems) that have to be placed somewhere in the vehicle front.

B.6.6 Benefit:Cost Ratio

Due to the small numbers of pelvis and upper leg injuries caused through pedestrian accidents with modern cars and the limitations of the existing test procedure, it is unlikely that any protection measure will be cost-beneficial. However, this should be reviewed if either a new procedure is accepted or if the existing procedure can be shown to offer benefit for thoracic and abdominal injuries as well as pelvis and upper leg injuries.

As an estimate, an upper legform and pelvis Benefit:Cost ratio is likely to be less than 0.9, with the exact value depending on effectiveness of the measure and countermeasures.

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B.7 Pedestrian adult head to windscreen protection

When the legislation for pedestrian protection was implemented there were concerns from the automotive industry that: i) the upper legform protection criteria proposed by EEVC Working Groups alongside that test were not feasible, and ii) the centre of the windscreen was 'safe' and not within the control of the vehicle manufacturer. As a result these tests were included for monitoring purposes only. Has sufficient progress been made to make these tests feasible for mandating?

If head contacts with the windscreen are to be regulated, should the consequence of Advanced Emergency Braking systems be considered? For instance, emergency braking has the potential to reduce the speed of a pedestrian accident and hence the severity of the head contact. Also a lower vehicle speed will lead to a smaller wrap-around of the pedestrian over the vehicle surface and change the head

B.7.1 Description of the Problem

In 2003, the European Union agreed a European Directive 2003/102/EC that requires car manufacturers to provide pedestrian protection in vehicles of the type covered by the scope of the Directive (principally passenger cars). The EC Directive consists of three principal test procedures each using different sub-system impactors to represent the main phases of a car-to-pedestrian impact. The three impactor types are:

- A legform impactor representing the adult lower limb to indicate lateral knee-joint shear displacement and bending angle, and tibia acceleration, caused by the contact with the bumper;
- An upper legform impactor representing the adult upper leg and pelvis to record bending moments and forces caused by the contact with the bonnet leading edge;
- Child and adult headform impactors to record head accelerations caused by contact with the bonnet top.

When the legislation for pedestrian protection was implemented there were concerns from the automotive industry that:

- The upper legform protection criteria proposed by EEVC (European Enhanced Vehicle-safety Committee) Working Groups alongside that test were not feasible;
- The centre of the windscreen was 'safe' and not within the control of the vehicle manufacturer.

As a result these tests were included for monitoring purposes only. It is now reasonable to ask if sufficient progress has been made so as to make these tests feasible enough that performance requirements can now be mandated. It can be noted that such a question is outside of the current scope of the informal working group active on Phase 2 of the GTR9 (Global Technical Regulation Number 9) on pedestrian safety.

Some important vehicle parts with respect to pedestrian protection, like the windscreen and A-pillars, were not included in the mandate of EEVC Working Groups when developing the test procedures used in regulatory testing now. It has always been known that these areas are impacted quite often by the pedestrian's or cyclist's head. As such further research in this area was recommended in order to see if a future extension of the Directive was reasonable (EEVC, 2002).

As early as 2003, the possibility of using airbags to protect the A-pillar was considered with an expectation that such solutions could also be extended to the upper windscreen frame (Maki et al., 2003). However, unlike the hard A-pillar structures, the centre of the windscreen had been assumed to be relatively safe when hit by the head of a pedestrian.

Whilst the centre of the windscreen may be safe, the glass towards the edge of the screen may not break at the same load. Also, at the base of the windscreen, it is likely that the head of a vulnerable road user would penetrate the glass sufficiently to contact the dashboard fascia underneath. The windscreen frame itself is very stiff to pedestrians, because it is an important load-bearing part of the vehicle's structure. Therefore impacts to the windscreen frame and around the edge of the windscreen can be considered to represent significant gaps in the protection assessed by the current legislation (Hardy and Carroll, 2008). Fredriksson et al. (2010) showed that from a sample of 161 pedestrians suffering AIS 3+ injuries, a majority could be related to the windscreen and its periphery, being areas that are currently not covered by pedestrian legislation. In a detailed review of contact points for pedestrians killed in a collision with a passenger car, Fredriksson (2011) identified fatal injury causing contacts for 36 pedestrians. The windshield area caused 88% of the fatal head and neck injuries, with 65% being attributable to the frame or near-frame and 23% to the instrument panel area.

Within Euro NCAP the windscreen and windscreen frame area is included in the head protection area up until a WAD (wrap-around distance) of 2100 mm. However, windscreen areas without any structures, up to this limit, receive a default green rating and A-Pillars are defaulted as red (an exception to this occurs with the presence of airbag solutions). The area falling within the driver's field of vision is not tested, but does fall within the region 'assessed' (i.e. assumed to be 'safe'), by Euro NCAP for the pedestrian protection headform score.

The EU Transport Pocketbook (European Commission, 2013) reports that between 2009 and 2011 there were, on average, 1,140,494 reported injury accidents in the EU27 per annum. Using the 2.5% to 3.5% range derived from in-depth studies, the numbers of (reported) pedestrian casualties arising from impacts with car fronts are estimated to be between 28,512 and 39,917 per annum (Carroll et al., 2014). Of these, about 6% (1,611 to 2,256) would be fatal and 50% (14,256 to 19,959) would be serious.

This topic covers the adult headform to windscreen monitoring tests and hence, considers a subset of that broad pedestrian casualty target population.

We now understand that 15% of all pedestrian injuries are caused through contact with the windscreen but that that around 80% of serious and fatal pedestrian injuries are to the head (Crandall et al., 2002) and around 80% of head contacts are with the vehicle's windscreen (Xu et al., 2009). Therefore a target population might be around 1,031 to 1,443 fatal injuries and 9,123 to 12,773 serious injuries each year in Europe.

B.7.2 Potential Mitigation Strategies

The study by Fredriksson et al. (2010) used data from the German In-Depth Accident Study for pedestrians impacted by the front of a passenger car or van between 1998 and 2008. From a total of 1030 cases, 155 were severely injured (AIS3+) pedestrians with a known injury source. 26% (19-33%, 95% CI) of these had at least one severe injury from 'head to windscreen area'. Head to windscreen contacts were the second most frequent following 'leg to front end'.

Structural parts of the windscreen area constituted 72% (CI 55-85%) of head impacts, 28% (15-45%) were to the glass area. Fredriksson et al. indicated that a countermeasure for the windscreen area extending 200 mm further than the current standards or ratings require would have a potential to protect approximately 50% more of the severely injured. This research suggests that the majority of the glass area can normally be assumed to be relative safe, but that the structural parts around the sides and at the base are a high priority for increased levels of pedestrian protection.

Those authors stated that countermeasures for 'leg to front end' and 'chest and head to bonnet' would have the potential to protect 44% (36-53% CI) of pedestrians from all of their vehicle-induced severe injuries. Adding 'head to windscreen' protection would have the potential to increase this to 63% (54-71%).

Using MADYMO multi-body modelling, Lyons and Simms (2012) showed that for a pedestrian car impact condition at 40 km/h, the head acceleration of the pedestrian in contact with the windscreen varied with windscreen angle. However, the direction of the trend was sensitive to the stiffness model of the windscreen glass. Using a real-world contact stiffness suggested that steeper windscreens (varying from 20° to 55°) would be associated with lower head acceleration peak values. Whereas, using a linear stiffness, the opposite trend was observed.

This might indicate that there are some things that can be done to improve the passive safety performance of the windscreen through vehicle design changes. In addition there is scope for deployable passive protection to offer additional protection for the regions with specific design conflicts (i.e. the windscreen close to the stiff A-pillars and the base of the windscreen).

However, other aspects may influence the performance of the windscreen which may not be so easily controlled (Pinecki et al., 2011):

- The adhesive that attaches the windscreen to the car;
    - [NB: It may be possible to control this during initial fitment but may vary with time and if a replacement screen is ever needed.]
- The curved shape of the windscreen;
- The windscreen thickness;
- The supplier;
    - [The automotive manufacturer will have control over the supplier used and could potentially choose one which offers the best pedestrian safety windscreen.]
- The batch (and even within batch variations);
- The distance to the windscreen pillar;
- The distance to the dashboard.

Those authors found that the biomechanical results of a headform impactor test into the windscreen are influenced by several parameters and present a high scattering. In particular, energy absorption depends on the supplier of the windscreen. This implies that options exist regarding the safety of the windscreen and the vehicle manufacturer may be able to choose the safest product from a range. With different energy absorption characteristics, care would need to be taken with regard to the different risk of head impact to the dashboard underneath the screen. This might put a greater emphasis on designing a compliant dashboard in anticipation of a head strike. Impact point proximity with the windscreen pillar also strongly increases the biomechanical values and a distance of 110 mm is needed to get HIC below 1000. Also, biomechanical results are not strongly influenced by the thickness of the glass layers. Head deceleration over time and HIC values are very similar even with an increase of 12% in the thickness.

Within the FP6 Project APROSYS, impact tests with windscreen glass samples were performed (Grünert, 2006). Variation in the results between samples was noted depending on the orientation of the glass plate in the laminate and the impacted surface during each test. This was attributed by Grünert to there being a 'fire' side and a 'tin' side, as a consequence of the manufacturing process, "where molten glass floats on a bath of liquid tin – hence one side has small level of tin impurities." In the windscreens produced via this process, there is no requirement to orientate the glass plates one way up or the other. Therefore, this feature could be a candidate for control in order to improve pedestrian protection in a relatively simple manner. The size of the effect could be large if it bridges the condition where the glass in one orientation fails progressively and the in the other it doesn't.

AEBS combine sensing of the environment ahead of the vehicle with the automatic activation of the brakes (without driver input) in order to mitigate or avoid an accident. For passenger cars, the level of automatic braking varies, up to full ABS braking capability. First generation AEBS are in production on current vehicles and are capable of automatically mitigating the severity of two-vehicle, front-to-rear shunt accidents (on straight roads and curves dependent on sensor line of sight and environment "clutter") as well as some collisions with fixed objects and motorcycles. Such systems are described in the specific measure on AEBS.

Passive protection for pedestrian to vehicle contacts leading to a head impact with the windscreen is considered in this measure. However, further to the passive safety is the potential for AEBS to reduce the collision speed in a pedestrian accident, thereby reducing the passive protection requirements with respect to those which would be required had the AEBS not been operational. This requires that the AEBS is effective and also that the pedestrian detection system identifies the prospective collision. The function of pedestrian detection systems is considered in the specific measure, 'Pedestrian/cyclists detection systems'. The potential reduction in required levels of passive protection for a given impact speed with a pedestrian detection and AEBS system (i.e. the effect on feasibility) will be considered below.

Looking at the possibility of integrating measures of AEB effectiveness directly into the assessment of the impact test performance of the vehicle, Searson et al. (2014) focussed on the pedestrian head impact safety assessment. They were investigating how the HIC limits could be modified to reflect the interaction of AEB on the available pedestrian protection.

The data presented provide a means for calculating 'risk-equivalent' HIC values for vehicles equipped with AEB. As an example, if a test location scores a HIC of 850, this corresponds to an average risk of an AIS 3+ injury of approximately 20% given the distribution of speeds presented by Rosén et al. (2010). If an AEB equipped vehicle were able to reduce the mean impact speed of the crashes to 25 km/h, from 28 km/h (with an associated reduction in crashes of 16.4%) an equivalent risk would be attained when the test HIC is equal to 1350.

The paper suggests that it might be more appropriate to maintain current HIC limits for those cars with AEB systems (that perform to a standard) but to reduce HIC limits for non-AEB vehicles to reflect the higher injury risk (due to higher impact speeds). They note that it is important to maintain an incentive to improve passive safety of the front of the vehicle; making concessions may lose this incentive.

A caveat to the results presented by Searson et al. is that the real-world effectiveness of AEB in reducing the incidence and severity of crashes is not yet proven. "A deterioration of performance in certain environmental conditions or at higher speeds might significantly change the effect of AEB on the incidence and severity of crashes, and hence it would be critical that AEB systems are subjected to a level of scrutiny during evaluation that will allow an estimate to be made about average effectiveness." The process for this evaluation of the effectiveness of AEBS on the target population is not yet understood.

B.7.3 Feasibility

Test data from the adult headform to windscreen monitoring tests of Directive 2003/102/EC and Regulation (EC) No. 78/2009 were reviewed for this project to show feasibility for current vehicle models. These data are discussed in the main body of the report. However, they indicate that about 40% of the cars type-approved via this legislation would have met the requirement of HPC (HIC15) ≤ 1000 for the centre of windscreen impacts.

From a review of the past test results, it was observed that many of the different classes of vehicle were capable of producing HIC 1000 to 1500 across the base of the windscreen, and in some areas the performance was even better. However, it was also seen that certain vehicle models of each class offered much less protection across the base of windscreen, in some cases with HIC values exceeding 2000 (Hardy et al., 2007).

The amount of the actual windscreen glazing that was tested was dependent upon where the upper limit of wrap around distance fell. For the larger passenger cars, this tended only to incorporate the lower edges. For all areas of the windscreen tested, inwards of the supporting frame, the resulting HIC values were shown to fall within the lowest Euro NCAP category of HIC < 650. These results show that the centre of the windscreen glazing, as was assumed, is a relatively safe area, away from the A-pillars. It should also be feasible for the base of the windscreen region to be improved to meet the HIC < 1000 requirement, if the impact speed could be reduced to 35 km/h, with some modification.

The Japanese New Car Assessment Programme (JNCAP) has tested the windscreen and windscreen frame as part of their pedestrian head protection assessment since 2004, allowing some inferences about the feasibility of testing the windscreen and surrounding area to be made. These tests are conducted at 35 km/h with a 3.5 kg child or 4.5 kg adult headform. From a review of the past test results, it was observed that many of the different classes of vehicle were capable of producing HIC 1000 to 1500 across the base of the windscreen, and in some areas the performance was even better. However, it was also seen that certain vehicle models of each class offered much less protection across the base of windscreen, in some cases with HIC values exceeding 2000. The area of the frame and windscreen close to the A-Pillar showed the worst performance, with every vehicle resulting in HIC values greater than 2000. For nearly all of the smaller, mini-sized cars, the upper wrap around distance limit of 2100 mm equated to the roof of the vehicle. For impacts to the upper edge of the windscreen, apart from the area adjacent to the A-Pillar, HIC values in the range of 651 to 999 were achieved. It can be concluded that A-pillars themselves and the glazing or roof adjacent to the pillars would require significant modification or deployable pedestrian protection solutions in order to meet the existing regulatory head protection requirements (Hardy and Carroll, 2008).

Alternative modular assessment strategies for the cowl and windscreen area, building on those of the pedestrian protection GTR and Euro NCAP procedures were reported by Bovenkerk et al. (2009).

Deployable systems have been in development for many years and now feature on some vehicles in the current fleet (Jakobsson et al., 2013). However, "providing a protection zone for the head impact in the windscreen frame region is a demanding target due to significant goal conflicts with the field of view and the occupant protection" (Bovenkerk et al., 2009). As a result, the available airbag system makes use of a U shaped design protecting the cowl area and the lower A-pillars. However, in its deployed state, this still creates a substantial obstruction to forward vision. This would be a problem if it substantially affected the likelihood of a secondary collision occurring, after the airbag had deployed.

In summary, the level of protection that could be provided feasibly for the windscreen and surrounding area varies by location:

- In the centre of the windscreen, away from the edges, previous research indicates that many cars already meet the monitoring level of HPC ≤ 1,000. Presumably other vehicles could also meet this limit, though care would have to be taken to ensure appropriate collaboration between windscreen suppliers and vehicle manufacturers to understand variations in test results as observed in research.
- Towards the base of the windscreen, further passive protection advances can be made and these are being encouraged through consumer information testing. It is not clear from the information reviewed whether or not a relaxed HPC requirement for this region would be feasible or not.
- The A-pillars are stiff structures as part of their functionality. It will not be easy to meet a stringent HPC requirement without adopting a deployable protection system. Such systems are available, but would need further consideration and research before being encouraged through legislation.

B.7.4 Costs

To avoid unacceptable inappropriate activation, deployable systems need a reliable pre-impact pedestrian sensing and triggering system. This previously precluded the expectation that such systems could be included in regulatory testing (Lawrence et al., 2004).

Alternatively, with structural design modifications, there is the question as to what the vehicle manufacturers can do to influence the performance of the windscreen. The material properties of the glass will be, to a certain extent, limited by the fabrication process. Therefore, the vehicle manufacturer can only alter effective properties by changing the overall windscreen design, for example, the curvature and angle of the screen. This may lead to feasibility issues or restrictions in vehicle design. It would be up to the windscreen supplier to take account of the fabrication process and fracture properties for the screen. As such, any requirements for type approval of the vehicle would have to be formulated in a manner that allows the windscreen supplier and vehicle manufacturer to work together in meeting them.

If the windscreen is considered as a valid test area, then the appropriateness of the current headform as a test tool may need to be taken into account. Dummy headforms have traditionally taken account of the mass of the head, but the skull part does not incorporate any specific deformation stiffness or frangible components. Nor do they have a mechanism to allow relative brain to skull movements to de-couple the brain mass. As a result the skin or flesh of the headform is the only part of a dummy head that deforms significantly.

Skull fracture is a feature of a real skull that is likely to dramatically change the kinematic response during a head impact, the effects of which are still to be quantified. If it is assumed that the impact of a pedestrian headform with a windscreen is effectively different from that which might be expected from a human head which is frangible / deformable, then any differences in linear head accelerations could affect both the windscreen glass failure mode and the measured head performance criterion (HPC). Therefore, before the current headform is transferred to the windscreen for regulatory use, it is strongly suggested that the appropriateness of using the HPC with a headform, in such conditions, is demonstrated. If it is found that the existing headform designs are not appropriate for use on windscreens, then a more realistic headform will need to be developed for windscreen testing.

Previous work has considered technical solutions to provide a headform with some brain mass decoupling. However, considerable further development would be necessary before such an impactor was ready, available and accepted for headform testing. This would be associated with costs for the research, development and validation.

OICA has reported at a GTR pedestrian protection informal group meeting that there can be large variations in the result when windscreens are tested with a conventional impactor (OICA, 2005). Windscreen panes from the same batch reportedly demonstrated two different failure mechanisms in identical tests. One mechanism allowed about 10 mm of bending (in about 1 ms) before the glass fractured whereas the other mechanism allowed up to about 30 to 40 mm deflection before a sudden fracture at around 3 ms. This difference gave very large variations in the amount of energy absorbed by the glass (three times greater for the longer bending and then sudden fracture mechanism) and the HIC value recorded during the test (e.g. from HIC15 of 410 to 725 or 1084). If tests that are broadly equivalent (i.e. the tests are to the same vehicle at the same impact point) can produce different results, then the performance of the glass itself must be questioned. Such variation may create issues for vehicle manufacturers if the windscreen was included for type approval testing to performance limits. The manufacturers may need sufficient tolerance in the expected results to accommodate both fracture modes. This would make the design have to be extremely conservative and potentially unfeasible. However, it is not clear from this retrospective review to what extent some of the variability could be constrained through tighter monitoring of the products supplied to vehicle manufacturer.

It is understood that, currently, a pedestrian airbag is roughly twice the cost of a passenger airbag or inflatable curtain. If produced at the same volumes as a passenger airbag or curtain these costs may fall, but are likely to remain slightly more expensive than occupant protection bags due to their larger size.

It may be worth considering that the new (2013) Volvo V40 has a pedestrian airbag (and pop-up bonnet) – so these concepts are now ‘feasible’. However, it doesn’t seem as though this technology is set for widespread adoption with many manufacturers concentrating on active systems, to avoid the collision altogether, rather than the passive option.

From a stakeholder consultation and literature review, Robinson et al. (2011) estimated that a pedestrian AEBS would cost somewhere between £1,000 and £1,500 as an optional extra to the customer. They assume an actual cost (to manufacturers) to be in the range of £400 to £800 per vehicle.

No cost information was found for other categories of vehicle.

In summary costs for M1 vehicles could be calculated assuming 12 million vehicles multiplied by €300 to €1,000 per vehicle. This gives a total cost somewhere between €3.6 and 12 billion). During stakeholder consultation, TRL received input that following the pricing pattern and similarities observed in literature (e.g. Abeles, 2004) we can confidently assume a sharp drop in expenditure within the first years of production due to economies of scale. A factor of ten was proposed as being possible for the reduction in costs in reaching mass production volumes. Such an effect may have an important influence on the balance of cost to benefit for this measure.

B.7.5 Benefits

Peng et al. (2012) performed simulations of pedestrian and bicyclist accidents with a MADYMO model to determine the relationships between conditions of the accident and head injury risk. They produced logistic regression results relating vehicle speed and head injury risk as shown below. This gives an indication of the potential that through reducing the impact speed, AEBS can reduce the risk of head injury for pedestrians and bicyclists.

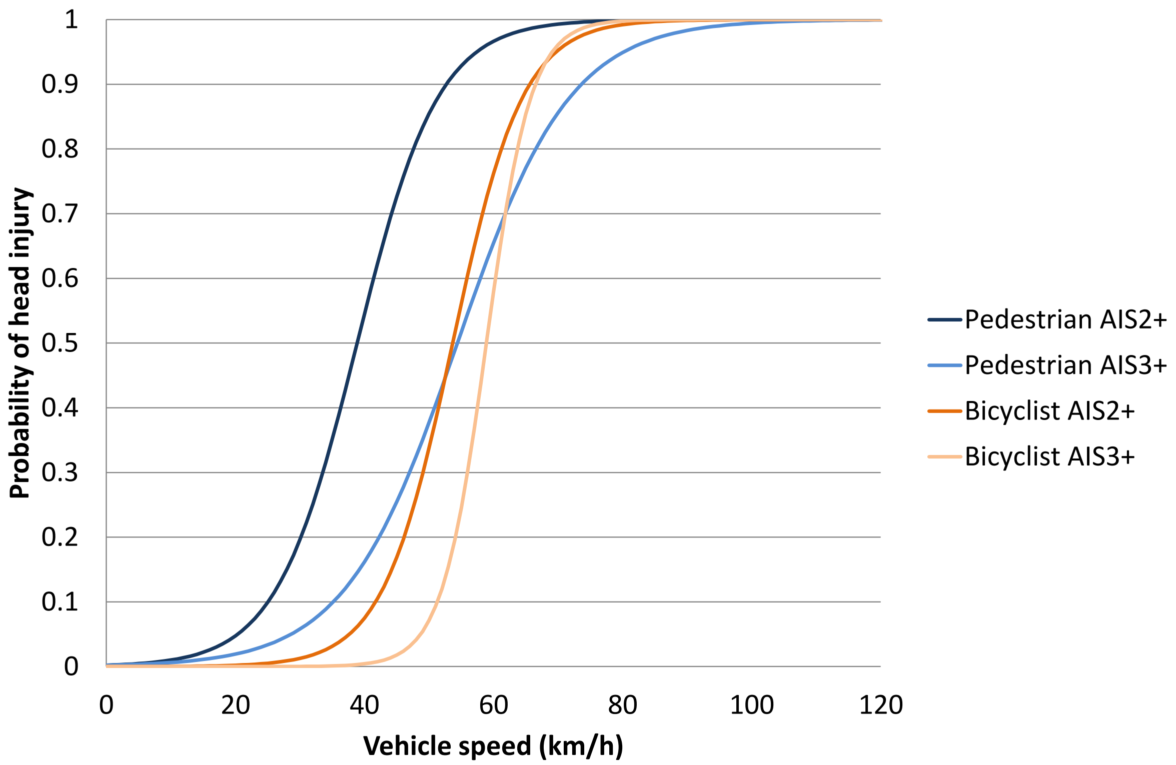

Figure B-1: Probability of head injury occurring at AIS 2 or 3+ for pedestrians and cyclists as a function of vehicle speed (Peng et al., 2012)

The windscreen and its periphery become more important as an injury causing contact when including head contact ponts for cyclists as the second big group of vulnerable road users after pedestrians. Several studies have already shown that, amongst other things, for an appropriate protection of cyclists the impact area would have to be extended by approximately 200 mm in vehicle longitudinal rearward direction (e.g. Zander et al., 2013).

A predictive study was completed by Robinson et al. (2011) to determine the effectiveness of pedestrian AEB systems. This was based on a review of On-The-Spot (OTS) and fatal file cases. Stats19 data were used to derive population wide estimates for GB. The three system options considered in the study related to the amount of pre impact braking available, being either 0.6 seconds, 1s or 2s. Robinson et al. produced the following overall effectiveness estimates.

Table B-8: Estimate of effectiveness for pedestrian AEB systems (Robinson et al., 2011)

	Fatalities	Serious	Slight	Cost (£m)	Saving (£m)
Original (target population)	174	5,805-7,095	20,623-25,205	1,593-1,886	0
Prevented					
0.6 second system	52	1,247-1,527	1,661-2,039		327-383
1 second system	71	2,478-3,031	8,666-10,596		673-798
2 second system	85	2,821-3,448	10,023-12,250		775-917

In casualty cost reduction terms, the modelled systems would have an overall minimum effectiveness ranging from 20% (i.e. 20% of the target population casualty costs are likely to be avoided) for the 0.6 s system to 49% for the 2 s system, with the 1 s system at 42%.

The aim of the investigation by Fredriksson and Rosén (2012) was to show the potential pedestrian head injury reduction from hypothetical passive and active countermeasures compared with an integrated system. This study used the GIDAS database from 1999 to 2008 for AIS3+ head injured pedestrians struck by car or van fronts.

The passive countermeasure was described as 'structural solutions with extra space under the bonnet as well as deployable bonnets and various pedestrian airbags'. The effectiveness of the system was specified exactly as the effect was modelled rather than the actual systems i.e. 'passive countermeasures that mitigate head injuries caused by the bonnet area, A-pillars and the remaining windscreen area up to 210 cm wrap around distance'. According to the author it was a study of the benefit of an airbag system compared with auto-brake, and finally combining the two systems, in reducing AIS3+ head injury.

Fredriksson and Rosén calculated that a passive countermeasure(s) that covers legal requirements plus protection for A pillars could have an 'effectiveness' of 17%, for just the legal requirements it would be 5% and for a system covering the complete bonnet and windscreen area its total effectiveness could be 41%.

In this study 31% of pedestrians with severe head injuries received at least one of these injuries from impacts to the ground or objects other than the car. These were classified as 'unprotected' by the passive countermeasures, which decreased its 'effectiveness'.

The conclusion was that autonomous braking, which has a high potential on its own, would benefit greatly from the addition of the passive countermeasures. The combination has a considerably increased potential compared with either system on its own. As the study was hypothetical and 'ideal' (i.e. passive countermeasures worked 100% up to 40 km/h and the active countermeasure detected all pedestrians in 180 degree view), the results should only be used as a comparison (i.e. isolated individual countermeasures versus integrated) not as absolute reductions in injury levels.

This work was updated in 2014 (Fredriksson and Rosén, 2014) to take account of experimental head impactor test data as well as updated GIDAS accident data with more cases in the 'pre-crash matrix'. The result was simila,r but with slightly lower effectiveness values compared with the previous study. These were in the range from 24-39% for the passive part and 28-55% for the active part. Although the authors noted the wide range of potential effectiveness for a 'high–end' system and one where the AEB system was limited to operate up to 60 km/h only, only trigger for a pedestrian in the vehicle path, and that only operated in daylight. Despite the sensitivity and slight differences with respect to the previous analysis, Fredriksson and Rosén still concluded that the individual systems alone were effective to reduce severe head injury but combining the two systems was more effective than any of the system concepts alone, with 32 ‐ 42% higher effectiveness than the best single system.

In the study by Hamacher et al. (2011), those authors noted the potential adverse effects of a reduced impact speed on head protection for an adult pedestrian. They reported that at an initial collision speed of 40 km/h, the area of the central windscreen (and surrounding A-pillar sections) accounts for more than 60% of head contacts. Whereas, if AEBS reduce that speed to 30 km/h then 75% of adults would impact the cowl and lower windscreen area. With variations in impact position it is reasonable therefore that whilst AEBS will generally have the potential to improve safety and mitigate injuries, certain specific conditions may see an increase in risk. As such it seems necessary to balance the provision of both passive safety measures and AEBS to avoid an increase in injury risk for any unfortunate vulnerable road user.

Seven pedestrian accident scenarios were identified by Wisch et al. (2013) (each divided into 'daylight' and 'dark' lighting conditions) which included the majority of the car front to ‐ pedestrian crash configurations. These test scenarios were developed by considering the identified Accident Scenarios and basic physics. Hypothetical parameters were derived describing the performance of pedestrian pre ‐ crash systems based on the assumption that these systems are designed to avoid false positives as a very high priority, i.e. at virtually all costs. From the calculated initial weighting factors the conclusion can be derived that the AsPeCSS Accident Scenarios cover nearly half of all killed pedestrians (46%), nearly half of all seriously injured and killed (KSI) pedestrians (49%) as well as 37% of all pedestrian casualties in Europe.

For EEVC WG17, Hardy (2005) reported on a study of the benefits of increasing pedestrian protection to cover the windscreen and windscreen frame of cars. Using IHRA and APROSYS accident databases, he considered factors such as impact speed, the parts of the vehicle recorded as causing specific injuries, and the likely remaining injury risk when pedestrian protection was provided, in order to estimate the percentages of those casualties still injured with the current test options that could be 'saved' by additional protection to the windscreen area. Compared with the EEVC WG17 test procedures, and assuming a similar level of protection would be offered for the windscreen area as for the bonnet, Hardy (2005) estimated that a further reduction of about 7% of all pedestrian fatal and serious casualties could be obtained assuming tests equivalent to the EEVC were used (i.e. a 40 km/h test speed and a HIC 1000 acceptance criterion). For 35 km/h and HIC 1700 (revised EU phase two and GTR equivalent, assuming the additional requirement was for the same acceptance criterion as in the lower protection zone on the bonnet), the benefits were estimated at about 2.5% of all pedestrian fatal and serious casualties. In both cases the percentage benefits would be higher if taken as proportions of those hit by cars rather than by all vehicles. The estimated benefits for the EU-25 were annual reductions in casualties of 500 fatalities and 11,000 seriously injured casualties for EEVC standard protection and 200 fatalities and 4,000 seriously injured casualties for a revised EU phase two, lower protection zone standard.

These estimates show the extent of the gap resulting from not including pedestrian protection requirements for the windscreen area, though the benefits estimated were much lower if lower levels of protection were assumed. In one respect the estimates made by Hardy may be somewhat pessimistic for Europe, because most of the accident data he used were somewhat old and the trend towards shorter bonnets in Europe will have transferred more head impacts from the bonnet to the windscreen area. Furthermore, additional benefit will be available if pedal cyclist casualties are included in the target population. It appears reasonable to expect additional benefit for pedal cyclists based on the research of Peng et al. (2012) and Zander et al. (2013), etc.

The potential for injury reduction from active pedestrian protection systems is greater than from the passive systems (GDV, 2012). However, so far estimates of active system effectiveness have been based on theory rather than a practical determination of the system effectiveness.

The previous conclusions concerning the adult headform to windscreen test (Hardy et al., 2007), still seem valid:

- Accident data show that providing protection in the windscreen area could be very effective in reducing serious and fatal head injuries. This area was excluded from the European Directive because no feasible protection measures for the area as a whole were ready for use at the time of its introduction.
- Although the central area of laminated windscreen glass away from the support frame and underlying structures is normally considered safe, a test to confirm this would be of benefit and can also be used to test underlying components such as the top of the dashboard, which are likely to cause serious head injuries if too rigid.
- N2 and N3 vehicles cause a disproportionately high number of pedestrian fatalities compared with the number of serious injuries. Therefore, consideration should be given to including these vehicles along with all M1 vehicles and possibly all N1 vehicles in the scope for future test methods.

The study recommended further development of headform test procedures including extension of the test area to the windscreen and windscreen frame. Further work is needed in the area of the mathematical models or physical dummies used in numerical simulation and physical testing, to improve the biofidelity of their kinematics and response to impact with a vehicle.

Based on a very approximate estimate, expanding the scope of the current EC Directive to cover all or most of the M and N vehicles over 2.5 tonnes would result in savings of the order of an additional 15 percent for serious casualties and 30 percent for fatalities of the current Directive's savings. The interactions of pedestrians with these larger vehicles are likely to lead to problems in using the Directive's test tools and methods. Although, suggestions have been made as to how the current test methods could be adapted for testing larger M1 and all N1 vehicles (Hardy et al., 2007).

The potential benefit for head-to-windscreen contacts is up to 500 fatalities and 11,000 serious injuries (~ €3 billion) in M1 vehicles. In M2/M3 and N2/N3 vehicles this could be up to 150 fatalities and 1,650 serious injuries.

It should be noted that benefit estimates for passive protection systems are usually based on test results with a direct head strike. With some deployable systems there is the potential that deployment will not catch the head of the pedestrian as intended. Furthermore, it is conceivable that the deployed technology could even present an injurious structure for pedestrians of different statures. For this reason care, should be taken in interpreting some of the benefit estimates presented.

B.7.6 Benefit:Cost Ratio

The Benefit:Cost ratio for headform protection measures can be anticipated to lie in the range from less than 0.25 to 1. The exact value will depend on the real-world effectiveness of the available countermeasures as well as the eventual cost.

Despite this range of ratios, it might be that the variation of performance of the windscreen material can be controlled more closely, and give safety improvements, via the arrangements between vehicle manufacturer and glass supplier. This could offer minor benefit with only minor cost. Therefore further research could be useful to isolate the relationship between variations in the windscreen fabrication process and HIC. Once that relationship is understood better, then the monitoring tests (to the central region of the windscreen) could become feasible.

From AEBS systems (operating with a pre-collision detection of either 0.6s / 1s / 2s), the Benefit:Cost ratio is reported to lie in the ranges 0.19-0.44 / 0.38-0.91 / 0.44-1.04.

Based on the Robinson et al. study the pedestrian AEBS were judged as being unlikely to be cost effective. Those authors note that system developers would either need to substantially improve their capability, so that they prevent a higher number of casualties, or reduce the system costs, or both. It is also not clear to what extent these estimates take into account the variable performance of AEBS in various scenarios and conditions.

Also, "The effective use of active safety systems generally demands an adequate passive pedestrian safety, as shown by the velocity related index calculation within the assessment procedure. Consequently, future cars should follow an integrated safety approach." (Hamacher et al., 2011).

B.7.7 References

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B.8 Influence of front registration plates (not present in type-approval testing) on pedestrian protection

The bumper test components of vehicle type approval are conducted without the front registration plates being present. However, when a vehicle is involved in an accident, this will be in place. Therefore it is possible that the real world safety levels are different from those assessed at the time of type approval. Testing with the registration plates in place would remove this discrepancy.

B.8.1 Description of the Problem

Currently when vehicles undergo the type approval process, the front registration plates are not present on the vehicle during testing. This aim of this document is to consider the impact of the plates being in place during tests, specifically on pedestrian safety, and hence the cost-benefit analysis of the inclusion of this measure.

There is no common specification for vehicle registration plates across the EU member states, and consequently there is significant variation both in the format of the identifier displayed and, more relevantly, in the material and dimensions used for the plate. Commission Regulation 1003/2010 concerns type-approval requirements for the space for mounting and fixing of rear registration plates on motor vehicles; however, there is no Commission legislation governing the mounting and fixing of front registration plates. There is also no legislation at European level governing the specification of the plate itself, for either the front or the rear of the vehicle. It is worth noting that there are classifications of vehicles that do not require a front registration plate such motorcycles or classic models of car.

Although there are a wide variety of registration plates across different countries, individual countries are sometimes subject to national legislation which covers the plates. An example of this is in the UK where registration plates are governed by 'The Road Vehicles (Display of Registration Marks) Regulations 2001' (SI 2001 No. 561). This covers, inter alia: fixing of rear plates, fixing of front plates, lighting of rear plates, specification of registration marks (layout, size, style) and specification of plate (see below). This latter section states that, for vehicles registered and new registration plates fitted on or after 1st September 2001, the plates must conform with BS AU 145d(1) (or equivalent). British Standard AU 145d:1998 'Specification for Retro reflecting number plates' covers design, marking, colour, retro reflection, resistance to bending, resistance to solvents, resistance to corrosion, resistance to weathering, resistance to vibration and shock, thermal resistance and most relevantly, resistance to impact. The resistance to impact of the registration plate must be tested using three sample units subject to a 1kg mass with 'striking nose' of 6.5 mm radius free-falling and impacting the geometric centre of the plate with an impact energy of 7.5 J.

It is unknown whether there are standards equivalent to this in other EU member states; however, the ISO standard 7591:1982 (reviewed and confirmed in 2010) is entitled 'Road vehicles – Retro-reflective registration plates for motor vehicles and trailers – Specifications'. This standard outlines very similar specifications to the British Standard and in particular the section defining 'resistance to impact' is identical and it seems likely that the latter was based on the former.

It is not known how many of the EU member states have similar legislation to SI 2001/561 and, where present, how closely this legislation includes or aligns with the international standard ISO 7591:1982. It is worth noting that some countries manage the situation very differently, for example, in Belgium, plates are driver-specific rather than vehicle-specific, and whilst the rear plate is supplied by the state, the front plate is supplied by the driver.

Despite the lack of legislation regarding the mounting of front registration plates, anecdotal evidence suggests that the majority of modern cars mount them on the surface of the front bumper. It is therefore assumed that any impact the registration plate may have on pedestrian safety would be during collisions where the pedestrian is struck by the bumper.

Based on SI 2001/561, the standard width of a registration plate in the UK is 520 mm. If vehicle width is normally within the range of 1600 to 1900 mm, then the registration plate spans approximately 25 to 30 percent of the total width.

Carroll et al. (2014) showed that the number of pedestrian casualties arising from impacts with car fronts lies somewhere between 2.5% and 3.5% of all reported accidents. The latest EU Transport Pocketbook (European Commission, 2013) reports that between 2009 and 2011 there were, on average, 1,140,494 reported injury accidents in the EU27 per annum. Using the 2.5% to 3.5% range, the numbers of (reported) pedestrian casualties arising from impacts with car fronts are estimated to be between 28,512 and 39,917 per annum. It was assumed that 50% of all reported pedestrian casualties from front-of-car impacts are seriously injured as a result. Therefore one may expect between 14,256 and 19,959 such casualties in the EU per annum. A range of correction factors of between 1.35 and 2.1 was used to account for under-reporting. This takes the likely numbers of casualties to between 19,246 and 41,913 per annum.

Given the size of the registration plates, then we can expect that between 4,811 and 12,573 seriously injured pedestrian casualties could be affected by a primary contact with the bumper in the region where the registration plate is fitted.

B.8.2 Potential Mitigation Strategies

The motivation behind this investigation is that, although registration plates are not present during testing, they will be present in real life during a collision with a pedestrian. Therefore it is possible that the real world safety levels are different to those assessed at the time of type approval and the type approval testing does not reflect an accurate level of risk. Testing with the registration plates in place would remove this discrepancy. Alternatively, the material or construction of the registration plate could be specified to ensure that it does not adversely affect safety in a pedestrian impact, or the mounting of the registration plate could be altered to account for the contribution of the plate and testing could be conducted with an exemplar plate.

B.8.3 Feasibility

Registration plates are different in different Member States. In order to maintain the mutual recognition of type approval, including the plate in EU-wide type approval procedures would require either standardisation of registration plates across Europe or repetition of the relevant tests for a range of plates. Both of these approaches (or a combination of the two) have significant costs and associated issues.

Harmonising registration plates across all Member States could be a costly undertaking, requiring the creation and enactment of European legislation. A pan-European certification scheme would also be required to ensure that all registration plates used on type-approved vehicles conform to the harmonised standard. Setting up and maintaining a certification scheme would be a significant (and ongoing) cost to the Scheme administrators.

An alternative to harmonising registration plates would be to test vehicles with a sample plate of each country in which it is sold. The relevant test is the legform-to-bumper pedestrian safety test and therefore the costs can be estimated based on the cost of the individual test and the number of repetitions required. If a vehicle is only sold in a single national market then the cost of including registration plates in the pedestrian safety tests would be minimal. However most, if not all, vehicle manufacturers sell their products in numerous countries and hence the additional testing required could cause rapidly increasing costs. In addition, it may not be possible to identify a 'sample plate' for each country if national standards do not exist, as the variety within the country may make such a representative meaningless.

It is worth noting that the problem is not restricted to the European market. Many vehicle manufacturers sell their vehicles in an international market and so testing would also need to include examples of registration plates from outside of the EU. As we move towards the implementation of UN Regulation and a Global Technical Regulation on pedestrian safety testing, this issue regarding testing all conceivable registration plates for the various markets into which a vehicle could be sold, at the point of type-approval becomes even larger. It does not seem reasonable (and may not be possible after acceding to the regulations) to reject a type-approval from one region because they could not provide a representative registration plate for another. Therefore this would remain an issue even if pan-European harmonisation had been achieved.

Logical consideration of the issue suggests that the presence of a plate during testing has the potential to have both a positive and negative impact on pedestrian safety. The severity of the injury may be lessened due to the plate absorbing some of the energy of the collision prior to impact with the non-deformable elements of the vehicle. Alternatively the plate may break into shards upon impact which may be injurious and increase the severity level. It is likely that the former option is more realistic, however the effect is likely to be insignificant compared with the large energies associated with the collision.

Furthermore, if it was shown that the presence of the registration plate increased the risk or severity of the pedestrian injury, then inclusion of the plate in type approval would likely require manufacturers to make plates ‘safer’. It is not clear how this would be achieved, although it would likely involve research and development into alternative materials with different impact resistance. Plates could be designed such that they break more easily upon impact, absorbing some of the kinetic energy and hence lessening the force acting on the pedestrian; conversely it may be preferable to design plates that either do not break upon impact or break in a particular way as to avoid creating shards of material which could cause lacerations. It is important to note also that the existing specifications for plates (where they exist) are based on the requirement that the vehicle identifier remains legible and the impact resistance measure specified in the standards is such that the plate does not crack or break under an impact energy of 7.5 J or below. Any changes to the material to make a plate safer to pedestrians may therefore directly conflict with these requirements.

B.8.4 Costs

As mentioned, harmonising registration plates across all Member States could be a costly undertaking requiring law-making at the European and Member States level.

Testing representative plates from a variety of countries initially seems simpler, with costs just reflecting the additional tests necessary and the corresponding replacement bumper components. However, in the light of worldwide regulations, this could quickly become unfeasible (and if feasible, more expensive)

If the introduction of plates in testing meant that subsequently there was a need for alternative plate design, there also is the potential for costs to be incurred through research and development, most likely by the manufacturers of the registration plates. Although it is not clear what form the required changes would take, such costs are likely to be significant.

B.8.5 Benefits

No theoretical, experimental or anecdotal evidence was identified that suggested that registration plates are a factor in pedestrian injuries as a result of bumper strikes. Therefore it is unclear whether there actually is a discrepancy between the type approval testing and real life collisions, and hence whether there is any opportunity to improve the fidelity of the testing. Without any evidence regarding the potential benefit of this measure, no expected benefit can be provided.

B.8.6 Benefit:Cost Ratio

As it is not clear that any benefit could be accrued through this measure, an initial estimate of the benefit:cost ratio is that it can be approximated to zero.

B.8.7 References

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B.9 Influence on safety of third-party (non-OEM) replacement parts, e.g. for pedestrian protection

For styling or accident repair purposes, aftermarket vehicle components can be purchased. These parts can be sourced from the original manufacturer or from a third party. Third party parts may not have been assessed for safety performance in the same way as the original parts and therefore safety could be degraded through the fitting of such parts. In principle it could be required for all automotive parts to have been assessed and certified to make sure that safety levels are maintained or will still meet type approval requirements. Alternatively, the fitting of third party parts that may affect pedestrian safety could be tracked and their effect monitored.

B.9.1 Description of the Problem

The automotive industry has a responsibility to its customers to support the longevity of their current vehicles by ensuring that these products can be serviced, repaired and maintained in such a manner as to not be detrimental to their function, safety and reliability. Spare parts for vehicles must meet the performance demands of the original part and function identically with associated systems and components to make sure that the function and safety of the vehicle is not adversely affected (ACEA, JAMA, KAMA and CLEPA, 2014).

However, when a vehicle ceases volume production, the part tooling and design drawings either remain under the responsibility of the original component manufacturer (mostly Tier 1 suppliers) or are transferred to an SME in order to continue production of the service parts in smaller volumes. Typically these SMEs are located in the EU and they have very little knowledge of part development and whether substituting certain substances will lead to detrimental effects on performance. These SMEs are also unable to validate any changes to the system or vehicle as a whole, which means that expected functionality cannot not be guaranteed.

Therefore, aftermarket vehicle parts which are purchased for replacement purposes can be sourced from either the original equipment manufacturer (OEM) or from a licensed supplier, or from a third party. OEM parts are expected to be identical to those fitted to a vehicle during the type-approval process and as such are likely to have been rigorously tested for safety performance; however, non-OEM parts from third parties have no such guarantee that they have been tested to the same standards and therefore the safety performance of the vehicle may be degraded through the fitting of these parts.

Aftermarket parts are extremely numerous potentially covering the full range of vehicle parts for all vehicles in the fleet. They may be used for a variety of purposes, such as accident repair, minor cosmetic damage or styling preferences. When considering pedestrian safety, the most common directly relevant parts are lights, bumpers, bonnets and wings being replaced following accident damage. Other replacement parts may influence the performance of other vehicle systems, including those that may impact on pedestrian safety such as brakes.

There are no accident data which explicitly document the involvement of aftermarket parts and their possible contribution to an outcome not expected with original parts.

As a proxy to these data, one could base expected accident involvement on the number of aftermarket parts fitted (or sold) compared with OEM parts. However, this would not provide the exact values required for this analysis. It is not necessarily the case that cars fitted with aftermarket parts are equally likely to be involved in accidents as cars with OEM parts. Also, the exposure (vehicle-km travelled and time before removal from the fleet) could be different between vehicles with OEM or aftermarket parts.

B.9.2 Potential Mitigation Strategies

In principle it could be could be made mandatory for all replacement parts to have been assessed and certified to make sure that safety levels are maintained or will still meet type approval requirements.

If this approach is too onerous, then as a monitoring step consideration could be given to marking parts and monitoring the involvement in accidents around Europe of either OEM or Tier 1 supplier parts compared with third-party components. This might demonstrate the likely need or influence of a further countermeasure. It could form the basis of another intervention if traceable marking was added to all legitimate and authorised parts. However, consideration would have to be given to the marking process and easy identification of non-approved parts.

B.9.3 Feasibility

The feasibility of assessing and certifying aftermarket parts depends somewhat on the reason why the replacement is being made. For example, it is easier to implement such certification into existing insurance processes for accident repair, than attempting to regulate aftermarket parts that are being replaced for cosmetic purposes in potentially entirely private transactions.

Use of non-OEM parts in accident repair has anecdotally increased over recent years, with more companies supplying such parts. This has been largely driven by the insurance industry since using replica parts can make substantial savings and keep insurance prices competitive. However there is a concern that the replica parts are of low quality and also may not fit correctly.

This concern has led to the development of individual schemes attempting to address the problem; an example of this is the Certified parts scheme run jointly by Thatcham Research and TÜV Rheinland. This scheme originated as the Thatcham Approved Parts scheme in 2001, driven by demand from insurers, and the joint Part Certification programme was launched in 2008. The scheme aims to “verify the quality of aftermarket non-structural repair panels and encourage the use of these non-OE parts in vehicle repair”. This includes verification of correct fitment in the workshop environment, as well as certification of the products and processes. A certified parts list and certified manufacturer list are maintained on the website, as well as a Recognised Installer scheme for aftermarket installation companies. A similar service is provided in the USA by the Certified Automotive Parts Association (CAPA).

Therefore, issues with safety levels of replacement parts are unlikely to be so prevalent for repairs carried out through approved suppliers and authorised repair shops, but instead could be more of a problem in independent repair shops using independent parts suppliers.

B.9.4 Costs

The costs of implementing this measure would depend on the approach taken by the Commission and are as difficult to estimate as with the potential benefits discussed below. There are a number of options, the one with the largest cost implications being the implementation of a pan-European Certification scheme. This would require a full legislative framework and certification processes outside of the existing type approval system and procedures. The administration and day-to-day operation of such a scheme is considerable.

There are between 1,000 to 4,000 suppliers providing spare parts to individual vehicle manufacturers or Tier 1 suppliers in Europe (ACEA, JAMA, KAMA and CLEPA, 2014). There would be significant costs for the third-party manufacturers in obtaining certification, and potentially very large additional development costs in order to achieve the necessary standard for certification. This cost will then almost certainly be passed on to the customer and the current benefit of using the third-party parts (i.e. lower part price) may be reduced or removed. Alternatively, the cost may be passed onto the repair workshops. Insurers currently benefit from the use of third-party replacement parts as they can significantly cut costs on older cars, however if such parts increased in cost then this benefit may also be lost.

Due to this uncertainty about where the cost burden would fall, it is difficult to make any predictions about acceptability to the general public. It is almost certain that costs in the industry would be passed onto the consumer and so acceptability is likely to be low unless the safety benefit can be demonstrated conclusively.

The EC is keen to create a 'competitive landscape' where independent repair shops can compete with authorised centres and hence reduce costs for the customer (The Boston Consulting Group, 2012). An example of this is the recent EU Regulation 566/2011 regarding access to vehicle repair and maintenance information which obliges manufacturers to release electronic data enabling the exact identification of replacement parts for vehicles. This means that independent operators will have the same access to repair information as authorised centres and therefore the position of such operators will be strengthened. It is not clear whether requiring certification of third-party replacement parts would assist or hinder this initiative. Independent centres are likely to lose the competitive edge that is provided by the lower costs; however it may make them a more attractive option to insurers and the general public.

B.9.5 Benefits

In order to assess the potential benefits of mandatory certification of third-party replacement parts, it is necessary to consider both the target population and the impact it may have on safety performance, i.e. the potential effectiveness of this measure.

The extent of population affected by the replacement parts market in Europe and such a performance-based measure is not known. The value of the replacement parts market is known for Germany, France, UK, Spain and Poland and aggregate figures for these countries suggest the value of accident repairs, wear-and-tear repairs, mechanical/electronic repairs, maintenance, tyre services and consumables and accessories to have been €115 billion (The Boston Consulting Group, 2012). Investigations by the Competition Commission (2013) in the UK found that the use of non-OEM parts in insurer-managed repairs is small (between 2 and 15% of all parts used, by value). This aligns with the assessment made when the Thatcham scheme launched in 2001 which suggested that non-OEM parts accounted for 3% of the parts market in the UK (Bauer Automotive, 2001), with the hope that this would increase to 9% as a result of the scheme. Note however that both estimates are limited to the UK and to insurer-managed repairs; as discussed previously, a proportion of third-party replacement parts will be used outside of insurance processes, and even outside of accident repair, and as such are even more difficult to quantify. The Boston Consulting Group (2012) reported that the proportion of repairs going through authorised repair shops compared with independent repair shops decreased as the age of the vehicle increased. For instance, for vehicles up to four years of age, 88% of accident repairs would be via an authorised repair shop, whilst the proportion was only 22% for vehicles over eight years of age. Maintenance, tyre services and consumables and accessories would use a smaller proportion of authorised suppliers even for new vehicles.

The other aspect of the benefits case is the question of whether there is degradation in safety performance when third-party replacement parts are used. There is very little evidence available to assist in answering this question; however two studies may be of interest and may provide an indication.

A study was carried out by MIRA (2006) which compared an original (2005) Ford Fiesta bonnet against three copy supplier bonnets in terms of pedestrian design. The study found that there were differences between the original and the copies that affected pedestrian protection:

- Depressions in the inner panel of the original not present in the copies, that created more space between the bonnet and the engine bay components
- Lower material specification and increased gauge of the copies, which allows easier pressing and processing than high strength materials (which are better for pedestrian protection)

- Difference in bonding material – the inner and outer panels on the copies were more likely to separate, increasing the probability of pedestrian secondary impact with the engine bay

Overall the report found that the tested copy bonnets produced higher injury levels than the original bonnet. It is important to note however that this study was commissioned by Ford and has subsequently been criticised for "not comparing like with like". (It was claimed that the original bonnet was compared with copies of an older design from before pedestrian safety standards were made a requirement.)

Another study, this time by CAPA in the USA (Certified Automotive Parts Association, 2003), tested 1031 aftermarket part numbers that were submitted for CAPA certification and found that 44% of these failed to meet CAPA standards for fit and appearance during their initial vehicle fit test. Note that this percentage was of those that were submitted for testing; CAPA also found that 83% of non-submitted parts, randomly selected from the marketplace, failed to meet the certification standards.

It is important to note that neither study is entirely independent and both have been carried out at a national level; there is no reason to believe that either is representative of the European market. Both are also very specific studies and possible extrapolation of results is limited.

Even if an accurate estimation of the size of the third-party replacement parts market could be calculated, it would be extremely difficult to convert this into an accurate prediction of safety degradation because the replacement parts may vary greatly in quality.

As already noted, there are also some questions regarding the feasibility of introducing such a measure. It seems likely that in order to be successful it would need to be limited (at least initially) to insurer-managed repairs, and to specific parts or panels. It could be extended to cover other vehicle parts if it was shown to be of benefit.

B.9.6 Benefit:Cost Ratio

Without an assessment of either the anticipated European benefit or the cost of introducing a certification scheme, no benefit:cost ratio can be provided.

B.9.7 References

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B.10 Consequences of rear impact for rear seat occupants

To make the best use of the available interior space and with regard to modern packaging constraints on the length of cars it can be the case (particularly for some styles) that occupants in the rear row are very close to the rear of the vehicle. Whilst not assessed by crash testing, there is a concern that these occupants could be at a greater risk of severe injury from intruding structures during a rear impact event than occupants in other seating positions.

B.10.1 Description of the Problem

Concerns about rear impact safety were raised in the U.S. during the 1960s. In 1968, Severy et al. reported experiments in which 55 mph rear impact collisions were simulated. They were investigating the influence of seat back height on risk of injury. To remove the complication of interference with the roof and window structures, the rear window and header were removed from the vehicles in preparation for the tests. These authors found that with a sufficiently high seat back and head restraint and the use of three-point seat belts, the kinematics could be controlled and severe neck bending and head contacts could be avoided. The vehicles tested in these experiments were large U.S. saloon cars. This UCLA research programme, and the efforts of their contemporaries, began to suggest that if a supporting structure had sufficient height and strength, then the worst of the injuries from severe rear impacts could be mitigated. For rear seat occupants, it is generally assumed that seat strength should not be a problem for saloons with a supporting parcel shelf. However, it is still potentially important for hatchbacks with folding rear seats. Furthermore, whilst Severy et al. deliberately removed the roof and window structures during their test work, in modern vehicles these could definitely be close to the heads of occupants on the rear row of seats and provide a potentially injurious source of contacts.

Anecdotal evidence suggests that hard head contacts with the interior surface of the vehicle can produce injuries in moderate to severe rear impacts. In addition to this, there could be further issues for small vehicles where the rear seat occupants sit close to the rear window and there is little vehicle structure between the rear bumper and the rear window. Theoretically, in such instances, the occupant could be exposed to either partial ejection through the rear window to contact the collision partner vehicle or direct loading from the intruding structures This direct loading had not been identified as a primary source of injury on the basis of the historic moderate severity rear impact testing. Finally, direct loading from objects in the boot remains a possibility in all types of car. The potential for loads in the cargo space to penetrate forwards under their own inertia is assessed in Regulation 17. The potential for objects to be driven forwards is not.

- UN Regulation 17 provides limits for head restraint height and seat back strength for all seats in cars and other passenger vehicles. Despite this, in comparison to the front seats, the geometry of the rear seat ratings is much poorer with regard to support for the head and neck in rear impact crashes (Avery et al., 2011). The implication of this is that the current rear row seating positions may not offer equivalent protection to front seats with respect to: Injurious interactions between the occupant and the seat structure
- Prevention from ejection or partial ejection
- Isolation from intruding structures.

According to Klinich and Flannagan (2009), in 2008, Viano and Parenteau reviewed 1996-2005 FARS to estimate fatality risk by seating row and PDOF. Vehicle model years were limited to 1990+. NASS-CDS was used to estimate exposure. They did not consider occupant restraint. Within the analysis, 9.6% of fatalities were to 2nd row occupants, who represented about 12.3% of occupants in towaway crashes. Less than 1% of fatalities were to 3rd row occupants, with 61% of those in rollovers. 3rd row occupants represented 0.7% of occupants in towaway crashes. Rear occupant fatality risk was highest in near-side impacts. They estimated fatality risk by occupant row and crash type according to Table B-9. For all occupants, the greatest fatality risk was in rollovers. Fatality risk for 2nd row occupants was less than that for front-row occupants except in rear impacts. Fatality risk of 3rd row occupants was always less than that of 2nd row occupants, even in rear impacts. Data on 4th row occupants appeared to be distorted by the small number of occupants in that seating row.

Table B-9: Fatality risk by occupant row and crash type (Viano and Parenteau 2008)

Row	Front 11-12-1	Right 2-3-4	Rear 5-6-7	Left 8-9-10	Rollover	Other/?	Total
Front	.63%	1.19%	0.31%	1.32%	3.05%	0.21%	0.93%
2nd	.36%	0.91%	0.53%	0.77%	2.52%	0.20%	0.70%
3rd	.20%	0.35%	0.22%	0.37%	2.01%	0.23%	0.52%
4th	.34%	14.63%		0.36%	2.06%		1.70%
Total	.59%	1.14%	0.34%	1.24%	2.97%	0.21%	0.89%

According to the ETSC (http://etsc.eu/wp-content/uploads/PIN_Flash_27_for-publication.pdf), a study analysing data of car occupants killed or injured in France between 1996 and 2006 shows that, among belted occupants, rear-seat passengers are twice as likely to be fatally injured as drivers in rear impact collisions (Martin and Lardy, 2009)

- The accident data reported by Jakobsson et al (2000) indicates a tendency to a higher risk rate for front seat driver and passenger as compared to rear seat passengers. There is a significantly higher risk of the driver sustaining a neck injury as compared to the passenger. There is also a noticeable difference between the front seat passenger and the rear seat passenger, which is, however, not significant.
- When considering whiplash injuries only (Berglund et al., 2003); for each seating position, the risk of whiplash injury was higher for females than for males. The highest risk was observed for drivers and the lowest for passengers in the rear seat, and this applied to both sexes.
- In contrast to other studies, Krafft et al. (2003) found that there was an increased risk for female passengers in the rear seat compared to the front seat passenger position. In this study, permanent disability was defined as long-term consequences judged by the Swedish Road Traffic Injury Commission; less severe disabilities (1–10%) were established by the insurance company. Also, only rear impacts with both front- and rear-seat occupants in the struck car were selected.

Therefore whilst there can be discussion on the need for further whiplash injury protection for rear seat occupants, there is a clear need to protect those occupants from more severe injuries in more severe crash events.

B.10.2 Potential Mitigation Strategies

UN Regulation 17 concerning vehicle seats, their anchorages and any head restraints and also Regulation 25, concerning head restraints, whether or not incorporated in vehicle seats, ensure that there is some protection for occupants in the event of a rear impact. They require a minimum strength for seats, that a head restraint is available with energy dissipating properties and that the seats and their head restraints exhibit no dangerous rough or sharp edges.

A minimum strength is a clear necessity. However, research for GM has shown that seats which 'pocket' the occupant in the seat back within a perimeter frame help to retain the occupant in severe rear impact events. Furthermore, this research has shown "high retention" seats to be effective for front seat occupants against fatal injury incidence (Viano and Parenteau, 2014)

For positions other than the front seats, the height of the head restraint shall be not less than 750 mm (measured according to Figure B-2). Although, the height of any head restraint designed to be provided in rear centre seats or seating positions shall be not less than 700 mm.

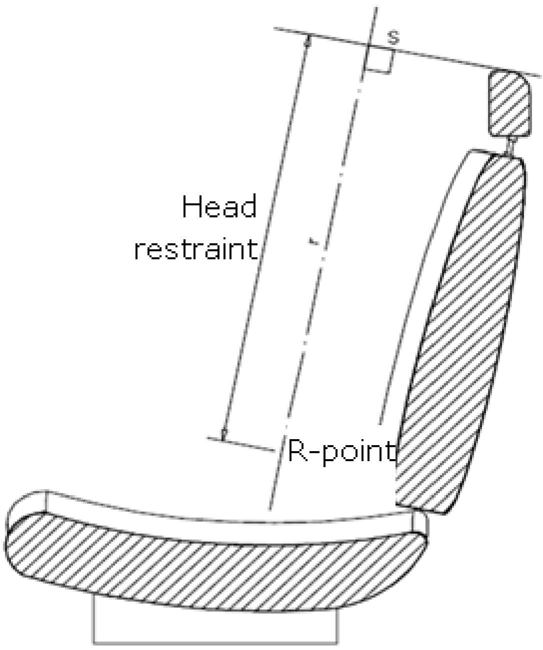

Figure B-2: Head restraint height (UN Regulation 17)

During the development of a cost-benefit study on head restraint geometry, Hynd et al. (2007) found that the Regulation 17/25 height measurement method overestimates the effective height of the head restraint and therefore overestimates the proportion of the population that would be protected by the head restraint. According to the calculations used in the cost-benefit study, a head restraint height of 800 mm, as required by the Regulations for front seat occupants would be expected to protect 55% of the UK male population and 98% of the UK female population from long-term whiplash associated disorders. For an example seat, it was found that the effective height was overestimated by 48 mm. With an error of 48 mm in the height measurement, these proportions protected become 8% and 64% respectively. These proportions will be lower again for head restraints with a regulatory required height of 750 mm or 700 mm.

It should be noted that the height of the head restraints can be lower than set out in the requirements where it is necessary to leave clearance between the head restraint and the interior surface of the roof, the windows or any past of the vehicle structure; though the clearance is not to exceed 25 mm. This exemption is supported by the concept that the head could not extend through such a small gap. However, it does not assess the potential for a hard contact with the interior surface to cause an injury to the occupant.

In terms of strength, Regulation 17 has dynamic and quasi static test procedures for the seat anchorage and seat-back, respectively. There are general requirements for instance stating that:

> *"No failure shall be shown in the seat frame or in the seat anchorage, the adjustment and displacement systems or their locking devices during or after the tests… Permanent deformations, including ruptures, may be accepted, provided that these do not increase the risk of injury in the event of a collision… "*

When testing the head restraint, there is a rearward displacement limit of 102 mm to be assessed when a moment of 37.3 daNm is applied about the R-point of the seat via a spherical headform pressing into the head restraint 65 mm below the top.

The requirements within UN Regulations 17 and 25 are not new. If there is evident that modern vehicles are still not mitigating severe rear impact injuries sufficiently, then it would indicate that the requirements in Regulations 17 and 25 are not adequate to drive the necessary safety solutions to this problem.

More recently, the whiplash related design features of vehicle seats have been assessed for both the front seats and the rear outboard seats. Front seats are tested statically and dynamically according to Euro NCAP Whiplash Testing Protocol. Rear seats are assessed according to the Euro NCAP Rear Whiplash Protocol. The seating position shall be deemed to have met the height requirements of this protocol if either:

- the effective height of the head restraint meets the requirements of both the following:
    - The effective height of the restraint is, in its lowest position, no less than 720mm
    - The effective height of the restraint is, in its highest position, no less than 770mm.
- if the interior surface of the vehicle roofline, including the headliner or backlight, physically prevents a head restraint located in the rear outboard designated seating position from attaining the height required by the statements above, the gap between the head restraint and interior surface of the roofline, including the headliner or the backlight when measured as described below, shall not exceed 50mm when the head restraint is adjusted to its highest position intended for occupant use:
    - If adjustable, adjust the head restraint to its maximum height and measure the clearance between the top of the head restraint or the seat back at all seat back angles for intended use and the interior surface of the roofline or the rear backlight, by attempting to pass a 50 ± 0.5mm sphere between them.

The adoption of the geometric assessment was supported by a proposal from Thatcham (Avery et al., 2011).

It will be interesting to see if vehicle design responds to the Euro NCAP assessment by providing fuller head restraint systems in rear seating positions. Provision of head restraints of a suitable height is part of a potential mitigation strategy for moderate to severe injury prevention in rear impact events.

Based on the regulatory and consumer information testing and requirements, there will be some provision for whiplash injury protection in vehicles. However, there is currently no assurance as to the high severity rear impact and injury protection. The requirements would not require a stiff head restraint capable of controlling the motion of the occupant in a severe event. There would be no assessment of the potential for injurious contacts to be made with the vehicle interior in off-axis impact events, where the head might escape from any head restraint. Also, there would be no assessment of the risk of injury posed by intruding structures from a collision partner.

UN Regulation 32 concerns the behaviour of the structure of the impacted vehicle in a rear-end collision. The main requirement is that during testing, the lengthwise displacement of the vehicle shall not exceed 75 mm. This is defined as being, "the amount of longitudinal displacement of the vertical projection on the floor of the "R" point of the vehicle's rearmost seat in relation to a reference point on a non-deformed part of the vehicle structure. The impact is administered by either a moving barrier or a pendulum. In either case, the impact surface is 2,500 mm wide, 800 mm high (with a 175 mm ground clearance) and made of plywood. The velocity is specified as being between 35 and 38 km/h and the aggregate mass of carriage and impactor as being 1,100 kg.

It should be noted that the EC has not acceded to UN Regulation 32. However, an equivalent test procedure is used in UN Regulation 34 when assessing the prevention of fire risks, although the 75 mm displacement requirement is omitted. Also, depending on the approval path, there is not always the requirement to perform the full-scale tests, instead component level tests and design requirements are a valid alternative.

If it could be guaranteed that, accounting for some deformation of the vehicle, sufficient space would always be available for uninhibited movement of the head of a rear seat occupant was possible in a severe rear impact, then this would go further towards the mitigation of injuries in such events.

B.10.3 Feasibility

"It is possible to increase the whiplash protection in rear seats." (García et al., 2012)

Therefore, it seems appropriate for whiplash protection development work to continue alongside the activities of consumer information and regulatory groups.

As there has been little consideration within the recent testing, it is not known what needs to, or can be, done to improve the resilience of vehicles against moderate and high-speed rear impact collisions.

The rear impact tests of UN Regulations 32 and 34 would offer an opportunity to assess rear impact performance of the full vehicle, if there were conducted routinely. Although, there would have to be some modifications to the protocols to include further evaluation of the injury risk for occupants.

FMVSS 301 includes a rear impact test for the assessment of the fuel system integrity. This specifies a mobile deformable barrier impact to the rear of the vehicle at 80 km/h, with a 70 percent overlap and 50th percentile test dummies in each front outboard seating position. However, the dummies are not instrumented for the purposes of assessing injury risk.

B.10.4 Costs

As examples of potential mitigation technologies were not identified during this review, no information on costs was available.

B.10.5 Benefits

No information on benefits was available as no solution was proposed.

B.10.6 Benefit:Cost Ratio

Without benefit or cost estimates, no benefit-to-cost ratio can be provided.

It is suggested that further research is needed to quantify the size of the target population and then consider potential mitigation technologies, their potential effectiveness and their cost; prior to a more detailed review of this measure.

B.10.7 References

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B.11 Strength of ISOFix Connectors

Strength of ISOFIX connectors installed in vehicles to provide appropriate protection of heavier children.

B.11.1 Description of the Problem

Part of the European Vehicle Type Approval process involves assessing the strength of the ISOFIX anchorages. UN Regulation 14 requires a pair of ISOFIX anchorages to be capable of withstanding a static load of 8 kN without deforming.

Regulation 44 (Reg.44) and Regulation 129 (Reg.129) attempt to limit the maximum force experienced by the ISOFIX anchorages by limiting the maximum combined mass of the occupant and child restraint to 33 kg. In Reg.44 the design restriction is well defined: a child restraint must not have a mass greater than 15 kg, thus assuming the maximum occupant mass would be 18 kg. However in Reg.129 the requirements are not restrictive. The manufacturer can specify the maximum mass of the occupant suitable for the child restraint. Therefore a manufacturer may choose to design a lightweight child restraint for a heavy occupant or vice versa, as long as the total does not exceed 33 kg.

There is little evidence at this time to relate this static load to an equivalent dynamic load rating that a vehicle would experience in a crash.

Data presented by Britax (2008) showed that some seats loaded the ISOFIX anchorages in excess of 10k N, with a maximum load estimated to be 13 kN. Child restraints with a support leg were found to create higher loads in the ISOFIX anchorages. This design of child restraint is likely to become more popular in Reg.129 as they will become "universal", i.e. fit in any Reg.129 approved vehicle seating position.

Consideration also needs to be made as to the effect of impact severity on the forces measured by the ISOFIX anchorages. Belcher et al. (2007) conducted a series of tests using the AS/NZS 3629.1 front impact test pulse (>49 kph, 24-34 g peak acceleration). The maximum force on the ISOFIX anchorages measured using a child restraint with top tether was 7.2 kN. Without the top tether 11 kN was measured. These results were comparable with those from the Britax testing.

In North America FMVSS 225 requires a static strength of 11 kN for the ISOFIX anchorages of vehicles. In addition the ISOFIX anchorages are tested simultaneously with the top tether anchorage with a load of 15 kN. The anchorages are tested to a higher load because FMVSS 213 allows an occupant mass of 65 lbs (29.5 kg) to use the ISOFIX anchorages.

During the development of Reg.129, Mercedes-Benz (2008) investigated the ISOFIX anchorage loads measured during a full-scale crash test. They attached a 40 kg force application device to the ISOFIX and top tether anchorages of the vehicle. This device represented a 30 kg 6 year-old child and a 10 kg child restraint. The vehicle was crashed according to US-NCAP: 56 km/h into a rigid barrier with 100% overlap. The results showed that the anchorages had deformed. As the anchorages were statically rated to 15 kN, Mercedes-Benz estimated that anchorages only rated to 8 kN would have failed.

Another variant that should be taken into account is that the child is not perfectly coupled to the child restraint, i.e. an occupant and restraint mass of 25 kg and 10 kg will not load the ISOFIX anchorages in the same way as a 10 kg occupant in a 25 kg seat.

Currently there is no accident data that shows that injuries in the field are occurring due to failure of vehicle ISOFIX anchorages. However it was noted that in a full-scale frontal vehicle-to-vehicle crash test conducted for the European Commission (Visvikis et al., 2014), the ISOFIX anchorages of a Group I (Reg.44) approved child restraint were deformed during the crash. This test was a 50 km/h, full-width impact using two identical vehicles.

That being said, Reg.129 has not been in force many years (since July 2013) and there are not many Reg.129-approved child restraints on the market at this moment in time. Therefore the exposure of these child restraints being involved in accidents is low. It is also only likely that the child restraint will only be used by a heavy occupant for a very short amount of time e.g. 3-6 months, before the child will have grown enough to be transferred to a booster seat. Therefore the exposure of the child and seat overloading the ISOFIX anchorages is relatively low. Nevertheless, the potential consequences of overloading the anchorages are severe.

The implications of allowing a heavier occupant to use an ISOFIX child restraint need to be considered. Pitcher et al. (2014) investigated the effects of testing a child restraint with the standard 50th percentile Q3 occupant (the maximum mass occupant permitted by Reg.129 to use the child restraint) and a 99th percentile three-year-old dummy (created by massing-up a Q3 dummy in appropriate proportions for each body region). The investigation found that the forces measured on the ISOFIX anchorages increased up to four times using the 99th percentile in a rearward facing child restraint, compared to the standard 50th percentile Q3. This highlights that the new designs of child restraint are likely to increase the forces on the vehicle ISOFIX anchorages.

Ideally the forces on the ISOFIX anchorages in a UN Regulation 94 or Euro NCAP test would be measured. However it is difficult to measure the loads in a vehicle without replacing the existing anchorages with load cells. This may then have an effect on the measured loads as the vehicle has been modified.

B.11.2 Potential Mitigation Strategies

There are several options for mitigating the potential effects of increased occupant mass and preventing overloading of the vehicle ISOFIX anchorages:

Increase the Strength Requirement of the ISOFIX Anchorages in the Vehicle

The strength requirement for the ISOFIX anchorages in the vehicle could be increased. Work has been done by several stakeholders to investigate the maximum load measured by the ISOFIX anchorages. Britax (2008) measured up to 13 kN with a child restraint and occupant with a combined mass of 34.1 kg. This is supported by the findings of Pitcher et al. (2014), who measured a maximum load of 9 kN, with a combined mass of 35.2 kg. Further investigation of the relationship between static strength and the dynamic strength is also required before a revised requirement is set.

However it may be an option to globalise the requirement by setting it to 11 kN so that it is consistent with North American requirements. It is likely that there are many vehicles that have shared platforms across the two regions and therefore meet the 11 kN ISOFIX anchorage force requirement already.

Limit the Force on the Anchorages

Firstly the relationship between static and dynamic forces will need to be investigated. Once this information is fully understood a force loading limit for the ISOFIX anchorages could be set. This limit should also be in reference to force loading of vehicle anchorages in full-scale vehicle crash tests. The ISOFIX forces could then be measured by load cells on the test bench during the child restraint type approval tests to ensure the limit is not exceeded.

An option to consider is to monitor the ISOFIX loads during child seat type-approval tests in order to understand the forces different child restraints will create.

Limit the Mass of the Child Restraint

This is the approach currently used in Reg.44. By limiting the child restraint mass there is a restriction on the total mass that will load the ISOFIX anchorages. This option would still require the manufacturer to specify a mass range for children using the child restraint.

However this is only appropriate if 33 kg actually does not overload anchorages that are only strong enough to withstand the 8 kN static pull force. Therefore an investigation would be required to confirm an 8 kN static pull force test was sufficient. This approach would also require parents to observe the mass limit specified by the manufacturer.

Limit the Mass of the Occupant

Manufacturers could state in the seat documentation a maximum mass of child that can use the child restraint. It is recommended that research be conducted to ascertain the effect of occupant coupling. Data would be required to demonstrate the force loading difference between a heavier child in a lighter restraint, compared to a light child in a heavier seat. Pitcher et al. (2014) recommended considering testing with a 99th maximum sized child occupant in Reg.129 to ensure that all test criteria are met whatever size of occupant uses the child restraint.

B.11.3 Feasibility

Increase the Strength Requirement of the ISOFIX Anchorages in the Vehicle

Vehicle manufacturers are likely not to favour an increase to the strength requirements as it will require an increase in cost for vehicles. However as most manufacturers will have vehicle platforms in North America it is likely they will already have designs that can at least meet a strength requirement of 11 kN (or 15 kN including the top tether attachment point).

This option would appear to be fairly straightforward to implement and would just require a change to Regulation 14, once a static test load has been derived.

Limit the Force on the Anchorages

Child restraint manufacturers are likely not to favour measuring the forces on the ISOFIX anchorages during a type-approval, as this may require an increase in cost to the manufacturers. However a number of different manufacturers are able to measure the ISOFIX loads in sled tests. Therefore the technology exists to implement this option. Any limit will need to be related to data from full-scale vehicle impact tests.

It remains to be seen what a sensible limit for the dynamic loading of the ISOFIX anchorages is and whether it is achievable with current designs. Therefore research would be required to confirm the appropriate force level requirement for the ISOFIX anchorages.

Limit the Mass of the Occupant or Child Restraint

It is likely that of the four options listed in Section D.11.2 the child restraint manufacturers will not favour either of the last two options as they fear it will limit their design freedom. However, either of these options would be simple to implement. They would require the manufacturer to state a mass limit of the occupant in the instruction manual. However, there would be nothing to prevent a consumer from still using the child restraint with a heavier child.

For these options to be suitable, an appropriate mass limit for the occupant or child restraint must first be derived and agreed.

B.11.4 Costs

All four of the options are reliant on research to derive an appropriate force limit for the ISOFIX anchorages. There would be costs associated with this research and they would vary depending on the scale of the research.

There would be costs associated with updating designs of child restraints. However, any change to the Regulations would not be applied retrospectively and therefore any design changes would be included in future new product development. Therefore costs for manufacturers are unlikely to increase.

Manufacturers are already selling Reg.129 type approved child restraints at an increased cost to the consumer, e.g. Reg.129 forward facing child restraint (€480) is €40 more expensive than its Reg.44 equivalent (€440).

If the strength of the vehicle anchorages has to be increased, this may result in extra cost for vehicle manufacturers. However the NHTSA final rule (NHTSA, 1999) for child restraint anchorage systems (Docket No. 98-3390) discusses the costs associated with ISOFIX anchorages. NHTSA estimated that it would cost $3.88-$7.76 to implement. This is equivalent to €3-€6.5 per vehicle. It is assumed that this would be from have no anchorages in the first place.

If manufacturers already have ISOFIX anchorages which are stronger than 8 kN then the cost would be less than this.

B.11.5 Benefits

The benefits of any action are likely to be small because currently there appears to be no evidence of related real world accidents due to failure of ISOFIX anchorages. However, the potential problem could increase as Reg.129 child restraints become more common over the next few years.

The benefits of increasing the ISOFIX anchorage strength in vehicles would be that older/heavier children would be able to use ISOFIX harness systems, which would reduce the premature switching of children to booster seats. This may prevent children suffering injuries in booster seats that would not have occurred if they were using a child restraint with a five-point harness, e.g. abdomen injuries.

B.11.6 Benefit:Cost Ratio

The limited amount of injury information relating to this topic means that it is difficult to estimate the benefits. This means it is not possible to create a benefit-to-cost ratio.

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B.12 Safety of Children in Hot Cars

Systems to raise the alarm or to cool the vehicle if the interior temperature exceeds a threshold and the presence of a child occupant is detected.

B.12.1 Description of the Problem

The addition of passenger front airbags in the early 1990s caused car safety experts to recommend that child seats should be moved to the rear of the car so that children occupying them avoid airbag-related injuries. Since then, the number of motor vehicle-related child hyperthermia[15] fatalities reported in the US has risen dramatically (Patek and Thoma, 2013). According to NHTSA, on average 38 children die each year and 1000 are injured by hyperthermia after being trapped in hot cars (Arbogast et al., 2012). Between 1998 and 2012, 556 child vehicular hyperthermia deaths were recorded. Fifty-two per cent of fatalities were the result of a child being forgotten by the responsible guardian. In other cases, children were riding in the car with their parents or were accidentally locked in the car while playing, without their parents' knowledge.

When trapped in a hot car, a child is more likely to suffer from hyperthermia than is an adult, because a child's body is less able to adapt to extreme temperatures. Under these circumstances, their core temperature may rise three to five times faster than an adult's. This may rapidly cause irreversible visceral and neurological effects, coma, and death. A study conducted by Booth et al. (2010) in the US found that fatalities can occur when a child is left in a hot car for as little as 30 minutes. The elapsed time between when a child was last known to be alive and when that child was found dead or dying inside a vehicle averaged 4.6 hours, with a range of 0.25-16 hours.

The internal environment of cars has also been examined in a study in California by McLaren et al. (2005). Regardless of ambient temperature, the temperature rise inside the vehicle was found to be 5.8°C per 5 minute interval, with 80% of the temperature rise occurring within the first 30 minutes. On a day where the ambient temperature was found to be 22.2°C, the internal temperature within the car reached 47.2°C. McLaren et al. reported that a child will die when their body temperature reaches 41.6°C.

In Japan, Sugimura et al. (2011) investigated the change in temperature of a child restraint system within cars parked in full sunlight. The study found that during this period, the ambient temperature ranged from 26.0 to 38.5°C whilst the temperature of the child restraint system ranged from 38.0 to 65.5°C. Although this temperature was not high enough to cause burns, the authors concluded that a young child placed in a seat at this temperature may have experienced discomfort, skin disorders and heat rash.

In February 2009, the Consumer Safety Commission in France conducted an inquiry to issue a recommendation on the prevention of children left unattended in motor vehicles (Commission de la Sécurité des Consommateurs, 2009). In their report, the authors asked the European Child Safety Alliance to collect European data by surveying each national member. Twelve members responded to the survey. From 1998 to 2009, the Netherlands, Iceland and Hungary all reported 1 fatality due to hyperthermia. Two non–fatal incidents were reported in the UK and 1 in Italy. Germany and Sweden reported zero incidents, leading the authors to believe that a societal factor, particularly in countries where parents take leave of absences for childcare, has an impact. This is especially true in Sweden where parental leave lasts 480 days. Both parents are entitled

[15] Hyperthermia is elevated body temperature due to failed thermoregulation that occurs when a body produces or absorbs more heat than it dissipates

to the leave and may share it. It may be postponed or taken in batches. Therefore, children are rarely entrusted to childcare providers before they are two years old. Since European countries have no official method of recording these incidents, the data was collected by each nation using news stories from the press and local radio stations, which only report the most dramatic cases. Therefore, it is likely that the problem is underestimated.

Research carried out by the Commission directly found that between 2007 and 2009 there were 24 cases of hyperthermia in France, including 5 fatalities (CSC, 2009). The investigators found that 54% of the parents had intentionally left their children in the car while 46% had forgotten to drop their child off earlier in the day. In Belgium, two fatal cases of hyperthermia were recorded in the same period.

Awareness of the dangers of leaving children in hot cars has been raised in the US through newspaper articles and safety campaigns, funded by the Alliance of Automobile Manufacturers. During the summer of 2014, NHTSA launched a heatstroke awareness campaign with the slogan 'Where's baby? Look before you lock' (Parents Central, 2014). However, neurologists and psychologists recognise that, as a brain function, forgetfulness is involuntary (Weinegarten, 2009). It is impossible to choose what the brain forgets. If an individual is tired or stressed and their daily routine is disrupted, it becomes much more likely that they will forget a sleeping child in the back of a car. Therefore, safety advocacy groups, such as Kids and Cars, believe that carmakers must develop reminder devices to warn a driver if a child is left behind.

B.12.2 Potential Mitigation Strategies

Vehicle Warning Systems

Several devices and technologies that analyse car environment (including biometric) parameters are already fitted to cars and have the potential to be adapted to warn the driver and third parties about children left in the car. Many of these systems can be found as standard or optional features on vehicles sold on the European market. According to experts consulted by Commission de la Sécurité des Consommateurs, the following systems in particular could be adapted to prevent children being left in hot cars (CSC, 2009):

- Seat-belt sensors: current systems detect a passenger or driver whose belt is not buckled when the car starts, or is moving. Similarly, these systems could warn the driver that a seat-belt is still buckled when he/she leaves the car and locks the doors. Such a device could operate with child restraint systems that use the vehicle seat-belts. However, it would have to be connected to a weight sensor to forestall false alarms if the restraint system is installed permanently in the car. However, this system would not be effective for seats with ISOFIX systems with an integral harness.

- Image Recognition: an increasing number of cars are already fitted with cameras, usually as an optional extra, that can recognise speed limit signs and detect pedestrians in the path of the car. Thermal and/or semi-infrared imaging cameras aimed at the back seat and connected to an image recognition programme could detect a child and trigger an alarm if the driver leaves the car, leaving the child behind. Other functions could be added to make the system cost-effective (adaptive deployment of airbags and seatbelt pretensioners, and so on).
    - Door Opening Sequence Analyser: this would detect a person on the backseat by analysing the car door opening sequence. For instance, take the following scenario:
    - The car is unlocked and the back door is opened to install a child and then closed;
    - The driver's door is then opened and closed, and the driver starts the car;
    - When the car stops, the engine is turned off and the driver's is door opened and closed.

- A sequence analyser would expect the back door to open. If the door has not been opened and car lock has been initiated, the system would assume that a person seated in the back may have been forgotten, and would alert the driver. On two-door vehicles, the system could operate when a front seat is pushed down.

- Airbag Deactivation Warning: deactivating the airbags in the front of a car to install a child seat could trigger a warning if the driver leaves the vehicle and locks it without reactivating the airbags. The system would only work for the front seats.

- CO_2 Analyser System: After the engine is turned off, the system could continuously scan the interior cabin/cargo and trunk space for exhaled carbon dioxide (CO_2). Multiple sensors could be located throughout the cabin space and could sense humans or animals left behind. The system could also have the ability to restart the engine to activate the air conditioning, unlock doors, and open the boot for the emergency services.

Some car manufacturers have developed technology in the past that may have the potential to raise the alarm if children are detected in hot cars. For example, in April 2001, General Motors unveiled a new low-energy radar sensor that detected motion (The Engineer, 2001). This included the detection of breathing by an infant sleeping in a rear-facing child safety seat. The sensor was designed especially for the rear seating area. If it detected a child or pet, it would activate a unique horn sound, similar to the SOS distress signal. Thresholds for the alarm were to be based on a study conducted by paediatric hyperthermia researchers at McMaster University.

Volvo has also unveiled technology in the past which may have the potential to prevent child deaths in hot cars (Woodyard, 2010). An intruder detector was offered as part of a $550 option package between 2007 and 2010. The system was able to detect an intruder from their heartbeat and alert drivers to anyone lurking in the rear seat.

In 2010, an Audi spokesman, Bradley Stertz, said that the Volkswagen Group was working on systems that could be adapted to child detection. Among these were interior cameras, heat sensors and motion detectors that were intended for other uses, but could possibly play a role in a detection device. The manufacturer stated that all technologies were in the concept stage, with no timeframe known as to when they would move closer to market.

Child Restraint Warning Systems

Several systems have been developed for use alongside child restraints:

- NASA sensing pad: In 2002, rocket scientist William Edwards led an effort to develop a child-left-behind warning device after a child, forgotten by an employee, died of hyperthermia in the NASA centre car park. The NASA device was simple and worked by adding a sensor under the child seat cushion, which was connected to a module attached to the side of the seat. This established a connection with an alarm attached to the driver’s key ring. If the driver walked away from the car while the child was still in the seat, the alarm sounded until the child was removed. (Stenquist, 2010).

- Smartphone apps: Several products involving smartphone apps are currently in development. One such product is Starfish. Similar to the NASA system, it also uses a weight-activated child seat sensor. However the system has the capability to notify a parent’s smartphone via Bluetooth if they leave their car without their child. Once a child is placed on Starfish, the device automatically pairs with the smartphone and sends a notification that the child is in the seat. If the parent moves outside a radius of 6 m of the child in the child seat, Starfish will automatically send a notification. If the parent does not respond within five minutes, the parent’s emergency contacts will also be notified. This type of product has the advantage of being able to fit in any car seat and is quick and easy to install. Several other systems involving smartphone apps and sensing pads have recently been launched onto the market (Robbins, 2014).

- Clip child restraint-based warning system: Some systems operate by replacing part of the child restraint system. The ChildMinder Smart Clip system replaces the child restraint's chest clip[16]. The receiver/key ring alarm unit is placed on an automotive key ring. The system reminds the parent with an alarm six seconds after they have moved more than 4.5 m from the child in the child restraint. The manufacturer claims that the ChildMinder Smart Clip system does not compromise the crash protection provided by the child restraint.

Feasibility

Experts have stated that technology to alert guardians to a child trapped in a car is feasible (CSC, 2009). However, when car manufacturers were asked about the warning devices in 2010, many replied that they had researched the idea, but none provided any specific details (Stenquist, 2010). In 2014, The Washington Post revealed that GM had abandoned the development of their low energy radar sensor technology after failing to make it 100% effective (Robbins, 2014).

Volvo's intruder detection system was also shelved in 2011. The technology was originally intended to detect children or pets left behind in the back seat but, due to the complexity of the problem, the technology was abandoned before this capability was achieved (Stenquist, 2010).

As for the child restraint warning devices mentioned above, the reliability of these systems has been called into question. In 2012, NHTSA carried out a study in America to evaluate products that claim they are designed to prevent children of up to 24 months old from being left behind in vehicles. This preliminary assessment was the first of its kind to evaluate this type of product. Their efficiency in sensing the presence of a child in a child restraint and alerting the guardian if he or she walks away from the car without removing them was evaluated. The study also examined the effects of child posture and weight.

The study was divided into three phases. In the first phase, a detailed market assessment was carried out to identify available and upcoming products. The second phase involved an evaluation of three of these devices through several tests to discover their sensing limits, resilience to liquids and effectiveness during any misuse scenario. In the final phase, human volunteers of different weights were buckled in child restraints instrumented with one of three heat stroke prevention devices and testing was carried out by simulating a daily commute.

It was found that across different evaluations, the devices were inconsistent and unreliable in their performance. They often required adjusting of the position of the child within the child restraint. The distance to activation varied across each trial and they experienced continual synching issues during use. For some of the devices evaluated, issues such as interference with other devices, inability to function in the presence of liquids, and variability in performance in the presence of a mobile phone were common. In summary, the devices required considerable effort from the guardian to ensure smooth operation and overall operation was inconsistent.

NHTSA also noted that none of the devices directly addressed the root cause of the hot environment that led to the potential for heat stroke. Most importantly, it should be noted that these devices, which integrate into a child restraint, would not be applicable in

[16] A chest clip is a plastic two-piece buckle found on the shoulder straps of car seat harnesses in the US. They are positioning devices that are essentially illegal in European child restraints due to the requirement for a single release harness release action following a crash.

scenarios where the child is playing and gets locked in the vehicle (30% of fatalities) or in a scenario where the guardian intentionally leaves the child in the vehicle (17% of fatalities). In an e-mailed statement, the federal agency said: "For NHTSA, for automakers or a guardian to consider relying on any technology it would have to be reliable enough to save lives. The technology is not there yet." (Robbins, 2014).

The two biggest barriers to success for any safety technology alerting drivers to the presence of children are liability and acceptability. For example, the NASA inventors of the sensing pad could not attract a commercial partner to manufacture their device because the manufacturing company would risk facing huge lawsuits if the device malfunctioned and a child died. A spokesman from Volvo also indicated that liability was part of the reason why their device was never developed further (Stenquist, 2010).

Even if the technology were available to buy as an optional extra, marketing studies suggest that such devices would not sell well, since the public believe that cases like this could never happen to them. The risk of unwittingly leaving a sleeping child in the car is entirely underestimated (Weinegarten, 2009). Therefore, guardians would need other methods of encouragement to adopt such devices.

According to a retired Ford design engineer, manufacturers would also be reluctant to install devices within cars due the minimal rate of occurrence of hyperthermia-related fatality cases. He believes that it would take regulation before a manufacturer would be willing to penalise every back-seat car in terms of cost (Stenquist, 2010). However, it would be difficult for manufacturers to pass their costs onto consumers who feel that the technology isn't necessary.

B.12.3 Costs

The following indicative costs associated with the technology were identified from the literature:

- Advertising costs: In America, safety campaigns on the risks of leaving young children in hot cars are extremely common. However, the Commission de la Sécurité des Consommateurs (2009) believe that these types of campaigns are rare in Europe and parents may be less likely to purchase products to prevent hyperthermia from occurring. Therefore, campaigns to raise awareness of the risk to children left in hot cars, and specifically the 'forgotten baby syndrome' are essential for prevention and a prerequisite for the rollout of any technology to limit the resulting accidents.

- Costs to car manufacturers: The literature search could not find any information on the costs incurred by manufacturers to fit such devices. From an economic standpoint, car makers and equipment suppliers say that engineering active safety equipment involves sizeable design and production investments.

- Costs to consumers: the sale price of warning systems developed for child restraint systems range from between €32-€230. However, due to the reservations by NHTSA over the reliability of the technology, it is unlikely that this type of technology could be considered as a solution to the problem, without further development. It was reported by the Commission de la Sécurité des Consommateurs (2009) that the estimated sales price of this equipment, sold as a vehicle feature, was between $1500 and $3000. Therefore, it is believed that the installation of this type of device cannot be made mandatory in one country alone. They believe that devices must be subject to European regulations, or international regulations of the United Nations Economic Commission for Europe (UNECE).

B.12.4 Benefits

No information on the benefits of potential systems has been reported in terms of a target population and likely reduction in child fatalities. Nevertheless, the benefits anticipated for such technology are:

- Fewer children would be left in hot cars, leading to fewer fatalities and fewer hospital admissions of children suffering from hyperthermia and dehydration.
- Legal costs to the child's parents and more broadly to society would be reduced - defence cases in America have run into hundreds of thousands of dollars.
- Fewer families suffering from mental anguish caused by unwittingly leaving a child in a hot car.

B.12.5 Cost:Benefit Ratio

Due to the lack of a systematic Europe-wide reporting mechanism for these incidents it is impossible to predict reliably the cost-to-benefit ratio associated with the installation of devices to raise the alarm if children are left in hot cars. The development of such a reporting mechanism would enable more detailed analyses to be carried out.

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Annex 5 CRASHWORTHINESS, HGV SAFETY AND FUEL SYSTEMS

Appendix C. CRASHWORTHINESS

C.1 Small Overlap Frontal Collisions (M1 vehicles)

Car (M1) occupant protection for small overlap frontal crashes, i.e. those with less than 20-25% overlap and no direct loading of the longitudinal rails. Note: some discussion of oblique frontal crashes also included, because some small overlap countermeasures may also help for oblique impacts.

C.1.1 Description of the Problem

Small overlap frontal crashes are those where the overlap is small (i.e. 25% of the width of the car) and there is no direct loading of the vehicle's main longitudinal structures. This results in a more direct loading of the vehicle's front wheel, suspension system and firewall and makes it more challenging to design the vehicle to manage the crash energy and maintain occupant compartment integrity. In addition, because the vehicle rotates substantially in these impacts because of the offset loading, the occupants move both forward and towards the side of the vehicle during the crash which makes it more challenging for the restraint system compared to impacts with higher overlaps in which the occupants move mainly forward only.

On behalf of the EC DG Enterprise and Industry, Richards et al. (2010) performed accident analyses to investigate the nature of the frontal impact crashes in Europe and highlight areas for potential changes to the frontal impact regulation. These analyses used the European CARE database, national data from Great Britain, Germany and France, and in-depth collision data from Great Britain (Co-operative Crash Injury Study) and Germany (German In-Depth Accident Study). Where possible, these analyses selected only Regulation 94 compliant vehicles (or those with an equivalent safety level) to ensure that the results were appropriate for use to set priorities for an update of Regulation 94. One of the conclusions of this study was that the distribution of casualties in the target population with overlap, in order of size, was:

- Offset (as represented by current Regulation 94 offset test)
- Full-width (as would be represented by a full-width test)
- Low-overlap (as would be represented by a low-overlap test)

This highlighted the need for a full-width test in Europe, but also the problem of low overlap was noted. For Great Britain the target population for low overlap crashes with no direct loading to the longitudinals was 5-12% of car occupant casualties in frontal impacts, depending on severity. From an analysis of the German Insurers Accident Research (UDV) accident database, Kuehn et al. (2011) identified the problem of low overlap in Germany. Specifically, Kuehn found that low overlap frontal impact accidents formed 25% of all car frontal accidents. Furthermore, Kuehn found that compared to large overlap accidents, the relevance of low overlap accidents varied in terms of the injury severity; for fatalities the relevance was low, whereas for serious injuries to the lower extremities (which have a high cost) the relevance was high. Lindquist et al. (2004) also identified small overlap frontal impacts as an important issue in Sweden. From an in-depth analysis of fatal front crashes from circa 2000 to 2001 and from an area covering approximately 40% of the 9 million inhabitants of Sweden, they found that small overlap crashes (defined as an overlap < 30%) accounted for 48% of the belted fatalities. There appear to be some contradictory findings from these analyses, in particular regarding the size of the low overlap problem and its relevance compared to other frontal impact types. Possible contributory factors to these differences could be:

- The analyses do not report results that are directly comparable, e.g. for GB the percentage is quoted as a proportion of all car occupant casualties whereas as for Sweden it is quoted as a proportion of belted casualties

The problem size actually varies between countries because of real-world differences, e.g. the roadside environment - more trees in Sweden than GB. Within the FIMCAR project, accident and benefit analyses were performed. These highlighted the issue of restraint-related deceleration injuries[17] which are injuries caused by occupant loading from the restraint system with no or little intrusion of the vehicle compartment (Thompson et al., 2013; Edwards et al., 2013). The small overlap problem was also identified. Analyses were performed using the UK Co-operative Crash Injury Study (CCIS) and the German In-Depth Accident Database (GIDAS).

A review by NHTSA of fatalities in frontal crashes despite the presence of seat-belts and airbags concluded that the main reason people are still dying, apart from the fact that a substantial proportion of the 122 crashes examined are exceedingly severe, is because so many crashes involve poor structural engagement between the vehicle and its collision partner (Bean et al., 2009). They specifically identified corner impacts, oblique crashes, impacts with narrow objects and under-rides. By contrast, few, if any of the 122 fatal crashes examined were full-frontal or offset-frontal impacts with good structural engagement, unless the crashes were of extreme severity or the occupants exceptionally vulnerable.

NHTSA expanded this analysis to establish key factors for injury causation where very limited or no engagement of the longitudinal structures occurred in frontal impacts. This was done by analysing, in detail, 380 cases from the National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) and the Crash Injury Research and Engineering Network (CIREN) (Rudd et al., 2011). These authors found that injuries to the thorax and pelvis were the most prevalent, and oblique loading played a role in thoracic and head injury causation. The outcome of this work was to initiate a vehicle crash research plan to assess the feasibility of recreating the real-world crash and kinematic responses expected from the case reviews.

In addition, the Insurance Institute for Highway Safety (IIHS) performed a detailed analysis of 116 occupants that received fatal or life threatening injuries in frontal impacts in cars that received good ratings in the IIHS frontal offset test (Brumbelow and Zuby, 2009). It was found that asymmetric or concentrated loading across the vehicle front often resulted in occupant compartment intrusion and associated injury. However, just as many occupants were in crashes without substantial intrusion and were injured by restraint system forces or impacts with the vehicle interior not prevented by restraints. Crashes producing injury without intrusion involved multiple impacts more than twice as often as those with intrusion. From this it was concluded that future test programs promoting structural designs that absorb energy across a wider range of impacts, such as small overlap, could reduce serious injuries in frontal crashes. Further restraint system improvements may require technologies that adapt to occupant and crash circumstances. It was unclear what types of full-scale crash testing would encourage these improvements.

C.1.2 Potential Mitigation Strategies

Potential mitigation strategies include:

- Improvements to the Body-in-White (BiW) structure to improve compartment integrity, in particular A-pillar and footwell intrusion

[17] It should be emphasised that these injuries would be expected to be much worse if a seat-belt was not worn

- Improved restraint performance to either prevent or provide additional protection for head impact against the A-pillar and Instrument panel. Note that is this because in low overlap and / or oblique impacts the occupants' motion is to the side as well as forward and a standard restraint system may not be sufficient to restrain them adequately and mitigate head injury.

C.1.3 Feasibility

Three test procedures either in use or in development in the USA could form the basis for the implementation of measures to improve occupant protection in low-overlap frontal crashes in Europe.

The first of these is a low overlap frontal test which the Insurance Institute of Highway Safety (IIHS) introduced in 2012 as part of their vehicle safety rating scheme (IIHS, 2014). This is a 25% overlap test into a rigid barrier at 64 km/h. The performance of the vehicle is assessed using vehicle structural deformation measurements, dummy injury criteria and dummy movement.

The other two tests are a low overlap crash test and an oblique impact crash test, which NHTSA are developing currently (Saunders et al., 2012; Saunders and Parent, 2013 – see Figure C-1) Both of these tests use a Mobile Deformable Barrier. The low overlap crash test configuration consists of a Mobile Deformable Barrier (MDB) at a speed of 90 km/h impacting into a stationary test vehicle with an overlap of 20% and an angle of 7°. The mass of the MDB is 2,486 kg. The oblique crash test is similar but with an overlap of 35% and an angle of 15°.

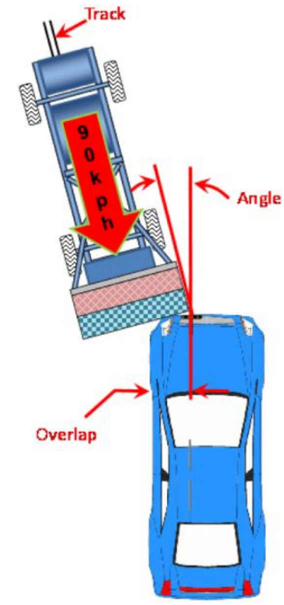


Figure C-1: NHTSA small overlap and oblique crash tests' configurations ('Angle' and 'Overlap' vary for the two configurations)

In summary for low (small) overlap there are two candidate test procedures, namely:

- IIHS longitudinal small overlap frontal test with a rigid barrier
- NHTSA small overlap test with a mobile deformable barrier (MDB)

NHTSA are also developing an oblique MDB test which could also be used to help improve occupant protection in oblique frontal impacts.

The feasibility of protection against longitudinal low-overlap collisions is clearly demonstrated by the response of car manufacturers to the new IIHS small overlap test procedure. An example of this are the modifications made to the Camry by Toyota to increase its rating in this test from poor for the 2013 model to adequate for the 2014 model, which also resulted in it regaining its top safety pick rating[18].

IIHS have investigated changes made to the structures of new vehicle models whose performance in the small overlap test has improved significantly compared to the previous model. They identified the addition of structural reinforcements, for example on the bumper beam (Figure C-2).

Figure C-2: Reinforcements added to bumper beam

(source IIHS: private communication, Hynd (2014))

They also identified other countermeasures which appeared to be added to help deflect the vehicle away from the barrier in the impact, possibly to minimise engagement and therefore vehicle deceleration and intrusion into the occupant compartment. Some modifications were to the driver's (impacted) side of the vehicle only (Hynd 2014).

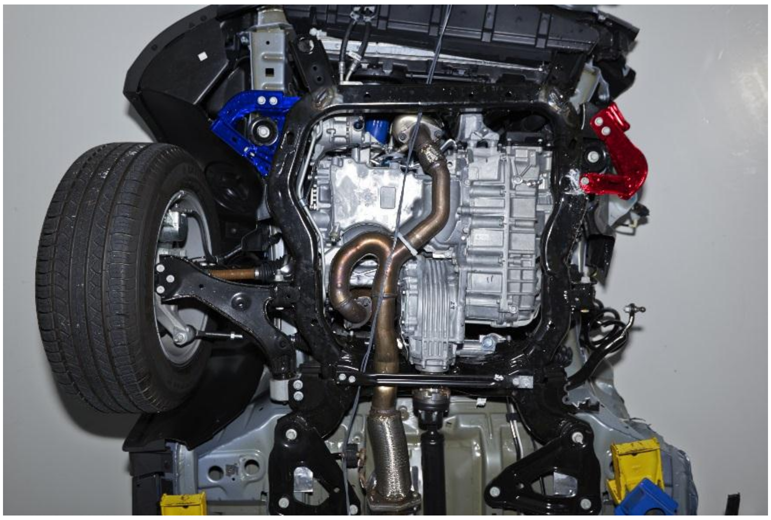


Figure C-3: Countermeasure added possibly to help deflect vehicle away from barrier

(source IIHS: private communication, Hynd (2014))

[18] Reference: www.iihs.org/iihs/ratings/vehicle/v/toyota/camry/2014

However, it is interesting to note that these types of modifications may not be sufficient for good performance in the oblique 'smallish (35%)' overlap loading condition that NHTSA is currently developing. NHTSA performed a series of oblique tests using 19 cars, five of which performed well in the IIHS small overlap test (i.e. 'top safety pick+') and 14 that did not (i.e. not 'top safety pick+'). It was found that although there was statistically significantly less intrusion in the top safety pick cars there were not any statistically significant differences for injury risk. From this it was concluded that some vehicles that perform well in the IIHS small overlap test may require additional countermeasures for the NHTSA oblique test (Saunders and Parent, 2014).

C.1.4 Costs

No specific cost information has been identified, but manufacturers have and are responding with design modifications to meet the IIHS small overlap test procedure.

C.1.5 Benefits

Low Overlap Frontal Impact

No specific benefit analyses have been identified. However, in the FIMCAR accident and benefit analyses, work was performed from which casualty target populations for low overlap frontal collisions can be estimated. The GB CCIS analysis used selection criteria as follows:

- Accident occurred between 2000 and 2010 (inclusive)
- A significant frontal impact occurred
- The casualty was in a Regulation 94 compliant car or one which had an equivalent crash safety level
- No rollover occurred before the first impact
- The casualty was killed or seriously injured (MAIS2+)
- The casualty was a belted front-seat car occupant
- No unbelted occupant was seated behind the casualty

A detailed analysis of the injury mechanisms for each fatally or seriously injured (MAIS2+) casualty was performed and each casualty was categorised according to the main contributory mechanism identified in terms of being:

- Compatibility related, (i.e. poor structural interaction or force matching / poor compartment strength);
- Deceleration / restraint related (i.e. no / little occupant compartment intrusion so injury related to restraint system); or
- No compatibility or deceleration / restraint issue (i.e. another issue such as high severity, large vehicle under-ride or no issue identified).

The results of this are shown in Figure C-4 for MAIS 2+ injured casualties and Figure C-5 for fatally injured casualties only. It should be noted that the small bias in the CCIS dataset to HGV impact partner is not taken into account in these figures, so the proportion of 'no issue – large vehicle under-ride' was likely be over-estimated. The green and orange squares indicate the casualties for which the introduction of a full-width test or a progressive deformable barrier (PDB) offset test should provide benefit, i.e. the target population for these tests.

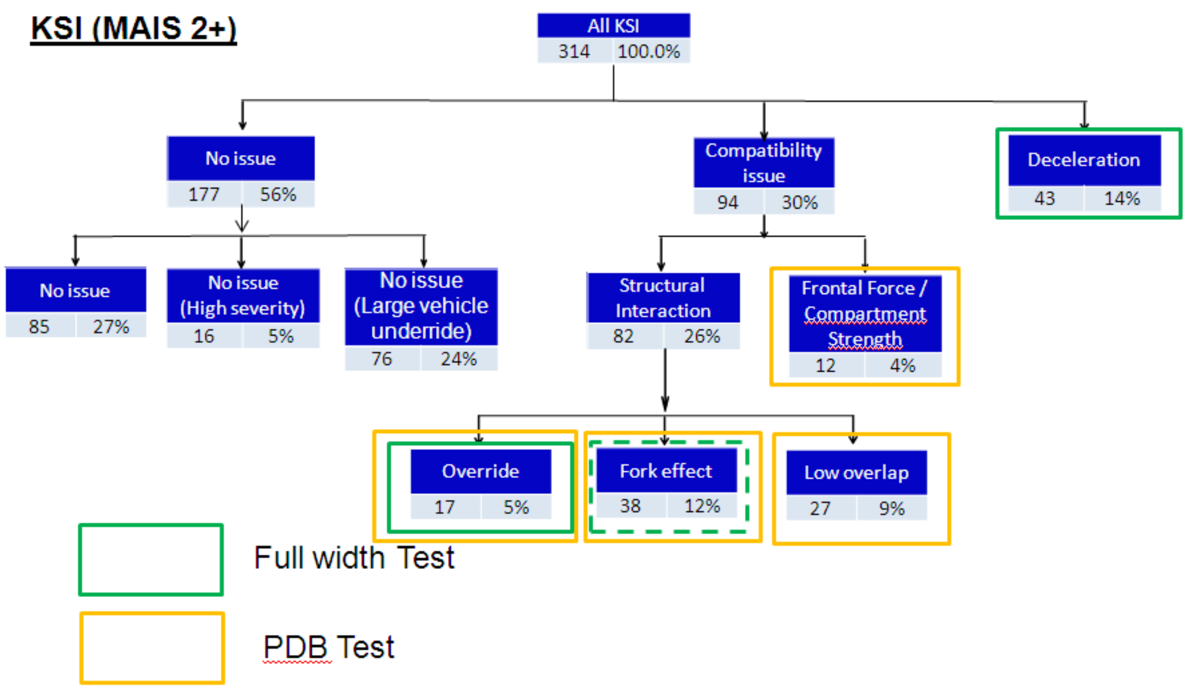


Figure C-4: Detailed case analysis (target population) main contributory cause breakdown of killed or seriously injured casualties (MAIS 2+) casualties

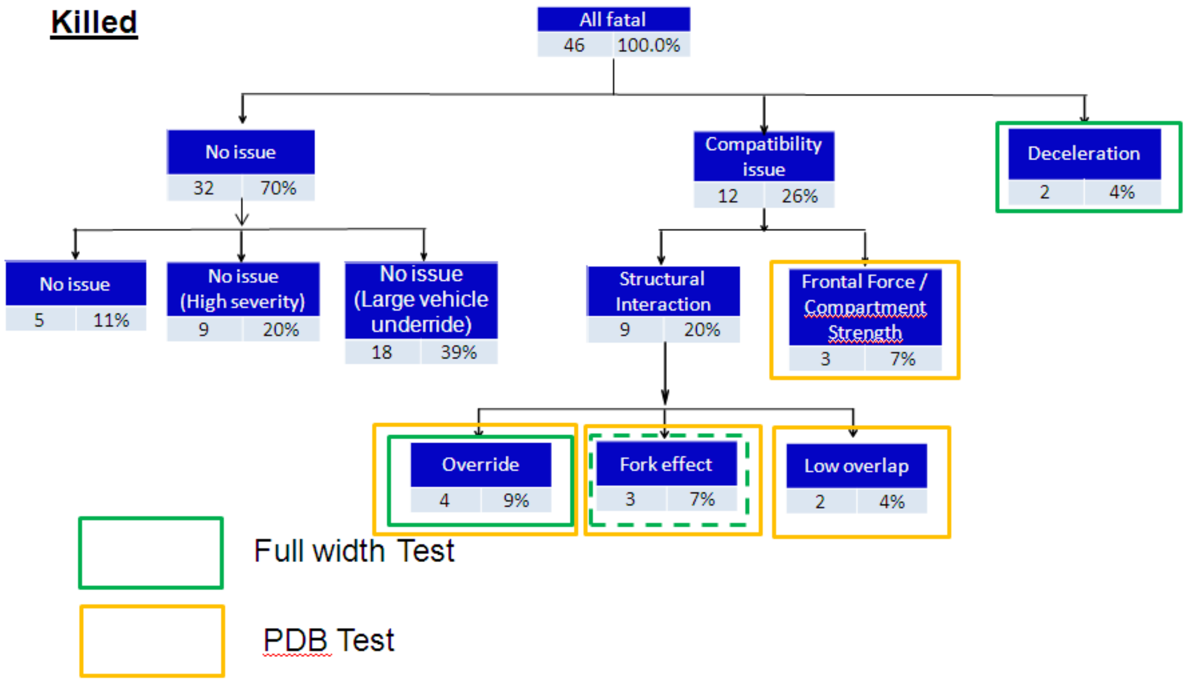


Figure C-5: Detailed case analysis (target population) main contributory cause breakdown of killed casualties)

Using equivalent selection criteria, an analysis with the GIDAS accident data was performed, the results of which are shown in Figure C-6.

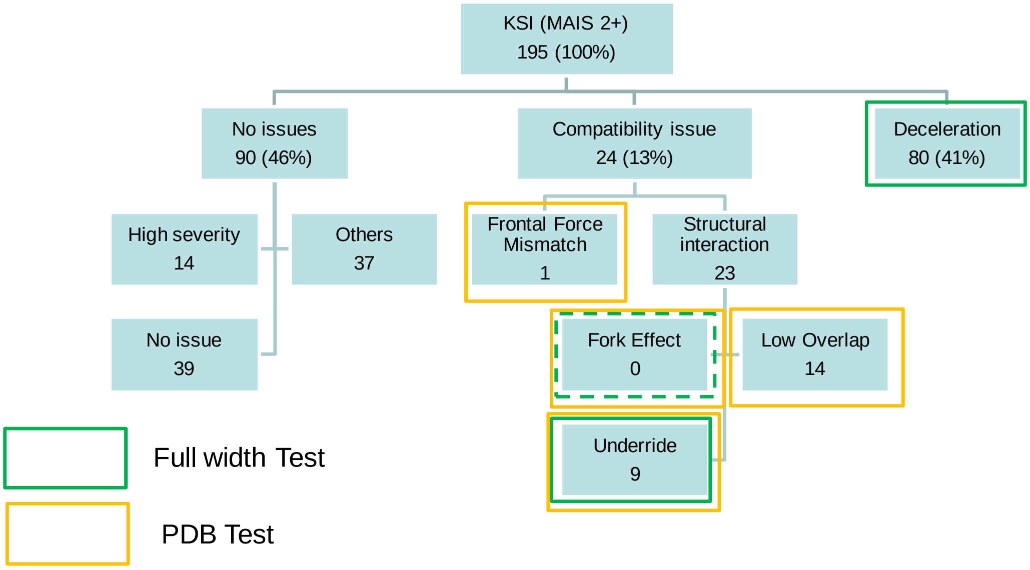


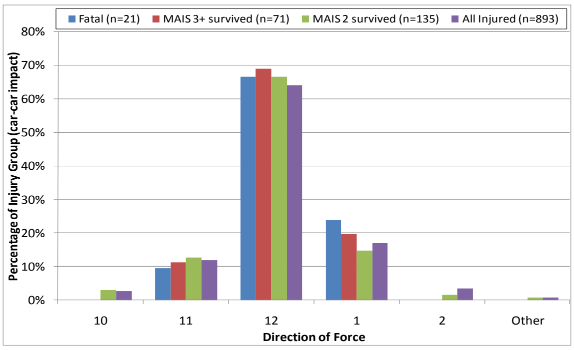
Figure C-6: German (GIDAS) detailed data sample target population breakdown KSI (MAIS 2+). Note: Germany classified frontal pole impacts as 'low overlap' issues whereas GB classified them as 'fork effect' issues hence the difference for fork effect and low overlap between the analyses

The FIMCAR analyses considered only belted casualties in frontal impact accidents where the car did not roll. These casualties were approximately 50 to 70 percent of all casualties in all car frontal impacts depending on casualty injury severity. Assuming 50 %, the target population for low overlap can be estimated using the information in Figure C-5 and Figure C-6 above. This gives a target population of about 5-7% of KSI (MAIS 2+) and 2% of fatals in car frontal impacts.

Note: for approximate scaling purposes car frontal impact fatalities are just over a half of all car fatalities and all car fatalities are just over a half of all road accident fatalities.

Oblique Frontal Impact

No specific benefit analyses have been identified for this collision configuration (i.e. the NHTSA test configuration to cause driver motion towards the A-pillar and passenger motion towards to centre of the instrument panel). However, the following information from Richards et al., 2010 can be used to estimate the target population.



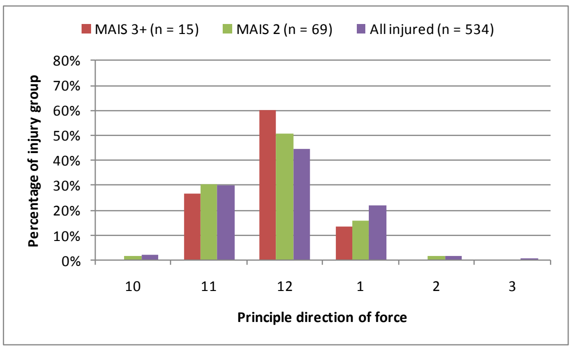


Figure C-7: Principle direction of force for car-car/LGV frontal impacts in Great Britain (left) and Germany (right)

The proportion of casualties in oblique impacts of this type (i.e. greater or less than 12 o'clock depending on whether right or left hand drive car), of all car frontal impacts, is

10-20% for GB and 20-30% for Germany depending on injury severity (see Richards et al., 2010). The target population is approximately half of these values because no/little benefit can be assumed for unbelted, impacts with rolls, etc. (see Richards et al., 2010).

Therefore, the target population for oblique frontal impacts is approximately 5 to 15% of all casualties injured in cars in frontal impacts depending on the injury severity and country.

Note: for approximate scaling purposes car frontal impact fatalities are just over a half of all car fatalities and all car fatalities are just over a half of all road accident fatalities.

Summary

No benefit estimates were identified for either test configuration in Europe. However, the benefits could be significant for a low overlap test. This is because, although the low overlap target population is small, effectiveness may be quite high because the countermeasures of improved structure and increased curtain airbag coverage and protection for the head are could reduce high societal cost head and lower extremity injuries significantly. It should be noted that an oblique test would probably encourage better airbag coverage than the low overlap test because the lateral motion of the dummy is greater in this test configuration. Also, indirect benefits are expected in terms of some reduction in head injury in side impact, frontal oblique and rollover accidents as a result of increased side airbag coverage (protection) in the region of the A-pillar. In summary, it is not possible to estimate the benefits for the low overlap test from the information identified in this review, but they are likely to be significant.

For the oblique test, it is not possible to make any comment other than that the target population is reasonably large but it is unknown what the effectiveness of the test may be because it is unknown what the countermeasures may be at present.

C.1.6 Benefit-to-Cost Ratio

Low overlap: As mentioned above, benefits could be significant. Costs may not be particularly high either, considering the response of manufacturers to meet the IIHS small overlap frontal test. It should be noted that there may be some carry-over benefit in Europe from introduction of the low overlap test by IIHS in the USA. This is because some manufacturers sell some car models both in the US and Europe and their body in White (BIW) structures are likely to be the same and so BIW improvements made for the IIHS low overlap test in the US will likely be incorporated in cars sold in Europe as well. However, unfortunately, this carry-over benefit is not likely to exist for benefits related to the restraint system (in particular airbags) because airbags for a US car model are often different to those for the European car model. For further information please refer to the crashworthiness section of the stakeholder meeting minutes in Annex 2.

Oblique: The benefit is unknown so no comment is possible. Also, it is likely more costly solutions than for the IIHS test may be needed to meet the NHTSA oblique low overlap MDB test.

In summary, using information available which was sparse, a possible benefit-to-cost ratio of greater than 1 was estimated for introduction of a low overlap test.

C.1.7 References

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C.2 Compatibility with Crash Partners (M1, N2 and N3 vehicles)

Better compatibility in crashes with other vehicles to minimise injuries in the accident overall. Includes compatibility with other cars (M1). To focus on M1/N1 and HGV rear under-run.

C.2.1 Description of the Problem

The objective of compatibility is to minimise injuries overall in crashes with other vehicles. To achieve this, a combination of both self and partner protection is required.

In Europe, the main focus for compatibility has been on car-to-car frontal accidents with some work performed on car-to-HGV (Heavy Goods Vehicle) accidents. For car-to-car frontal accidents the main issues for improving compatibility are:

- Structural interaction
- Global force matching
- Compartment strength and stability

Structural interaction describes how the contact forces are distributed across collision partners and the stability of the deforming structures. Good structural interaction does not always occur in accidents because of differences in vehicle sizes and crashworthiness designs. Poor structural interaction can lead to phenomena such as over/under-ride or fork effect which in turn can lead to poor energy absorption in the front-end structures and intrusion of the occupant compartment. Frontal force level matching and a strong and stable compartment is desirable to ensure that crash energy is appropriately shared between collision partners and absorbed in the vehicle’s front-end structures without excessive occupant compartment deformation. Current international consumer and regulation test methods encourage frontal crush forces to be mass dependent and encourage heavier vehicles to be stiffer than lighter vehicles. This can cause heavier vehicles to over-crush lighter vehicles and produce undesired occupant compartment deformations in the lighter vehicle.

For car-to-HGV accidents the main issue for improving compatibility is to improve the partner protection of the HGV, in particular to prevent under-run. It is also desirable to provide some energy absorption capability on the HGV, in particular for frontal impacts which in general are more energetic (i.e. have a higher change in velocity) than rear impacts.

In recent years, two European framework projects have performed research work on car crash compatibility, namely the VC-COMPAT FP5 (Edwards et al., 2007) and FIMCAR FP7 (Johannsen, 2013) projects. The VC-COMPAT project researched both car-to-car frontal impact and car-to-HGV impact compatibility. The FIMCAR project researched car-to-car compatibility only.

Car-to-car Frontal Impact

For car-to-car frontal impact the VC-COMPAT project focused on the development and initial validation of two test procedures to assess a car’s compatibility, namely the Full-Width Deformable Barrier (FWDB) and Progressive Deformable Barrier (PDB). The context for this was the EEVC WG15 road map for the improvement of compatibility, which required a test to assess a car’s structural interaction potential as a first step. Both of these tests had the potential to assess this. It was not possible to choose a definite set of procedures because the FWDB and PDB approaches were so different that an adequate comparison between them could not be made. The current status of each of the approaches was reported, including road maps for their possible implementation. A cost-benefit analysis for the implementation measures to improve compatibility was performed also.

The FIMCAR project continued the work of the VC-COMPAT project. Its objective was to propose a frontal impact assessment approach which addressed self and partner protection in frontal impacts. Research strategies and priorities were based on results from earlier research programs (mainly VC-COMPAT) and the accident data analysis performed within the FIMCAR project, which focused on recent data / cars. Within the project, different frontal impact test candidates, including the FWDB and PDB tests from VC-COMPAT, were analysed regarding their potential for future frontal impact legislation. These analyses included both a crash test programme and numerical simulations. The result of this work was a proposal for a frontal impact assessment approach consisting of the following:

- Full-Width Deformable Barrier test (FWDB) with a high resolution load cell wall and compatibility metrics
- Existing Offset Deformable Barrier (ODB) as described in UN-ECE Regulation 94 with additional cabin integrity requirements to assess better compartment strength and stability

The main reasons for this proposal were:

- The full-width deformable test compared to the full-width rigid test produced a deformation and compartment deceleration pulse of the car that was more representative of a car-to-car impact
- The introduction of a mobile PDB test was not considered appropriate because compatibility metrics for it could not be developed

A benefit analysis for the introduction of this proposal into legislation was also performed. This analysis estimated that the benefit for implementation of a full-width test in an appropriate manner would be between 5% to 12% of all car occupant killed and seriously injured (KSI) casualties. This benefit consisted of:

- Structural alignment (under/over-ride related to structural alignment): 0.3% to 0.8% of KSI casualties. However, it should be noted that the benefit related to structural alignment was likely to be under-estimated.
- Restraint system: (restraint-related deceleration related injuries): 5% to 11% of KSI casualties.

Following completion of the FIMCAR project, work on car-to-car compatibility and car frontal impact continued in the GRSP Informal Working Group on Frontal Impact in Geneva. This group is currently working on a proposal for a full-width rigid barrier test with a focus on the restraint system i.e. without compatibility metrics (Edwards, 2014). The decision to go in this direction and effectively drop assessment of a car’s compatibility may have been influenced by:

- The result of the FIMCAR benefit analysis (noted above) which indicates that most of the benefit of a full-width test would be related to restraint system improvements with little benefit from geometric compatibility.
- Harmonisation issues, i.e. a full-width rigid test is used in regulation in many other parts of the world currently whereas a full-width test with a deformable face is not used anywhere at present.

Car-to-HGV Impact

For car-to-HGV impacts, energy absorbing front under-run protection systems (FUPs) were tested in the VC-COMPAT project and a number of test procedures to assess FUPs were proposed and investigated regarding their advantages and disadvantages. A definite decision for a final test procedure with performance criteria could not be made, simply because the supporting data from baseline tests were missing. However, all test procedures had the potential to be used as a final procedure in assessing energy absorbing front under-run protection structures on trucks.

For rear under-run, accident data and crash tests showed that rear under-run protection devices of the time as required by legislation of the time were inadequate for collisions of modern passenger cars into the rear end of a truck/trailer with closing speeds greater than 50 km/h. In the project the properties of an improved RUP structure were determined and tested to prevent impacting passenger cars from under-running the truck/trailer at speeds up to at least 56 km/h. From this work, recommendations for amendments to be implemented in directive 70/221/EEC (including amendment 2006/20/EC) and UN Regulation 58 were made. These recommendations were published shortly after the 2006 amendment and recommended even higher test loads for P1 of 110 kN (50 kN), P2 180 kN (100 kN) and P3 150 kN (50 kN) as well as a reduced ground clearance of 400 mm (550 mm) and an increase in the height of the RUP cross-member to 200 mm (100 mm) – note that current requirements today (2014) are in brackets. Also, cost-benefit analyses were performed for implementation of energy absorbing FUPs and the upgrades recommended to the RUP.

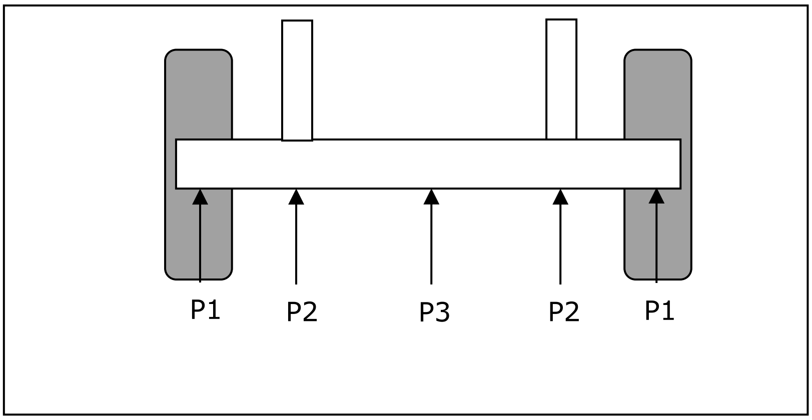

Figure C-8: Static loading positions on underrun protection devices

It should be noted that at the time of the VC-COMPAT work the 2006/20/EC amendment and the equivalent revision 2 amendment for UN Regulation 58 were not in force. The revision 2 amendment for Regulation 58 entered into force in July 2008. Therefore the legislative requirements for test loads at the time of the work were P1 25 kN, P2 100 kN and P3 25 kN. These were increased to the current levels – P1 50 kN, P2 100 kN and P3 50 kN as a result of the amendments. Tests conducted in Germany (ADAC, 2006) also showed that a RUP, that passed the higher test loads required by the latest amendment of 70/221/EC (2006/20/EC), i.e. the current loads, was still not sufficient to withstand the impact of a small family car at 56 km/h. In response to the new information available, the European Commission contracted TRL to carry out further research to develop the recommendations from the VC- COMPAT project into a proposal for a further amendment to Directive 70/221/EC (Smith et al., 2008). A preliminary proposal to amend Directive 70/221/EEC was produced. The main difference between this proposal and the VC-COMPAT one was the addition of a load condition, specifically, a load of 100 kN should be applied simultaneously to each of the three points P1, P2 and P3 on one side of the device. Therefore total force of 300 kN should be applied.

At present a proposal to amend UN Regulation 58 is being considered in Geneva (UNECE, 2013a). The main changes specified are for a change in the test loads for P1 to 100 kN (was 50 kN), P2 180 kN (100kN), P3 100 kN (50 kN) and a reduced ground clearance for most vehicles to 450 mm (550 mm). It does not contain the additional simultaneous load condition specified by Smith et al. (2008) possibly because this report was not published until recently (2014).

Other Regions

Compatibility issues in the US are mainly dominated by LTV/SUV (Light Truck Vehicles / Sport Utility Vehicles) impacts with smaller passenger cars. The most noteworthy development in the US has been the industry voluntary commitment (coordinated through the Alliance of Automobile Manufacturers) (Auto Alliance, 2003; Barbat, 2005) to provide geometric overlapping of structures on LTVs for frontal impacts with passenger cars. The commitment was initiated in 2003 and required 100% compliance for vehicle geometric designs by 2009. Both the Alliance and NTHSA have performed research into the parameters controlling compatibility. One of the test methods under investigation is a high resolution load cell barrier that measures the force distribution over the vehicle front during a full-width rigid barrier test. Metrics such as the Average Height of Force (AHOF), Initial Stiffness (Ks), and Work Stiffness (Kw) have been derived from this type of test data and correlated to real world crashes (Summers and Prasad, 2005). US stakeholders have focussed their research efforts on a Full-Width Rigid Barrier (FWRB) because it is the foundation of US frontal impact regulation.

C.2.2 Potential Mitigation Strategies

Car-to-car Frontal Impact

Three test procedures have been researched and are available to improve the structural interaction aspect of compatibility of cars (including LTVs and SUVs) in frontal impacts. There are no procedures available with performance criteria for other aspects of compatibility (i.e. global force matching and passenger compartment strength) for this type of impact. The procedures available are:

Full-Width Deformable Barrier (FWDB) test

Test procedure

- Test speed 50 km/h.
- Load Cell Wall (LCW) consisting of cells of nominal size 125 mm x 125 mm which cover a minimum area 2 m wide and 1 m high (Figure C-9).
- Deformable barrier, two layers each 150 mm thick. Front layer consists of honeycomb 0.34 MPa crush strength. Rear layer consists of honeycomb 1.71 MPa crush strength and is segmented into blocks 125 mm x 125 mm which are aligned with the segments of the LCW (Figure C-9)

Figure C-9: FWDB test showing deformable element and LCW

Metric

The metric proposed in the FIMCAR project (Johannsen, 2013) to assess geometrical alignment states that a vehicle must fulfil minimum load requirements in Rows 3&4 and can use loads in Row 2 to help meet this requirement under certain conditions (Figure C-10). The minimum load requirement promotes structural alignment and the credit of loads from Row 2 encourages vertical load spreading. The metric can be defined as:

- Up to time of 40 ms:
    - F4 + F3 ≥ [MIN(200, 0.4FT40) kN
    - F4 ≥ [MIN(100, 0.2FT40) kN
    - F3 ≥ [MIN((100-LR), (0.2FT40-LR))]

where:

FT40 = Maximum of total LCW force up to time of 40 ms

Limit Reduction (LR) = [F2-70] kN and 0 kN ≤ LR ≤ 50* kN

*Note values to be confirmed taking into account the new test velocity

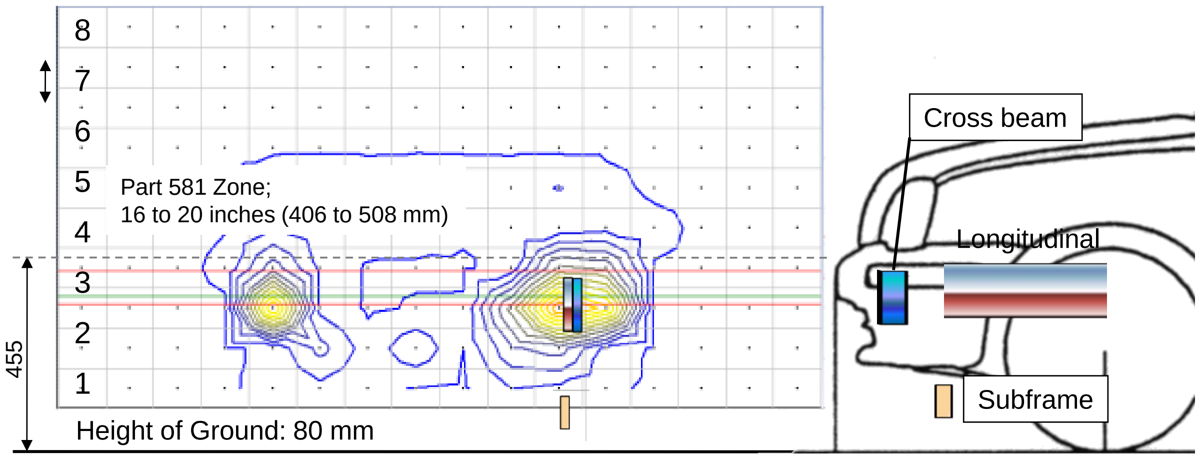

Figure C-10: Geometric assessment of structural alignment

Full-Width Rigid Barrier (FWRB) test

Test procedure

- Test procedure and LCW same as for the FWDB test, but without the deformable element

Metric

- Specific metric not defined at present but a number of potential candidates exist as a result of the FIMCAR project and NHTSA research (Johannsen 2013; Summers and Prasad 2007). However, these would require further development.

Auto Alliance voluntary commitment for geometric requirements for LTVs

The Auto Alliance developed the following requirements which were announced in 2003 as a first step towards improving geometrical compatibility: Participating manufacturers will begin designing light trucks in accordance with one of the following two geometric alignment alternatives, with the light truck at unloaded vehicle weight (as defined in 49 CFR 571.3):

Option 1: The light truck's primary frontal energy absorbing structure shall overlap at least 50% of the Part 581 zone AND at least 50% of the light truck's primary frontal energy-absorbing structure shall overlap the Part 581 zone (if the primary frontal energy-absorbing structure of the light truck is greater than 8 inches (20 cm) tall, engagement with the entire Part 581 zone is required), OR,

Option 2: If a light truck does not meet the criteria of Option 1, there must be a secondary energy absorbing structure, connected to the primary structure, whose lower edge shall be no higher than the bottom of the Part 581 bumper zone. This secondary structure shall withstand a load of at least 100 kN exerted by a loading device before this loading device travels 400 mm as measured from a vertical plane at the forward-most point of the significant structure of the vehicle.

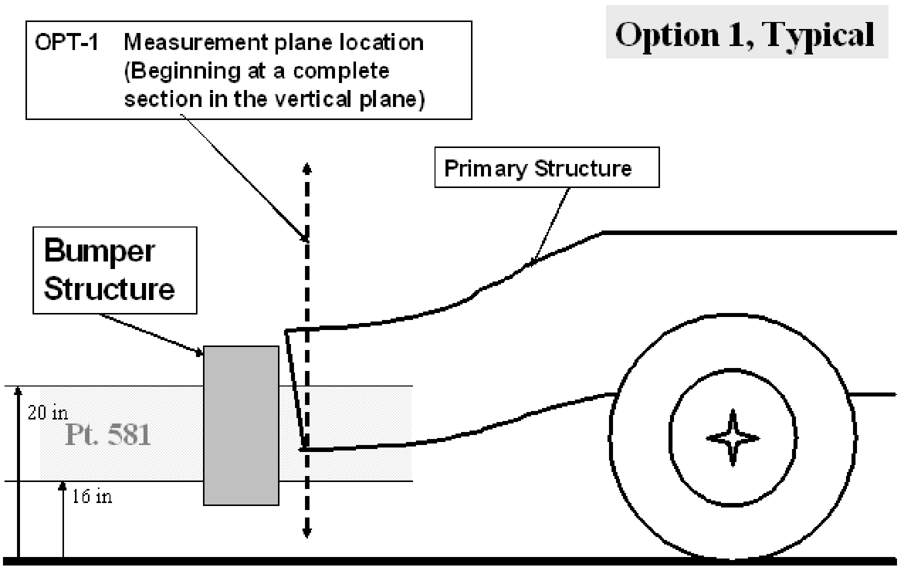

Figure C-11: Typical front rail geometry and definition of Part 581 zone for voluntary standard

Car-to-Rear of HGV Impact

Mitigation strategies are to increase the strength of the Rear Underrun Protection (RUP) on the HGV and improve its geometry for better interaction with a car's main structures. As mentioned above, currently a proposal to amend UN Regulation 58 is being considered in Geneva (UNECE, 2013a). The main changes specified are for a change in the test loads for P1 to 100 kN (was 50 kN), P2 180 kN (100 kN), P3 100 kN (50 kN) and a reduced ground clearance for most vehicles to 450 mm (550 mm). However, this proposal does not contain the additional simultaneous load condition specified by Smith et al. (2008). The authors believe that it is very likely that this additional load condition will be necessary in order to ensure that the RUP is strong enough to prevent underrun of a small family car at 56 km/h.

C.2.3 Feasibility

Car-to-Car Frontal Impact

Some current vehicles have been shown to meet the proposed test requirements for all three potential mitigation strategies listed, therefore feasibility is demonstrated clearly (Johanssen, 2013; Summers and Prasad, 2007; Auto Alliance, 2003).

Further work would be required to finalise test and assessment procedures suitable for application in regulations.

Car-to-Rear of HGV Impact

Tests within the VC-COMPAT project showed that improved protection is possible with closing speeds of up to 75 km/h, therefore feasibility is demonstrated clearly (Edwards et al., 2007).

Notes:

6. Many research programmes agreed that the RUP should be able to withstand impacts with a closing speed of 56 km/h. (Smith et al., 2008).
7. Tests in VC-COMPAT were for front under-run protection but are applicable for rear under-run also as far as guard strength and geometry concerned.

Some further work would be required to finalise test and assessment procedures suitable for application in regulations.

C.2.4 Costs

Car-to-Car Frontal Impact

No specific cost information was identified for compatibility alone. However, for improved frontal protection overall (i.e. both improved self and partner protection) the VC-COMPAT project made an estimate of costs of between €102 and €282 per car depending factors such as the number of that model of car manufactured and the starting level of crashworthiness assumed, e.g. Euro NCAP 4 or 5 star rated.

Car-to-Rear of HGV Impact

Using stakeholder consultation, Smith et al. (2008) estimated the cost to modify a RUP to comply with the changes to Regulation 58 detailed above, i.e. the increased load requirements including the simultaneous load requirement and geometry changes. A range of costs were provided by the respondents from €100 to €4600 depending on the complexity of the design and whether or not the development of the RUP was included in the cost. For this analysis, the following assumptions were made in determining the ranges of costs used:

8. The minimum cost is the lowest cost over and above what is currently spent on the RUP. This excludes development costs and is estimated at €100. This cost is used to calculate the maximum benefit-to-cost ratio.
9. If all vehicles were fitted with a fixed RUP and were not exempted the upper cost would be expected to be approximately €200. This cost is used to calculate the upper minimum benefit-to-cost ratio.
10. In reality there will be a mixture of different designs of RUP of different complexity. Information provided during the consultation indicated costs for folding RUP of €850 to €1600 and €1900 to €4600 for sliding or extending RUP, which includes the costs associated with development of the RUP. A third benefit-to-cost ratio is calculated assuming that 20% of the vehicle fleet are fitted with a folding RUP and 5% with a sliding/extending RUP. The cost assigned to these RUP designs is the mid-range cost for each type. The remaining 75% are fitted with a fixed RUP costed at €200. This assumption results in the lower minimum benefit-to-cost ratio.

The VC-COMPAT project also estimated costs to modify a RUP, but to meet requirements not including the simultaneous load (Edwards et al. 2007).

Current RUP devices cost €100-€200 per vehicle. Additional costs ranging from €20 to €100 were estimated for ‘low profile’ improved RUP, while additional costs for more complex folding devices may exceed €200 per vehicle.

C.2.5 Benefits

Car-to-car Frontal Impact

The FIMCAR project (Johannsen, 2013) assumed that the introduction of a full-width test with appropriate compatibility and dummy metrics had the potential to address compatibility issues related to under/over-ride and structural mis-alignment, and self-protection issues related to restraint-related deceleration type injuries. A benefit of 5% to 12% of all car killed and seriously injured (KSI) casualties was estimated for the introduction of an appropriate full-width test. However, it should be noted that most of this benefit would be related to a reduction in restraint system deceleration related injuries and only a very small amount to improved compatibility:

11. Compatibility issues related to under/over-ride and structural mis-alignment 0.3% to 0.8% of KSI casualties
12. Self-protection issues related to restraint-related deceleration type injuries 5% to 11% of KSI casualties.

Car-to-Rear of HGV Impact

Smith et al. (2008) estimated the benefit in terms of the number of fatal and serious casualties prevented for fitting an improved RUP to all HGVs in the European fleet for EU15 and EU25 as shown in Table C-1 and Table C-2.

Table C-1: Estimated reduction in number of fatalities prevented from improved RUP and associated financial valuation

	Estimated reduction in number of fatalities		Estimated fatality prevention financial benefit (€M)	
	EU-15	EU-25	EU-15	EU-25
Minimum	17	23	18.9	25.2
Maximum	181	242	197.6	263.2
Best Estimate (minimum)	32	43	35.4	47.1
Best Estimate (maximum)	70	93	76.1	101.4

Table C-2: Estimated benefits of improved RUP for serious casualties prevented and associated financial valuation

	Estimated reduction of serious casualties		Estimated serious casualty prevention financial benefit (€M)	
	EU-15	EU-25	EU-15	EU-25
Minimum	225	300	28.6	38.2
Maximum	3057	4072	389.0	518.1
Best Estimate (minimum)	521	694	66.3	88.4
Best Estimate (maximum)	1549	2063	197.1	262.5

A cost-benefit analysis was performed by Germany to support the proposal they submitted for more demanding requirements for rear under-run protection devices (UNECE 2013b). As part of this analysis it was estimated that for Germany the changes proposed could reduce the number of fatalities by 53 to 78% and the number of seriously injured casualties by 27 to 49% in car front to HGV rear accidents, which is equivalent to 20 fatalities and 95 seriously injured casualties per year. In monetary terms, the benefit for Germany was estimated to be 35.7 million euros.

C.2.6 Benefit:Cost Ratio

Car-to-Car Frontal Impact

Potential test procedures exist to improve the structural alignment of compatibility in car-to-car frontal impacts. However, no suitably developed test procedures exist to improve other aspects of compatibility such as frontal force matching and compartment strength. On the basis that the benefits estimated for improving the structural alignment aspect of compatibility are small, costs of implementation would need to be even smaller to give an acceptable benefit-to-cost ratio of greater than one. This is not likely to be achieved unless measures to improve compatibility are packaged with other measures which have a higher benefit-to-cost ratio and help to reduce costs of the compatibility component. Alternatively, an appropriate manufacturer voluntary commitment, such as that applied already in the USA, may offer a cost-effective approach.

Car-to-Rear of HGV Impact

Smith et al. 2008 estimated the benefit-to-cost ratio for the improvements to the RUP that they proposed. The analysis process used resulted in a number of different benefit-to-cost ratios being calculated. Using figures for the EU-15, the benefit-to-cost ratio was estimated to be between 0.2 and 15.4 based on the overall minimum and maximum values. However, it is more likely to lie within the range 0.5 to 7.2 based on the best estimates. For the analysis based on EU-25 the benefit-to-cost ratio was estimated to be between 0.3 and 18.7. However, using the best estimate figures the range was reduced to between 0.6 to 14.8.

This analysis showed that the proposed improvements to RUP would be likely to have economic benefits based on reductions in fatal and serious casualties. However, the positive benefit-to-cost ratio would be likely to depend quite strongly on the proportion of vehicles that may require specialist design to meet the proposed requirements and overcome operational difficulties such as the use of 'Roll-On, Roll-Off' ferries or use off-road. It should be noted that potential benefits associated with a reduction in accident severity reducing the delay time and congestion caused or the additional costs associated with reduced payload because of the increased mass of the RUP were not considered.

As mentioned above, a cost-benefit analysis was performed by Germany to support the proposal they submitted for more demanding requirements for rear underrun protection devices in UN Regulation 58 (UNECE, 2013b). In monetary terms, the benefit was estimated to be 35.7 million euros. The costs for the goods vehicles and trailers affected each year were estimated to be between 5 and 20 million euros, depending on how the costs were estimated. Thus, the benefit-to-cost ratio for the proposed changes was between 1.78 and 7 for Germany. Related to relevant accidents at EU 27 level based on a CARE database analysis, the benefit was estimated to be higher than in Germany by at least a factor of 9, whereas fleet-dependent costs were estimated to exhibit a factor of 4 only. Thus, for the European commercial vehicle fleet and the accidents in which they are involved, it was estimated that the effectiveness at EU 27 level would be at least as high as in Germany.

It is also interesting to note that Germany also estimated the benefit-to-cost ratio for fitting ideal emergency braking systems to cars to resolve this problem rather than strengthening the rear under-run guard. This gave a result of between 0.9 and 1.7 which is significantly less than the between 1.78 and 7 estimated for strengthening the rear under-run guard.

C.2.7 References

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C.3 Increased Crash Speeds (M1 vehicles)

Increased test speed in current regulatory test R.94 frontal impact for cars (M1). Either increase speed of current test or add another test.

C.3.1 Description of the Problem

Passenger car occupant fatalities account for about half of road accident fatalities in Europe, (CARE 2014). About half of passenger car killed and seriously injured casualties occur in frontal impacts. These occur over a range of impact speeds illustrated by the cumulative frequency plots of casualty injury in car-to-car and Light Goods Vehicles (LGV) accidents against equivalent energy speed (EES)[19] for GB and Germany shown in Figure C-11 and Figure C-12, respectively (Richards et al., 2010). It should be noted that:

- Casualty numbers are low for fatals, so frequency plots are unlikely to give statistically meaningful results, in particular for Germany.
- The EES of the 56 km/h current regulatory test is about 50 km/h and of the 64 km/h Euro NCAP frontal offset test about 56 km/h for a mid-sized car. This is because the barrier absorbs some of the impact energy.

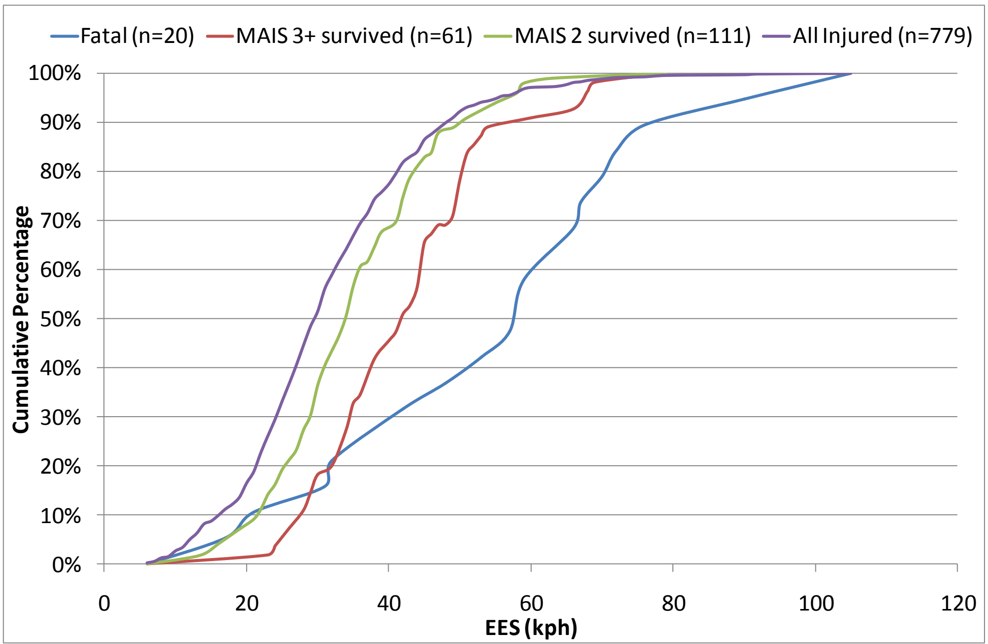

Figure C-12: Cumulative percentage of EES for drivers in car-car/LGV impacts in GB

[19] Equivalent Energy Speed is an estimate of the accident speed made based on the deformation (energy absorbed) of the vehicle. For impact with a rigid object these speeds are equivalent to the change in velocity (delta-v).

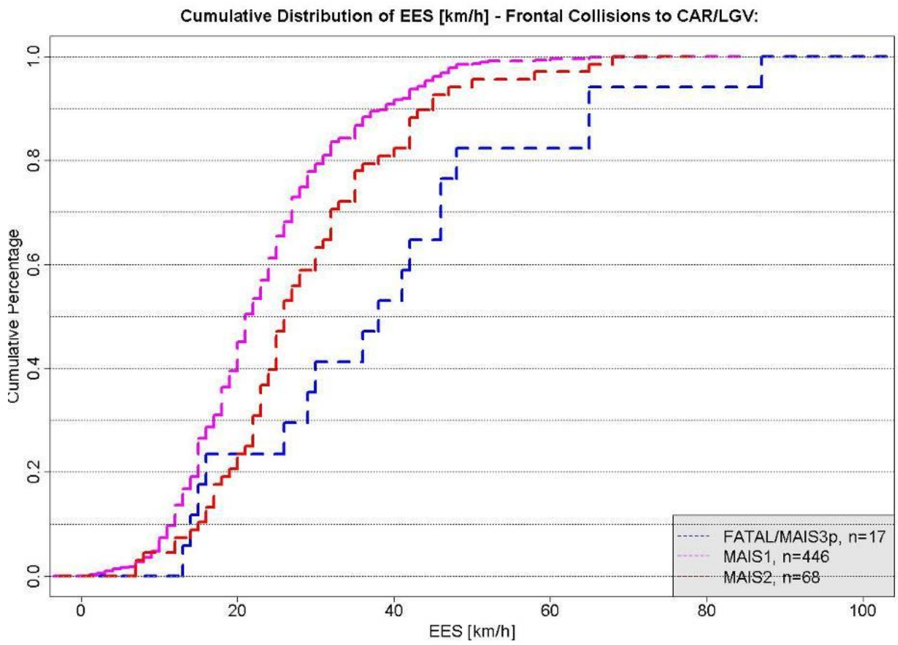

Figure C-13: Cumulative percentage of EES for car-car/LGV impacts in Germany

The current frontal impact regulatory test (Regulation 94) has a test speed of 56 km/h. It was introduced with this test speed in 1998 although the accident analysis at the time suggested a higher test speed would be more appropriate (Lowne 1994). The reason that the lower test speed was chosen was that the test programme conducted at the time suggested that car designs at that time would need substantial modification to achieve good results at 60 km/h and it was advisable to initiate testing at 56 km/h until the designs required to deal with the higher energies were understood better (Lowne, 1994). The test with a speed of 56 km/h and a 40 percent overlap is approximately representative of a 50 km/h car-to-car impact with 50 percent overlap and both cars travelling at 50 km/h.

In 2000, the frontal and side impact Directives were reviewed and as part of that review the question was asked of whether or not the test speed should be increased. Research performed by the UK concluded that the test speed should be increased to about 65 km/h (Edwards et al., 2001). The main reasons for this were:

- The current test speed only addresses 34 and 18 percent of MAIS3+ and fatal restrained occupants, respectively, in GB which is clearly not sufficient. A test speed increase to about 65 km/h would address 50 and 30 percent of MAIS3+ and fatal restrained occupants, respectively. For GB this would give the benefit of addressing approximately a further 225 MAIS3+ seriously injured occupants and 38 fatalities per year for car to one other vehicle collisions.
    - It should be noted that a direct comparison between the target populations quoted above and those quoted by Richards et al. (2010) should be made with caution because the populations quoted above are for all car occupant casualties in all frontal impacts whereas those quoted by Richards are for casualties in car to car / LGV frontal impacts where the occupant was belted and the car did not roll.
- It has been shown that a test speed around 65 km/h would not necessarily result in car designs that are stiffer in low speed impacts, which could lead to increased injury in lower speed accidents.
- A number of manufacturers are currently producing cars that would comply with a Directive having a test speed of about 64 km/h, albeit these cars are generally the mid-engine sized models.

However, the EEVC recommended that the frontal test speed should be increased to 60 km/h because of concerns that increasing the test speed further might result in stiffer structures that perform worse in lower speed accidents (Reference to original report not available but summary of report contained in Edwards et al. 2010). This was despite an accident analysis at the time showing that the test speed should be increased further because the current speed of 56 km/h addresses significantly less than 50 percent of belted occupants having MAIS 3+[20] injuries (Wykes, 1998). The EEVC recommendations were reported to the European Commission DG Enterprise in January 2000 for the purpose of reviewing the Directive.

The frontal impact legislation (UN Regulation 94) provides a minimum standard of safety for new cars. However, most new models are also tested by the European New Car Assessment Programme (Euro NCAP). Euro NCAP is a consumer information programme that encourages car manufacturers to exceed the legislative requirements. The Euro NCAP frontal impact test is based on that in Regulation 94, but the impact speed is 8 km/h higher i.e. 64 km/h. This approximately represents a 50 percent overlap car-to-car collision with each car travelling at around 55 km/h.

In addition another fundamental difference between legislation and Euro NCAP should be noted. For legislation, it is assured that all models of the type been approved will meet the test requirements, so generally the model tested is one that is expected to perform worst in the test or one is specially built to give assurance that all models produced will meet the test requirements. In contrast, for Euro NCAP only one model is tested which is often not representative of the worst case. Generally, the best-selling model of the range is chosen with a safety specification (in terms of airbags fitted etc.) that is standard fit throughout Europe.

C.3.2 Potential Mitigation Strategies

In simple terms, it is generally agreed that both offset and full-width tests are required in order to assess and control a car’s crash protection in frontal impact; an offset test to control intrusion, i.e. ensure that the car’s structure can absorb the impact energy in its front end without significant occupant compartment intrusion, and a full-width test to control occupant deceleration, i.e. provide a hard deceleration pulse to assess the restraint system (O’Reilly 2003).

As mentioned above, as a result of the review of the frontal impact Directive in 2000 the EEVC recommended that the test speed should be increased only to 60 km/h rather than about 65 km/h because of concerns that increasing the test speed further might result in stiffer structures that perform worse in lower speed accidents because of the reduced ride-down distance resulting in higher compartment decelerations.

Accident analysis within the FIMCAR project indicated that restraint-related injury without significant compartment intrusion is an important issue. In the analysis, (described in more detail in Appendix D.1), casualties whose injuries were caused by deceleration (related restraint injuries without significant compartment intrusion) formed a large proportion of the target population, 14% MAIS 2+ for GB (Figure C-4) and 41% for Germany (Figure C-6). This indicates that deceleration restraint-related issues are a large problem for non-fatal casualties. For fatal casualties, the problem appears to be related much more to issues of high severity accidents and large vehicle under-ride (Figure C-14).

[20] An Abbreviated Injury Scale 3+ (AIS3+) injury severity level describes a "serious" injury, and the MAIS3+ description is applied to any occupant who was injured at or above this severity.

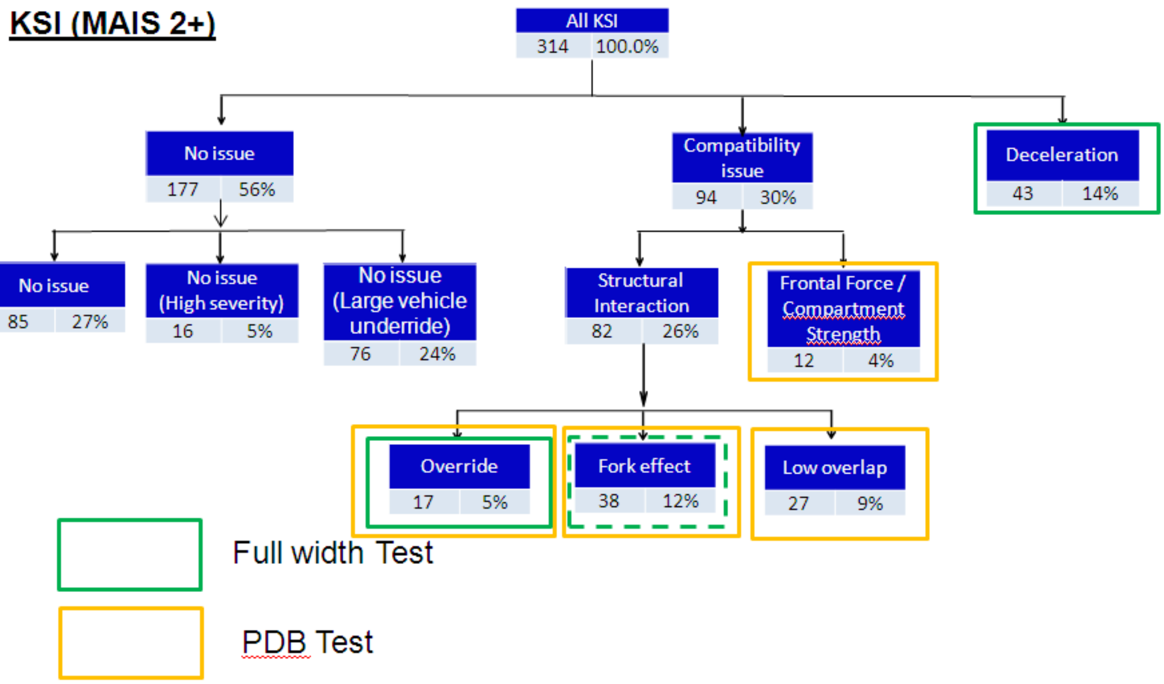

Figure C-14: Detailed case analysis (target population) main contributory cause breakdown of killed or seriously injured casualties (MAIS 2+) casualties

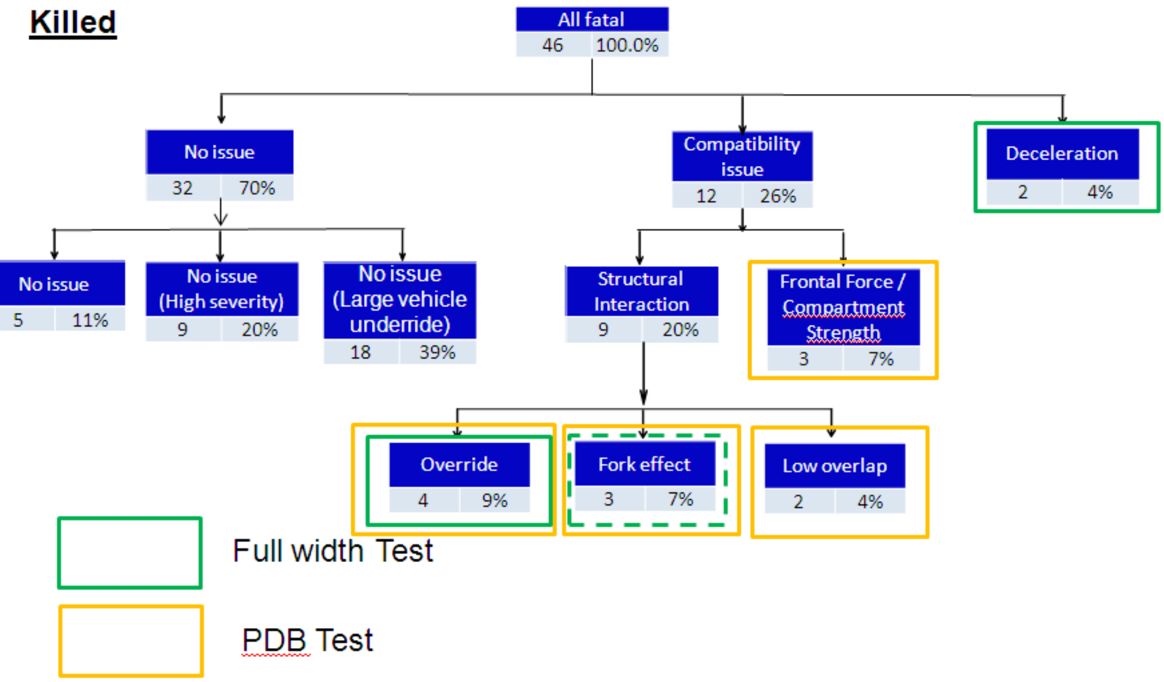

Figure C-15: Detailed case analysis (target population) main contributory cause breakdown of killed casualties)

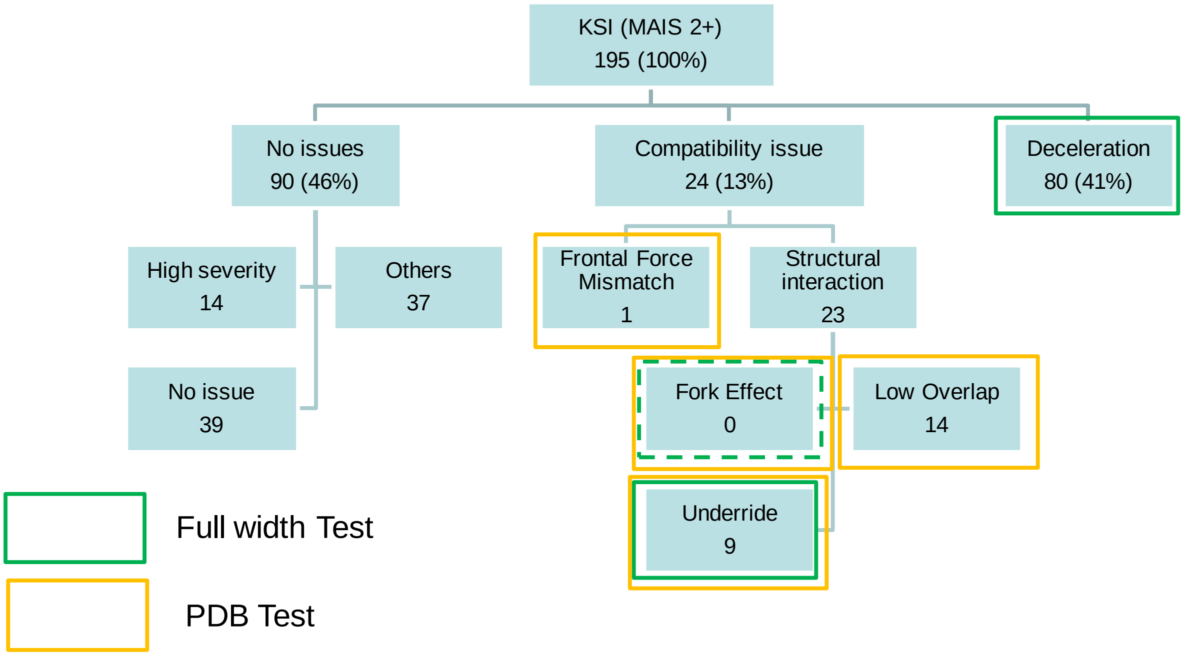

Figure C-16: German (GIDAS) detailed data sample target population breakdown KSI (MAIS 2+)

For a similar accident data set, Richards et al. 2010, calculated the proportion of casualties for whom significant intrusion was recorded for GB (Figure C-16) and Germany (Figure C-17).

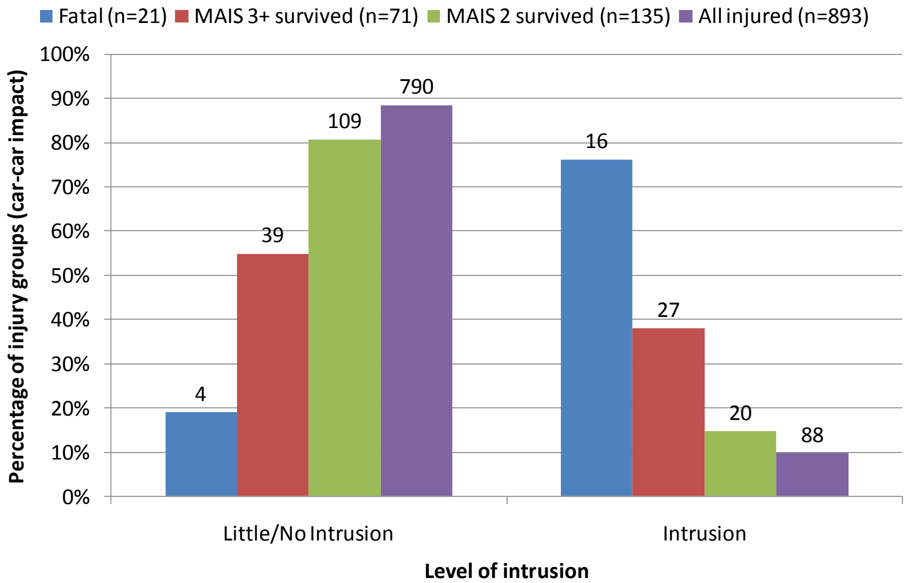

Figure C-17: Level of intrusion as a percentage of injury group for drivers in car-car/LGV impacts in GB

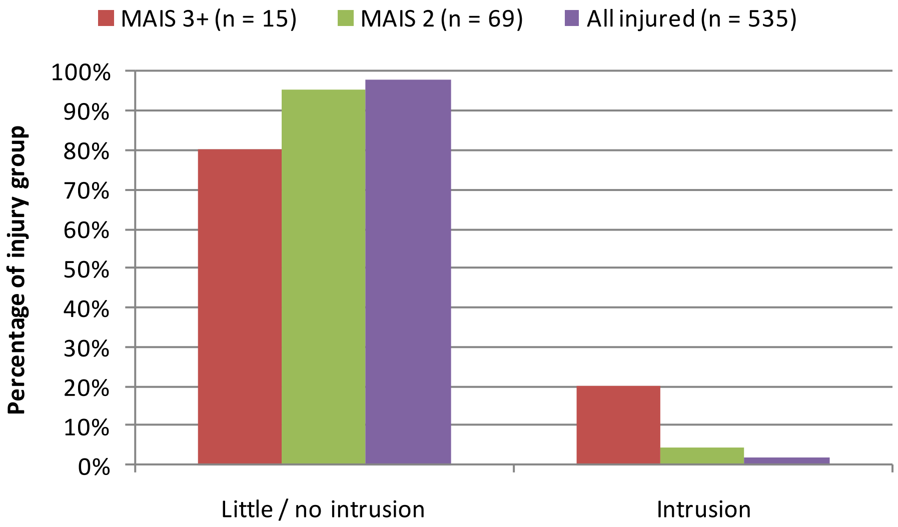

Figure C-18: Level of intrusion as a percentage of injury group, in Germany

For GB, Figure C-16 shows that a large proportion of fatalities had intrusion of 10 cm or greater. As expected, intrusion was also found to be related to higher speed crashes. When impacts with an EES over or under 56 km/h were compared, a greater proportion of impacts above 56 km/h involved intrusion of 10 cm or greater.

For Germany, similar to GB, Figure C-17 shows that the proportion of occupants with significant intrusion increases as the injury level increases. However, the proportion of occupants with significant intrusion is much lower in Germany than in Great Britain. This may be because intrusion has been measured differently in the German in-depth accident data. Intrusion in the German data is defined as a loss of stability in the compartment (of the A-pillar, dashboard, or firewall) where the door space has been reduced by more than 10 cm. This is different to the definition used for GB, where intrusion was defined as intrusion of 10 cm or more of the footwell, A-pillar, facia, or steering wheel. This difference in definition is the most likely reason why less intrusion is reported in the results from Germany.

These analyses indicate that for non-fatal casualties the deceleration related issue is larger than the intrusion related one. For fatal casualties indications are that intrusion is the larger issue, but this is possibly related to accidents of high severity and large vehicle under-run (see Figure C-14) which increasing the Regulation 94 test speed would not help address.

In summary, the main issue is that increasing the test speed in Regulation 94 will encourage manufacturers to make their vehicles stiffer so that they can absorb more energy in their front-ends without significant compartment intrusion which in turn increases the compartment deceleration pulse which could lead to more deceleration restraint-related injuries although it should reduce the number of intrusion related injuries in accidents with energies less than the test. At present, indications from the accident data found are that the proportion of deceleration related casualties is substantial and intrusion related ones for which a test speed increase could help somewhat uncertain. Therefore caution is recommended in considering increasing the test speed unless measures to reduce deceleration related injuries are taken in parallel.

C.3.3 Feasibility

The good performance of cars in Euro NCAP is a strong indicator that it is feasible that cars could be designed to comply with an increase in the Regulation 94 test speed to about 65 km/h assuming that the performance limits were the same. It should be noted that although Euro NCAP does not test the worst performing car, the vehicle's performance usually exceeds those required by Regulation 94 substantially, which indicates that even the worst performing car would probably meet the Regulation 94 performance limits at the Euro NCAP test speed of 64 km/h.

C.3.4 Costs

No specific cost information was identified. However, the good performance of cars in Euro NCAP is a strong indicator that costs should not be that large because many cars should meet a test speed increase of up to about 65 km/h already.

C.3.5 Benefits

Richards et al. (2010) estimated the target population size for an increase in the test speed from 56 to 64 km/h for GB and Germany from a calculation of those casualties in a frontal impact accident with an equivalent energy between that of a Regulation 94 test with a test speed of 56 km/h and one with a speed of 64 km/h (see Figure C-11 and Figure C-12). For GB, the target population was estimated to be 4% of car occupant fatalities, 5% of all MAIS 3+ car occupant casualties and 3% of MAIS 2 surviving car occupant casualties in car frontal impacts. For Germany, the target population was estimated to be 1% of MAIS 2 surviving car occupant casualties in car frontal impacts.

The main factors that influence benefit are the size of the target population and the effectiveness. Although the target population for increasing the test speed from 56 to 64 km/h is reasonably large, the effectiveness may not be particularly high because of the following reasons:

- Euro NCAP tests at 64 km/h, so many cars would be likely to meet the new requirements already; these cars would not change and hence there would be no or little benefit for these cars.
- For cars that would not meet the enhanced requirements, there is a possibility that modifications made to meet them may increase their stiffness and the likelihood of deceleration restraint-related injuries which could effectively cancel out gains made in reducing intrusion related injuries

In summary, although the target population size appears significant the size of the benefit is unknown because the influence of factors affecting the effectiveness are not quantified at present.

C.3.6 Benefit-to-Cost Ratio

Because the benefit is unknown, the benefit-to-cost ratio is unknown. However, in summary, the main issue is that increasing the test speed in Regulation 94 will encourage manufacturers to make their vehicles stiffer so that they can absorb more energy in their front-ends without significant compartment intrusion, which in turn increases the compartment deceleration pulse; this could lead to more deceleration restraint-related injuries although it should reduce the number of intrusion related injuries in accidents with energies less than the test. At present, indications from the accident data found are that the proportion of deceleration related casualties is substantial and intrusion related ones for which a test speed increase could help somewhat uncertain. Therefore caution is recommended in considering increasing the test speed unless measures to reduce deceleration related injuries are taken in parallel.

These arguments also apply to the proposal to add another test, unless it was possible to alter the performance limits of the current 56 km/h test to ensure protection for MAIS 2 injured occupants and encourage adaptive restraint systems. However, further research is required to determine the feasibility of this possibility.

C.3.7 References

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C.4 Full-overlap Frontal Crashes (M1 vehicles)

Crashworthiness in case of full overlap frontal crashes, i.e. those with more than about 80% overlap and with direct loading of both rails (longitudinals), to better assess occupant restraint systems.

C.4.1 Description of the Problem

Passenger car occupant fatalities account for about half of road accident fatalities in Europe, (CARE 2014). About half of passenger car killed and seriously injured casualties occur in frontal impacts. These occur with a range of overlaps as illustrated the plot of longitudinal loading as a percentage of injury group for drivers in car-to-car/LGV impacts in GB shown in Figure C-18 (Richards et al. 2009). It is seen that a large proportion of the casualties occur high overlap impacts (91-100%). Richards et al. (2009) also show that this situation is similar for Germany.

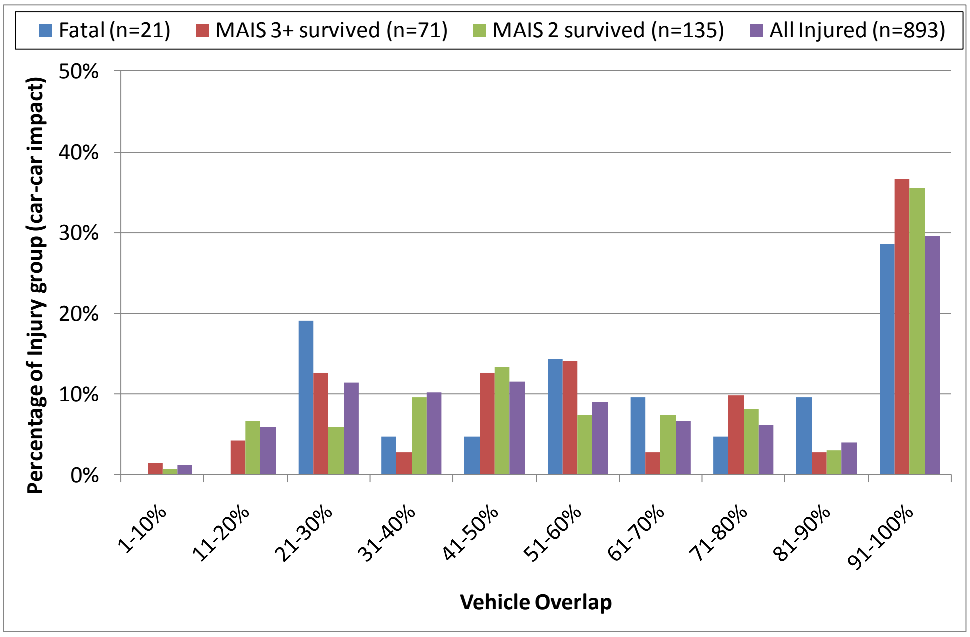

Figure C-19: Vehicle overlap as a percentage of casualty injury level group in GB for drivers in car-car/LGV impacts in GB

Accident analysis within the FIMCAR project indicated that restraint-related injury without significant compartment intrusion is an important issue (Johannsen 2013). In this analysis, (described in more detail in the 'small overlap frontal collisions' section), casualties whose injuries were caused by deceleration (related restraint injuries without significant compartment intrusion) formed a large proportion of the target population, 14% MAIS 2+ for GB (Figure C-4) and 41% for Germany (Figure C-6). This indicates that deceleration restraint-related issues are a large problem for non-fatal casualties. For fatal casualties, the problem appears to be related much more to issues of high severity accidents and large vehicle under-ride (Figure C-14).

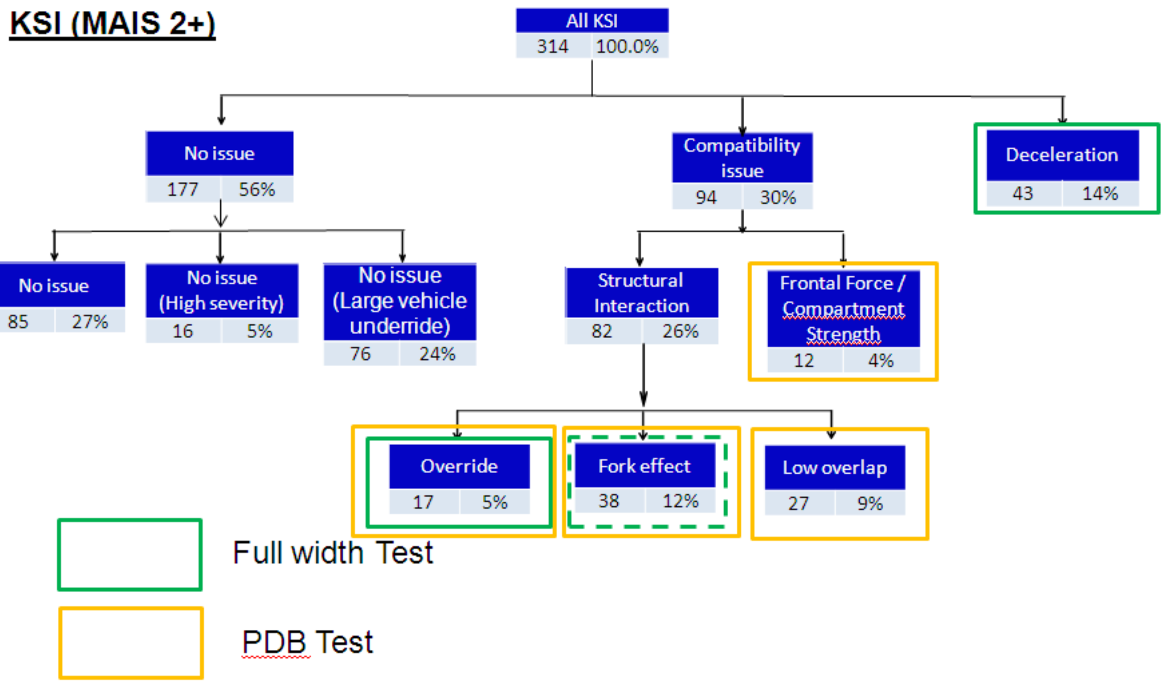

Figure C-20: Detailed case analysis (target population) main contributory cause breakdown of killed or seriously injured casualties (MAIS 2+) casualties

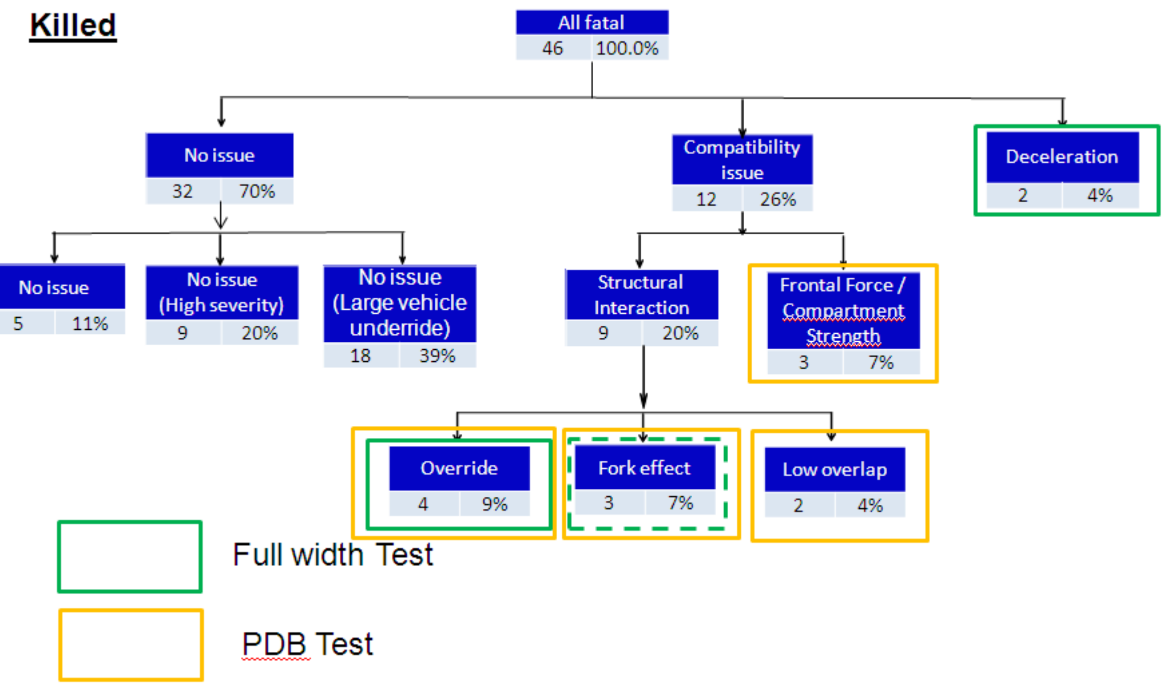

Figure C-21: Detailed case analysis (target population) main contributory cause breakdown of killed casualties)

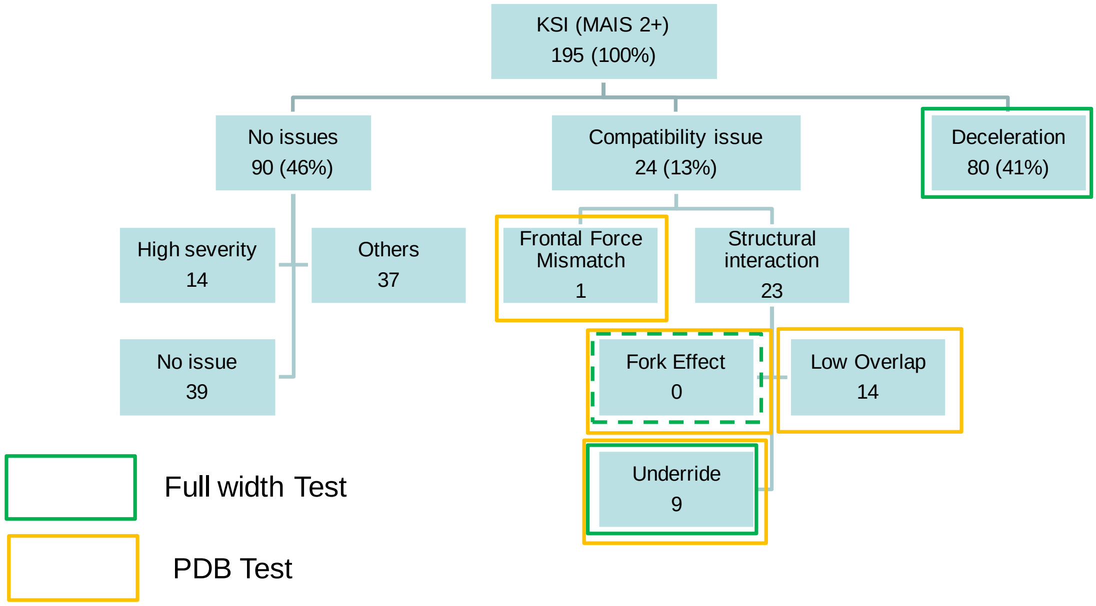

Figure C-22: German (GIDAS) detailed data sample target population breakdown KSI (MAIS 2+)

This evidence shows that there is a problem with high overlap impacts and deceleration restraint-related injuries although it does not show that the two are linked. However, analysis of the GIDAS database in the FIMCAR project showed that the frequency of injuries related to the restraint system increased with overlap whereas the frequency of injuries related to intrusion decreased (Figure C-22).

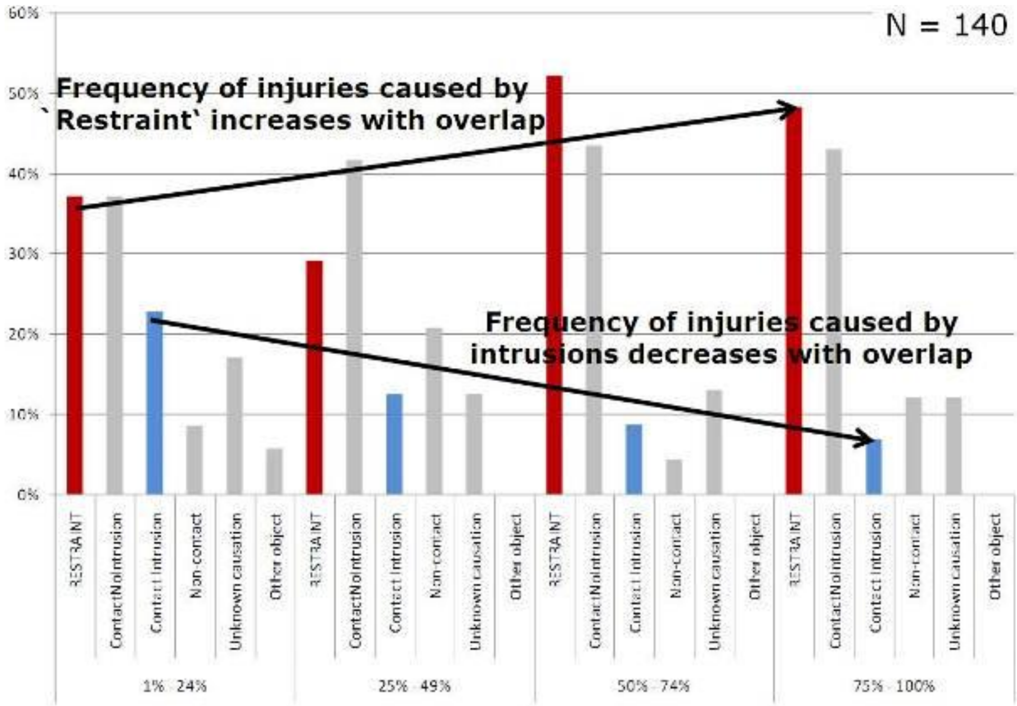

Figure C-23: For GIDAS database, proportions of AIS 2+ injuries by frontal overlap groups for car-to-car crashes (each combination of frontal overlap and injury causation group represents 100% - missing percentages are assigned to AIS0, AIS1 and unknown injury severity)

Richards et al. (2009) also investigated the population injured and the frequency and severity of injury for casualties in car frontal impacts. They concluded that:

- The age and gender of occupants in different seating positions is substantially different. The majority of front seat passengers are female, and a large proportion of these are elderly. A suitable dummy to represent the most frequently injured casualty in the front passenger seat would therefore represent a female or elderly female.
- A large proportion of the target population were elderly occupants aged 66 or older, accounting for 12-25% of all frontal impact casualties in Great Britain depending on severity. Even though elderly occupants were over-represented in this CCIS sample, the German analysis also showed that elderly occupants could make up 15% of the target population of MAIS 2 surviving occupants – the same proportion as for MAIS 2 surviving occupants in Great Britain.
- In Great Britain, for all injury severities, injuries to the thorax, arms, and legs are the most frequent. For fatalities, injuries to the abdomen are also frequent. The target population of casualties with MAIS 2+ injuries to the thorax is 23-42% of casualties depending on severity; arms are 25-32% of casualties; legs are 17-32% of casualties; and abdomen are 30% of fatalities.
- The injury distribution in Germany is slightly different - for MAIS 2 surviving occupants more head injuries and fewer leg injuries are seen compared to Great Britain. The target population of MAIS 2 casualties with head injuries in Germany is 21%, compared to 6% in Great Britain, suggesting that measurement of head injury is also important.
- For car drivers in car-car/LGV impacts in the GB data, the injury mechanisms are related to both the injury severity and the individual body regions.
    - For MAIS 2 surviving drivers, injuries to the thorax are generally related to the restraint system, injuries to the legs are related to contact with non-intruding structures, and injuries to the arms are related to a combination of both these causes (the restraint induced injuries are probably to the clavicle and shoulder area, and the contact injuries are likely to be to other regions of the arms).
    - As the injury severity becomes more severe, a larger proportion of injuries are related to contact with intruding structures. For fatalities, the majority of injuries to all body regions (with the exception of the abdomen) are related to contact with intruding structures. For MAIS 3+ surviving occupants, the majority of thorax injuries are still related to the restraint system, but injuries to the legs are distributed between contact with intruding and non-intruding structures.
- No difference was found in the injury distribution of male and female drivers in impacts with cars or LGVs in Great Britain. The injury distribution of different age drivers showed that the proportion of MAIS 2 casualties receiving thorax injuries is greatest for elderly casualties.

Carroll et al. (2010) also investigated thorax injury in car frontal impacts using accident data from the UK, Germany and France. They found that:

- There was an increased risk for older occupants to sustain a torso injury.
- There tends to be a greater torso injury risk for occupants seated in the front passenger seat compared with the driver’s seat.
- Fractures to the ribs and then the sternum were the most frequently occurring types of injury at the AIS 2 severity level.
- Injuries to the lungs were the most frequently occurring visceral injuries to the torso.

In summary, deceleration restraint-related injuries which occur with greater frequency in higher overlap impacts are a significant problem. Improved protection is needed, in particular, for the thorax and the elderly.

C.4.2 Potential Mitigation Strategies

To address the problem described above improved restraint systems are needed. Ideally, these systems should be adaptive and provide optimum protection for the full range of occupant sizes and changes in accident severity, in particular for the thorax. In principle, by doing this, protection for the elderly, who are less biomechanically tolerant, would also be addressed because the adaptive system should offer the best protection, i.e. lowest loading regime, for the occupant irrespective of age. This should reduce the injury risk for all occupants, with possibly the reduction being greater for the elderly depending on the particular injury and change in the relation of injury risk to loading with age.

Hynd et al. (2011) investigated the benefits and disbenefits of potential changes to the current regulatory test to encourage fitment of restraint systems to improve protection for different sized and older occupants. They found that an adaptive smart system tuned to adapt to a wide range of occupant sizes and collision severities offered the maximum benefit. However, it was noted that two legislative test procedures with different collision severities and with different dummy sizes would be necessary to encourage fitment of these systems.

On behalf of NHTSA, Cassatta et al. (2013) performed an ‘Advanced Restraint Systems’ project to evaluate the potential benefit of using pre-crash information associated with two unique crash configurations (one vehicle-to-vehicle scenario and one vehicle-to-object scenario) to tailor an advanced restraint system to the occupant and crash type. An overall occupant injury reduction benefit with a tailorable advanced restraint system was demonstrated for both test modes at the higher impact speeds; whereas for the lower speed conditions, the baseline versus advanced restraint system performance was comparable with an overall benefit not clearly shown.

However, it should be noted that the baseline vehicle performed well and was the only vehicle architecture evaluated. Thus, the applicability of the results to other vehicle architectures across the fleet was unknown. Also, during development vehicle manufacturers consider structural response, compartment / occupant packaging and interior component construction, and these are tuned coincidently for several crash modes with the restraint performance tuned and optimized accordingly. Thus, the “retrofitting” of hardware onto the existing project vehicle architecture may have limited the estimate of the potential benefit of the restraint system configurations evaluated. Significantly more research of test and field data and analysis of baseline vehicle restraints systems available to consumers today are necessary to extrapolate and predict overall real-world benefit potential with advanced restraint systems.

In summary, advanced adaptive restraint systems appear to have the potential to mitigate the problem of deceleration related restraint injuries and protection for the thorax and elderly. However, further work is required to develop these systems, in particular the link between the restraint system and the pre-crash / accident avoidance system, and to estimate their potential benefit.

C.4.3 Feasibility

Studies such as Hynd et al. (2011) demonstrate that adaptive restraint systems are feasible. However, further research is needed to determine how adaptable these systems can be made, such as how much they can be tuned to accident severity and how reliable information can be obtained about the severity of the accident about to occur to tune them. One potential route is to use information from pre-crash / accident avoidance systems.

The other aspect of feasibility is how to ensure the adoption of adaptive restraint systems assuming that the technical issues described above are resolved. Hynd et al. (2011) indicate that at least two legislative tests (or an equivalent, i.e. sled tests or numerical analysis (CAE)) at different accident severities and with different dummy sizes are needed.

The GRSP informal working group on frontal impact (IWGFI) are currently working on a proposal for the introduction of a full-width test at 50 km/h into legislation to complement the current Regulation 94 Offset Deformable Barrier (ODB) test and encourage the fitment of improved restraint systems. They also propose that the performance limits of the ODB test should be made more stringent to encourage better protection, in particular for the thorax (GRSP, 2013). For a later phase this group propose the introduction of the THOR dummy. The THOR dummy is more biofidelic than the current Hybrid III and should offer better assessment of occupant protection in particular for the thorax (Lemmen et al., 2013).

The authors believe that the GRSP IWGFI current proposal for the introduction of a full-width test at 50 km/h into legislation will not be sufficient to ensure the introduction of adaptive restraint systems as described in the section above, mainly because there is not enough difference in the severity of the proposed tests and therefore a non-adaptive system will likely be able to meet the requirements proposed.

NB: In the FIMCAR project a full-width deformable barrier (FWDB) test was performed with a FIAT 500, a car which was regarded to have quite a stiff structure. It is interesting to note that a chest compression of 37 mm was measured for this car in the FWDB test which indicates that it would meet the requirement of 42 mm proposed by the GRSP IWGFI for the full-width rigid barrier test.

The authors proposed to the GRSP IWGFI that three tests (or their equivalent e.g. sled tests or CAE) were needed to enforce the introduction of adaptive restraint systems (Edwards, 2013):

- Current ODB test with performance limits appropriate for mitigation of MAIS 3+ / fatal injuries
- Full-width test at higher speed (~56 km/h) with performance limits appropriate for mitigation of MAIS 3+ / fatal injuries
- Full-width test at lower speed (~40 km/h) with performance limits appropriate for mitigation of MAIS 2 injuries

Note that the dummy sizes used in tests would need to be selected to ensure that the restraint system protects the full range of occupant sizes / weights.

The main problems with this proposal were:

- Fundamentally, three tests were proposed but the group had decided already that only two tests could be allowed otherwise costs would be too high and the proposal would not be acceptable
- The current Hybrid III dummy would not be biofidelic enough to measure performance limits appropriate for mitigation of MAIS 2 injuries

For these reasons this proposal was not taken forward. However, in the authors' opinions it is worthy of further consideration in the longer term, when the current Hybrid III dummy is replaced with the THOR or CAE becomes more acceptable for legislative purposes.

C.4.4 Costs

No specific cost information was identified.

C.4.5 Benefits

The benefit analysis performed as part of the FIMCAR project (Johannsen, 2013) estimated that the benefit for the introduction of measures to reduce deceleration restraint-related injuries, i.e. adaptive restraint systems, would be prevention of between 5% and 11% of killed and seriously injured car occupant casualties.

C.4.6 Benefit-to-Cost Ratio

The FIMCAR project also calculated break-even costs for the 'introduction of a full-width test', the benefits of which were nearly all for the reduction of deceleration restraint-related injuries assuming that the full-width test enforced the introduction of adaptive restraint systems. These costs were calculated by dividing the monetary value of the benefit by the number of new cars registered per year. Break-even costs of between €84 and €175 per car were estimated.

For comparison, in the APROSYS project costs per car of €32 were estimated to improve the restraint system to meet Regulation 94 performance limits in a full-width test (Edwards and Tanucci, 2008). As part of the final impact assessment to add an oblique pole test to the legislation, NHTSA estimated costs of between $243 (€182) and $280 (€210) ($1 = €0.75€) to add a two or four sensor curtain airbag system (NHTSA 2007).

This gives some indication that the benefit-to-cost ratio could likely be greater than one and on that basis further research is recommended to:

- Develop adaptive restraint systems further, in particular the link between the restraint system and the pre-crash / accident avoidance system
- Estimate the potential benefits and costs of adaptive restraint systems more accurately, including consideration of fitment for rear-seated occupants.
- Assuming that the two items above indicate a promising benefit-to-cost ratio, develop a cost-effective method of enforcing the introduction of these systems, potentially using a legislative route

C.4.7 References

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C.5 Rollover (M1 vehicles)

Car (M1) static roof strength testing similar to FMVSS 216 to ensure minimum roof strength to reduce roof crush and protect occupants in rollover accidents. Ejection mitigation testing similar to FMVSS 226 is also included because it is closely related.

C.5.1 F.3.1 Description of the Problem

Rollover refers to accidents in which the vehicle overturns onto its side or roof any time during the crash. Accidents in which rollover occurs tend to be particularly injurious. For the USA, NHTSA report that vehicles roll in 2 to 3 percent of all crashes but these crashes account for about a third of passenger vehicle occupant deaths (in 2012, 21,795 passenger vehicle occupants died in crashes of all kinds and of those 7,559 (34%) died in crashes where the vehicle rolled (NHTSA, 2013)). This type of data is not available for the whole of Europe, i.e. it is not available in the CARE database, but GB STATS19 data can be used to illustrate the injurious nature of rollover accidents in Europe. In GB in 2012, 7% of car occupants who were injured were injured in accidents in which the car overturned, whereas 19% of car occupants who were killed were injured in rollover accidents.

Most rollovers occur when a driver loses control of a vehicle, and it begins to slide sideways. When this happens, something can ‘trip’ the vehicle and cause it to roll over. This tripping object can be a kerb, or soft ground, or uneven ground such as an embankment or ditch on the side of the roadway. Rollovers can also be caused by a prior impact, for example a vehicle struck in the side may be pushed over by the striking vehicle. In addition, some rollovers are caused by a driver turning the vehicle too aggressively – at high velocity or with a tight turning circle and less frequently when one side of a vehicle is flipped up by a ramp-like object or dropped down an embankment or into a ditch.

The European Commission FP5 ROLLOVER project reports that in most European countries the official national accident statistics contain no information on rolling cars, only Great Britain can deliver official statistical data (ROLLOVER 2006). Because of this, the project focused mainly on analysis of detailed accident databases, in particular the UK’s Co-operative Crash Injury Study (CCIS) and the German In-Depth Accident Study (GIDAS). More global information was provided by investigating databases from Spain. Estimations made for the frequency of rollover accidents in Europe were 4-5% of all accident cases, and 15% of all fatal crashes. The ROLLOVER project also compared European and US rollover accident data. Although the vehicle fleets in Europe and the US differ substantially, for example the US has a significantly higher proportion of SUVs, MPVs, pickups and other vehicles with a high centre of gravity, and there are differences in the environment and legislation, the following common observations were made:

- Occupant ejection is an important factor, especially when serious injuries are considered
- The risk of injury increases substantially when occupants are unrestrained
- Most rollovers occur about the longitudinal axis of the vehicle
- Most vehicle rollovers involve one complete roll or less
- Ejection takes place most frequently through the side windows.

In an analysis of the UK’s CCIS, Cuerden et al. (2009) differentiated the different types of rollovers for MAIS 2+ injured occupants:

- Rollovers which do not involve a significant impact (30.1%);
- Rollovers followed by impact(s) (13.1%); and
- Impacts followed by rollovers (56.5%).

For cars which rolled first, 33% were described as travelling on bends (turning) and 'sliding' laterally and 22% were described as originally intending to proceed 'forwards', but had also 'lost control'. Electronic Stability Control (ESC) was identified as an important countermeasure with respect to potentially preventing a proportion of these rollover accidents. For cars which had an impact before rollover, the potential effectiveness of ESC is likely to be less.

The most common roll initiation influence was off-road soft ground (grass or earth) applying force to both wheels on one side of the vehicle (right or left). Casualties in cars which became airborne during the roll suffered proportionally more serious injuries.

Occupants, who were either fully or partially ejected from their cars, were strongly linked to severe injury outcome. The body regions injured most frequently in roll-only accidents at AIS 2+ and 3+ levels were the head and limbs for seat-belted occupants and for non-belted occupants the head, thorax and limbs. Non-belted occupants generally had more injuries to more body regions. Seat-belts (ideally used in conjunction with other restraint devices such as curtain airbags designed to prevent either all or part of the occupants' body leaving the car through window apertures during the rollover) were shown to be effective.

An analysis of the German In-Depth Accident Study (GIDAS) by Otte and Krettek (2005) reports that the majority of rollover accidents were caused by sliding and only a small proportion (13.7%) was caused by a previous impact. For the sliding cases, for 38% the car swerved, for 45.4% the sliding was into an embankment either downwards or upwards and for 3% a trip occurred because of impact of the wheels against an object such as a kerb. The most frequently injured body regions were the head, upper extremities and the thorax. Regarding injury mechanisms, the analysis found that for belted occupants the risk of severe head injuries was much greater for roof deformation depths greater than 30 cm. It is also interesting to note that the paper reports that isolated rollovers are not as injurious as rollovers where there is an additional impact. However, this is not surprising because an additional impact will inevitably increase the severity of the accident and the likelihood of an additional impact probably increases with higher speed accidents. The analysis concluded that the following countermeasures are important:

- For rollover prevention:
    - Avoidance of vehicle sliding (63% of cars with a rollover slipped before the rollover). Note that potentially fitment of ESC could be an important countermeasure with respect to preventing a proportion of these rollover accidents
    - Reduction of driving speed (80% of cars with a rollover were driven in excess of 70km/h)
    - Reduction of trip initiators, such as changes from low to high friction surfaces in the areas of the wheels (38% of accidents with rollovers were initiated by lateral sliding)
    - Implementation of a paved flat strip beside the road on the same height-level, avoiding ditches, trees and other fixed objects
- For injury prevention within a rollover event:
    - Use of seat-belts, implemented with pretensioning devices to pull the seat-belt tight
    - Development of stiffer structures of the vehicle cell especially avoidance of the roof deformations > 30 cm
    - Positioning of padding together with additional airbags in potential lateral head and roof contact positions

At first sight, there appear to be substantial differences between the results of this analysis and the one mentioned above by Cuerden et al. (2009), in particular regarding the percentage of casualties or cases in which the vehicles were sliding or lost control for which fitment of ESC could potentially help prevent. The UK analysis indicates about 24% and the German analysis 63%. However, there are some substantial differences between the analyses which will likely contribute to at least some of this difference: namely that the UK analysis is for MAIS 2+ (seriously) injured casualties only and the German analysis includes casualties of all injury severities. Also, the UK analysis counts casualties whereas the German analysis counts cars, although this will only cause a large difference if many cars have more than one occupant in them. These differences in the analyses will cause some of the difference in the result, although they are unlikely to account for it all. This leads to the conclusion that there are significant differences in the causes of rollover accidents between countries in Europe.

C.5.2 Potential Mitigation Strategies

Potential mitigation measures can be divided into two categories: firstly, primary safety measures to help prevent the rollover occurring; and secondly, secondary safety measures to mitigate injury during the rollover:

Primary safety:

- Fitment of Electronic Stability Control (ESC) to help prevent loss of control of the vehicle and the subsequent slippage leading to rollover
- Improved vehicle stability factor

Secondary safety:

- **Improved vehicle roof crush strength to help limit roof crush**
- **Measures such as the fitment of curtain airbags to help prevent ejection and partial ejection**
- Improved seat-belt wearing rate
- Fitment of restraint systems which better restrain occupants in a rollover

Fitment of ESC

The General Safety Regulation requires fitment of ESC on new types of M1 and N1 vehicles from 01/11/2011 and for all new vehicles from 01/11/2014. Starting from 2007, fitment of ESC for passenger cars was also encouraged by Euro NCAP.

Research predicts that fitment of ESC should result in a substantial reduction in all accidents, in particular those involving loss of control. However, predictions are variable with Tingvall et al. (2004) estimating an effectiveness of 22% for all crashes in contrast to 45% estimated by Becker et al. (2003). A more recent study by Thomas and Frampton (2007) estimated an effectiveness of 7% for all crashes and 36% for rollover crashes in the UK.

Currently, because ESC fitment will take some time to penetrate the vehicle fleet, it is not known precisely how much effect its fitment will have on rollover accidents, although it is predicted that it will be substantial and hence could reduce the size of the rollover problem substantially. A similar situation exists in the USA, namely that ESC is fitted to new vehicles but it will take some time to penetrate the vehicle fleet fully. To provide an estimate of the effect of ESC on rollover accidents IIHS have reported that for 1 to 3 year old passenger vehicles of all types the rollover fatality rate has declined from 27 driver deaths per million registered vehicles in 2000 (i.e. before fitment of ESC) to 6 deaths (i.e. with fitment of ESC) in 2012. However, it should be noted that, in the US compared to Europe, the initial rollover problem size circa 2000 was likely larger because of the greater proportion of more unstable SUVs in their vehicle fleet and that the US have taken other measures such as enhanced roof crush strength requirements as well as fitment of ESC to help reduce the number of casualties in rollover accidents.

Improved Vehicle Stability Factor

The Static Stability Factor (SSF) of a vehicle is defined as its track width, T, divided by twice its centre of gravity height, H; i.e., SSF = T/2H. Originally, in 2000, NHTSA used this measure to determine its rollover resistance rating for its safer car consumer information programme (NHTSA, 2000). However, although NHTSA showed that this metric correlated reasonably well with rollover risk, it is essentially just a measure of the vehicle's geometric properties, i.e. how 'top-heavy' it is, and does not take into account dynamic factors such as suspension design and ESC. Because of this, in 2004, a dynamic test was introduced into the rollover rating scheme which is a similar type of test to the UN Regulation 13-H test for ESC.

In summary, the SSF was a metric that was used in the past as a measure of a vehicle's rollover propensity based on its geometric properties. However, it has been superseded by dynamic tests which also take into account dynamic factors such as suspension design and ESC.

Improved Roof Crush Strength

During the past 30 years, there has been much debate about the association between roof crush in rollovers and serious head and neck injuries. Some studies have reported that roof strength and injury are not causally related but that occupants are injured as they 'dive' into the roof before it crushes (Bahling et al., 1990; James et al., 2007; Orlowski et al., 1985).

Conversely, other researchers maintain that injuries occur when the roof buckles into the occupant compartment and contacts the people inside (Friedman and Nash, 2001; Rechnitzer et al., 1998).

However, the present author believes that it is clear that roof strength is a significant contributory factor to the mitigation of injuries in rollover accidents in that it is necessary to provide a space in which the occupant restraint systems can work, although the mechanisms may be unclear. This position is supported by analyses by the US Insurance Institute for Highway Safety (IIHS) who have demonstrated a correlation between roof strength and injury risk (Brumbelow et al., 2009a; Brumblelow and Teoh, 2009b). They showed that stronger roofs reduce the risk of injury for occupants remaining in the vehicle and also the risk of ejection.

To help address the issue of roof strength in the USA, FMVSS No. 216 was upgraded in 2009 (FMVSS 216a) with a gradual phase-in from 2013 to 2017. This rule modifies FMVSS 216 to require that vehicles with a gross vehicle weight rating (GVWR) of 2722 kg or less have a roof strength sufficient to withstand the application of a force loading device up to 3.0 times the vehicle's unloaded weight prior to head contact with a 50th percentile male head position or 127 mm of platen travel, whichever comes first. The test is conducted sequentially on the driver and passenger side of the vehicle. This is a significant change from the previous requirement (FMVSS 216) which specified a test load of 1.5 times before the device moved 127 mm on one side of the roof only. In addition, the 216a requires that vehicles with a GVWR between 2722 to 4536 kg meet the same testing requirements but with a 1.5 times requirement. It is expected that this rule will be met by strengthening reinforcements in roof pillars, by increasing gauge of steel used in roofs, or by using higher strength materials.

The final regulatory impact analysis (FRIA) estimated that the benefit of the introduction of this rule should be to save 190 equivalent fatalities per year at a cost of $6.1 million (3% discount rate) to $9.8 million (7% discount rate) per equivalent life saved (NHTSA, 2009). Taking into account the cost of modifications to vehicle designs, net benefits of between a loss of $458 million to a benefit of $6 million were calculated based on a monetary value of $6.1 million per equivalent life saved.

Ejection Mitigation Measures

As reported above, Otte and Krettek (2005) and Cuerden et al. (2009) both cite that ejection and partial ejection are correlated strongly with severe injury. Whereas increased seat-belt use can help to prevent full ejection, it may still allow partial ejection because the upper torso may slip out of the shoulder belt. To help address the ejection issue in the USA, FMVSS No. 226 was introduced in 2011 with a gradual phase-in from 2013 to 2017. This rule requires that occupant containment measures are fitted to motor vehicles with a GVWR 4536 kg or less. These measures will be tested by impact from a guideless 18 kg headform traveling laterally and horizontally. The performance criterion is a displacement limit of impactor travel of 100 mm beyond the inside surface of the window at the target location being tested. It is expected that curtain airbags will be used to meet the test requirements. The final regulatory impact analysis (NHTSA, 2011) estimated that the benefit of the introduction of this rule should be to save 373 lives and prevent 476 serious injuries annually. The net costs per equivalent life saved were estimated to be from $1.4 million using a 3% discount rate to $1.7 million for a 7% discount rate. Net benefits per year of between $1,307 million and $1,773 million were calculated based on a monetary value of $6.1 million per equivalent life saved. It is interesting to note that the majority of the benefits were predicted for unbelted occupants, but 12 percent of the benefit was predicted for belted occupants (10 percent from rollovers and 2 percent from side impact crashes where partial ejection is an issue).

It should be noted that a rollover test is included in FMVSS No. 208. The vehicle is rolled sideways off an angled platform travelling at 50 km/h which is stopped in less than 1 m. Performance requirements are the same as those for the full-frontal test for a Hybrid III dummy placed in the front outboard seating position on the vehicle's lower side as mounted on the platform. These include containment of all portions of the dummy within the passenger compartment, HIC, chest deflection, upper leg injury, neck injury criteria, etc.

Improved Seat-belt Wearing Rate

As mentioned above, Cuerden et al. (2009) concluded that occupants who were either fully or partially ejected from their cars were strongly linked to severe injury outcome and full ejection was strongly related to seat-belt non-use. Further detail shows that whilst seat-belts prevented virtually all full ejection, much partial ejection occurred with belted occupants which implies that other additional measures are needed to reduce and prevent partial ejection. Otte and Kretteck (2005) concluded that injury outcome in current vehicles in rollover accidents can be reduced by wearing seat-belts which supports the conclusions from Cuerden et al. (2009).

From this, it is clear that an improved seat-belt wearing rate should improve the injury outcome in rollover accidents. Currently, additional regulatory measures to improve the seat-belt wearing rate are under consideration, in particular extension of seat-belt reminder (SBR) regulatory requirements to other seating positions and vehicle categories for the European market (currently driver and M1 only).

Fitment of Restraint Systems which Better Restrain Occupant in Rollover

In a rollover, the lap part of the three-point belt certainly restrains the occupant from being ejected fully out of the vehicle; however, as noted above, the upper torso may slip out of the shoulder belt. Some research has been performed to better restrain the upper torso to the seat. Bostrom et al. (2005) investigated the benefit of a seat integrated, buckle pretensioned, three-point belt with reversed geometry and an inflatable inboard torso side support. The repeatability of the method in terms of the buck and ATD motion (kinematics) was concluded to be good. Reversing the geometry of a three-point seat belt showed improvement of the shoulder belt's ability to restrain the torso of a non-leading side occupant in a tripped rollover without causing harmful belt-to-neck loading. Recently, research on this topic appears to have reduced possibly because effort shifted to research to support the development of ejection mitigation measures and FMVSS 226 described in the section below. However, some research has been performed on rollover test bucks such as the design of a roof structure to be used to perform rollover crash tests that simulate the loading (deformation) response of a modern vehicle (Toczyski et al., 2013).

Discussion

From above it can be seen that the main potential mitigation measures for rollover accidents are:

- Fitment of ESC
- Improved roof crush strength

- Ejection mitigation measures
- Improved seat-belt wearing rate

The first of these is already being implemented in European regulation, with ESC fitment mandatory for new types of car (M1) from 01/11/2011 and for all new cars from 01/11/2014. It should be noted that the benefit for rollover accidents is predicted to be substantial with a 36% effectiveness estimated by Thomas and Frampton (2007). However, it will take the order of ten years for the benefit of this measure to be realised fully to allow ESC fitment to the whole vehicle fleet although this period may be less because Euro NCAP started to encourage the fitment of ESC in 2007.

Also, measures are being considered currently for improving seat-belt wearing rate. A proposal to extend the fitment of seat-belt reminders (SBR) to more occupant seating positions (currently only driver) and other vehicle categories (currently only M1) is under consideration at the moment.

C.5.3 Feasibility

Improved Roof Crush Strength

The feasibility of improving roof crush strength is clearly demonstrated by the response of car manufacturers to the upgrade of the roof crush strength standard in the US (FMVSS216 to FMVSS216a which increased the strength to weight ratio (SWR) requirement for cars under 2722 kg from 1.5 to 3.0) and the roof strength crush test introduced by the IIIHS in the US. The IIHS award a good rating for cars having a SWR greater than 4.0 which many cars have achieved and some have exceeded with a number of cars achieving over 5.0.

Ejection Mitigation Measures

The feasibility of ejection mitigation measures is demonstrated clearly by the response of car manufacturers to the introduction of the ejection mitigation standard in the US (FMVSS 226, which requires an occupant containment countermeasure – in practice a side curtain airbag – which can limit the travel of an 18 kg headform, travelling at speeds up to 20 km/h, to 100 mm beyond the inside surface of the window at the target location being tested). Information from NHTSA shows that a number of 2014 vehicle models (about 50) are already certified to this standard, even though it will not be phased in fully until 2017 (personal communication, 2014).

C.5.4 Costs

Improved Roof Crush Strength

The only relevant information found for the costs of improved roof crush strength was in the final regulatory impact analysis (NHTSA, 2009) for the upgrade of the roof crush resistance US federal standard FMVSS 216 to FMVSS 216a. The main additional requirements of FMVSS 216a are an increase in the roof crush strength from an SWR of 1.5 to 3.0 for vehicles under 2722 kg GVWR and the addition of a SWR requirement of 1.5 for vehicles between 2722 kg and 4536 kg GVWR.

NHTSA predicted that manufacturers will meet this standard by strengthening roof pillars, either by increasing the gauge of steel used in roofs or by using higher strength materials. Based on this, they estimated that the upgrade to FMVSS 216 would increase lifetime consumer costs by $69-$114 (2007 US dollars) per affected vehicle. These costs consist of redesign costs which were predicted to increase affected vehicle prices by an average of about $54 and added weight costs which were predicted to increase the lifetime cost of fuel usage by $15 to $62 for an average affected vehicle. Affected vehicles were estimated to comprise 82% of vehicles under 2,722 kg and 40% of vehicles over 2,722 kg.

Ejection Mitigation Measures

The only relevant information found for the costs for fitment of ejection mitigation measures was in the FRIA for ejection mitigation US federal standard FMVSS 226.

NHTSA estimated that potential compliance costs for the linear impactor headform test will vary considerably and are dependent upon the types of the FMVSS 214 head/side air bags that will be installed by vehicle manufacturers to comply with the oblique pole test requirements. For vehicles with two rows of seats to be covered with a curtain air bag, they estimated an ejection mitigation system (consisting of 2 window curtains, 2 thorax air bags for the front seat occupants only, 2 side impact sensors and 1 rollover sensor) would cost about $348.82 at 2009 prices, when compared to a vehicle with no side air bags. This was $49.18 more than a vehicle with two rows of seats with a side air bag system designed to meet the FMVSS No. 214 pole and MDB tests. The estimated MY 2011 sales show that 22% of light vehicles will have a cargo area behind the second row and 14% will have third row seat. When the first to the 3rd row and the cargo area behind the second row are covered with a curtain air bag, the cost per vehicle was estimated to increase by $52.31, when compared to a vehicle equipped with a FMVSS 214 curtain system.

C.5.5 Benefits

Improved Roof Crush Strength

In the final regulatory impact analysis (NHTSA, 2009) for the upgrade of the roof crush resistance NHTSA estimated that the changes to FMVSS 216 will prevent 135 fatalities and 1,065 non-fatal injuries annually after all vehicles in the on-road fleet meet the new requirements. Overall this benefit does not appear to be particularly large in the context that there were 23,400 deaths in passenger cars and light trucks in 2009 in the US (US Census Bureau, 2012).

However, the benefit estimate does take into account the reduction in the number of rollover accidents expected as a result of the compulsory fitment of ESC and the increase in the size of the target population expected because of an increase in the safety-belt wearing rate. It is interesting to note that the target population defined by NHTSA for the benefit analysis only included belted occupants although comments were received that stronger roofs should benefit the unbelted as well. NHTSA concluded from its investigations that roof intrusion during rollovers is related to increased injuries to the head, neck and face among the belted population. However, they did not find compelling evidence of a statistically significant relationship between roof intrusion and head, neck and face injuries to unbelted occupants or between roof intrusion and total ejection. In summary, there was much debate about injury mechanisms and injury predictors related to roof crush which was not resolved fully. NHTSA decided to use the somewhat pessimistic assumption of including only belted occupants in the target population.

It is impossible to use this information to give much guidance for what the benefit may be for the introduction of an FMVSS 216a type test in Europe, except that it is likely to be small on the basis that the benefit for the US is predicted to be small, i.e. 0.6% of passenger car, SUV and pickup fatalities (135/23,400*100). However, the benefit for Europe may be higher because the roof crush strength of cars in Europe may be much less than the US because the FMVSS 216 standard has been in force for many years already in the US whereas there is currently no legislative standard for roof strength in Europe. Also, the target population may be higher because of the higher belt wearing rate in Europe. Alternatively, the roof strength of cars in Europe may be similar to that of cars in the US because many European cars are also sold in the US and the target population may be lower because there are proportionally fewer fatalities in rollover accidents in Europe (in 2012 34% of US passenger car fatalities died in crashes where the vehicle rolled whereas in GB 19% of killed car occupants were injured in roll-over accidents – note these statistics are not available for the whole of Europe).

Ejection Mitigation Measures

In the final regulatory impact analysis (NHTSA 2011) for the introduction of FMVSS 226 for ejection mitigation measures, specifically fitment of a full side curtain airbag compliant with the regulation, NHTSA estimated the benefits to be 373 lives saved and 476 serious injuries prevented annually. The majority of the benefits were predicted for unbelted occupants, but the analysis showed that 12% of the benefits would be for belted occupants (10% from rollovers and about 2% from the side crashes considered). The analysis was adjusted for full compliance with ESC fitment. It was also adjusted for the increase in belt wearing rate which has occurred in recent years, specifically up to 2009, an 84% belt use rate.

C.5.6 Benefit-to-Cost Ratio

Improved Roof Crush Strength

In the final regulatory impact analysis (NHTSA, 2009) for the upgrade of the roof crush resistance NHTSA estimated that the benefit of the introduction of this rule should be to save 190 equivalent fatalities per year at a cost of $6.1 million (3% discount rate) to $9.8 million (7% discount rate) per equivalent life saved. Net benefits (taking into account the cost of the predicted vehicle modifications) of between a benefit of $6 million and a loss of $458 million were calculated based on a monetary value of $6.1 million per equivalent life saved. However, using an alternative value of $8.7 million per statistical life saved a net benefit of $388 million to a net loss of $151 million was calculated. These impacts were disproportionately influenced by the relatively large contributions to costs and small contributions to benefits from vehicles over 2722 kg GVWR, which yield net losses rather than net savings to society. It should be noted that M1 vehicles over 2722 kg are very uncommon in Europe. Therefore, in relation to Europe because of the different vehicle fleet composition the benefit would be relatively higher than for the US. In summary, the FRIA shows that the benefit-to-cost ratio for the upgrade of the roof crush resistance standard, FMVSS 216a, is marginal at best, although for Europe it should be somewhat better because of the different vehicle fleet composition.

It is not possible to use this information to provide good guidance for what the benefit to-cost ratio may be for the introduction of an FMVSS 216a type regulation in Europe. However, it is unlikely to be much better than for the US. This is because costs are likely to be higher in Europe because there is not a roof strength requirement in European regulation at all at present, so the starting point is lower than for the US. Also benefits are likely to be lower because the target population may be lower judged on the fact that there are proportionally less fatalities in rollover accidents in Europe.

However, in contrast it may be the case that many European vehicles would comply with such a regulation already because they are sold in the US and a similar Body-in-White (BIW) structure is used for vehicles sold in Europe. This would reduce costs and help increase the benefit-to-cost ratio.

Ejection Mitigation Measures

In the final regulatory impact analysis (NHTSA, 2009) for ejection mitigation measures NHTSA estimated the net costs per equivalent life saved for the full curtain countermeasure ranging from $1.4 million per equivalent life saved, using a 3% discount rate to $1.7 million per equivalent life saved, using a 7% discount rate. A net benefit from $1,307 million (7% discount rate) to $1,773 million (3% discount rate) was estimated assuming a $6.1 million cost per life and fitment of curtain airbags and rollover sensors to 44% and 55% of vehicles, respectively, without introduction of the standard.

It is very difficult to use this information to give much guidance for what the benefit-to-cost ratio may be for the introduction of an FMVSS 226 type regulation in Europe except that it would most likely be lower. This is because the target population for Europe is likely to be smaller because:

- There are proportionally fewer fatalities in rollover accidents in Europe (in 2012 US 34% of passenger car fatalities died in crashes where the vehicle rolled whereas in GB 19% of killed car occupants were injured in roll-over accidents – note these statistics are not available for the whole of Europe).

- The main benefit for the introduction of this standard is for unbelted occupants and the belt wearing rate is much higher in Europe than the US (95% compared with 85% for front seated passenger car occupants).

Discussion

Based on the above, two main options arise for the way forward to address protection of occupants in rollover accidents. The first is a 'do nothing more' option, in which no additional regulatory measures are proposed. For this option benefit in rollover accidents should be obtained from measures in the process of implementation – fitment of ESC – and those under consideration – extension of seat-belt reminder (SBR) requirements and possibly carry-over benefits could be obtained from regulatory measures, in particular FMVSS 216a and 226, implemented recently in the USA because some cars sold in Europe may meet these US regulations. However, it should be noted that in the stakeholder meeting (see stakeholder meeting minutes) it was indicated that although the Body in White (BIW) structures of car models sold in both the US and Europe are likely to be similar, the restraint systems, including the curtain airbags, are often different. This means that there could be carry-over benefits in Europe from the implementation of FMVSS 216a in the USA, but there are unlikely to be any carry-over benefits from the implementation of FMVSS 226 because this standard is related to restraint systems.

The second option is to implement legislation similar to FMVSS 216a and 226 in Europe. If this option were chosen, further work would be necessary to determine the costs and benefits of implementing one or both of these regulations in Europe. At present the benefit-to-cost ratio for implementation of either of these legislative measures is estimated to be at best break-even with a strong likelihood of it being less cost-effective. However, implementation of these legislative measures would help improve harmonisation with the US.

Noting that there could be possible carry-over benefits in Europe from the implementation of FMVSS 216a in the USA, but not from the implementation of FMVSS 226, a sub-option to option 2 emerges. This is to implement only legislation similar to FMVSS 226 in Europe.

C.5.7 References

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C.6 Vehicle Submersion (M1 vehicles)

Requirements to ensure that vehicle occupants are always capable of escaping a vehicle that is submerged in water.

C.6.1 Description of the Problem

Vehicle accidents where cars are submerged in deep water, such as waterways or canals, or in a roadside ditch, are often serious and complex. In the Netherlands, a country with a large amount of open water alongside roads, accidents in which cars are submerged in water are not rare and can be severe. From 1997-2000 accident data, there were 50 injury accidents a year in the Netherlands where a car ended up in deep water, with an average of 22 deaths a year (Van Kampen, 2002a). For the period 1987-2011, there has been an annual decrease of the number of fatalities in accidents resulting in vehicle submersion to 3.0%. This decrease is slightly smaller than the decrease of the total number of fatalities among car occupants (~4.7%).

Accident data from eight other European countries (i.e. Germany, France, Belgium, the United Kingdom, Austria, Finland, Denmark and Sweden) has shown that the problem of cars submerged in water is minor in those countries (Van Kampen, 2002b).

A study was undertaken in the Netherlands to gain insight into problems connected with car occupants trying to escape from cars submerged in water (Van Kampen, 2002b). This study concluded that new cars are equipped with more and more electronic facilities, such as central door locking devices and anti-hijack locks. These may hinder both entrance to, and exit from, a submerged vehicle; thus affecting the ability to escape and increasing the fatality risk of car occupants. There are additional types of car developments, such as strong laminated bonded side windows, that could present additional problems for escaping from submerged vehicles, as laminated glass windows are almost impossible to smash open from the inside (Transport Safety Board, 2002). Other modern car developments that could hinder escape from submerged vehicles include electrically operated windows and anti-theft devices where they are not functioning correctly after an accident, or if they are short-circuited by water.

Another study was undertaken into the effects of water on the operation of electronic window controls and central door locking systems (Buning et al., 2008). Tests were conducted with the most popular models of car sold in the Netherlands in 2005 and 2006. They showed that, in most cases, electronic window controls and window mechanisms become dysfunctional and unreliable after contact with water which will impede the escape from an immersed car. Test results also showed that the problem of inoperable central door locking systems caused by the effect of water on the locks was small in comparison to that of malfunctioning window systems. However, electronic door locks can become impeded on immersion in water and may become unreliable (Buning et al., 2008). These safety-related problems occur mainly in newer cars that use modern electronic systems extensively.

As electrical and electronic vehicle facilities can lead to additional problems with escaping from a submerged vehicle, a safety hammer can be of assistance (SWOV, 2012). An emergency hammer within reach in a vehicle can be used by occupants to break the glass of a side window in order to escape (Burning et al, 2008).

The correct use of seat-belts, before and while hitting the water, is also of great importance to prevent injury and increases the possibilities of escape (SWOV, 2012). Most crash fatalities result from the force of impact or from being thrown from the vehicle, not from being trapped in a submerged vehicle (NHTSA, 2013).

A safety campaign was conducted in the Netherlands in 2009 to inform motorists what to do if a car enters the water. This information included recommending an escape through the side windows of the car, trying to break the window in a corner of the glass and not in the middle and exiting from the vehicle as quickly as possible before the cabin is completely filled with water. Following this campaign, there was increased awareness that escaping from a car in water is best achieved using an emergency hammer and subsequently there was a 4% increase in the number of drivers having a hammer in their car (Verkeer en Waterstaat, 2010).

Electronic Stability Control (ESC) plays an important role in the prevention of run-off-road accidents and would therefore also reduce submerged car accidents (SWOV, 2012). ESC has been compulsory for new types of passenger car from November 2011 and will become compulsory for all new passenger cars, also for existing models from 1st November 2014. Other starting dates have been set for certain types of trucks and buses.

Other mitigation measures include the use of Intelligent Transport Systems, such as eCall and Electronic Vehicle Identification (Wegman and Aarts, 2006). eCall could speed up the arrival of assistance which could reduce the consequences of vehicle submersion accidents in some, but probably few, cases.

C.6.2 Potential Mitigation Strategies

Strategies could include a combination of the following measures:

- Electronic Stability Control (ESC)
    - As mentioned in the previous section, to help prevent the accident occurring in the first place
    - Note that legislation for the fitment of ESC is in place already
- eCall
    - As mentioned in the section above, eCall could help speed up the arrival of assistance which could reduce the consequences of vehicle submersion accidents in some, but probably few, cases
    - Note that legislation for the fitment of eCall is being considered currently
- Seat-belt
    - The correct use of seat-belts, before and while hitting the water, is of great importance to prevent injury in the accident and therefore increase the possibilities of escape
    - Note that changes to the legislation for seat-belt reminders are being considered currently. These should help increase seat-belt wearing rate
- Emergency safety hammer
    - Emergency safety hammers are objects, with sharp points. Their installation in a vehicle could result in a safety hazard to all the vehicle's occupants if the hammer becomes detached as a result of the initial collision, or when the vehicle hits the water. Emergency safety hammers are provided with a mounting bracket. Some manufacturers of this safety equipment recommend that the mounting bracket is attached either to the vehicle console or the carpet of the vehicle by Velcro, duct tape, double-sided tape or by screws. The hammer should be located so that it is easily reached by the driver and the front-seat passenger. If the front seat passenger is a child (particularly a young child), this could provide an additional safety hazard, as the child might attempt to remove the hammer from its mounting bracket. To prevent this from happening, the safety hammer must be located so that it is out of a child's reach.
- Water resistant electric window regulator
    - Electric window mechanisms become dysfunctional and unreliable after contact with water, which will certainly impede escape from an immersed car (Burning et al., 2008). When water enters an electric window motor, it can cause it to short circuit, resulting in the electric window fuse blowing. A re-designed electric window regulator unit, which prevents water ingress, would improve its reliability in the case of vehicle submersion.

- Water resistant central locking solenoid actuator motor
    - Electronic door locks can become unreliable on immersion in water. This may lead in some car models to situations where doors can no longer be opened, causing difficulties for the occupants to escape from the immersed car (Burning et al., 2008). When water comes into contact with the solenoid motor, it can cause the motor to short circuit and blow the relevant fuse, making the car's central locking inoperable. A re-designed solenoid actuator motor, which prevents the ingress of water, would enable a greater probability of escape through the doors of a partly submerged vehicle.
- Automatic water sensing window operating system
    - An automatic water sensing, window operating system has been developed by King Abdullah University of Science & Technology (KAUST), Saudi Arabia. The vehicle submersion detection module comprises a water sensor that detects vehicle submersions. The location of the sensor in the vehicle enables it to quickly and automatically open the windows in response to detection of an incident, thus giving the vehicle occupants extra time to escape from the vehicle before it is fully submerged. A positional sensor, also installed in the vehicle, detects the orientation of the vehicle. This positional sensor ensures that the windows are only opened once the car has fully rotated to an upright position, to prevent the car filling with water at head level while passengers are upside down.
        - Website: https://innovation.kaust.edu.sa/technologies/submerged-vehicle-safety-system/
- Automatic glass breaker mechanism
    - An automatic glass-breaker mechanism is a patented device (US 7988078 B1) that includes both a sensor component and a glass-breaker component.
    - The sensor component is installed at a low point within the drivers' door of a vehicle. The sensor component contains a water-soluble material that retains a spring in its compressed state so long as the water-soluble material is dry. If the vehicle is immersed in water, the water-soluble material dissolves, releasing the spring. The spring drives a pin into the end of a pressurized gas (e.g. CO2) cartridge, releasing the gas. The gas passes through a tube to the glass-breaker component installed upon the glass just below the top of the door to drive a spiked piston into the glass and shatter the window.

It should be noted that apart from the ESC, seat-belt and eCall measures, all the other measures assume that the occupant is capable of escaping the vehicle, i.e. is conscious and not severely injured.

C.6.3 Feasibility

M1 vehicles		
Mitigation measure	Feasibility	Comments
Emergency safety hammer	Feasible	Regulations would need to ensure that vehicle manufactures provide a safe installation of the safety hammer.
Water resistant electric window regulator	Feasible	Unit would need to be totally water resistant to guarantee improvement in reliability with immersion.

M1 vehicles		
Mitigation measure	**Feasibility**	**Comments**
Water resistant central locking solenoid actuator motor	Feasible	Unit would need to be totally water resistant to guarantee improvement in reliability with immersion.
Automatic water sensing window operating system	Possibly feasible	Installation and integration into a vehicle are said to be straightforward (according to the equipment designer), but there are safety concerns that the unit would not open the windows automatically if the car is submerged upside down.
Automatic glass breaker mechanism	Probably not feasible	The technology is complex and would probably require a considerable amount of development to integrate the unit into a car door.

C.6.4 Costs

Based on a retail cost of about €6, the cost for an emergency hammer to a vehicle manufacturer buying in bulk was estimated to be about half, i.e. €3.

No specific costs could be found for the other escape related measures considered, but it is likely that they would be higher than for an emergency hammer on the basis that they are considerably more complex.

C.6.5 Benefits

The target population is small:

- In the Netherlands, a country with a large amount of open water alongside roads, accidents in which cars are submerged in water are not rare and can be severe. From 1997-2000 accident data, there were 50 injury accidents a year in the Netherlands where a car ended up in deep water, with an average of 22 deaths a year (Van Kampen, 2002a).
- Accident data from eight other European countries (i.e. Germany, France, Belgium, the United Kingdom, Austria, Finland, Denmark and Sweden) has shown that the problem of cars submerged in water is minor in those countries.
    - For example, in the UK there were 9 reported single vehicle fatal accidents in 2012 where the vehicle was submerged in water.

And the effectiveness is likely to be small because:

- Most crash fatalities result from the force of impact or from being thrown from the vehicle, not from being trapped in a submerged vehicle (NHTSA, 2013).
- The correct use of seat-belts, before and while hitting the water, is also of great importance to prevent injury and increase the possibilities of escape (SWOV 2012)

Therefore the benefit is likely to be small.

C.6.6 Benefit-to-Cost Ratio

As an example, a rough calculation for an emergency hammer for the UK:

$$Benefit \;=\; target\ population * effectiveness * conversion\ into\ monetary\ value$$

$$= 9\,fatals * 0.10\,(estimate\ save\ 1\ in\ 10) * €1{,}546{,}503\,(Edwards\ et\ al.\ 2014;\ European\ Commission\ 2014) = €1{,}391{,}852$$

$$Cost = Number\ of\ new\ registered\ cars\ per\ year * cost\ per\ car\ of\ fitting\ countermeasure$$
$$= 2{,}264{,}737\ for\ year\ 2013\,(ACEA\ 2014) * €3 = €6{,}794{,}211$$

$$Estimated\ benefit\text{-}to\text{-}cost\ ratio\,(BCR) = 0.2$$

This indicates that the BCR is much less than 1 for the UK for the emergency hammer countermeasure. Other countermeasures are likely to be more expensive, so therefore the BCR is likely to be worse.

The BCR indicates that it is currently not worthwhile introducing requirements into legislation into Europe to ensure that vehicle occupants are always capable of escaping a vehicle that is submerged in water. However, it is recommended when considering measures for legislation for other purposes, such as anti-theft measures, the effect of these on escape from a vehicle should be quantified before their implementation.

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Appendix D. HGV Safety

D.1 Lateral Protection of Trailers/Trucks (removal of some exemptions)

Goods vehicles with a maximum mass exceeding 3.5t and trailers with a maximum mass exceeding 3.5t are required to be fitted with structures to reduce the open space ahead of the rear axle(s) to provide protection to pedestrians and cyclists in collision with the side of such vehicles, reducing the likelihood of them being run over. Currently there are some exemptions to fitting these structures and this measure looks at the potential costs and benefits of ending these exemptions.

D.1.1 Description of the Problem

Early research demonstrated that in collisions of trucks against bicycles and mopeds, the nearside of the truck was the most frequently contacted and the most dangerous impact location (Walz et al., 1990). Those authors suggested that in all new trucks, flat side guard panels should be integrated and current trucks should be retrofitted correspondingly. This was on the expectation that side guards prevent unprotected road users (users of mopeds and bicycles, pedestrians) from being thrown under the truck side and subsequently over-run by the wheels.

UN Regulation 73 provides uniform provisions concerning the approval of goods vehicles, trailers and semi-trailers with regard to their lateral protection. The aim of this regulation is that those vehicles covered within the scope offer effective protection to vulnerable road users against the risk of falling under the sides of the vehicle and being caught under the rear wheels. This Regulation applies to the lateral protection of complete vehicles. It applies for goods vehicles with a maximum mass exceeding 3.5 tonnes (N2 and N3) with a maximum design speed greater than 25 km/h, and trailers (including semi-trailers) with a maximum mass exceeding 3.5 tonnes (O3 and O4) with a design speed greater than 25 km/h.

The equivalent Council Directive 89/297/EEC is to be repealed by Regulation (EC) No 661/2009 (General Safety) with effect from 1 November 2014.

In a review of the existing under-run legislation, Bovenkerk (2006) noted;

> *"Regulation 73 concerns lateral attached guards for heavy good vehicles, trailers and semi-trailers. These side guards represent an effective under-run protection for pedestrians and cyclists in case of a lateral impact. In addition parts which stand out from the vehicle have to be arranged in such a way that no sharp edges evolve… Components permanently fixed to the vehicle, e.g. spare wheels, battery box, air tanks, fuel tanks, lamps, reflectors and tool boxes may be incorporated in the side guard, provided that they meet the dimensional requirements of this regulation."*

When the rear under-run and side guard regulations were introduced there was strong opposition from industry, with the main concern being the effect of smaller ground clearances on operations. This opposition was overcome by exempting some vehicles from the regulations. This includes many tipper, construction, cement lorries etc. These vehicles involved in the construction industry are responsible for many of the cycling fatalities (European Cyclists' Federation, 2014). Accident studies have suggested that a number of fatalities could be prevented if such vehicles were not exempt from the Regulation (Knight et al., 2005).

The exemptions for the UN Regulation are:

- Tractors for semi-trailers;
- Vehicles designed and constructed for special purposes where it is not possible, for practical reasons, to fit lateral protection devices.

The exemptions for the EC Directive are:

- Tractors for semi-trailers,
- Trailers specially designed and constructed for the carriage of very long loads of indivisible length, such as timber, steel bars, etc.,
- Vehicles designed and constructed for special purposes where it is not possible, for practical reasons, to fit such lateral protection.
- By derogation from the above provisions, vehicles of the following types need comply only as indicated in each case:
  - An extendible trailer shall comply with all of the geometrical and strength requirements when closed to its minimum length; when the trailer is extended, the side guards shall not comply with the ground clearance requirement, the upper edge to vehicle structure requirement or the strength requirements, also the distance from either the front or rear wheel; extension of the trailer shall not produce gaps in the length of the side guards;
  - a tank-vehicle that is a vehicle designed solely for the carriage of fluid substance in a closed tank permanently fitted to the vehicle and provided with hose or pipe connections for loading or unloading, shall be fitted with side guards which comply so far as is practicable with all the requirements; strict compliance may be waived only where operational requirements make this necessary;
  - On a vehicle fitted with extendible legs to provide additional stability during loading, unloading or other operations for which the vehicle is designed, the side guard may be arranged with additional gaps where these are necessary to permit extension of the legs.
  - On a vehicle equipped with anchorage points for Ro-Ro (Roll-on, Roll-off) transport, gaps shall be permitted within the side guard to accept the passage and tensioning of fixing lashings.

Robinson et al. (2010) estimated EU-27 casualty numbers in accidents involving N2 or N3 vehicles (see Table 3). These figures are based on average numbers from the years 2005-2007 and involved up-scaling from EU-16 data.

	Lower estimate	Mid estimate	Upper estimate
Fatally injured	7,070	7,070	7,212
Seriously injured	21,950	35,352	44,189
Slightly injured	84,203	212,109	371,191

Table D-3: Estimated annual EU-27 casualties involving N2 or N3 vehicles, based on numbers from 2005-2007 (Robinson et al., 2010)

The latest publicly available European fatality numbers (year 2011) are summarised in Table D-4. It can be seen that the numbers have decreased since the study by Robinson et al. was performed. The average annual reduction of fatalities involving N2/N3 vehicles between 2001 and 2011 was 6% (ETSC, 2013). The percentage breakdown by type of road user killed remained stable between 2001 and 2011 (ETSC, 2013). Numbers cited by ACEA for EU-24, which were collated from various external sources, are slightly higher (4,800 fatalities) with a similar distribution by type of road user (HGV occupants: 15-20%; passenger car occupants: 55-65%; VRUs: 15-25%) (ACEA, 2014). Using the ETSC figures for further calculations can therefore be considered a conservative approach.

Table D-4: EU-27 fatalities involving N2 or N3 vehicles in 2011 and estimated breakdown by type of road user killed (ETSC, 2013)

	Fatalities
Fatalities in 2011	4,254
of which:	
HGV occupants	511 (12%)
Passenger car occupants	2,127 (50%)
VRUs (including PTWs)	1,191 (28%)
Other road users	425 (10%)

Volvo Trucks (2013) estimated that in more than 75% of the fatal accidents involving pedestrians and cyclists, the unprotected road user is run over by one or more of the truck wheels.

Welfers et al. consider the scenarios in which VRUs are Killed or Seriously Injured (KSI) by an HGV. One of the prominent HGV-VRU scenarios was the involvement of the HGV side with the VRU when the vehicle was turning. Depending on the source of this information, this scenario accounted for 18 to 26% of the VRUs that were KSI. A figure of 20% is also cited by ACEA (2014) and Feist (2006) for unprotected road user accidents involving a heavy truck during a turning manoeuvre. Another prominent scenario was the rear of the HGV versus the unprotected road user, where the HGV is driving past, or overtaking the VRU. This scenario accounts for another 10 to 22% of the VRUs that were KSI (e.g. Volvo Trucks, 2013). Applying this range of percentages to the number of VRUs killed in accidents involving N2 or N3 vehicles, as shown in Table D-3, yields the target populations shown in Table D-5.

Table D-5: Estimated annual EU-27 fatality target population for improved HGV side interactions

	Total number of EU-27 fatalities	Proportion of these potentially affected by HGV side guards	Resulting target population
VRUs involved when HGV is turning	1,191	18%-26%	214-310
VRUs involved when HGV is overtaking	1,191	10%-22%	119-262

No estimate was identified for the target population of seriously or slightly injured casualties. The distribution of accident scenarios among these could be markedly different compared to fatal accidents.

D.1.2 Potential Mitigation Strategies

Technological solutions exist to help avoid VRU accidents involving HGVs. For instance, camera systems are available to enhance the field of view around the vehicle for the driver. Other systems attempt to detect VRUs and alert the driver of the HGV to their presence. Less technologically advanced primary safety solutions may also include blind spot mirrors.

However, until these systems eradicate VRU accidents with HGVs, secondary safety systems could also deliver a safety benefit. Therefore, it has been asserted that as many vehicles as possible should be fitted with side guards, there should be only a few cases where the side guards are not fitted because it is considered "not practical" (Bovenkerk, 2006). In the UK approximately 20% of HGVs are currently exempt from fitting side guards. In a review of conditions leading to fatal cyclist accidents in London, Talbot et al. (2014) recommended that, "Vehicle manufacturers and lorry operators … fit and retrofit all lorries (unless proved impossible or impractical) with front and redesigned full (horizontal and vertical) side guards without exception."

Knight et al. (2005) considered what alternative statements could be made about vehicles in order that an exemption from the lateral protection regulation was based on design or operational factors rather than a subjective interpretation of practicality. Their analysis of the exemptions in the UK and EC Regulations/Directives suggested that the basic factors determining whether a vehicle is exempt are as follows:

- The off road capability (e.g. tippers, agricultural vehicles, military vehicles etc.)
- The use of ancillary equipment essential to the vehicle function (e.g. road sweepers, concrete mixers etc.)
- The presence of chassis/body structure in the areas covered by the safety guard requirements

Each of these was then considered to see whether such a factor is relevant to any particular vehicle and whether they merit an exemption.

> *"<u>Off-road performance;</u>*
>
> *At present, it is considered that many of the exemptions from safety guard regulations have been based on the requirement for that specific type of vehicle to be able to travel "off-road". However, the exemption tends to be awarded based on vehicle type such that the "off-road" use is never objectively defined.*
>
> *It is possible to consider a number of levels of "off-road" performance:*
>
> - *On-road – that is roads made of hard surfaces such as concrete or asphalt*
> - *Unmade road – clearly travelled roads, tracks or trails, constructed from packed earth and/or gravel*
> - *Completely off-road – travel where no road, track, or trail exists. Surfaces and profiles can be anything that naturally occurs from rock through to deep mud or water and can involve steep gradients*
>
> *Initial consideration of how to define vehicles that should be exempt was based upon the definition of off-road vehicles contained in EC Directive 70/156. This definition (Type G) specifies a range of criteria such as ground clearance, ramp angles, number of driven wheels etc., which must be met in order to qualify…*
>
> *It can be seen that using the type G classification to define the exemptions from safety guard regulations would offer substantial benefits by reducing the number of exempt vehicles on the road. However, the definition would need to be made considerably more demanding to end the exemptions for many other vehicles that do not get used in very severe off-road operations.*

An alternative approach to this problem would be to require adjustable or demountable safety guards for off-road vehicles such that they are equipped when travelling in areas of risk (on-road) and can move or remove them when required to travel off road. Guards that were adjusted manually could potentially be achieved relatively simply with little cost or weight implications but would require enforcement action to ensure that drivers always deployed them on-road. Guards that could be adjusted automatically from switches in the cab would be more likely to be used but would be more complex and would therefore increase cost and weight.

Ancillary equipment;

The use of ancillary equipment can create genuine difficulties installing underrun guards. However, in many cases it would still be possible to fit guards that improved safety without compromising operational performance, although in some cases this may require innovative design and increase cost… A suitable approach to this particular problem may be to keep a generic exemption but then to issue guidelines or a code of practice for type approval agencies that helps them to define what constitutes "impractical" or "inconsistent with its use". This could be based upon a variety of specific criteria relating to the type of vehicle and its use as well as more generic criteria perhaps associated with certain percentage cost or weight increases if safety guards are fitted. Guidelines or a code of practice also have the advantage that they are easier to amend and update than regulations such that it will be relatively easy to keep them up to date in light of new technology or vehicle designs.

The presence of chassis/body structure;

The presence of chassis or body structure in areas where underrun protection is required can potentially remove the need for underrun protection. However, there are a number of vehicles currently exempt from the Regulations, for example fire engines or dustcarts, that do voluntarily have body structure in the areas covered by the safety guard regulations. For these vehicles the structure does not have to conform to any of the strength or protrusion requirements of the Regulations and, therefore, may not offer the protection intended by the regulations.

An appropriate way to deal with such vehicles may be to end any specific exemptions and to amend the regulation such that vehicle or body structure may replace the safety guard provided that it can be demonstrated that it fulfils the principal requirements for dimensions, strength and presenting a smooth surface to vulnerable road users. A vehicle such as a fire engine could still be exempt from the requirements if it can be categorised as an off-road vehicle and vehicles such as a dustcart could still be exempt if it can be shown that the use it is put to makes it impractical to do so under the guidelines system discussed above." (Knight et al., 2005)

As an alternative to trying to rule out exemption and derogation paths, Smith (2006) reported on test procedures and assessment criteria for a Heavy Vehicle Aggressivity Index (HVAI). The aim of the HVAI was to encourage HGV manufacturers to develop vehicles that could reduce the number or severity of VRU casualties from accidents involving HGVs. It included a component based on the risk of the casualty being run over by the HGV, as developed by IKA. The assessment was made via modelling which involved the vehicle turning into a VRU, an overtaking scenario and head-on strikes. Some refinement of the procedures would be necessary before they could be adopted for routine use in assessing side guard effectiveness, for example as part of a consumer information programme or certification scheme. Without further assessment, it is not certain whether this approach could be adopted for use in a legislative framework in its current guise.

It is possible that changes to existing side guard designs could mitigate the severity of injury for VRUs involved in a collision with an HGV. However, this measure considered the additional fitting of lateral protection to vehicles without any side guards, rather than changes to existing structures. Therefore those potential benefits were outside of the scope of this review. However, it was recommended by some stakeholders to consider changes to the existing side guard regulation to improve lateral protection as well as this measure to improve the fitment of side guards throughout the vehicle fleet.

It was mentioned during the stakeholder consultation that the implementation of exemptions is inconsistent throughout Europe, with some vehicles having removable lateral protection whilst others have no protection due to derogation. Any explicit definition which harmonises the situation across Europe may have additional side-benefits which are not assessed in this review.

Following the stakeholder consultation, ACEA put forward the proposal that it could be considered to include in the section of the regulation relating to exemptions a sentence saying that any exemption should be considered only after every possibility to fit the device has been considered and found impossible. This could be sufficient.

D.1.3 Feasibility

The main difficulties with side guards are well established. The first is that reduced ground clearance is important for optimum safety performance, but this can cause manoeuvrability problems in some circumstances. Ground clearance is important on vehicles that are required to take part in manoeuvres over raised obstacles such as ferry-ramps or uneven terrain. There were no publications identified that proposed full solutions to these difficulties. The second problem is that the side guards represent additional weight, which in turn reduces the vehicle payload (Knight et al., 2005).

To be able to remove exemptions from the UN lateral protection regulation or EC Directive, consideration would need to be given as to how feasible it is for all vehicles to have side guards fitted. In the previous section Knight et al. (2005) was cited as introducing several levels of 'off-road' performance. Assuming that some off-road lorries may need only to travel over a slightly irregular unmade road, then it may be feasible for side guards to be fitted. Conversely, if a vehicle genuinely needs a high ground clearance to be able to perform its required functions, then side guards may not be fitted reasonably. Although, technical solutions could be found via adjustable or removable side guards, these would be higher cost items than may be needed for other vehicles.

To evaluate the potential safety improvements for lorries in London, Robinson and Cuerden (2014) estimated the proportion of HGVs travelling within this city that did not have lateral protection fitted, compliant with the Regulation/Directive. They estimated that between 10.5 and 26 percent of the HGV fleet required side guard fitting to improve lateral protection further. They also noted that, "Those vehicles typically exempt from side guards are far more frequently the largest heaviest type of rigid vehicle." (Robinson and Cuerden, 2014)

An additional question is, 'For how many vehicles one could fit side guards without preventing them from completing their usual functions?' No information was found to address this. Transport for London (TfL) notified TRL of a project 'Operational Conditions Research' (by AECOM) which aims to research, develop and launch a system classifying construction and other off-road sites by the ground conditions. This classification will determine the specification of the vehicle required to service each typology in terms of its off-road capability and through detailed specification aid the uptake of safer, lower vehicles fitted with lateral and other under run protection. However, whilst the issue of functional off-road requirements remains open, it may conflict with implementation and enforcement options for on-road use. One solution would be to require side guards to be in place, at least, during on-road use. However, no assessment is available demonstrating how the burden of fitting adjustable or removable side guards to those vehicles genuinely involved in off-road activities may affect the potential balance of benefit and cost. Equally, no enforcement solution has been proposed at the national or international level, rather than for a city with cameras and automatic number plate recognition.

It was generally agreed during the stakeholder consultation that the removal of the exemptions would be welcomed and no evidence has been obtained which demonstrates why this is not feasible.

D.1.4 Costs

Costs for side guards have been estimated by the Fleet Operator Recognition Scheme (FORS, n.d.). The price band is £400 - £1,500 (€480 - €1,800) for retrofit solutions. It is anticipated that a vehicle manufacturer may be able to obtain side guards at a considerably lower cost than through this route at the point of production. However, no information was found with which to quantify that reduction in cost, therefore these values have been taken as a 'worst case' in the subsequent sections.

D.1.5 Benefits

Cookson and Knight (2010) considered the effect of side guards on accidents where cyclists collide with the side of an HGV passing, approximately, in a straight line. They state that side guards have no effect on the frequency of accidents but have been very effective in reducing the severity of injuries received by pedal cyclists when such accidents do occur. However, when the effect of side guards on accidents where a cyclist collides with the nearside of an HGV turning to the nearside was considered, the findings were more variable. In-depth accident case studies suggested that turning left accidents often involved a collision with a cyclist towards the front of the vehicle which knocks the cyclist to the ground. As the HGV progresses with its turn, the rear of the vehicle 'cuts-in' to the corner and the side guard passes over the top of the cyclist who gets run over by the rear wheels.

Cookson and Knight (2010) also performed an analysis of the UK Stats19 accident data considering accidents prior to the introduction of side guards (1980-1982) and after that (2006-2008). They further separated the collision types to consider only those manoeuvres where the HGV was overtaking a moving vehicle on its offside or was turning to its nearside. As mentioned, the change in proportion of casualties being fatally injured if involved in an accident of this type was very different for the two scenarios. The numbers were small but indicated that the fatality risk had dropped by 54% for the overtaking scenario but increased by 19% for the turning scenario.

The multibody Madymo computer simulation work carried out by Knight et al. (2005) compared the loads transmitted to, and injuries sustained by, pedal cyclists and pedestrians falling against the side of an HGV moving in a straight line and equipped with either traditional rail type side guards or smooth integrated side guards. The results of the simulations showed that a traditional side guard design was very effective at preventing the upper body of vulnerable road users from being run over by the rear wheels. However, it also showed that it was still possible for the vulnerable road user to receive severe injuries which could prove fatal, particularly head injuries resulting from contact with the ground.

When Knight et al., studied the U.K. national accident data, they found evidence to support the simulation findings that current side guards prevent cyclists being run over by an HGV travelling straight ahead. The injury severity distribution for cyclists colliding with the nearside of an HGV has changed substantially with a 61% reduction in the proportion of casualties killed. In addition to this it was shown that exempt vehicles were statistically over-involved in accidents of this type. However, there was much less accident evidence of the effectiveness of side guards in other manoeuvres and where pedestrians were involved.

The benefits of ending the exemptions from the side guard regulations were estimated by Knight et al. based on enhanced STATS19 data. The proportion of registered vehicles that are not exempt and are involved in accidents was calculated (Table D-6). This proportion was then applied to the total number of registered vehicles in the fleet to estimate the number of casualties there would be if the exemptions were ended.

Table D-6: Estimated percentage of HGV collision casualties prevented by ending exemptions to side guards (Knight et al., 2005)

	Vehicle stock values	Percentage change in number of HGV collision casualties		
		Fatal	Serious	Slight
Pedal cyclists	Mid	-5.5 %	-1.5 %	+1.5 %
	Lower	-6.3 %	-2.3 %	+2.1 %
Pedestrians	Mid	-0.3 %	-0.3 %	+0.7 %
	Lower	-0.9 %	-1.4 %	+6.3 %

Based on European casualty figures for all accident types, we would expect 2.8 times more pedestrian casualties than cyclists (CARE, 2012). A similar figure may also be expected for HGV accidents where the side of the vehicle is involved: Robinson et al. (2009) report a factor of 3.2 for accidents involving HGVs. Applying the appropriate percentage change in pedal cyclist and pedestrian fatalities to the target population figures provided in Table D-5, then the absolute minimum and maximum casualty savings would be between 5 and 13 fatalities each year for the EU. This seems to agree, in broad terms, with the estimate from Feist (2006) who predicted that 14 fatalities could be prevented in 2016, assuming several safety features were implemented in the HGV fleet, including better side skirts.

The monetary benefits that can be expected from the reduction in fatalities may be in the range from approximately 7.8–20.3 million Euros per annum across EU-27 (see Table D-7). However, the precise implications for the exemptions on the casualty population in Europe cannot be determined without data on the rate of derogations/exemptions for all countries.

Table 7: Annual monetary benefit from fatality reduction for EU-27

Annual fatality reduction	5-13
Cost per fatality[21]	€1,564,503
Annual monetary benefit (from fatality reduction)	€7,822,515 –€20,338,539

As part of the stakeholder consultation process, ACEA made the suggestion that the benefit identified here may overlap with other measures being considered; therefore, that the combined benefits of other measures should be included in the analysis. One measure under consideration is to allow the use of the side lights as direction indicators that could address some of the same accidents with turning trucks and cyclists as the target population for lateral protection. Another measure potentially targeting the same accident type is the additional lower window in the passenger door. It should be noted that where target populations overlap implementation of one measure may reduce the available benefit for another. However, this wouldn't affect the benefit on offer for any single measure now.

[21] European average value. See main body of report for details.

D.1.6 Benefit-to-Cost Ratio

A break-even cost per vehicle is calculated to give an indication of the tolerable costs. Each year there are 295,050 new N2 and N3 vehicles registered in EU-27 (figure from 2012) (ACEA, n.d.). However, we expect that only 10.5 to 26% of these are exempt from the lateral protection requirements. Therefore assuming between 30,980 and 76,713 vehicles could benefit from improved side guards, and using the expected annual monetary benefit from reductions in fatalities (Table D-8), the break-even value per vehicle for removing vehicle exemptions to the lateral protection would be €102-€657.

Table D-8: Break-even cost of removing lateral protection exemptions for HGVs per vehicle for EU-27

Break-even cost per vehicle of category N2/N3	€102–€657

It should be noted that this excludes trailers from the calculation.

Using the cost figures obtained from the Fleet Operator Recognition Scheme, the benefit-to-cost ratio for fitting the currently exempt N2 and N3 vehicles with lateral protection would lie in the range from 0.06:1 to 1.37:1.

D.1.7 References

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D.2 Safer HGV Front End Design

An amendment to the weights and dimensions legislation for HGVs has been proposed by the European Commission (EC) to permit changes to the design of vehicle front ends to improve aerodynamics and can also be used to improve road safety. This change in legislation might offer an opportunity to define mandatory technical requirements improving the design of HGV front ends, which has the potential to improve the protection of car occupants and Vulnerable Road Users (VRUs) involved in accidents with HGVs, as well as HGV drivers and passengers themselves.

D.2.1 Description of the Problem

Background

HGVs are involved in a disproportionally high number of fatal collisions; more precisely in about twice as many per distance travelled as the average vehicle (ETSC, 2013). The casualties in these collisions are in most cases occupants of passenger cars and vulnerable road users. HGV occupants are also fatally injured in collisions, but much less frequently.

An amendment to Directive 96/53/EC, the weights and dimensions legislation for HGVs, has been proposed by the European Commission (EC) to increase the design freedom for changes to the vehicle front ends that would improve aerodynamics (and therefore fuel economy) and road safety. Today, all HGV cabs have a similar design featuring a flat front end in order to maximise the interior space in the cab at a given cab length. The current legislation effectively limits the length of HGV cabs[22] which somewhat restricts the design of safe front ends. It was proposed to grant derogation from this length limit on the condition that the changes in cab design lead to enhanced aerodynamics and fuel saving. The changes in cab design could also be used to improve road safety (European Commission, 2013b). The Position of the European Parliament suggests making safer cab designs mandatory after a certain lead time (European Parliament, 2014).

This change in legislation might offer an opportunity to define mandatory technical requirements improving the design of HGV front ends, which has the potential to:

- Improve the protection of VRUs (e.g. by an improved field of view for the HGV driver, and by vehicle front end shapes that deflect VRUs to the side in impacts to prevent run-over injuries);
- Improve the protection of car occupants (e.g. by an improved, energy-absorbing front under-run protection); and
- Improve the self-protection of the HGV occupants (e.g. by crumple zones at the HGV front end).

The present study focuses on safety aspects associated with mitigation strategies made possible by the amended legislation. Fuel savings through aerodynamic improvements are not in scope.

[22] The length of the cab is not specifically limited; however, the limited maximum overall vehicle length and the commercial need to maximise the load space behind the cab in a competitive market effectively limits the cab length.

Casualty Numbers and Target Population

Robinson et al. estimated EU-27 casualty numbers in accidents involving N2 or N3 vehicles (see Table D-9). These figures are based on average numbers from the years 2005-2007 and involved up-scaling from EU-16 data (Robinson et al., 2010a).

Table D-9: Estimated annual EU-27 casualties involving N2 or N3 vehicles, based on numbers from 2005-2007 (Robinson et al., 2010a)

	Lower estimate	Mid estimate	Upper estimate
Fatally injured	7,070	7,070	7,212
Seriously injured	21,950	35,352	44,189
Slightly injured	84,203	212,109	371,191

The latest publicly available European fatality numbers (year 2011) are summarised in Table 10. It can be seen that the numbers have decreased since the study by Robinson et al. was performed. The average annual reduction of fatalities involving N2/N3 vehicles between 2001 and 2011 was 6% (ETSC, 2013). The percentage breakdown by type of road user killed remained stable between 2001 and 2011[23] (ETSC, 2013). Numbers cited by ACEA for EU-24, which were collated from various external sources, are slightly higher (4,800 fatalities) with a similar distribution by type of road user (HGV occupants: 15-20%; passenger car occupants: 55-65%; VRUs: 15-25%) (ACEA, 2014). Using the ETSC figures for further calculations can therefore be considered a conservative approach.

Table D-10: EU-27 fatalities involving N2 or N3 vehicles in 2011 and estimated breakdown by type of road user killed (ETSC, 2013)

	Fatalities
Fatalities in 2011	4,254
of which:	
HGV occupants	511 (12%)
Passenger car occupants	2,127 (50%)
VRUs (including PTWs)	1,191 (28%)
Other road users	425 (10%)

Based on the above cited numbers from 2005-2007 and on assumptions about distribution of accident scenarios, Welfers et al. estimated the casualty target populations

[23] The overall annual reduction and the breakdown might change in the future due to factors such as: primary safety technologies (for example, autonomous emergency breaking systems (AEBS) addressing front-to-rear impacts against other vehicles) and secondary safety measures (for example, the recently increased cab strength requirements) on the one hand; or increased trends towards urbanisation and higher cyclist rates on the other hand. No estimate was available to quantify these influences for the present initial review.

for improved HGV frontal structures, i.e. the annual number of casualties that can potentially be expected to be influenced by improved HGV front ends (Welfers et al., 2011). The figures are summarised in Table 11. A range of assumptions had to be applied by the researchers: for example, an identical involvement rate of different road user groups in EU-27 as in EU-18. TRL considers the general approach taken for the calculation valid and considers them a reasonable indication of the situation in the years 2005-2007, although the ranges given seem narrow, considering the magnitude of the assumptions taken.

Table D-11: Estimated annual EU-27 fatality target population for improved HGV frontal structures for the years 2005-2007 (Welfers, et al., 2011)

	Total number of EU-27 fatalities (2005-2007)	Proportion of these potentially affected by HGV front end design	Resulting target population (2005-2007)
HGV occupants	989	62%-100%	613-989
Passenger car occupants	3,535	60%-75%	2,121-2,298
VRUs (potentially affected by deflecting front end)24	1,555	30%-35%	467-544

Research by Cook et al. suggests that current vehicle designs exhibit considerable blind spots for the driver (Cook et al., 2011c). Unfortunately, the target population for improved direct vision was not quantified by Welfers et al. Based on data about different accident scenarios included in their report it is possible to estimate an upper boundary of the target population at 61% of the VRU casualties.[25] According to unpublished figures cited by ACEA, approximately 7% of all fatal casualties involving an HGV are VRUs related to visibility[26] (ACEA, 2014). This ratio is used to provide the lower boundary of the target population.

Note that this sub-group of VRUs partially overlaps with the target population for deflecting front ends, which is why the numbers cannot simply be summed.

Applying these estimated proportions of potentially affected fatalities to the most recent casualty numbers (Table D-10) results in the estimate of the European fatality target population for safer HGV front end designs as detailed in Table D-12.

No estimate is available for the target population of seriously or slightly injured casualties. The distribution of accident scenarios among these could be markedly different compared to fatal accidents.

[24] Accident scenarios 1 (HGV front vs. VRU when pulling away) and 3 (HGV vs. VRU crossing road) from (Welfers, et al., 2011). It is not clear from the report whether PTWs are included.

[25] Accident scenarios 1 (HGV front vs. VRU when pulling away), 3 (HGV vs. VRU crossing road) and 4 (HGV side vs. VRU when turning) from (Welfers et al., 2011). It is not clear from the report whether PTWs are included.

[26] The document cites 1% in frontal collisions with pedestrians and 6% in collisions with cyclists. Throughout the document, the ratios are sometimes presented as fatalities and sometimes as severe accidents.

Table D-12: Annual EU-27 fatality target population for improved HGV frontal structures

	EU-27 fatality target population
Passenger car occupants	1,276-1,595
HGV occupants	317-511
VRUs	357-727
of which[27]:	
VRUs (potentially affected by direct vision)	(298-727)
VRUs (potentially affected by deflecting front end)	(357-417)
Total	2,198-2,833

D.2.2 Potential Mitigation Strategies

Improvements to Direct Vision

The driver's field of view is made up of the areas that can be seen through front and side windows (direct vision) and via mirrors or other supporting devices such as cameras (indirect vision[28]). Many accidents between HGVs and VRUs occur because pedestrians or cyclists are not visible to the driver (Volvo Trucks, 2013) and could be prevented by improved direct vision to the front and to the side from the HGV driving position.

Cook et al. performed a large amount of previous work on problems and potential improvements to HGV vision (Cook et al., 2011a), (Cook et al., 2011b), (Cook et al., 2011c). The problems in conventional cab designs were also recently assessed in a study by Delmonte et al. (2012). Using laser scanning on three current HGV models, the study analysed the direct visibility of a cyclist of 1.5 metres height placed at different positions in proximity of the cab (see Figure D-23). Through the windscreen, only cyclists 13 and 14 were entirely visible and cyclists 9, 11, 12 were partially visible (see Figure D-24); all other cyclists were not visible. Through the nearside window, only cyclist 7 was partially visible (only in some models); all other cyclists were not visible.

With an adapted design, the driver would be able to detect a larger proportion of VRUs around the vehicle who would be occluded in current cab designs. Direct vision will mitigate mainly the problem of low-speed run-overs (some reports cite closing velocities of up to 20 km/h (Feist and Faßbender, 2008)) in critical situations, such as pulling away from traffic lights and turning.

Note that other accident scenarios, such as side-swipe collisions with cars, can also be influenced by improved direct vision. While these occur rather frequently, the resulting number of fatal and serious casualties is expected to be relatively low (Summerskill and Marshall, 2014), which is why they are not addressed further in the present study.

[27] Note that the two groups of VRU casualties are not distinct, which is why the total number cannot be obtained by summing the numbers. See earlier explanation in relation to (Welfers et al., 2011).

[28] Note that indirect vision is not in scope of the present section of this study.

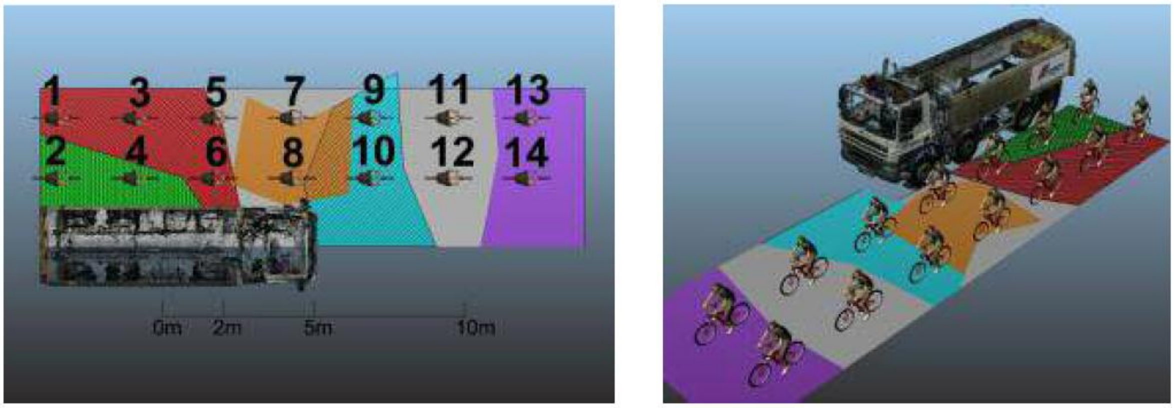

Figure D-24: Visibility of cyclists (positioned 1–3 metres sideways from cab) from the driver's position (British right hand drive model). Ground projection of direct vision through windscreen is shown in purple; ground projection of direct vision through side window is outside of the displayed area; indirect vision through mirrors is shown in other colours. (Delmonte et al., 2012)

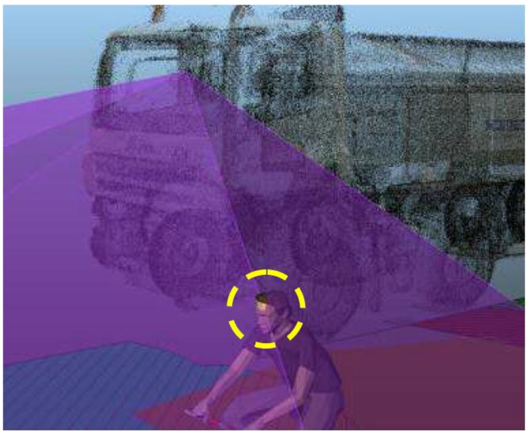

Figure D-25: Three dimensional illustration showing the small area of the forehead that is directly visible in the lower nearside corner of the windscreen (Delmonte et al., 2012)

An improvement of direct vision could be achieved by adding extra glazed areas to the driver's cab. An example of a historic vehicle using this approach to a limited extent is the Leyland Roadrunner (built 1984–1993) which featured an additional 'kerb window' for improved direct vision. An improvement could also be achieved by adding extra glazed areas or designing larger windscreens and side windows that extend further down than in current designs, as visualised, for example, in a virtual design study by the London Cyclist Campaign (London Cyclist Campaign, 2013). The window on the passenger's side is of particular importance with respect to turning accidents (Niewoehner and Berg, 2005).

Lowering the overall position of driver and cab and thereby bringing the driver's line of sight closer to the level of cyclists and pedestrians could also contribute to a better detection rate. To allow for this to happen, other structural parts would have to be relocated, which could be facilitated by extended cab dimensions. Note that the nose cone design, discussed in the following section, also reduces blind spot areas.

Improvements to VRU Impact Performance

The injury outcome of VRUs in collisions with HGVs is dependent on the phase of primary contact between vehicle and VRU, on the secondary contact with the road surface or road-side objects, and on whether or not a subsequent run-over occurs. All three of these phases are to a certain extent determined by the front end design of the impacting

HGV. Nevertheless, the protection of VRUs in this respect is not currently covered in legislation.

The EC-funded project Advanced Protection Systems (APROSYS), which finished in 2009, started by carrying out a review of strategies for a pedestrian- and cyclist-friendly design (Bovenkerk, 2006). This review concluded that many improvements would be possible within the limits of the current cab dimension legislation, such as:

- Reducing the stiffness of key components in front- and side structures;
- Optimising the shape of front structural components with respect to impact behaviour (as known from passenger cars);
- Covering the wipers to avoid contact with an adult pedestrian/cyclist's head;
- Reducing ground clearance by increasing the bumper size to reduce over-runs;
- Adding energy-absorbing covers to the mirror frames; or
- Raising the mirror location to eliminate head contact.

Based on this review, Feist and Faßbender developed and tested two pedestrian and cyclist friendly front end designs to mitigate impacts at closing velocities between 15-40 km/h (Feist and Faßbender, 2008): Firstly, a safety bar made of steel tubes and energy-absorbing expanded poly-propylene foam structures intended to reduce injuries to the head and lower extremities from the primary impact (see Figure D-26). Secondly, a 'nose cone', i.e. a tapered front end, made of foam that is intended to reduce the run-over frequency by deflecting impacted VRUs to the side and also to eliminate sharp corner impacts (see Figure D-27). These structures could be realised in HGVs using the design freedom granted by extended cab dimensions. Note that an extended nose cone structure would also contribute to the visibility of VRUs because it eliminates a blind spot area in front of the cab.

Figure D-26: APROSYS safety bar impacting a standing pedestrian dummy (Feist and Faßbender, 2008)

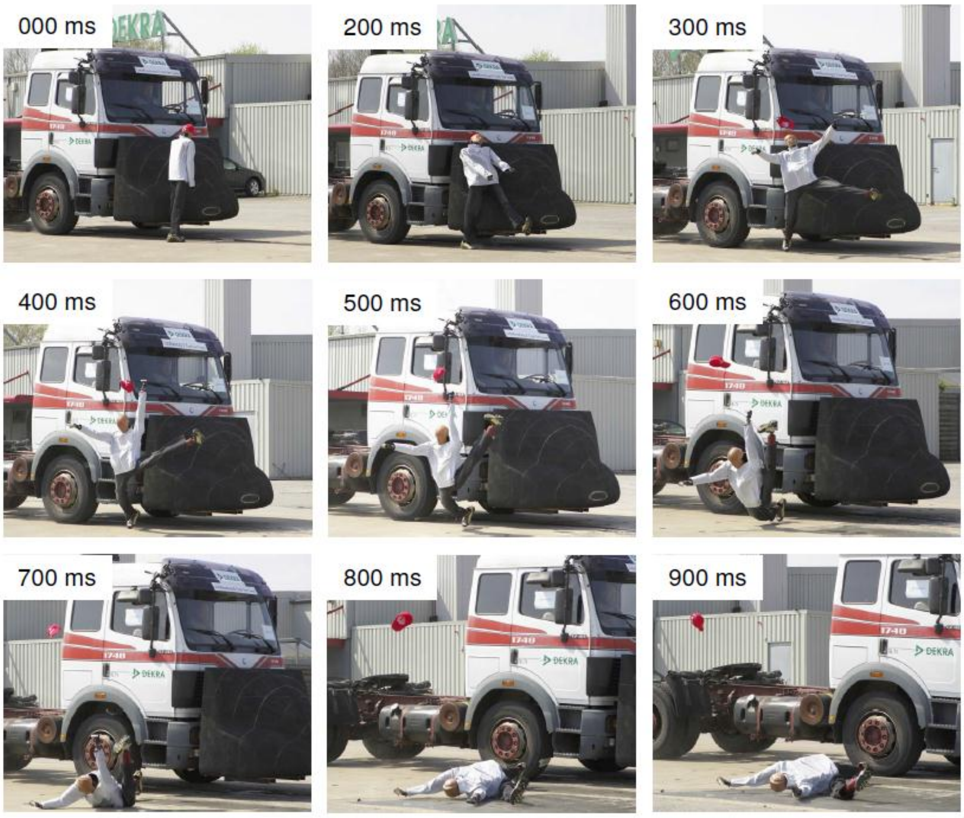

Figure D-27: APROSYS nose cone attached to an HGV front end deflecting a pedestrian dummy to the side in an impact test (Feist and Faßbender, 2008)

Based on the results from the APROSYS project, Welfers et al. from FKA developed a potential re-design of the cab front end of a tractor unit for a 40-tonne HGV making use of the design freedom that would result from increased maximum cab dimensions (Welfers et al., 2011). The design was optimised under aerodynamic considerations, so as to improve safety performance and fuel economy at the same time (see Figure D-28).

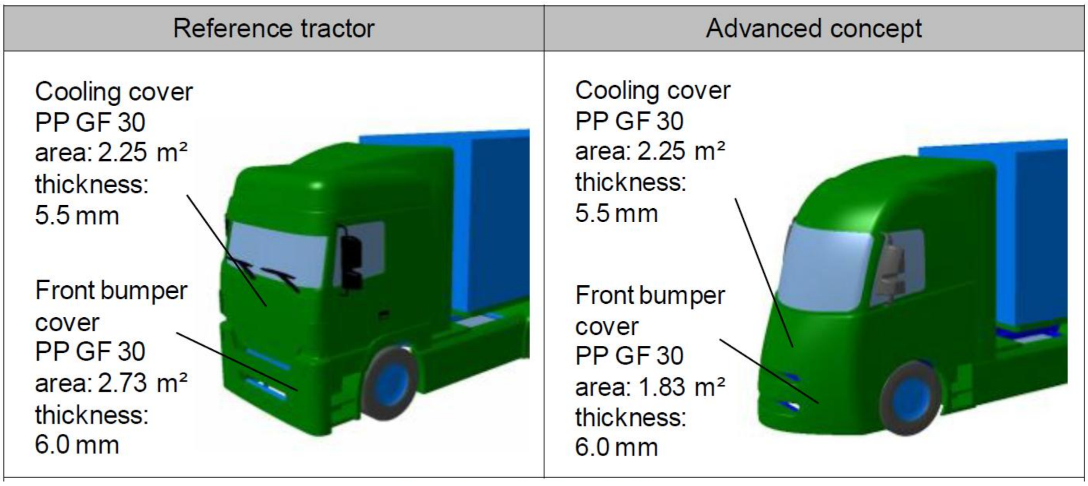

Figure D-28: FKA front end design for improved safety and aerodynamics (Welfers et al., 2011)

Note that primary safety systems are not in scope of the present section of this study.

Improvements to Vehicle Occupant Safety

Because of the high mass of HGVs, their collisions are generally characterised by a high level of kinetic energy that needs to be dissipated. In collisions with other HGVs (e.g. front-to-rear motorway accidents) this has severe implications for the safety of the occupants of the impacting HGV; in collisions with lighter vehicles such as passenger cars this mainly affects the safety of the occupants of the light vehicle. Crumple zones on the vehicle front, placed at a height suitable for interaction with the rear chassis of other HGVs (typically 700-1,100 mm from the ground), can dissipate energy by deforming under load. The effectiveness of this concept is dependent on the available deformation length before the rigid passenger compartment and can, therefore, be increased by larger permissible cab dimensions. If this concept is integrated fully during the cab design (and not just added to the front of an existing cab design), a high effectiveness can be reached by simultaneously increasing the cab strength to increase the amount of energy absorbed by the deformable structure (Robinson et al., 2010).

A serious issue in car-to-HGV frontal collisions is the general lack of geometric compatibility, with the passenger car being much lower in height than the HGV. Cars under-running HGVs in collisions at high closing speeds can lead to severe deformation and intrusion in the passenger compartment of the car because the main load paths cannot interact with the heavy vehicle (Gwehenberger et al., 2004). To alleviate this problem, rigid Front Under-run Protection Systems (FUPS) (typically 400-500 mm from the ground) are already a current legislative requirement for N2 and N3 vehicles (Regulation (EC) No 661/2009 mandating UN Regulation No. 93). Higher compatibility and thereby better protection for the car occupants in accidents could be accomplished by FUPS designed to deform in a controlled way and absorb any residual energy that cannot be absorbed by the car's front end. These energy-absorbing frontal under-run protection systems (EAFUPS) can be realised with the current cab size limitations because they are located underneath the cab (see Figure D-29). Because the principle of energy absorption by deformation requires to compromise between allowing room for deformation and limiting the extent of under-run, extended cab dimension to the front would, however, allow for larger deformation zones and therefore better energy absorption capabilities and higher effectiveness. Structures preventing vehicle under-run can be integrated into the general crashworthiness design of the vehicle.

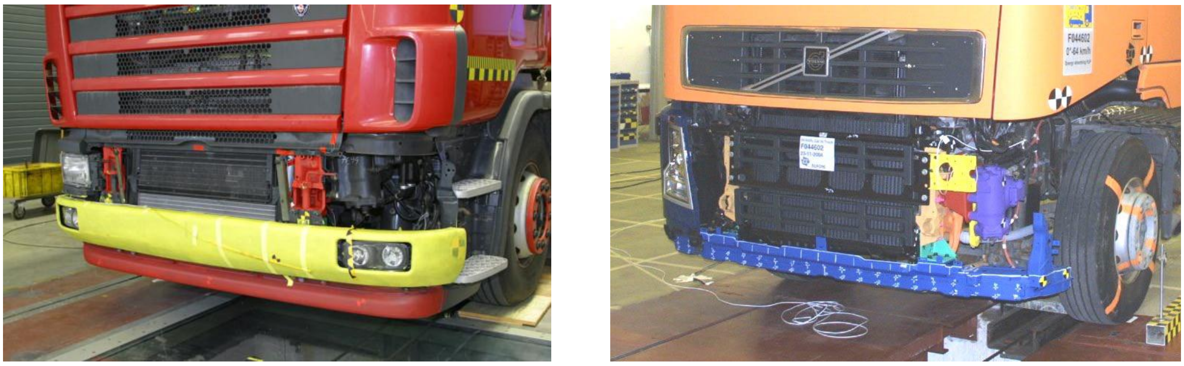

Figure D-29: Rigid FUPS (left) and energy-absorbing FUPS (right) integrated in current cab designs (Edwards et al., 2007)

The nose cone front end structure developed by APROSYS can, for instance, be filled with energy-absorbing material of different strengths which can serve self-protection and protection of lighter vehicles' occupants (Welfers et al., 2011).

The tapered front end of the FKA concept features aluminium substructures in the form of two bumper beams with crash boxes (see Figure D-30).

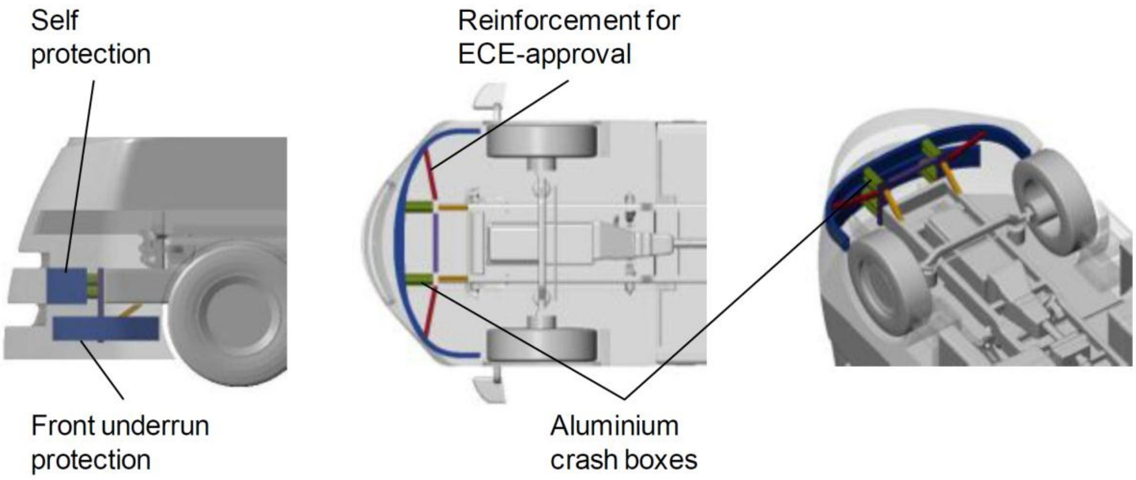

Figure D-30: Crash management system of FKA concept (Welfers et al., 2011)

In 2003, Scania presented a concept truck with an additional 600 mm added energy-absorbing structure to the front, which would, according to information from Scania, considerably increase the chances of survival in car-to-HGV frontal collision (see Figure 31). For this concept to be realised, exemptions from the existing length limitations would be required (Trafikstyrelsen - Danish Transport Authority, 2011).

Figure D-31: Scania Crash Zone Concept Truck with extended front end (Scania, 2003)

The safety effectiveness of these solutions was found to increase strongly with an increased extension of the cab length (Robinson et al., 2010). Other factors such as manoeuvrability or excessive weight increase needed, however, be taken into consideration.

Note that primary safety systems are not in scope of the present section of this study.

D.2.3 Feasibility

Technical Feasibility

Improvements to direct vision

A possible cab design for improved direct vision within the existing boundaries of Directive 96/53/EC is realised in the production vehicle Mercedes-Benz Econic. This low-entry vehicle has a particularly large windscreen area and improved glazed areas to the side. The design leads to certain limitations (engine size is limited because of packaging problems; no hydraulic cab support), which limit it to regional services and don't allow long-haul traffic (Welfers et al., 2011). A proposal by the Danish Transport Authority on extended cab dimensions states that Mercedes-Benz had demonstrated the feasibility of designing trucks with improved direct vision (via larger window areas and low driving position) by extending the cab length by 500 mm (Trafikstyrelsen - Danish Transport Authority, 2011). It is uncertain if the above mentioned limitations have been overcome by this.

A futuristic concept vehicle design presented by Volvo Trucks in 2010 demonstrates a potential design solution for improved direct vision (see Figure D-32) (Volvo Trucks Europe, 2010). The design exceeds the current cab size boundaries.

Figure D-32: Volvo Concept Truck 2020 with improved direct vision (Volvo Trucks, 2010)

As way of advocating a direct vision requirement, Summerskill and Marshall performed a design study to provide an example of how direct vision could be improved in HGV design (Summerskill and Marshall, 2014). Design iterations based on the FKA concept showed that blind spots in the direct vision of the driver could be considerably reduced. Design Iteration 1 (Figure D-35, left) improves direct vision to the nearside and front nearside corner through larger glazed areas and reduced dash area. Design Iteration 2 (Figure D-35, right) adds improved vision to the front offside corner through a driving position lowered by 230 mm. The authors acknowledge that Iteration 2 might lead to reduced off-road capabilities of the vehicle. Industry stakeholders suggested that this design would be very difficult to achieve due to the number of appliances located in the frontal part of current cabs (e.g. air ducts, heater, tachograph, and electric, electronic and pneumatic functions linked to the dashboard) and due to the recently increased cab strength requirements.

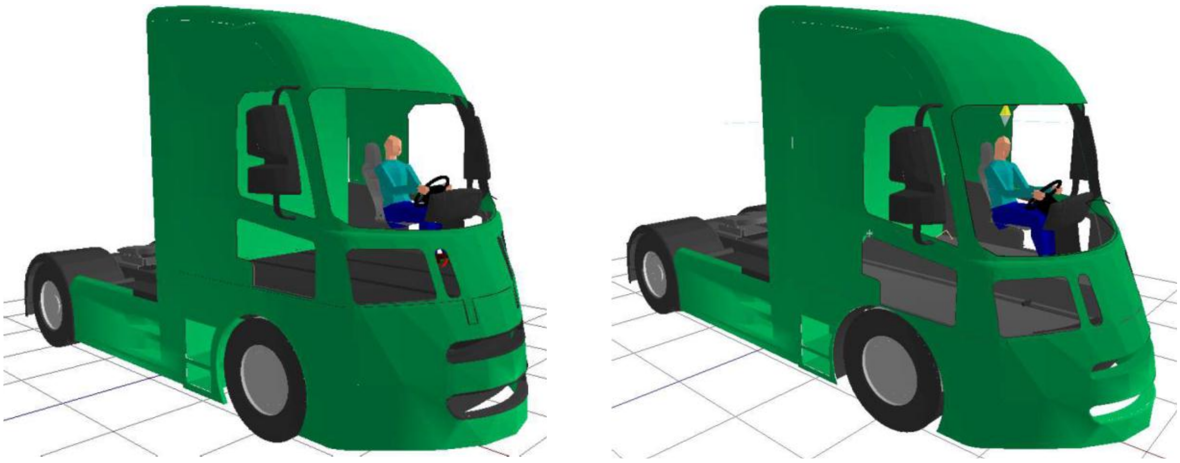

Figure D-33: Loughborough design iterations of the FKA concept for better direct vision (left: Iteration 1; right: Iteration 2) (Summerskill and Marshall, 2014)

These examples of a production vehicle, a concept vehicle design and two detailed studies demonstrate that design improvements for improved direct vision are technically feasible. Extended cab dimensions would allow for increased freedom in packaging which could help overcome limitations, for example with regard to the engine size. However, cab strength requirements and appliances located in the front might put a limit to the extent of additional glazed areas that can be realised. Appropriate solutions for improved direct vision might be different depending on the vehicle use case, i.e. between urban delivery vehicles, regional delivery vehicles and long haul vehicles.

Improvements to VRU impact performance

The tapered front end design (to deflect VRUs sideways in impacts), initially developed in the APROSYS project and further evolved by Welfers et al., was demonstrated in the form of retrofittable prototypes and computer models (Welfers et al., 2011). Crash tests using pedestrian dummies demonstrated its effectiveness (Feist and Faßbender, 2008). The design still awaits demonstration in a production vehicle, but there are no principal technical concerns preventing the adoption of a tapered front end.

Energy-absorbing structures at the front end can offer protection to VRUs during the primary impact. The characteristics of the material used (e.g. stiffness and strength) need to be adjusted for unprotected road users. The APROSYS project successfully tested structures made of poly-propylene foam (Feist and Faßbender, 2008). Nowpada et al. studied the use of an 'egg box structure' made of thin-walled aluminium and found it was fit for purpose for pedestrian protection (Nowpada, 2010).

Depending on the design of the tapered, energy-absorbing vehicle front end, larger glass areas might be necessary in order to maintain appropriate direct vision.

Improvements to vehicle occupant safety

Energy-absorbing structures for HGV occupant self-protection (by frontal crumple zones) and for the protection of passenger car occupants (by EAFUPS) need different material characteristics than those for VRU protection. Given the design freedom of extended cab dimensions there is no principal technical reason preventing adoption of such design.

Volvo's Concept Truck 2020 (Figure D-34) and Scania's Crash Zone Concept Truck (Figure D-32), for example, have added frontal crumple zones of 500 mm and 600 mm length respectively. The additional weight for Scania's design amounts to 250 kg (Welfers, et al., 2011). Industry stakeholders commented that improvements to self-protection of HGV occupants would also be possible without extension of the front.

EAFUPS under the limitation of the current dimension legislation are available as optional equipment from all manufacturers (European Commission, n.d.). This and the project VC-COMPAT show that EAFUPS are technically feasible (Edwards et al., 2007). Extended cab dimensions would allow for larger deformation zones and therefore better energy absorption capabilities. Welfers et al. have integrated EAFUPS using additional available design space in the FKA concept (Welfers et al., 2011).

The aims of protecting passenger car occupants and self-protection are somewhat conflicting design goals because the former requires structures collapsing under less load than the latter. This needs to be resolved during vehicle design by balancing the material characteristics, but should not prevent realising a benefit for both groups.

Enforcement Feasibility

In 2011, Welfers et al. proposed to allow a length increase of the cab of 800 mm to allow for the implementation of the design changes found beneficial in their study (Welfers et al., 2011). Additional type-approval requirements might be used to ensure that effective safety measures are implemented.

Improvements to direct vision

Direct vision requirements do not currently exist for N2 or N3 vehicles. Direct vision requirements for passenger cars (M1 vehicles) are defined in UN Regulation No. 125. A direct application of these for HGVs is not possible because of the differences in vehicle dimensions and design. However, the definition of direct vision requirements can be considered a task of limited technical complexity compared to impact performance requirements and could also be implemented independent of the other items.

In 1999, Tait and Southall examined opportunities to improve the combined direct and indirect field of view of large vehicles (Tait and Southall, 1999). The defined aim was that a 180° forward facing area around the driver should be visible by direct and indirect means. The resulting recommendations were mainly based around means of indirect vision.

Cook et al. have undertaken extensive research into direct and indirect vision of vehicles including HGVs which could inform a potential legislative process on direct vision (Cook et al., 2011a, Cook et al., 2011b, Cook et al., 2011c).

A report by the European Cyclists' Federation (ECF) explains the Japanese vision requirements for HGVs as follows (Woolsgrove, 2014): A vertical cylinder representing a 6 year old child (1 m height by 0.3 m diameter) must be partially visible (by direct or indirect vision, including cameras) if placed at any location within 2 m forward and 3 m sideways (nearside) from the vehicle.

American requirements for school buses, regulated in FMVSS No. 111, follow a similar approach.

The legislative approaches combining direct and indirect vision are considered sub-optimal by ECF because this might lead to a reliance on indirect vision and reduced effectiveness (Woolsgrove, 2014). Incorrectly adjusted mirrors, for example, can lead to a reduced effectiveness of indirect vision (Dodd, 2009).

In 2009, the Danish Ministry of Transport made a proposal specifically for direct vision of HGVs; cited after (Dings, 2012):

> *"The driver shall be able to directly see an object placed 1.5 m above ground level, at a distance more than 0.5 from the side or front of the vehicle, and in front of the rear cabin wall. Exceptions shall be allowed for areas around pillars, door-frames, and mandatory mirrors."*

Improvements to VRU impact performance

Requirements for the protection of VRUs do not currently exist for N2 or N3 vehicles. Performance-based requirements for passenger cars (M1 vehicles) are defined in UN Regulation No. 127. A direct application of these is not possible because the vehicle designs and the problems offered by real-world accident typology are different.

The APROSYS project developed a rating system and test methodology for assessing the aggressivity of HGV front ends in accidents with VRUs (Smith, 2008). The 'Heavy Vehicle

Aggressivity Index' rates vehicles on a scale from 0 to 10 by a combined assessment of their:

- 'Structural aggressivity';
- 'Run-over aggressivity'; and
- 'Active aggressivity' (including direct and indirect vision).

This involves headform tests, measurements of the field of view and computer simulations to determine the run-over risk. A final assessment whether these would form a suitable base for legislative test procedures is outside the scope of the present study.

In order to ensure that a deflecting front end design is adopted, Welfers et al. proposed changes to the dimensions legislation that would offer a rounded design space to manufacturers (Welfers et al., 2011):

> *"2. An additional point shall be integrated into 96/53/EC, ANNEX 1, point 1.1: No point of the vehicle shall project beyond an examination geometry that is defined as follows:*
>
> > *a. Two circles span the surface of the examination geometry.*
> >
> > *b. The first circle is located on the street plane. The radius of the circle is 1.45 m. The centre point is located on the centre plane of the vehicle.*
> >
> > *c. The second circle is located on the centre plane of the vehicle. The radius of the circle is 6.45 m. The centre point is located on the street plane.*
> >
> > *d. Both circles intersect at a reference point. This point is located 5 cm in front of the foremost point of the vehicle in the street plane and in the centre plane of the vehicle."*

Further research would be required to determine whether this design-based approach would lead to the most effective shape in real-world vehicles or whether performance-based requirements would give manufacturers the freedom to design more effective solutions.

ETSC generally recommends designing a simple deflection test procedure with separate impactors for the appropriate zones of the front end and an un-instrumented standing dummy to assess the deflection laterally and the risk of the pedestrian being run over (ETSC, 2014).

A study by Chinnaswamy et al. discusses potential performance-based requirements and test methods to assess the energy absorption of HGV front ends in impacts with VRUs (Chinnaswamy et al., 2009). A combination of impactor tests, standing dummy tests and virtual test methods (numerical simulation) is suggested. The authors recommend specific test protocols derived from passenger car legislation. The tests appear to be designed for conventional flat front end designs. An assessment of the suitability in general and in particular for tapered front ends is outside the scope of the present study.

Improvements to vehicle occupant safety

Vehicle occupant safety combines two aspects which potentially require different assessment methods:

- Self-protection of the HGV occupants; and
- Compatibility in impacts with lighter vehicles, such as passenger cars.

The self-protection of vehicle occupants is commonly assessed in performance-based full-scale crash tests, such as UN Regulation No. 94 to assess the frontal impact performance of passenger cars. Legislative full-scale test procedures for HGVs do not currently exist. Numerical simulations or quasi-static component tests of the energy-absorption capabilities of frontal crumple zones might also be suitable. These test procedures are also not currently available.

Welfers et al. recommended an alternative design-based approach: A zone of at least 68 mm of energy-absorbing material behind all non-transparent exterior parts of the front should be mandated (Welfers et al., 2011).

The improved compatibility with passenger cars was addressed by the VC-COMPAT project with the aim to develop car-to-HGV compatibility test procedures (Edwards et al., 2007). Different possibilities were comprehensively assessed and tested, including: virtual testing (numerical simulation); quasi-static testing; rigid sled testing; moving deformable barrier tests and full-scale tests. The authors concluded that further work was still required to decide on the best procedure because not all aspects could be adequately covered with a single approach.

Finished test procedures for EAFUPS are therefore not currently available. If regulatory test procedures should be developed, the comprehensive base work performed by the VC-COMPAT project would accelerate this procedure. Experts estimate the time required for development of a performance-based regulatory test procedure to be approximately four years (Knight, 2014).[29]

Acceptance

No specific research into the acceptance of the above discussed measures has been identified.

In TRL’s view, the acceptance among vehicle users can be expected to be high. Secondary safety measures (such as crumple zones, EAFUPS and tapered front end) are not intrusive and therefore generally well accepted. Improved direct vision would reduce the driver workload and should therefore be welcomed by drivers. However, additional glazed areas provide other road user’s with a view into the cab which could be experienced as a reduced level of privacy by the driver. It is conceivable that drivers undertake attempts to cover these areas up in order to restore privacy.

Acceptance among vehicle manufacturers might be partially given. Major vehicle manufacturers have presented concept studies addressing some of the discussed problems years ago. ACEA states it supports safety improvements and concludes from an analysis of accident data that additional safety requirements must be developed, however demands considering primary safety measures as well (which are not in scope of the present section of this study) (ACEA, 2014). Aerodynamic improvements which can be realised by the granted design freedom might compensate for the weight increase by the discussed measures. The growing public discussion about the hazards HGVs present to VRUs might increase acceptance. HGVs have, however, a long product life cycle and major manufacturers have recently released new models which might increase resistance for economic reasons.

D.2.4 Costs

Published information on costs of the discussed measures is very limited. A recent presentation by the European automobile manufacturers association ACEA on the revision of Directive 96/53/EC did not contain cost figures (ACEA, 2014).

In 2007, VC-COMPAT estimated that EAFUPS added a cost of approximately €100–€200 per vehicle compared to rigid FUPS (Edwards et al., 2007).

In 2011, the FKA concept was estimated by Welfers et al. to cost about €400 per vehicle (Welfers et al., 2011). This accounts for changes in the size of parts and hence increased material costs. The production technologies used would remain unchanged, according to the authors.

Based on these figures it is not possible to provide an overall estimate of the current cost for re-design and production of the vehicle front end in accordance with the above discussed measures. It can be assumed that the costs involved for vehicle manufacturers will predominantly be one-off design costs (rather than increased production costs) which need to be partially attributed to achieving non-safety related improvements made

[29] Note that alternatively (if EAFUPS would not be mandated) UN Regulation No. 93 (the current legislation on rigid FUPS) would need to be amended in order to overcome problems that would arise from current definitions in combination with the extended dimensions. This is assumed to require at least 15 months (Knight, 2014).

possible by extended dimensions, such as improved aerodynamic performance and increased driver comfort. However, the design costs involved will be higher than for the design of a usual new model because a new vehicle concept including re-engineering of the chassis (front axle would need to be moved forward due to the approach angle; instep to the cab might need to be located behind the front axle) would be necessary.

D.2.5 Benefits

The potential safety benefits of an improved HGV front end design apply to three groups of road users:

- HGV occupants (self-protection);
- Occupants of other vehicles; and
- VRUs.

The HGV occupants, i.e. driver and in some cases passenger, would benefit from reduced impact energy through added energy-absorbing frontal structures. These crumple zones will come into play in frontal impacts with other vehicles or road-side objects. The effect of self-protection is most relevant in cases where another heavy object or heavy vehicle is impacted. A typical case would be a frontal impact into the rear of another HGV.

The occupants of other vehicles would also benefit from the reduced impact energy through deformation of additional frontal structures on the HGV. This will apply to accidents where lighter vehicles impact or are impacted by the front end of an HGV and would in most cases experience most of the impact energy due to the unequal mass distribution and front end stiffness. The deceleration of smaller vehicles and the frequency of catastrophic deformation due to under-run can be reduced. A typical case would be a front-to-front impact between car and HGV.

VRUs would benefit from improved direct vision, which would allow the HGV driver to spot VRUs in a larger proportion of the area surrounding the vehicle. This would apply mainly to low-speed run-overs. A typical case would be a run-over accident while turning or pulling away from traffic lights.

If VRUs are impacted by an HGV, they would further profit from reduced stiffness of the HGV front end, which would reduce the energy from the primary impact, and an optimised tapered shape, which would deflect sideways and prevent a subsequent run-over. This would influence the injury outcome of higher-speed cases. A typical case would be a pedestrian on the road in a built-up area being impacted by an HGV.

Several of the previously mentioned studies quantified potential casualty savings (mainly focused on fatalities) of individual measures or among individual groups of road users. These are summarised and combined to overall figures in the following.

Fatality Reductions by Improvements to Direct Vision

Research acknowledges that improved frontal and lateral direct vision is effective in preventing VRU casualties in accident scenarios such as run overs while the HGV is pulling away or turning, or while a VRU is crossing the road in front of the HGV (Summerskill, 2011; Welfers et al., 2011), (Volvo Trucks, 2013). However, no study could be identified that quantified the effectiveness of improved direct vision.

Not all casualties in these accident scenarios will be prevented by direct vision, but only those cases where the driver did look but was not able to see the hazard. Summerskill and Marshall performed a study assessing the benefits of improved indirect vision (via mirrors) in HGVs based on police reported accidents in Great Britain (STATS19 database) (Summerskill, 2011). The ratio of accidents where the police reports noted ‘Driver failed to look properly’ as a contributory factor was found to be 24% of fatal accidents involving VRUs. These cases could possibly not be prevented by improved direct vision. The remaining 76% of fatalities could be expected to be influenced and can therefore be used as an estimate of the upper boundary of the casualty reduction potential (Table D-13). Note that there is broad agreement among experts that improved direct vision would be effective in preventing casualties. The lower boundary of zero casualties in Table D-13 is owed purely to the fact that no quantitative estimate of the effectiveness was available in published research. The actual value will be higher than zero.

No estimate is possible for the reduction of seriously or slightly injured casualties.

Table D-13: Annual VRU fatality reduction potential for EU-27 by improved frontal and lateral direct vision

	Annual EU-27 fatality reduction
VRUs[30]	0-553

Other accident scenarios, such as side-swipe collisions with cars, can also be influenced by improved direct vision. While these occur rather frequently, the resulting number of fatal and serious casualties is expected to be relatively low (Summerskill and Marshall, 2014), which is why they are not addressed further in the present study. Additional monetary benefits can be expected from prevention of these accidents.

Fatality Reductions by Improvements to VRU Impact Performance

In 2010, Robinson et al. carried out a benefit analysis for different HGV safety measures for GB based on in-depth accident data from the HVCIS database (Robinson et al., 2010). Benefits of fitting HGVs with different front end structures (length increase between 0.50 and 2.25 metres) were analysed in detail on a case-by-case basis, taking into consideration, for example, the age of casualties or the belt wearing status of car occupants. The estimated casualty savings for GB (based on average casualty numbers from 2006 to 2008) if all HGVs were equipped with a tapered front end structure to deflect VRUs sideways are cited in Table D-14.

Table D-14: Estimated annual VRU fatality reduction for Great Britain (GB) by tapered front end design (Robinson et al., 2010)

	Prevented fatalities	Proportion of target population saved
Tapered frontal structure (nose cone)	17-28	ca. 29-47% of VRU fatalities in frontal impacts with HGVs[31]

The prospective study by Welfers et al. predicted potential VRU casualty savings by the FKA front end design, which was based on the APROSYS nose cone. The calculations are based on the target population numbers from 2005–2007 and estimates about the effectiveness of the front end design in preventing VRU fatalities in impacts at different speeds (see Table D-15). The fatality reduction figure cited in Table D-16 does not include potentially avoidable casualties due to improved direct vision of the driver.

[30] Note: This group overlaps partially with the casualties influenced by a tapered front end design

[31] Including the resulting reduced blind spot areas due to nose cone.

Table D-15: Estimated effectiveness of FKA front end design in preventing fatal injuries of VRUs in impacts with HGVs (Welfers et al., 2011)

Impact speed	Effectiveness
≤40 km/h	70%
40-50 km/h	30%
>50 km/h	0%

Table D-16: Estimated annual VRU fatality reduction for EU-27 by the FKA front end design (Welfers et al., 2011)

	Prevented fatalities	Proportion of target population saved
FKA front end design	232-296[32]	ca. 42-63% of VRU fatalities in target population

It can be seen that the assumed effectiveness, i.e. proportion of target population saved, in the two studies varies between 29% and 63%. Applying this range to the estimated up-to-date target population (see Table D-12), yields the following indicative range of potential fatality savings across EU-27 (Table D-17). No estimation is possible for the reduction of seriously or slightly injured casualties.

Table D-17: Annual VRU fatality reduction potential for EU-27 by tapered front end design

	Prevented fatalities	Proportion of target population saved
FKA front end design	232-296[33]	ca. 42-63% of VRU fatalities in target population

Fatality reductions by improvements to vehicle occupant safety

The above mentioned study by Robinson et al. also analysed the effects of improvements to vehicle occupant safety (EAFUPS and crumple zones for self-protection). The estimated casualty savings for GB, if all HGVs were equipped, are cited in Table D-18.

[32] *Not* including the resulting reduced blind spot areas. These are acknowledged by the authors but not quantified.

[33] *Not* including the resulting reduced blind spot areas. These are acknowledged by the authors but not quantified.

Table D-18: Estimated annual fatality reductions amongst vehicle occupants for Great Britain (GB) by different measures (Robinson et al., 2010)

	Fatality reduction	Proportion of target population saved
Energy-absorbing frontal underrun protection (EAFUPS)	3-12	ca. 6-22% of car occupant fatalities in frontal car-to-HGV impacts
HGV crumple zone	2-6	ca. 13-38% of HGV occupant fatalities in frontal impacts with other HGVs/ heavy objects

In 2004, the VC-COMPAT project estimated potential casualty savings through EAFUPS for EU-15 (Gwehenberger et al., 2004). The baseline situation for the study was HGVs equipped with rigid FUPS, which are mandatory equipment in Europe. The predicted potential casualty savings are summarised in Table D-19. The authors acknowledge that these are conservative estimates. These figures are based on a case-by-case analysis of in-depth accident data from six European countries that was scaled up to EU-15 casualty numbers from the year 2000.

Table D-19: Estimated annual casualty reductions amongst vehicle occupants for EU-15 by energy-absorbing frontal underrun protection (Gwehenberger et al., 2004)

		Reduction	Proportion of target population saved
Energy-absorbing frontal underrun protection (EAFUPS)	Fatalities	190-204	10-11% of car occupant fatalities in frontal car-to-HGV impacts
	Seriously injured	1,497	30% of serious car occupant casualties in frontal car-to-HGV impacts
HGV crumple zone[34]		n/a	n/a

The study by Welfers et al. did not quantify potential casualty savings among vehicle occupants (Welfers et al., 2011).

A Scandinavian study from 2002 by Avedal and Svenson (2002) is cited by De Ceuster et al. (2008) to have estimated that EAFUPS could save 12,000 serious or fatal injuries across Europe per year. The original study could not be obtained for review. The number cited appears extremely high compared to the numbers estimated in VC-COMPAT (see Table D-19).

Applying the range of estimates about system effectiveness from the studies by Robinson et al. and Gwehenberger et al. to the estimated up-to-date target population (see Table D-12), yields the following indicative range of potential fatality savings across EU-27 (Table D-20). No estimate is available for the reduction of seriously or slightly injured casualties.

[34] Not assessed in VC-COMPAT

Table D-20: Annual vehicle occupant fatality reduction potential for EU-27 by energy-absorbing frontal underrun protection (EAFUPS) and HGV crumple zone

	Annual EU-27 fatality reduction
Passenger car occupants	128-175
HGV occupants	41-194
Total	169-369

Monetary Benefits from Fatality Savings

The ranges of expected fatality reductions established in the preceding sections are summarised in Table D-21.

Table D-21: Summary of fatality reduction potential for EU-27

	EU-27 annual fatality reduction
Passenger car occupants	128-175
HGV occupants	41-194
VRUs	104-553
of which[35]:	
VRUs (potentially affected by direct vision)	(0-553)[36]
VRUs (potentially affected by deflecting front end)	(104-263)
Total	273-922

The monetary benefits are calculated based on a cost per fatality of €1,564,503. The annual monetary benefits that can be expected from the reduction in fatalities range from approximately 0.4–1.4 billion Euros per annum across EU-27. Table D-22 provides the monetary benefits per casualty group.

[35] Note that the two groups of VRU casualties are not distinct, which is why the total number cannot be obtained by summing the numbers.

[36] Note that there is broad agreement among experts that improved direct vision will be effective in preventing casualties. The lower boundary of zero casualties is owed purely to the fact that no *quantitative* estimate of the effectiveness was available in published research. The actual value will be higher than zero.

Table D-22: Annual monetary benefit from fatality reduction for EU-27

	EU-27 annual monetary benefit (million Euros)
Passenger car occupants	200.3-273.8
HGV occupants	64.1-303.5
VRUs	162.7-865.2
of which[37]:	
VRUs (potentially affected by direct vision)	(0-865.2)
VRUs (potentially affected by deflecting front end)	(162.7-411.5)
Total	427.1-1,442.5

Other Benefits

Other benefits can be expected from safer front end designs:

- Significant reductions of seriously and slightly injured casualties can be expected alongside the fatality reductions discussed;
- Additional monetary benefits can be expected from the reduction of damage-only accidents, such as reduced side-swipe collisions with cars due to improved lateral direct vision;
- Significant fuel saving benefits can be expected because a tapered front end design allows optimising the aerodynamic performance of the vehicle (Robinson et al., 2010; Welfers et al., 2011; European Commission, 2013a);
- Improved direct vision could reduce driver workload, particularly in inner-urban traffic conditions; and
- The re-design of the cab would allow improving the interior cab design in order to alleviate factors causing driver discomfort, such as limited interior space and cabin temperature (European Commission, 2013a).

These additional benefits cannot be quantified within the scope of this initial review.

D.2.6 Benefit:Cost Ratio

Break-even Cost per Vehicle

Due to the lack of cost figures for the discussed measures it is not possible to calculate a benefit-to-cost ratio. A break-even cost per vehicle is calculated instead, to give an indication of the tolerable costs.

Per year there are 295,050 new N2 and N3 vehicles registered in EU-27 (figure from 2012) (ACEA, n.d.). Based on this number and the expected annual monetary benefit from reductions in fatalities (Table D-22), the break-even value per vehicle of a safer

[37] Note that the two groups of VRU casualties are not distinct, which is why the total number cannot be obtained by summing the numbers.

front end design (improved direct vision, tapered front end, crumple zones and EAFUPS) is in the range of €1,448–€4,889 (Table D-23).

Table D-23: Break-even cost of a safer front end design (improved direct vision, tapered front end, crumple zones and energy-absorbing frontal underrun protection (EAFUPS)) per vehicle for EU-27

Break-even cost per vehicle of category N2/N3	€1,448–€4,889

Note that this range can be considered a conservative estimate because it only accounts for benefits from prevented fatalities. Other, arguably significant, benefits were not included due to a lack of statistical data: for example, reductions of seriously and slightly injured casualties, reduction of damage-only accidents, or potentially significant fuel savings due to improved aerodynamic performance.

Conclusion

Based on an initial review of the available research, the discussed measures for safer HGV front end design can be expected to be cost-beneficial if the cost per vehicle is below €1,448–€4,889. TRL's expert opinion is that this initial data justifies further investigation because it is likely that the measures are cost-beneficial. The potential mitigation strategies could also be examined individually, because individual measures such as improved direct vision might yield a high benefit while being easy to implement (technically and with regard to developing legislation).

Note that this study performed an initial analysis based on available material. More detailed work would be needed to assess, in detail, the impacts of future trends in road casualty numbers and the depreciation of future costs and benefits, and to quantify the monetary benefits that can be expected from serious, slight and damage-only accidents. Reliable cost information will also be required to draw firm conclusions about the benefit-to-cost ratio.

Primary safety technologies (e.g. 360° camera view and VRU avoidance, VRU warning or start inhibit systems, or aftermarket VRU warning technologies (Stannard and Tindall, 2014)) might also have the potential to address a proportion of the reported casualties. These were not in scope of the present review but should be considered in a more detailed review, not least because primary safety technologies might be introduced with a shorter lead time and therefore reduce casualties in the interim.

D.2.7 References

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Appendix E. Fuel Systems

E.1 Fuel System Testing and Automatic Extinguishers

An amendment to the weights and dimensions legislation for HGVs has been proposed by the European Commission (EC) to permit changes to the design of vehicle front ends which would improve road safety. This change in legislation might offer an opportunity to define mandatory technical requirements improving the design of HGV front ends, which has the potential to improve the protection of car occupants and Vulnerable Road Users (VRUs) involved in accidents with HGVs, as well as HGV drivers and passengers themselves.

E.1.1 Description of the Problem

Vehicle fires

Statistics collected from the UK Department for Communities and Local Government show that between April 2012 to March 2013 fire and rescue authorities responded to 23,900 road vehicle fires (DCLG, 2013): 15,700 fires occurred in cars (66%), 2,200 in vans (9%), 1,100 in HGVs (5%) and 550 in coaches, buses or minibuses (2%). The remaining 18% of fires occurred in 'other' vehicles such as agricultural vehicles, motor cycles, motor homes, trailers, caravans and tankers. In total, there were 39 fatalities associated with vehicle fires during this period, equating to 1.6 fatalities per 1000 fires. There were also 555 non-fatal casualties, equating to 23 non-fatal casualties per 1000 fires. The proportion of these fires which resulted from a collision or from other scenarios relevant to automatic fire extinguishers is unknown.

Statistics based on European roads were collected by Egelhaaf and Wolpert (2011) whilst conducting a study on vehicle fires. In Germany, 21,000 vehicle fires were reported to insurance companies in 2006. The Swiss automobile club recorded 3000 vehicle fires in Switzerland in 2002. Austrian fire service statistics show 1850 vehicle fires occurred in 2004. Automobile clubs in all three countries estimate that there are roughly 100 fatalities associated with vehicle fires each year. The exact figures are unknown due to a lack of statistical information regarding frequency of vehicle fires.

One of the most detailed sources of fatality rates from vehicle fire data was collected by the Swedish Transport Administration between 1998 and 2008. In-depth data was recorded from fatal crashes involving passenger cars, SUVs, vans and minibuses. Viklund et al. (2013) summarised the findings of the study relevant to vehicle fires. In total, 181 fire related deaths caused by 133 separate road crashes were recorded, which accounted for 5% of all road fatalities that occurred during this period. Fire and smoke were ruled as the primary cause of death in 55 cases. It is certain that the occupants did not suffer any contributing trauma injuries in 39 of these 55 cases, highlighting the potential lifesaving benefits of on board automatic extinguisher systems or improved emergency response times. The source of the fire was not identified for 61 of the 133 cases. The authors highlighted the lack of skilled fire investigators to carry out the analysis of the ignition point location. However, in the remaining cases where the ignition point was known, 31 fires were found to have started within the engine compartment and 16 near the fuel tank.

Bus fires have been of particular concern in Northern Europe, leading to a large amount of research carried out in this area. A report by Kokki states that since 2000, the frequency of bus fires in Finland has increased. Between 2010-2011, there were 5 bus fires per 1000 buses in Finland. During this period, 4 people were injured and 7 buses were completely destroyed. Hand-held extinguishers were not deemed sufficient to tackle engine fires since the engine compartment area is not accessible to the driver. The report recommended fixed extinguishing systems to be installed in the engine compartment and additional heater.

Vehicle fires are one of the most frequent causes of multi-fatality road incidents worldwide. However, they can also lead to huge economic losses due to the costs of repairing infrastructure damage, attendance by the emergency services, paying out insurance claims and compensating vehicle operators due to the loss of their vehicle. Vehicle fires within tunnels can be particularly costly. For example, in 1999 an HGV transporting a flammable load caught fire in the Mont Blanc Tunnel. The tunnel, which provided an important link between France and Italy, had to be closed for three years resulting in huge economic losses (Lacroix, 2001). However, since the Mount Blanc incident, tunnels all over the world have been subjected to a vast amount of major safety improvements such as the installation of fire suppression systems (Ansell, 2014). Nevertheless, there have been instances in recent years where HGV fires have closed tunnels for several hours in the UK (BBC News, 2011) and for five days in Norway in 2013 (BBC News, 2013). It is unknown whether a fire suppression system would have been relevant to this case. However, the frequency of tunnel fires in general may be reduced by the fitment of automatic suppression systems to HGVs.

E.1.2 Potential Mitigation Strategies

Background

Automatic fire extinguishers may be fitted within the engine compartment to reduce the severity of vehicle fires by containing or extinguishing the fire at the ignition point, preventing it from spreading to the passenger compartment. However, at present it is not mandatory to install automatic fire extinguishers on vehicles within Europe.

During the 1990s, research was conducted through the Halon Replacement Programme for Aviation and the Next Generation Programme (NGP) in order to replace Halon 1301 (CF3Br) as an extinguishing agent, due to its detrimental effect on the ozone layer. Both programmes were supported by the U.S. Department of Defense (DoD), leading to the creation of technologies and extinguishing agents that were also relevant to vehicle fire protection (Hamins, 2007).

Systems

Several different types of automatic fire extinguisher systems in varying levels of development were identified during the literature review. However, the most commonly found types of systems are the polymer detection hose system and the linear heat detection cable.

Polymer detection hose

The polymer detection hose system is equipped with a pressurised polymer detection hose that is unwound across the engine compartment. This detection hose ruptures at any location where the temperature rises above a predetermined point and deploys the fire extinguishing agent (most commonly FE-36TM or 3M™ Novec™ 1230). Therefore, if a fire is detected in the engine compartment, the area of the tube closest to the fire will react by bursting, causing the extinguishing system to be deployed at the source of the fire.

Linear heat detection cable

The linear hear detection system is similar to the polymer detection system except that discharge nozzles are placed in strategically located positions across the engine compartment. A linear heat detection cable is installed spanning across the entire compartment area. This automatically detects any regions where the temperature of the compartment has risen over a pre-determined level. The extinguisher nozzles closest to the fire will be activated. A power supply is integral to each firing head mechanism.

Several different cables with different temperature ratings may be selected depending on the desired operation temperature of the extinguishers. Lifeline-fire offers systems that can be activated at 68, 88, 138 and 180°C.

Extinguishing Agents

A review of current extinguishing agents offered for extinguishers intended for vehicle fire protection was carried out to determine the most widely accepted replacements for Halon 1301.

Table E-24: Extinguishing agent analysis

Extinguishing Agent[38]	Description	Advantages	Disadvantages
ABC Dry Powder	Can be used on class A[39], class B and class C fires	Versatile and inexpensive	Leaves a residue that could damage electrical equipment. Can be corrosive to soft metals
AFFF Foam	Suitable for class A and class B fires	Particularly suited to fight liquid spill fires such as petrol, oil, fats, paints, etc.	Not suitable for use on fires involving live electrical equipment but may be used on 12-24 volt vehicle electrics
HFC227ea (FM200)	Can be used on class A, B and C fires	Leaves no residue and is safe for use in occupied spaces. Most common metals and rubber, plastic, and electronic components are unaffected when exposed	The discharge of FM-200® into a hazard may reduce visibility for a brief period
CO2	Can be used on class A, B and C fires	A CO2 discharge leaves behind no residue, eliminating the need agent clean up and helping reduce downtime	Protected areas must not be occupied. Even small amounts of CO2 can be harmful or fatal if inhaled
Monnex Powder	Can be used on class A, B and C fires	More effective than ABC Dry powder	Expensive and leaves a residue
FE-36	Can be used on class A, B and C fires	Effective in small enclosures and does not leave residue. Electrically nonconductive and noncorrosive. Zero ozone depletion potential	Toxic if large quantities are intentionally inhaled
NovecTM 1230	Can be used on class A, B and C fires	Safe to use in occupied spaces. Considered a green gas and poses no threat to the ozone layer	Expensive and cannot be stored in cold areas

[38] Sources: www.fireandsafetycentre.co.uk, www.safefiredirect.co.uk, www2.dupont.com, solutions.3m.com

[39] Class A: Burning solids; class B: liquid fires; class C: gas fires

E.1.3 Feasibility

Automatic fire extinguishing systems for vehicles are commercially available as off-the-shelf items and are therefore technically feasible. The systems are available with several extinguishing agents which no longer damage the ozone layer.

Type-approval of extinguishers appears to be a more complicated issue since standard tests for these systems do not exist. During his review of research needs for automatic fire extinguishers, Hamins (2007) described several considerations which must be made when designing, installing and testing a suppression system:

- The placement of the system must be carefully considered in order to ensure that it does not interrupt the vehicle functioning or reduce the survivability of occupants in a collision.
- The geometry of the vehicle must be considered as this will influence the ignition point and fire behaviour.
- The appropriate mass and volume of the system.
- Ambient factors should be considered so that the system will work regardless of temperature, wind velocity and incline.
- The system should still be effective regardless of vehicle orientation e.g. still work if fire occurs after rollover event.
- The system should still be effective after a collision.

The need for a standardised test procedure to measure the effectiveness of automatic fire extinguishers on road vehicles, particularly after a collision, is frequently repeated in the literature (Hamins, 2007). Various unsuccessful attempts have been made to develop testing protocols for fire suppression systems in the U.S.

In 2000, General Motors collaborated with the Department of Transportation to allow NIST (National Institute of Standards and Technology) to develop experimental protocols to measure the effectiveness of several different existing and emerging fire suppressant technologies using static, uncrashed vehicles. The experiments were carried out using laboratory test devices, reduced scale engine compartments and a static uncrashed mid-size passenger vehicle. Experiments were developed to measure the effect of operating conditions on extinguisher effectiveness (Hamins, 2000).

Experimental fire suppression test protocols were developed for moving and static vehicles by Santrock and Hodges (2002) based on the experimental procedure outlined by Jensen and Santrock (1999). By repeating experiments carried out by NIST on stationary vehicle mock-ups with no crash damage, they were able to prove that dynamic factors such as vehicle motion, crush and airflow through the engine dramatically affect the efficiency of suppression systems.

In 2005, Ford Motor Co. introduced automatic extinguishers as an optional extra on their Crown Victoria Police Interceptor line due to the concern over the number of fire-related fatalities associated with high-speed rear impacts in parked Crown Victoria vehicles. However, Ford did not publish a report describing their testing protocol and there has been no comprehensive, independent testing of these systems. There has also been much scepticism in the media as to whether these suppression systems are effective since two fire-related fatalities have occurred in cars with suppression systems installed (Beall, 2011). Ford also ruled out the option of retrofitting the system to previous models as the sophisticated electronics involved with the system prohibit them from offering it as an after-market product.

Bus and coach fire safety has been an active area of research in Norway and Sweden for many years. The Road Administrations from both countries initiated a research project with SP Technical Research Institute of Sweden in 2005 to carry out several fire safety projects including the development of test methods for fire suppression systems installed in engine compartments. Eleven fire suppression system test methods are described in SP method 4912 using an engine compartment mock up rig. Testing of all components within the system is also required. Detectors, electrical/electronic components and control panels are performance tested for harsh environments, temperature and humidity extremes.

Proposals for amendments to Regulation 107, which defines provisions concerning the approval of category M2 and M3 vehicles with regard to their general construction, have been submitted to GRSG based on same tests developed with the SP Technical Research Institute of Sweden. The amendments were prepared to introduce fire suppression systems for buses and coaches upon detection of fire in the engine and/or heater compartment (experts from Sweden, 2014). Suggested modifications to the Regulation include requirements for type approval of fire suppression systems and tests to examine the system's ability to extinguish fires in the environment of an engine compartment. Test equipment, test conditions and test scenarios are described to ensure that the test methods are repeatable and correspond to realistic fire scenarios.

Type-approval may not be the only method to encourage operators to install automatic fire suppression systems. In 2004, Swedish insurance companies changed their regulations so that buses and coaches could only be insured if they were equipped with an approved fire suppression system in the engine compartment. This led to 60% of buses and coaches in Sweden installing these systems, with the remaining 40% becoming non-insured or self-insured (Rosén, 2011).

Hamins (2007) pointed out that it would be useful for manufacturers to gauge the willingness of the public to pay the additional costs of on-board fire extinguishers by carrying out a survey. The public must decide whether the decrease in risk of fatality or injury outweighs the cost of purchasing and maintain the system and the decrease in fuel efficiency due to the additional added weight associated with the system.

Hamins highlighted events in the past when the demand from safety-conscious customers has driven the development of side airbags. An analysis of the opinions of consumers informed about the costs and benefits of automatic extinguishers would inform manufacturers of any marketing opportunities created by offering them as additional safety features.

E.1.4 Costs

The following costs are associated with the addition of automatic fire extinguishers on vehicles:

- Costs incurred by manufacturers to redesign engine compartments in order to fit space for an extinguishant storage tank and additional equipment.
- Swedish experts estimate that the cost of an approved suppression system will be €1,100 for a bus. The cost of fire testing to pass type-approval is also estimated to be €17,000. The one-off cost to set up an engine mock-up for testing is estimated to be between €12,000-17,000.

Table D-25 shows the cost of a one-off purchase of three different systems from one extinguisher retailer. It should be assumed that the unit cost of each system would be lower for a vehicle manufacturer.

Table E-25: Cost of different heat detection cable systems

To protect enclosed volume not exceeding:-	Filled with ABC dry powder	Filled with FE-36 or NovecTM 1230	Filled with CO2 fitted with direct valve	Fitted with standard Trace detection tube
1 cubic metre	£310 (1 kg)	£436 (1 kg)	£498 (2 kg)	3 m long
2 cubic metre	£334 (2 kg)	£570 (2 kg)	£644 (5 kg)	4 m long
4 cubic metre	£448 (4 kg)	£898 (4 kg)	Use Indirect	5 m long

(Source: www.firetrace.co.uk/price-list-2013-2)

Additional costs include regular servicing and maintenance costs. Several manufacturers recommend that the FE-36TM or 3M™ Novec™ 1230 extinguishing agent is serviced every 2 years.

E.1.5 Benefits

The installation of automatic fire extinguishers in vehicle engine compartments has the potential to reduce the severity of vehicle fires, providing several direct benefits to society. These include:

- The reduction of vehicle fire fatalities and casualties.
- The reduction of damage associated with vehicle fires.
- The reduction of economic losses. The office of the Deputy Prime Minister estimated that the average cost of each vehicle fire to the UK economy was €6015 in 2003.
- The effectiveness of the installation of automatic fire extinguishers has been demonstrated on Swedish buses. In 2004, Swedish insurance companies changed their regulations stating that all buses had to be equipped with an approved fire suppression system. Before this was implemented there were on average 6-7 complete burnouts of buses caused by fires in engine compartments every year. Between 2004 and 2010 there were no complete burnouts of insured buses. (Rosén, 2011). This is shown in Figure E-34.

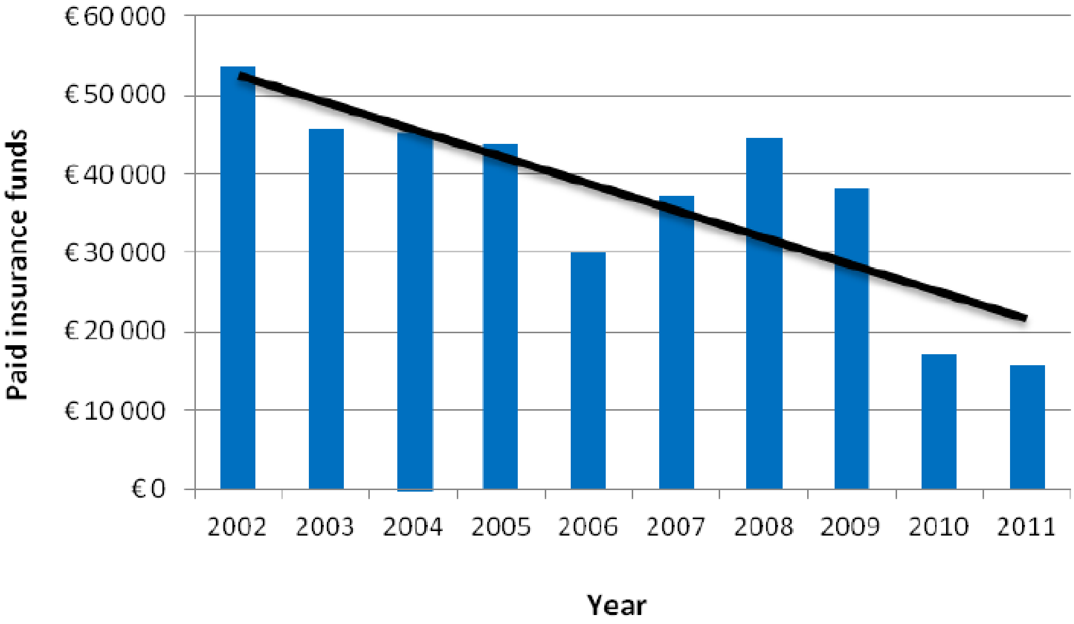

Figure E-34: Average cost per bus fire for insurance companies in Sweden

However, it should also be noted that at least 40 percent of the buses in Sweden are not equipped with suppression systems as they are non-insured or self-insured. The reason for the significant decrease in complete burnouts is therefore most likely more complex than simply the introduction of suppression system requirements. In 2001, the Swedish Motor Vehicle Inspection introduced compulsory fire safety inspection of buses, which has almost certainly led to improved overall bus maintenance, and therefore, a reduced number of bus fires.

E.1.6 Cost-to-Benefit Ratio

There has been no cost-benefit information identified in the area of automatic fire extinguishers during the literature review. However, many authors have postulated that it may be possible to justify the expenses of their installation based on the potential savings made in the reduction of costs to society associated with vehicle fires (Ahrens, 2005).

Using figures obtained during the literature review, a break-even cost may be estimated for the UK market. It is assumed that figures provided by the DCLG are for passenger cars only to obtain values for the maximum amount of benefit obtainable.

The cost to the UK economy per vehicle fire × the number of vehicle fires per year in the UK:

$$€6015 \times 23900 = \mathbf{€143,758,500}$$

The cost of a life is valued at €1,564,503 million, a serious casualty as €231,278, a slight casualty as €17,753. The DCLG data states that there were 555 casualties during this period but does not distinguish between minor and serious casualties. The European Commission estimates that for every 8 serious casualties, there are 50 minor casualties. Therefore, it is assumed that during this period there were 76.5 serious casualties and 478.5 minor casualties.

Therefore, the total cost of vehicle fires in the UK in the period of April 2012 to March 2013 is estimated to have been:

$$€143{,}758{,}500 + (39 \times €1{,}564{,}503) + (76.5 \times €231{,}278) + (478.5 \times €17{,}753) = \mathbf{€230,961,694}$$

According to the Society of Motor Manufacturers and Traders (SMMT, 2014), 2.3 million new cars were registered in the UK in 2013.

Therefore, the benefit of adding automatic extinguishers to cars (assuming 100% effectiveness of automatic fire extinguishers) may be estimated as:

$$€230{,}961{,}694\, million\ /\ 2.3\, million\ =\ €100$$

Therefore, the fitment of automatic fire extinguishers to cars is unlikely to be cost-beneficial. However, a similar analysis carried out for buses and coaches may prove that automatic fire extinguishers are cost beneficial.

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E.2 CNG Vehicle Fire Requirements

Specific enhanced requirements for Compressed Natural Gas (CNG) vehicles in the event of fire

E.2.1 Description of the Problem

CNG Bus Fires

In the Netherlands in 2012, a CNG-powered public transport bus caught fire whilst travelling between two villages. Once the driver had stopped the bus and evacuated all passengers, the fire spread from the engine compartment to the interior of the bus. The fire brigade arrived at the scene and decided to allow the fire to burn out in a controlled manner. However, the intensity of the fire caused the natural gas cylinders, located on the roof of the bus, to heat up. The temperature within the CNG tank exceeded the threshold required to activate the pressure relief safety valves and natural gas was vented out into the atmosphere. The valves, which are located on the sides of the CNG cylinders, are mandated as a safety measure in order to prevent an explosion. However, the escaping natural gas was ignited, resulting in horizontal flames of up to 20 m long lasting for four minutes.

The bus was completely destroyed in the fire. There were no casualties as a result of this incident, although this was mainly due to the fact that the bus stopped in a remote location. If the bus fire had occurred in a built up area it is possible that the consequences would have been far more severe. In this instance, the environmental damage was limited to the road surface, trees and shrubs.

The incident prompted the Dutch Safety Board to conduct an investigation to determine the cause of the accident and to recommend measures to prevent such incidents from recurring. The main conclusion of the investigation was that the CNG storage system complied with UN Regulation 110 and functioned as intended by this regulation, since the fuel tank did not rupture (Joustra et al., 2013). However, the direction of venting and potential risks to property and persons adjacent to the vehicle had not been considered. Several measures were recommended to be put in place to control the risks of CNG systems such as regulating the direction of flames caused during a release of gas through the pressure relief valves, modifying bus engine compartment covers to make access to engine fires easier and mandating automatic fire extinguishers.

Joustra et al. (2013) highlighted a number of additional issues that would need to be addressed to ensure the safety of the public during the operation and storage of CNG-powered buses:

- The bus driver was not trained to handle CNG-powered bus fires and was not aware of the potential size and direction of shooting flames.
- At the time of the incident, the firefighting strategy employed by the fire service was inadequate for handling CNG-powered bus fires. The fire service was not consulted during the decision making process to adopt CNG-powered buses and only began to prepare for dealing with CNG-powered bus fires after they were in service.
- Local councils may lack knowledge on the safety risks of CNG-powered buses and how to mitigate these risks, particularly at depots and garages. This is due to the fact that, according to Joustra et al. (2013) nationwide safety standards regarding parking facilities and garages for these vehicles do not exist. Without appropriate ventilation, any leaks from a CNG cylinder may cause a flammable gas cloud to be produced within a confined space.

The CNG bus fire in the Netherlands was caused by an oil leak in the engine cooling system. None of the gas cylinders exploded; however, several other incidents of CNG bus fires have been recorded in EU Member States, some which involved shooting flames and explosions:

- An engine compartment of a CNG bus caught fire in a depot in Saarbrucken, Germany, in 2003. In this case, the fire spread to a second CNG bus and one of the twenty tanks exposed to the fire burst, causing considerable damage within a radius of 25 m. This was due to the failure of two pressure relief valves to open in time, since the temperature within the tank did not rise quickly enough. Therefore the tank could not be depressurised before the maximum operating pressure was exceeded.
- In Montbéliard, France, in 2005, a CNG bus fire, originating from the engine compartment, caused damage to property over 60 m away when one of the fuel tanks exploded. Firemen reported jets of flame around 5 m long pointing vertically and horizontally due to the pressure relief device releases. The cause of the explosion was largely put down to the out of date regulation (before UN Regulation 110) which stipulated a maximum flow rate of gas release out of the tank that was not fast enough to prevent overpressure and explosion. The jets of flame, which were produced by the pressure relief devices, were also thought to have been directed towards the rest of the storage system, causing severe localised thermal stress on the central part of the tank.
- In Bordeaux, in 2005, similar jets of flames were witnessed from a CNG bus when vandals set fire to it. Although one of the fuel tanks burst, damage was said to be limited. The case highlights the vulnerability of the buses to vandalism, since fires propagate rapidly.
- In September 2011, a video was released showing long jets of flame shooting horizontally out of a CNG bus in Jesi, Italy. However, no further information is known on the incident. (Thenewsman, 2011)
- In February 2012, two CNG buses in Helsingborg, Sweden, collided at low speed. The collision led to a gas and oil leak in the engine compartment and flames rapidly spread through both buses causing two complete burnouts.
- During the investigation in the Netherlands, a second CNG-powered bus caught fire. A defective inlet valve caused a fire to start within the engine compartment, although the fire brigade managed to put out the fire before the pressure relief valves were activated.

According to the European Commission (2013) there are approximately 1 million CNG vehicles on European roads accounting for approximately 0.5% of the total vehicle fleet. The Commission expects this figure to increase ten-fold by 2020. Therefore, similar incidents could occur more frequently. Joustra et al. (2013) report that, in the Netherlands, 600 buses are currently powered by CNG alongside 3100 passenger cars and 2400 commercial vehicles, all of which have the same pressure relief devices responsible for producing jets of flame. Their report adds that CNG powered trucks are in development which carry a similar volume of fuel to buses and may also lead to the same severe consequences.

E.2.2 Potential Mitigation Strategies

Following the Dutch Safety Report, experts from the Netherlands recommended four preventative measures focusing on type-approval of new vehicles:

Revise UN Regulation 110

The pressure relief device, compliant with the current version of UN Regulation 110, produced a horizontal jet flame lasting for several minutes. This could have had serious consequences for other road users and the area around the vehicle. Therefore, experts in the Netherlands consider it necessary to amend UN Regulation 110 to regulate the direction of discharging the pressure relief devices of the CNG containers. Proposals detailed below have been devised by experts from the Netherlands (2013) to regulate the discharging direction of CNG containers, based on existing provisions within Regulation (EU) No. 79/2009 on hydrogen vehicles.

"The CNG gas discharge from pressure relief device (temperature triggered) shall not be directed:

- *towards exposed electrical terminals, exposed electrical switches or other ignition sources;*
- *into or towards the vehicle passenger or luggage compartments;*
- *towards any class 0 component;*
- *forward from the vehicle, or horizontally from the back or sides of the vehicle.*

Additionally, where any fuel container is fitted inside the vehicle the pressure relief device shall be fitted to the fuel container in such a manner that it can discharge the CNG into an atmospheric outlet that vents outside the vehicle."

Mandate smoke detectors and fire alarms

UN Regulation 107, Revision 3, now stipulates an acoustic and visual fire alarm in case of excess temperatures within the engine compartment. The European Union has mandated this for new type approvals, via the General Safety Regulation, from 1-11-2012 and for new registrations as from 1-11-2014. In addition, Revision 3, amendment 4 mandates smoke/fire detection in toilet compartments, driver's sleeping compartments and other separate compartments as from 26 July 2014 for new types and as from 26 July 2015 for all types. Contracting Parties may refuse registration of new vehicles when these provisions are not met.

Mandate automatic fire extinguishers and alter engine cover design

Dutch experts recommended the installation of automatic fire extinguishers in the engine compartments of CNG buses to eliminate or reduce fires spreading from this area (Joustra et al., 2013). Additionally, the Dutch Safety Board also stated that holes in the engine cover would allow access to the source of engine fires making manual extinguishers more effective when attempting to extinguish fires in this area.

Mandate the provision of UN Regulation 118 for CNG powered buses and coaches

UN Regulation 118 contains provisions for the burning behaviour of materials used in the interior of class II and III M3 Category vehicles, but excluding class I vehicles (city buses). Dutch safety experts have proposed applying this regulation to class 1 vehicles that use a CNG propulsion system. As a result, the speed at which a fire would spread could be reduced or extinguished before any CNG is discharged.

E.2.3 Feasibility

Dutch safety experts believe that the changes brought into force by an amended version of UN Regulation 110 would be technically feasible since they are based on provisions within Regulation (EC) No. 79/2009 on hydrogen vehicles, which use similar technologies to store and vent hydrogen. It also appears that the bonfire test, stipulated in in UN Regulation 110, does not consider the vehicle as a whole or examine the synergetic effects of the system during interaction with fire.

Several different automatic fire extinguisher technologies exist that are appropriate to buses (please refer to document on mandating automatic fire extinguishers). Swedish experts have carried out large amounts of research into this area, which has led to the development of proposals for amendments to UN Regulation 107 on the general construction of buses and coaches. These proposals introduce fire suppression systems into the regulation and were submitted in February 2014. They detail several fire tests that may be included as part of the type-approval process (Experts from Sweden, 2014).

The addition of holes in the engine cover in order to allow access to the source of engine fires, making manual extinguishers more effective, is also a technically feasible option. This has been demonstrated by MAN Lion's City CNG-powered buses operating in The Hague.

The extension of the scope of UN Regulation 118 to class I M3 vehicles has been proved to be technically feasible since it is applied to class II and III vehicles currently in service.

The changes to the regulations will be put into effect via the type-approval process for new vehicles. However, applying safety modifications to existing fleets of CNG powered vehicles is seen as the responsibility of individual countries. Joustra et al. (2013) noted that encouraging operators to carry out changes to their existing vehicles is likely to be extremely difficult due to the nature of the market for public transport. Unlike the passenger car market, safety is not a selling point for public transport users since most operators compete strongly on price.

Type-approval may not be the only method to encourage operators to install automatic fire suppression systems. In 2004, Swedish insurance companies changed their regulations so that buses and coaches could only be insured if they were equipped with an approved fire suppression system in the engine compartment. This led to 60% of buses and coaches in Sweden installing these systems, with the remaining 40% becoming non-insured or self-insured (Rosén, 2011).

It is unlikely that changes to buses caused by the regulation will be deemed as unacceptable to drivers or passengers unless fare prices were to rise as a result.

E.2.4 Costs

As a result of the modifications to regulations recommended by Dutch experts, the following areas of cost have been identified based on the available literature; however, in most cases, specific values were not reported:

- Costs incurred by manufacturers to redesign the location of pressure relief devices of future vehicles to comply with Regulation 110.
- Costs incurred by manufacturers to fit smoke detectors and fire alarms to future fleet vehicles.
- Costs incurred by manufacturers to redesign the engine compartment and install automatic fire extinguishers a. Swedish experts estimate that the cost of an approved suppression system will be €1100 for each vehicle.
- The cost of fire testing to pass type-approval is also estimated to be €17000.
- Costs incurred by manufacturers to replace materials in class I buses with more fire resistant materials.

E.2.5 Benefits

No information on the benefits of these potential measures has been reported in terms of a target population and likely reduction in fires and their costs. Nevertheless, the anticipated benefits of following the recommendations of the Dutch experts are as follows:

• By altering the position of the emergency relief valves, jet flames will no longer be created in a horizontal direction. This would reduce the potential for the system to cause death, serious injury or damage to the surrounding environment. It is difficult to estimate this benefit in financial terms due to the fortuitous nature of the previous flame jet cases which occurred in rural areas. However, if this was to occur in a built up area, the consequences could be much more severe.

• If automatic fire extinguishers were to be installed on CNG powered buses, engine fires could be mitigated or their severity reduced, decreasing the chances of the entire bus being destroyed. Since the requirement by Swedish insurers for operators to install automatic extinguishers on buses in 2004, the average cost in insurance funds per bus has decreased. This is shown in Figure E-34.

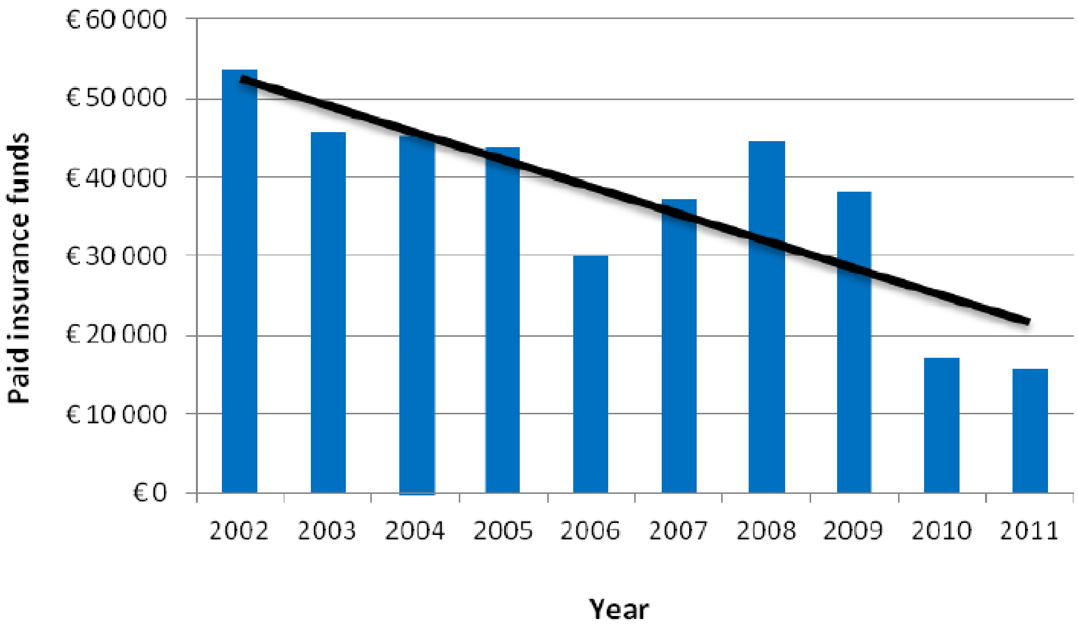

Figure E-35: Average cost per bus fire for insurance companies in Sweden

- The addition of fire resistant materials to inner city buses will increase the amount of time taken for flames to propagate through the bus. This would allow more time for passengers to evacuate and the emergency services to arrive at the scene to put the fire out. This could also lead to fewer complete bus burnouts as the CNG system would take longer to heat up enough to cause catastrophic results.

Benefit-to-Cost Ratios

Limited information was identified on the costs and benefits of the further measures proposed to reduce the risk of CNG bus fires. Nevertheless, it is clear that some high-profile incidents have occurred that have the potential to erode the public's confidence in CNG, and possibly in alternative fuels and powertrains more widely. With the increasing use of such vehicles by local authorities and governments seeking to reduce CO2 and improve air quality in towns and cities, further investigation of these measures would appear to be worthwhile. As a minimum, the following should be considered, because they are likely to be of relatively low cost and provide significant benefits:

- Implementation of some of the requirements for Hydrogen vehicles (Regulation EU/79/2009) in CNG vehicle requirements (Un Regulation 110)
- Applying the requirements of UN Regulation 118 regarding the burning behaviour of materials to class I vehicles with a CNG propulsion system

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E.3 Rear Impact Protection of the Tank

E.3.1 Description of the Problem

Rear impact vehicle fires

A rear-end collision is defined as a crash in which the front of one vehicle collides with the rear of another vehicle, and any one vehicle may be involved in several collisions. Thus, a driver involved in such a crash may be the driver of a striking vehicle, of the struck vehicle, or of the vehicle that both struck and was struck (Singh, 2003). Statistics from various sources have been collected concerning rear impacts:

- Kampen (2003)carried out an analysis of ten European countries using accident statistics from the CARE database (Community Road Accident Database). In 1998, 116,024 casualties were recorded as a result of rear-end impacts.
- A detailed analysis of rear impacts was carried out Eis et al. (2005), using data from the German In-Depth Accident Study ("GIDAS") including accidents from 1996 to 2004. The frequency of rear impacts compared to other modes was investigated, followed by an in-depth review of single rear impacts and rear impacts in multiple impact crash sequences. The study reported that 19% of all passenger cars involved in an accident have at least one rear impact.
- In the USA, The National Highway Traffic Safety Administration (NHTSA) estimated that approximately 29.7% of all crashes in the year 2000 were rear-end crashes. These were responsible for 30% of all injuries and 29.7% of the property damage (Singh, 2003).

Fewer accident statistics exist regarding the frequency of vehicle fires in the EU and the USA, especially cases where fires have been caused by a rear impact. However, there have been a number of cases where this problem has received a lot of media attention:

- Fires caused by rear impact incidents involving the Ford Pinto (1971-1976 model) were claimed to be responsible for 27 fatalities (Wojdyla, 2011). The location of the fuel tank behind the rear axle meant that it was located within the crushable zone at the rear of the car making it vulnerable to being punctured. During an accident, fuel that leaked from the tank would ignite due to sparks caused by the contact between the vehicle structures.
- In 2005, Ford introduced automatic extinguishers to their Crown Victoria Police Interceptor line due to the concern over the number of fire-related fatalities associated with high-speed rear impacts in stationary Crown Victoria vehicles (Beall, 2011).
- NHTSA are currently investigating Chrysler due to a number of incidents where several of their Jeep models have caught fire following a rear impact. It is reported that, in its current location, the fuel tank is highly vulnerable to being punctured in a rear impact event (George, 2013). Federal regulators have linked 51 deaths to fire due to rear-end crashes involving 1993 through 1998 Jeep Grand Cherokees and 2002 through 2007 Jeep Liberty SUVs (Rogers, 2014).

One of the most detailed sources of fatality rates from vehicle fire data was collected by the Swedish Transport Administration between 1998 and 2008. In-depth data was recorded from fatal crashes involving passenger cars, SUVs, vans and minibuses. Viklund et al. (2013) summarised the findings of the study relevant to vehicle fires. In total, 181 fire related deaths caused by 133 separate road crashes were recorded nationally, which accounted for 5% of all road fatalities that occurred during this period. Fire and smoke were ruled as the primary cause of death in 55 cases. The source of the fire was not identified for 61 of the 133 cases. However, of the remaining 72 cases, 16 fires were found to originate from the fuel tank. Two fuel tank fires were found to be caused by rear end impacts.

E.3.2 Potential Mitigation Strategies

In an effort to reduce the number of fire-related fatalities occurring as a result of rear impacts, manufacturers must prove that the integrity of their vehicle fuel system is sufficient as part of the certification process. Manufacturers must comply with different fuel system Regulations depending on the country where their vehicles are sold. In Europe, manufacturers must ensure that their fuel systems comply with either Directive 70/221/EEC or UN Regulation 34 (Visvikis et al., 2010). UN Regulation 34 goes further than the Directive and at the manufacturer’s request allows for the approval of vehicles with regard to the prevention of fire risks. This includes front, lateral and rear-end tests on the vehicle. Therefore, the rear-end impact test is not compulsory for manufacturers selling in Europe.

In contrast, vehicles sold in America must be certified to the Federal Motor Vehicle Safety Standard 301 (FMVSS 301). This regulation requires a rear impact crash test and has a much wider scope than UN Regulation 34.

Modifying the European methods of type approval to include a compulsory rear impact test would aid the process of harmonising vehicle regulations so that vehicles sold in Europe also comply with the rear impact protection requirements of the tank, stipulated in America. The following section provides a summary of some of the main differences between UN Regulation 34 (United Nations, 2012) and FMVSS 301 (DOT, 2012) regarding the rear impact test:

Scope

- UNECE Regulation 34 applies to vehicles of categories M, N and O. Part II is specifically dedicated to collision mitigation and is performed only at the request of the manufacturer.
- FMVSS 301 applies to all vehicles 4,536 kg or less Gross Vehicle Weight Rating (GVWR) and school buses over 4,536 kg GVWR.

Rear Impact Tests

- UN Regulation 34 defines a 35 to 38 km/h rear moving flat rigid barrier impact test. The ECE test device weighs 1,100+20 kg. A pendulum can be used as the impactor.
- For vehicles manufactured before September 2006, FMVSS 301 requires a rear impact test to be carried out at 48 km/h. Vehicles manufactured after September 2006 must be struck from the rear by a moving deformable barrier travelling at 80 km/h. The test vehicle and barrier face are aligned so that the barrier strikes the rear of the vehicle with 70 percent overlap toward either side of the vehicle. So aligned, the barrier face fully engages one half of the rear of the vehicle and partially engages the other half. 50th percentile test dummies must occupy each front outboard designated seating position.

Performance Requirements:

- UN Reg. 34 states that no more than a slight leakage of liquid in the fuel installation should occur on collision. If there is continuous leakage in the fuel installation after the collision, the rate-of leakage should not exceed 30 g/min. No fire maintained by the fuel shall occur.
- FMVSS 301 states that fuel spillage in any fixed or moving barrier crash test shall not exceed 28 g from impact until motion of the vehicle has ceased, and shall not exceed a total of 142 g in the 5-minute period following cessation of motion. For the subsequent 25-minute period, fuel spillage during any 1 minute interval shall not exceed 28 g.

The impact speed and test configuration specified in UN Regulation 34 would have to be altered in order to align the Regulation with FMVSS 301.

E.3.3 Feasibility

UN Regulation 34 states that the rear impact test is optional and there is no data available that indicates how many manufacturers volunteer to carry out the assessment on their vehicles. Therefore, the feasibility of the test is unknown.

In the US, tests are known to be technically feasible. However, their efficiency may be called into question due to incidents that have recently come to light involving Jeeps bursting into flames in rear impacts. It is not yet clear whether the apparent dangers posed by the fuel system design on these vehicles is related to a limitation of the test procedure or due to the implementation of the test procedure within the self-certification process used in the US.

Limitations to the rear impact test specified in FMVSS 301 include the unrealistic shape of the barrier and the barrier height. The flat surface of the barrier striking the rear of the vehicle provides a uniform force distribution which is unlikely to occur during a rear impact on the road. It is also unlikely that the barrier height is representative of the height of the leading edge of all vehicles on the road.

According to George (2013), NHTSA analysed Jeep’s accidents involving rear impacts and fuel leaks, and also began investigating Chrysler's self-certification tests for FMVSS 301. However, no further comment on the outcomes of this analysis has been found.

E.3.4 Costs

No specific information on costs were encountered during the literature search. However, the likely costs associated with implementing the FMVSS 301 rear impact test include:

- Additional testing costs
- Potential re-design of the fuel system by some manufacturers

E.3.5 Benefits

The potential benefits associated with implementing the rear impact test include:

- Adoption of the test alongside the rear occupant test could lead to a better understanding of safety of rear occupants and a reduction in the number of rear occupant fatalities.

E.3.6 Cost-to-Benefit Ratio

During their investigation using Swedish national data, Viklund et al. (2013) found that during a 10 year period, 2 car fires were caused by a rear ending incident by another vehicle, leading to at least two fatalities. Therefore, even including costs related to rear end incidents causing serious injury and other economic costs such as road damage and congestion, it is unlikely that data from Sweden will show that the implementation of a rear impact test will be cost beneficial.

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Annex 6 Driver interface and distraction and ITS

Appendix F. Driver interface and distraction

F.1 Standardisation of uniform vehicle controls

Standards exist for some aspects of vehicle control interfaces. However, with new Advanced Driver Assistance System (ADAS) functions emerging, manufacturers have been differing in the way in which they implement the new functions available to the driver. This measure relates to the standardisation of new vehicle controls to ensure that drivers moving from one vehicle to another have a consistent driving experience and reduce the likelihood of control misuse.

Standardising the location of emergency buttons (including the horn and hazard light), parking brake, gear shift patterns, indicator stalk/wiper stalk location, etc may also help to reduce driver errors.

This measure is closely linked with the 'Improving the Intuitive Operation of Vehicles' section as standardising controls is likely to improve intuition.

F.1.1 Description of the Problem

According to the ETSC (2014), over 1.3 million road accidents occur each year in the EU, killing around 36,000 road users. Although it is not known to what extent the operation of vehicle controls contributes the accident statistics, intelligent transport systems (ITS) that assist drivers may enhance driver safety as well as operational efficiency. However, these types of systems can be implemented differently by different manufacturers, creating inconsistency and increasing the likelihood of drivers who use different vehicles making errors.

The following is a list of existing technologies and controls, some of which must be present in all vehicles. A description of the system is provided and the potential different methods of application are noted. In addition, some vehicle controls, such as parking brakes and hazards lights are also discussed in the 'Improving the Intuitive Operation of Vehicles' section.

Table F-5:

System	Description	Application	Possible methods of use
Speed management	Technologies which assist the driver in the task of speed control	Advising the driver of the speed limit Advisory speed warnings to alert drivers when they are exceeding the speed limit Restricting the vehicle to drive at or below the speed limit	Stalk to activate and adjust speed limiter Push buttons to activate and adjust speed limiter Rotary buttons to adjust speed limiter

System	Description	Application	Possible methods of use
Adaptive cruise control	Vehicle speed is automatically adjusted to maintain a safe following distance to the vehicle ahead	-	Automated (Have to switch it on and off sometimes, not preferred distance above min)
Forward collision warning	Warns drivers when they are too close to the vehicle ahead	Visual and auditory warnings	Automated
Lane departure warning system	Warns a drivers when the vehicle starts to move out of its lane	Warnings provided to driver if vehicle starts to move out of its lane. Warning provided to driver and if no action is taken, the system automatically takes steps to keep the vehicle in lane.	Automated (often on/off, feedback mechanisms may differ)
In-cab warnings and interlock systems for vehicles with lifting equipment	Systems to alert or prevent driving when lifting equipment is raised	Interlock systems to prevent the vehicle from being driven when equipment is not lowered sufficiently. Visual and/or audible warning when lifting equipment is in the raised position. Audible warnings can be turned off using a switch but visual warnings can only be turned off by lowering the equipment.	Automated

System	Description	Application	Possible methods of use
Indicators	Blinking lamps which are activated by the driver to show intent to turn or change lanes	-	Indicator stalk may be mounted on the left or right Click stalk up or down to indicate right or left Indicator stalk may remain in the 'up' or 'down' position while indicating or may revert to the neutral position Flicking the stalk up or down may give 3 or 4 flashes for changing lanes on some vehicles
Windscreen wipers and rear screen wipers	Removes rain and debris from the windscreen	Press, pull or twist for water jets	Windscreen wiper stalk may be mounted on the left or right Twist function to operate some windscreen wipers Push/pull function to operate wipers Up/down function to operate wipers (Combined up/down and twist for intermit speed or this may be via another switch/toggle)
Hazard lights	Push button to activate hazard warning lights	-	Button may be located in different places on different vehicles
Parking brake	Latching brake used to keep the vehicle stationary	-	Pull handle Push button Gear Lever Switch Foot pedal Push button and switch have different types of feedback when engaged
Horn	A sound is made to warn others of the vehicle's presence	-	On the steering wheel – either at the bottom, on the left and/or right sides or both (e.g. Vauxhall Ampera) Push button on the end of the indicator/windscreen wiper stalk

System	Description	Application	Possible methods of use
Gear shift patterns	Gears provide controlled application of power	Manual gearbox where the driver selects the appropriate gear Automatic gear box where the driver must choose 'drive', 'neutral' or 'park' but is not required to change gear whilst the vehicle is moving	Reverse may be on the bottom right, top right or top left Sometimes need to push button on gear stick, push down on gear stick or pull level on gear stick shaft up to engage reverse gear
Lights	Lights provide illumination for the driver and increases the conspicuity of the vehicle	-	Rotary control on indicator stalk Rotary control on dash Push/pull for full beam lights on indicator stalk
Cruise control	System automatically controls the speed of the vehicle	Driver selects desired speed and the system maintains that speed	Disable system by pressing 'cancel' button Disable system by pressing brake or clutch Cruise control can be set using a button or stalk Speed can be adjusted by pressing up/down buttons or stalk
Air conditioning	Can lower or raise the temperature inside a vehicle	Heaters are present in modern vehicles but not all vehicles have air conditioning to lower the temperature	Temperature and fan speed can be controlled using a dial Temperature and fan speed can be controlled using + and – buttons Air conditioning to lower the temperature can be selected using an on/off button Temperature of driver and passenger zones can be controlled independently in some vehicles
Fog lights	Fog lights increase the conspicuity of a car when visibility is seriously reduced	-	Rotary control on indicator stalk Push button on dash

System	Description	Application	Possible methods of use
Radio/phone controls on steering wheel	Controls provided on the steering wheel to allow a driver to control the radio or their phone without needing to move their hands away from the steering wheel	-	Rotary buttons to adjust volume/channel Push buttons to adjust volume and channel
Infotainment	Collection of devices which provide audible and visual information and entertainment		Infotainment systems can be controlled using the following methods: • Touchscreens • Push buttons • Rotary buttons • Dials Audible feedback can be provided Visual feedback can be provided

These systems can be activated and controlled in different ways and there is virtually no standardisation of the functions between different manufacturers. For example, speed limiters or cruise control functions can be activated using a stalk behind the steering wheel or a variety of buttons on the steering wheel for example.

F.1.2 Potential Mitigation Strategies

Standardising uniform vehicle controls would require changes to the operator interface to ensure that all controls are located in a consistent manner across different vehicle brands and models. In some cases, a complete re-design of the vehicle controls may be required.

F.1.3 Feasibility

All of the technologies described in Section H.1.1 are currently available but not all are included on all vehicles brands and models.

Technical feasibility

It would be technically possible to standardise the operation and location of controls in new vehicles but would be almost impossible to adapt existing vehicles accordingly. However, it is likely that if the measure was to be introduced it would be a few years down the line in order to prevent undue disruption to current pre-production vehicle designs. The timeframe may vary between geographic/financial/trade/administrative regions. Larger areas will probably require more time to reach consensus and/or implement new regulations. It may be possible to issue non-regulatory industry guidelines, which could be implemented much more quickly but may not achieve desired level of homogeneity.

The measure would be of similar relevance across all vehicle types. However, the space available and layout of vehicle cabs would mean that standardising vehicle controls across all types of vehicles could be difficult. It therefore seems sensible to suggest that vehicle controls should be standardised for each type of vehicle first, e.g. a lorry, van or car, and across different vehicle types if possible.

For some control inputs, what is deemed to be intuitive varies between cultures. As such it may never be possible to standardise fully across all markets (disparities between Asian and European countries being particularly pronounced).

Encouragement feasibility

The standardisation of vehicle controls would require an agreement written into new car design requirements as it is unlikely that methods other than regulation will be enough to encourage vehicle manufacturers to fully standardise the design and location of controls. Although some manufacturers may be willing to adapt some vehicle controls when designing new models, they may be reluctant to standardise all controls unless required to do so, particularly if they have worked to establish the vehicle controls as a unique feature (e.g. BMW iDrive).

Acceptability

Some drivers who are used to using certain control inputs may initially be opposed to any changes which would standardise them, but any resistance to the measure should reduce over time if control inputs are intuitive.

There is, however, likely to be more resistance from vehicle and systems manufacturers. In addition, developing innovative systems, which could potentially improve some functions might be limited if all controls are standardised and must meet certain legislative criteria.

Furthermore, some people may not be opposed to the changes but some changes may be deemed unnecessary modifications as they will not directly increase driver safety.

F.1.4 Costs

There are a range of costs associated with standardising vehicle controls. These include the purchase and fitment of the equipment, monitoring and maintaining the fitted devices and managing the administration of the programme. In some instances it would not be possible to retrofit the systems, defeating the purpose of the standardisation activities entirely.

These costs will be relevant to the vehicle manufacturer and, although firm costs are not available, they are likely to be in the medium range.

In addition, legislation will need to be updated and standards developed that vehicle and systems manufacturers must adhere to. There is likely to be a cost associated with these activities which will probably be in the low range, but again no evidence was available to support this estimate.

F.1.5 Benefits

Although no evidence is available to indicate the number/proportion of the target population collisions/casualties that are expected to be mitigated, standardising key vehicle controls will mean that vehicle users are able to quickly and easily identify and locate a control to operate it accurately and efficiently. This will be of benefit to drivers who use different vehicles on both a regular or irregular basis.

Standardisation of vehicle controls is also likely to reduce driver distraction when operating an unfamiliar vehicle or when using different vehicles regularly.

Although not quantifiable, collisions through driver distraction may be reduced, and where the application of ITS is standardised and used in all vehicles, rear-end collisions and accidents associated with speed and lane drifting may also be reduced.

Standardising the way in which vehicle controls are activated and controlled is not likely to have any non-collision benefits, but making these systems available in all vehicles may increase fuel efficiency and reduce the number of driving offences.

F.1.6 Benefit:Cost Ratio

No accident statistics for incidents that occur as a result of non-standardised vehicle controls are available and no cost-benefit studies were therefore found. It is difficult to determine whether the standardisation of such controls would reduce the number of road traffic accidents, injuries and fatalities because baseline data is not available for comparison.

However, it is felt that the benefit:cost ratio will depend upon the user groups to which this measure applies. For professional drivers, who may only drive one or two different vehicles on a regular basis and are familiar with the operation of their controls, the costs of standardising vehicle controls are likely to be similar to the benefits (benefit:cost ratio = 1). However, as mentioned previously, it is difficult to estimate the benefit:cost ratio as no data is available to determine to what extend non-standardised vehicle controls contribute to accidents.

Standardising vehicle controls may be particularly beneficial for the general public who may be required to drive different / unfamiliar vehicles on occasion, such as hire cars, pools cars, etc. These drivers are more likely to benefit from standardised vehicle controls as it will be easier to quickly locate and operate control inputs across different types of vehicle. This, along with the likely relatively low cost of standardising vehicle controls on new vehicles, suggests that the benefits are likely to slightly outweigh the costs for these drivers (benefit:cost ratio >1). However, as many of these types of drivers are likely to use unfamiliar vehicles fairly infrequently, other methods of mitigating confusion in relation to vehicle controls may be just as beneficial as standardisation. For example, drivers hiring a vehicle or using a pool car at work could be provided with a short demonstration of the key vehicle controls and / or a brief guide to their use.

F.1.7 References

ETSC (2014). FAQ. Retrieved 18 March 2014, from: www.etsc.eu/faq.

F.2 Improving the intuitive operation of vehicles

The way in which vehicles are driven is evolving. New active safety and comfort systems are changing the ways in which drivers interact with their vehicles. Additional vehicle functionality can bring additional complexity to vehicle interface. Controls that are not intuitive to use are more likely to be misused resulting in a potential increase in collision risk or disused such that the driver fails to take advantage of the potential safety/comfort benefits that such systems may deliver. This measure would improve the intuitive operation of vehicle systems to minimise these risks and maximise the benefit of the systems.

F.2.1 Description of the Problem

To highlight the value of making controls intuitive, consider the vehicle steering function, which is the perhaps the most ingrained control mechanism contained within a vehicle. Pretty much every vehicle on the market provides a wheel for this purpose and all use the same format: clockwise turns right, anticlockwise turns left. In theory, this is a potentially ambiguous interface, as neither clockwise nor anticlockwise movements contain any inherent direction change within the controlling medium, other than rotationally. However, there is such a strong association in users' minds between clockwise-right and anticlockwise-left that it becomes an automated response, to such an extent that giving a driver directions using the (technically) more accurate descriptors of 'clockwise' and 'anticlockwise' would actually be far more confusing and require greater mental processing than saying 'left' and 'right'. From this it becomes clear that to switch such an interface within a vehicle, such that turning the wheel clockwise turns the vehicle to the left, and vice versa, would be so counter-intuitive that it would make driving much more difficult and would likely result in frequent input errors, which in turn would likely cause accidents. Not all in-vehicle control interfaces are so ingrained as this, yet it highlights the potential value in ensuring that all interfaces are as intuitive as possible. Doing so minimises the likelihood of input error and reduces driver cognitive workload, thus freeing up mental capacity to concentrate on other aspects of the driving task.

The following is a list of technologies/functions currently found within vehicles for which there are potential issues related to control input intuitiveness. Also provided is an assessment of available or commonly-used input mechanisms, specific control actions associated with these, and examples of where there is potential conflict:

Table F-6:

Function	Input method	Action	Issues
Steering	Steering wheel	Clockwise-right Anticlockwise-left	None
Indicators	Stalk on steering column (can be mounted to the left or the right)	Pushing down on the stalk indicates in the same direction as which side of the column the stalk is mounted	Stalk may be mounted on either the left or the right, which may cause confusion.
Hazard lights	Push-button Rocker switch	Press to turn on or off	Button may be located anywhere on console, potentially making it difficult to locate quickly, causing a distraction.
Parking brake	Pull-handle Push-button Gear lever Switch	There are various available control inputs on the market, each with different actions	If user is unfamiliar with the design, the input may be difficult to identify, difficult to operate or difficult to determine its state (i.e. engaged or disengaged). This may cause confusion, distraction or selection errors.
Headlights	Rotary control on indicator column Rotary control on dash	Various available control inputs, but usually involve a rotary control	Location can vary between models, making it potentially hard to locate (and at a time when vehicle may be in motion and driver vision impaired by low ambient lighting levels).
Full-beam headlights	Indicator column Rotary control	Pull or push (depending on permanent or single use) May be a selection on the rotary control, or require a pull/push action	Dependent on which side steering stalk is located Activation method may vary, even with similar control type.

In addition to the hard controls outlined in the table, vehicle functions in modern vehicles are increasingly controlled in the form of inputs using digital displays (either through soft keys around the display or through a touch-screen interface. These features tend not to exhibit problems with activation of the control itself, but rather with the user's ability to find the feature within the menu structure of the software. In theory, a user experiencing difficulty in this regard should not pose an increased crash risk directly, as interface menus may be locked down when the vehicle is in motion. However, if the driver fails to utilise a safety feature through an inability to activate it or to set it up correctly, this may indirectly influence crash risk. There is also the possibility that the driver may continue to attempt to access the interface even if the function is not available at the time, thus posing a distraction risk.

F.2.2 Potential Mitigation Strategies

Making controls more intuitive is a catch-all goal, which does not in itself indicate any specific mitigation strategies. However, the following example highlights the sorts of strategies that could be applied, although these would all be on the principle of developing design standards either as voluntary or mandatory legislation.

The electronic parking brake is, in the author's opinion, possibly the least intuitive of commonly-found in-vehicle controls, and where intuitive design fails on a number of factors:

- The control is often positioned in a relatively tucked away position. Legislation could specify that the control is clearly visible to the driver and, more specifically, mounted no more than, say, 200mm from the gear stick (this is important as this is the control most relevant to the parking brake as it will most likely be used immediately prior to activating the parking brake)
- The control often gives no indication of system state or a poor indication of system state. For an example of a poor indication of state, consider a button that lights up. Does this indicate that the brake is on (light indicates brake has been activated), off (light is alerting user to the need to activate the brake) or faulty (light is indicating that the brake has not applied properly)?
- The control activation may not map to the user's expectation. For example, some controls are a push button for both on and off functions, whereas some may require the user to pull to activate and push to deactivate (or vice-versa). Legislation would specify a standard mode of operation based on sound principles of typical user expectations.

F.2.3 Feasibility

Technical feasibility

For some control inputs, what is deemed to be intuitive varies between cultures. As such it may never be possible to standardise fully across all markets (disparities between Asian and European countries being particularly pronounced) (BS ISO 12214:2010). However, within Europe these conventions are generally fairly consistent. In addition, conventions relating to specific vehicle controls have developed over time and formalising this into a set of industry-wide standards should help to homogenise

It is also clear that design regulations have been implemented in the past and are in force today, demonstrating that standardisation is clearly achievable if there is agreement on the need for its introduction.

It is less clear how legislation would govern the intuitive design of digital interfaces, as each manufacturer currently uses their own software architecture, and structuring of menus and inputs will be governed by what features are available within a vehicle, as well as the interface technology installed (e.g factors such as the size of the display or whether the display is touchscreen etc.). Legislation on these levels may instead relate to a governing of what functions can be accessed by the driver whilst the vehicle is moving, how the interface must indicate that a function is currently unavailable, or what information must be available to the driver at all times. Legislation could also potentially relate to how large certain controls must be, what level of brightness a display must achieve, or ability to be seen under different lighting conditions, for example.

Encouragement feasibility

- Coordinated change to control design would require an agreement written into new car design requirements, probably a few years down the line in order to prevent undue disruption to current pre-production vehicle designs. The ease of coordinating change may vary between geographic/financial/trade/administrative regions. Larger areas will probably require more time to reach consensus and/or implement new regulations. It may be possible to issue non-regulatory industry guidelines, which could be implemented much more quickly but may not achieve the desired level of homogeneity. There currently exists the European Statement of Principles on HMI (EC, 2008). This forms a set of high-level guidelines on good design principles for designers of in-vehicle information systems.

Acceptability

Some members of the public may disagree with what is deemed to be an intuitive control input, however, by definition, the majority of the public would agree.

F.2.4 Costs

Fitment costs would depend on whether changes are to be applied retroactively. More likely would be that changes would apply to new vehicles only, which would largely avoid additional fitment costs.

Fitment costs will be relevant to the vehicle manufacturer, largely relating to design work and re-tooling, and these are likely to be in the medium range.

Legislation will need to be updated and standards/guidelines developed that vehicle and systems manufacturers must adhere to. There is likely to be a cost associated with these activities that will probably be in the low range.

F.2.5 Benefits

Key vehicle controls to be located in intuitive places and operated in an intuitive and consistent manner so that vehicle users are able to quickly and easily identify and locate a control and to operate it accurately and efficiently. This should help to reduce driver distraction when operating an unfamiliar vehicle, or even a familiar vehicle when using an infrequently used control (e.g. hazard lights). The degree of consistency in design may vary by vehicle type and so benefit may be reduced if driver is moving between different vehicle types.

F.2.6 Benefit:Cost Ratio

The benefit:cost ratio depends upon the user groups to which this measure applies. For the general public, who may only drive one or two different vehicles on a regular basis and are familiar with the operation of their controls, the costs of standardising vehicle controls may be similar to the benefits (benefit:cost ratio = 1).

Improving intuitive control design may be particularly beneficial for professional drivers who are likely to drive a range of different vehicles on a regular basis as it will be easier to locate and operate control inputs across different types of vehicle. The benefits should therefore outweigh the costs for these drivers (benefit:cost ratio >1)

F.2.7 References

BS (2010). BS ISO 12214:2010 'Road vehicles - Direction-of-motion stereotypes for automotive hand controls'.

EC (2008). Commission recommendation of 26 May 2008 on safe and efficient in-vehicle information and communication systems; update of the European Statement of Principles on Human-Machine Interface. European Commission.

F.3 Infotainment

Measure: Driver interface provisions and restrictions for on-board infotainment systems.

Interpretation: In-vehicle display, communication and computing technologies are advancing rapidly. There is the potential for drivers to access complex functionality through native vehicle systems and/or smartphone connectivity. This measure examines provisions and restrictions for on-board infotainment systems that may deliver this functionality without distracting the driver.

F.3.1 Description of the Problem

In-Car Entertainment, (sometimes referred to as ICE, or IVI as in In-Vehicle Infotainment), is a collection of hardware devices installed into automobiles, or other forms of transportation, to provide audio and/or audio/visual entertainment, as well as automotive navigation systems (SatNav). Infotainment systems today integrate radios, navigation Systems (standalone), multi-media interface (MMI), navigation systems (via MMI), external devices, auto changers, iPod adapters, music interfaces, rear seat entertainment systems (RSEs) and paired mobile phones (Audi, 2014; Jaguar Land Rover, 2013). Also increasingly common in ICE installations are the incorporation of video game consoles into the vehicle. Peer reviewed publications exist related to driver behaviour and distraction while using an in-car infotainment system (Kaber et al., 2012; Birrell and Fowkes, 2014; Platten et al., 2013; NHTSA, 2013a,b). The distraction due to the use of infotainment systems are related to:

- Visual stimulus (the driver taking the eyes off the road to attend to another source of visual stimuli, such as display screens, text messages on mobile phones, visual messages on other portable devices)
- Auditory stimulus (the driver attending to auditory stimuli, such as a phone call or sound alerts an electronic device makes)
- High attentional workload due a combination of the above and the driving task.

Studies based in NSW Australia (Lam, 2002) and Europe (ERSO, 2012) have shown that distraction is the cause of approximately 3-8% (respectively) of all road accident causing death or serious injury. However, both in-vehicle and external distraction was included in the 8% figure from ERSO (2012). In addition, studies have shown that in-vehicle distraction is responsible for the majority of distraction-related collisions (e.g. Lam, 2002, Stutts et al., 2005). However, not all in-vehicle distraction is caused by an on-board infotainment system. Other sources of in-vehicle distraction include portable electronic devices (phones), conversation with passengers, children in the vehicle, eating, drinking, smoking, and pets.

No peer reviewed publications exist that report the number of people killed or seriously injured in road accidents where infotainment was identified as a source of distraction. It is estimated that serious or fatal crashes due to driver distraction by an on-board infotainment is likely to be a portion of the 3% reported by the studies (Lam 2002; ERSO, 2012).

No peer reviewed publications exist that independently review infotainment systems in vehicles today and evaluate how effective restrictions to these infotainment systems are. This may be due to the fact that:

- The car manufacturing industry is highly competitive and car manufacturers keep the results of their HMI research studies confidential,
- Technologies evolve at a fast rate in line with customer demand and

- There are hundreds of vehicles makes and models in the market today, all with different infotainment systems and inherent restrictions.

To be able to fully evaluate infotainment systems and their restrictions in vehicles, a large-scale comprehensive research study would be required, with access to either:

- A vehicle from each car manufacturer (for each make and model) or
- Proprietary HMI design information held by vehicle manufacturers.

In addition, no technical or scientific reports could be located that outline cost-benefit analyses of restricting on-board infotainment systems.

For this reason, various infotainment systems and their inherent restrictions are briefly outlined below, based on information available in the public domain from vehicle manufacturers and transportation related articles in trade publications.

F.3.2 Potential Mitigation Strategies

Potential mitigation strategies include restrictions via technology and legislation:

- Restrictions of Infotainment Systems Specific to a Car Manufacturer
- Restrictions of Generic Infotainment Systems
- Restrictions via on-board diagnostic systems
- Restrictions via Legislation

Infotainment Systems Specific to a Car Manufacturer

Certain car manufacturers design their own infotainment systems which have built in restrictions to mitigate distraction. There are hundreds of car makes and models in the market today and it was not possible to review all of the infotainment restrictions available within the scope of this study. Three examples are described below: Jaguar Land Rover, Chevrolet and Ford.

Jaguar's touchscreen infotainment system includes a satellite-navigation system as well as a DVD player. According to Jaguar this touchscreen is a split screen that ensures that the driver can view navigation information while the passenger is able to view a DVD that the system is playing simultaneously. The system ensures that the DVD is not visible to the driver (Jaguar Land Rover, 2013).

Chevrolet claims (Chevrolet, 2014) that the infotainment system available in one of their models has built-in features intended to reduce distraction by disabling some functions when driving. Some functions of the system are greyed-out (disabled) when the vehicle is moving. The reviewed document (Chevrolet, 2014) provides very little information on what functions are disabled when the vehicle is moving. These include

- Some applications on the Infotainment system's Home Page
- Bluetooth phone pairing.

Chevrolet (Chevrolet, 2014) also provides the following warning in the User Manual to one of its models:

> *"Taking your eyes off the road for too long or too often while using the infotainment or navigation system could cause a crash. You or others could be injured or killed. Do not give extended attention to these tasks while driving. Limit glances at the vehicle displays and focus your attention on driving. Use voice commands whenever possible."*

Ford claims that their MyFord infotainment system lets the driver perform some functions (adjust temperature settings or make calls) while the car is in motion, while its built-in web browser works only when the car is parked (Vance & Richtel, 2010).

Generic Infotainment Systems

Generic Infotainment system platforms include MeeGo, Blue & Me™ and Drive Link.

The GENIVI Alliance, a consortium of several car makers and their industry partners, used Moblin with Qt as base for its 'GENIVI 1.0 Reference Platform' for In-Vehicle Infotainment (IVI) and automotive navigation system as a uniform mobile computing platform. GENIVI Alliance and BMW Group announced in April 2010 the switch from Moblin to MeeGo (Genivi, 2014). MeeGo is a framework consists of a wide variety of original and upstream components, all of which are licensed under licenses certified by the Free Initiative (such as the GNU General Public License) (MeeGo, 2014). MeeGo enables each vehicle manufacturer using this system to encode restrictions into their infotainment system.

Blue & Me™ is a widespread on-board infotainment system, with over 1,500,000 units installed in cars and commercial vehicles (e.g. Iveco vans). The TextCenterWith Blue & Me™ feature allows the driver to make phone calls without ever removing the hands from the wheel (using Bluetooth interface and controls on the steering wheel). The system dialogues with electronic engine and vehicle control systems and is the key component of Blue&Me™ Fleet (Iveco, 2014).This means that information about whether or not the vehicle is in motion and its current speed is available to the infotainment system and can be used to enable and disable certain functions on the infotainment system (for example web browsing or sending emails).

Samsung’s Drive Link is an application that is designed for drivers and passengers to use smart phones and tablets while on move. The feature will also offer on-board diagnostics and vehicle lifestyle management information (AutoExpo, 2014). Samsung's 'Drive Link Application' on MirrorLink technology allows the driver to navigate, answer calls and access music but blocks certain features such as using the internet when the vehicle is in motion (Samsung, 2014). Samsung states that the Drivelink app “has been designed to conform to the safety regulation set by Automotive industry standards”. Samsung has a global collaboration with the German auto maker BMW and Tata Motors is planning to launch passenger vehicles next year equipped with (AutoExpo, 2014).

On-board diagnostic systems

Through the years, on-board diagnostic systems on vehicles have become more sophisticated. A standard called OBD-II was introduced in the mid-1990s, providing partial monitoring of the chassis, body and accessory devices, as well as the diagnostic control network of the vehicle (Delphi Connect, 2014).

Delphi’s Vehicle Diagnostics System called Delphi Connect can be integrated on a number of vehicles, including delivery van or family car. The hardware device has to be plugged directly into the vehicle’s OBD-II connector port for seamless, constant connectivity both inside and outside the vehicle (Delphi Connect, 2014).

Potential applications may include infotainment systems that could limit a motorist's activities under certain circumstances, such as under certain road conditions (that can be defined by a ‘super user’ such as fleet manager or a regulator) (Sedgwick, 2013). The system is able to allow a motorist engage in safe behaviour – for example, using voice commands to place a call. However, the system can be configured to deny the driver sending text message while driving at any speed or over certain speeds (which can be configured by a ‘super user’ or regulator.). This system could determine that some functions that are normally allowed when the vehicle is moving should be shut down due to certain road conditions (Sedgwick, 2013). A ‘super user’ such as a fleet manager or regulator is able to ‘lock’ these settings to ensure that they cannot be overridden by the driver.

Current features of this device enable remote monitoring of the vehicle’s location, condition, speed from mobile devices, such as smart phones, including a geo-fencing capability (Delphi Connect, 2014). Based on the car's telematics system, real-time information can be captured and feedback provided to the driver on their driver performance (Sedgwick, 2013).

Legislation and Regulation in Europe

In 2006, the European Commission released a set of European Statement of Principles applying in vehicle entertainment (EC, 2006).

The European Commission requested that vehicle manufactures and the suppliers of portable in vehicle devices should enter into a voluntary agreement to follow these principles (EC, 2006).

These design principles are as follows:

1. The system supports the driver and does not give rise to potentially hazardous behaviour by the driver or other road users.
2. The allocation of driver attention while interacting with system displays and controls remains compatible with the attentional demand of the driving situation.
3. The system does not distract or visually entertain the driver.
4. The system does not present information to the driver which results in potentially hazardous behaviour by the driver or other road users.
5. Interfaces and interface with systems intended to be used in combination by the driver while the vehicle is in motion are consistent and compatible (EC, 2006).

For each of these principles, the EC (2006) document outlines detailed explanations, examples, applications, verification and references. For brevity, this document only provides the principles.

"Consistency" mentioned in point 5. involves for example the following design issues:

- Use of common terminology between systems; e.g. 'slow traffic', 'next junction';
- Use of words and/or use of icons to represent concepts or functions; e.g. 'Help', 'Enter';
- Use of colours, icons, sounds, labels (to optimise a balance between similarity and differentiation);
- Physical dialogue channel issues; e.g. single/double-click, timing of response and time-outs, mode of feedback e.g. visual, auditory, tactile (depending on functionality feedback should be different in order to avoid misinterpretation);
- Grouping of concepts and similar menu structures (for related functionalities);
- Overall design of dialogue and order of concepts.

A set of Installation principles also apply, including:

6. The system should be located and securely fitted in accordance with relevant regulations, standards and manufacturer's instructions for installing the system in vehicles.
7. No part of the system should obstruct the driver's view of the road scene.
8. The system should not obstruct vehicle controls and displays required for the primary driving task.
9. Visual displays should be positioned as close as practicable to the driver's normal line of sight
10. Visual displays should be designed and installed to avoid glare and reflections (EC, 2006).

The European Commission also recommended the following a set of principle regarding:

- Information presentation
- Interaction with displays and controls
- System behaviour
- Information about the system

Within the scope of this research it was not possible to quantitatively evaluate to what extent vehicle manufacturers and the manufacturers of portable electronic devices adhere to these principles in practice. No comprehensive an independent report could be found on this topic. Given hundreds of vehicles makes and models on the market in Europe today, a large scale systematic research would need to be carried to out determine exactly to what degree vehicle manufacturers align themselves with the European Commission's principles.

In addition to the European Commission's principles, all of the 27 EU Member States and Switzerland and Iceland, except Sweden have adopted specific regulations on mobile phone use while driving (Janitzek et al., 2009). However, with regards to Personal Navigation Devices (PNDs), music players and TV/video players, the picture is rather varied (Janitzek et al., 2009). Some European countries address the use of these devices through both specific and/or general regulations; however, in other countries there is no legislation applicable to the use of any devices other than mobile phones. 16 out of the countries address the use of PNDs, 13 states have articles in place that concern the use of music players, and 15 countries have legislation adopted that can be applicable to TV/video player use (Janitzek et al., 2009).

Legislation and Regulation in the US

The U.S. Department Of Transport (DOT) released Guidelines to Minimize In-Vehicle Distractions in 2013.

Issued by the DOT's National Highway Traffic Safety Administration (NHTSA), the voluntary guidelines establish specific recommended criteria for electronic devices installed in vehicles at the time they are manufactured that require drivers to take their hands off the wheel or eyes of the road to use them (NHTSA, 2013a).

The guidelines include recommendations to limit the time a driver must take his eyes off the road to perform any task to two seconds at a time and twelve seconds total. The guidelines also recommend disabling several operations unless the vehicle is stopped and in park, such as:

- Manual text entry for the purposes of text messaging and internet browsing;
- Video-based entertainment and communications like video phoning or video conferencing;
- Display of certain types of text, including text messages, web pages, social media content (NHTSA, 2013b).

The recommendations outlined in the guidelines are consistent with the findings of a new NHTSA naturalistic driving study, The Impact of Hand-Held and Hands-Free Cell Phone Use on Driving Performance and Safety Critical Event Risk. The study showed that visual-manual tasks associated with hand-held phones and other portable devices increased the risk of getting into a crash by three times (NHTSA, 2013b). Implementing the above recommendations would mitigate this risk.

Legislation and Regulation in Japan

The Japan Automobile Manufacturers Association (JAMA)'s Guidelines for in Vehicle Display Systems (2004) include:

- "Preferably, a display system is so designed that its adverse effect on safe driving will be kept to a minimum.
- Preferably, a display system is installed in such an in- vehicle position that the driving operation and the visibility of forward field will not be obstructed.
- Preferably, the types of information to be provided by a display system are such that the driver's attention will not be distracted from driving; for example, entertainment types of information need to be avoided.
- Preferably, a display system can be operated by the driver without adversely affecting his or her driving work."

JAMA's Guidelines for in Vehicle Display Systems (2004) include extensive detail on:

- Installation positions of display systems,

- Installation positions of display monitors,
- General display function,
- Display and content of visual information,
- Presentation of auditory information,
- Display system operation while vehicle in motion,
- The presentation of information to users

F.3.3 Feasibility

In-vehicle infotainment systems currently on the market are designed with some level of restriction on how and when they are used. Infotainment systems are designed for and installed in both personal and commercial vehicles. For some vehicle makes, a full infotainment system is only available in the higher-end models. For other makes and models, the system is standard. Examples of this were provided above in section A.1.3. The technology exists to introduce additional restriction measures, which would have to be coded into the infotainment systems. In line with software development life cycles, allowing for design, development and testing time, the time to deploy would typically range from 6-12 months, depending on the complexity of changes needed.

Alternatively, the vehicle’s infotainment system could be integrated with a system similar to Delphi's Vehicle Diagnostics described in section A.1.2.3, capable of restricting the actions the driver can perform on the infotainment system. As Delphi’s device does not currently include infotainment restrictions, software development would also be required. This would require following software development and integration lifecycles, typically ranging from 6-12 months, depending on the complexity of changes needed.

As restrictions to the infotainment systems need to be coded into the infotainment platform, different restrictions could be applied to different fleets (i.e. depending on personal use versus commercial use, or depending on the size or weight of the vehicle, or depending on how hazardous the cargo is, etc.).

Restrictions could be coded to apply at all times or in certain situations (related to for example weather conditions, road conditions, road type, driver behaviour, time of day, etc…). For example, restriction could be applied to ensure that the driver is unable to make voice activated calls or programme the Sat Nav system in heavy traffic or heavy rain fall or freezing conditions if the vehicle is in motion. Safety research studies would need to be conducted to specify in what combination of circumstances and what restrictions would improve safety most.

It is possible to write the restriction code to ensure that the user is unable to override the restrictions. For example, it is possible to ensure that the driver is unable to make calls, view text messages via the on board infotainment system or interact with the internet while the vehicle is in motion (or other criteria specified by relevant HMI and Safety research). Whether there are situations where the user should be able to override the restrictions should be the subject of HMI studies.

For people with basic computer literacy, minimal to no training is required for drivers to learn to use a restricted infotainment system if the infotainment system and its restrictions are seamlessly integrated with the vehicle’s other systems and if the interface design follows good HMI principles.

User Acceptance

Given existing regulations limiting the use of hand held mobile phones while operating vehicles, in our opinion it is likely that the public has some level of acceptance of the need to limit the use of infotainment functionalities while driving. In addition, all current infotainment systems already have some inbuilt restrictions to functionality, so the public is already familiar with some restrictions applying to using infotainment systems.

Privacy

Privacy issues may arise as some motorists may not want a device such as Delphi's Vehicle Diagnostics to monitor their actions or location so closely. Privacy concerns may extend to what other parties may gain access to that driver data, how these data are stored, transmitted, shared and protected (Sedgwick, 2013). However, regulators would not need to obtain sensitive information, such as location or driver behaviours for the restrictions to apply. The system could be coded to ensure that location and driver behaviour data is used as part of the infotainment restrictions but not shared with the regulator or any other third parties.

Standardisation

Some common in-car infotainment standards currently exist as outlined in section A.1.2.2 Generic Infotainment Systems. There are indications that the automotive industry is aware of the importance of voluntary standardisation (OICA, 2014).

The Society of Automotive Engineers' (SAE's) Safety And Human Factors Standards Steering Committee has a number of standards related to Infotainment, including SAE J2831 and SAE J2830.

SAE Standard J2831 (SAE, 2012) "provides recommendations for alphanumeric messages that are supplied to the vehicle by external (e.g., RDS, satellite radio) or internal (e.g., infotainment system) sources while the vehicle is in-motion. Information/design recommendations contained in this report apply to OEM (embedded) and aftermarket systems." (SEA, 2012)

SAE Standard J2830 (SAE, 2014) describes a process for testing the comprehension of symbols or icons. This process has been developed specifically for testing ITS active safety symbols or icons (e.g., collision avoidance), or other symbols or icons that reflect some in-vehicle ITS message or function (e.g., navigation, motorist services, infotainment).

No ISO standards are known related to in-vehicle infotainment.

While no sources could be found that state the percentage of all cars equipped with a full infotainment system (to include internet browsing capability), a recent study by IEEE has forecast that by 2025, 60% of the cars on the road will be connected to the internet (IEEE, 2013). Visiongain assesses that the global automotive infotainment technologies market will total $31.72bn in 2013 (PRWeb, 2013).

F.3.4 Costs

The restrictions to the infotainment systems would need to be coded into the infotainment platform or into a device such as Delphi's Vehicle Diagnostics unit.

H.1.18.1 Cost of coding restrictions into the vehicle's infotainment platform

For the code changes, the cost is driven by the HMI design and software development time required in line with standard software development lifecycles. The software development time depends on the complexity of the changes required. Timescales may run for 6-12 months and cost of changes may range from £180,000 - £600,000 (depending on complexity of changes and assuming a small team of software developers working for 6-12 months). This would be a one-time cost per infotainment platform and could be then deployed on all new vehicles using that platform. It is assumed that this cost would be initially borne by the vehicle manufacturer or the manufactures of the infotainment platforms. A fraction of this cost could potentially be passed on to individual customers. As most vehicle manufacturers sell over a million vehicles per year, this cost per customer could be minimal.

Cost of installing Delphi's Vehicle Diagnostics unit and coding restrictions into this unit

Delphi's Vehicle Diagnostics unit currently retails at about £35 - £50 per unit with an additional £35 - £50 in additional charges and fees. A mobile data plan for the unit would have to be purchased by the customer at market rates (£10-£20/month). One option is that that the cost of the unit would be borne by consumer. Other options include the vehicle manufacturer covering some of the cost of the device.

Delphi's Vehicle Diagnostics' current features do not allow for specific restrictions to the infotainment system. These restrictions would need to be coded into the device with a one-time cost similar to the cost listed above (£180,000 - £600,000, in line with standard software development lifecycles and depending on complexity of changes needed). It is assumed that this cost for these software changes would be initially borne by the company manufacturing the devices and potentially passed on to vehicle manufacturers and/or consumers. If the device is sold at high volumes (over 1 Million per year), this cost per customer could be minimal.

Infrastructure costs?

None. Existing infrastructure (such as existing satellite navigation and mobile communications infrastructure) would be used to operationally implement certain the infotainment restrictions. This infrastructure provides relevant information to the driver and may be used in sophisticated restriction conditions (such as blocking calls in certain traffic patterns, location or weather conditions). However, the infrastructure is not required to implement certain simple restriction rules (for example, block web browsing if the vehicle is in motion).

Legislation costs

There will likely be legislation costs associated with introducing restrictions to vehicle infotainment systems, which are difficult to estimate at this stage. There would also be additional costs associated with testing and validating the restrictions. These would depend on European legislative rules and the complexity of legislation required.

F.3.5 Benefits

Benefits

Collision types related to driver distraction would be reduced if the use of the infotainment systems is appropriately restricted (Lam, 2002; Stutts et al., 2005). This would mean a reduction of distraction related deaths, injuries, possible infrastructure damage, insurance claim payments and the impact these have on public services (health services, police force, legal system).

However, the estimated proportion of collisions where distraction is a contributory factor is relatively small (e.g. UK 2012 data – 3%, NSW Australia - 3.8% of all injury accidents have 'Distraction in-vehicle' as a contributory factor.) In addition, only a portion of in-vehicle distraction related serious accidents are caused by an infotainment system. It is not known what proportion of this is due to distraction due to using an infotainment system. It is estimated that serious or fatal crashes due to driver distraction by an on-board infotainment is likely to be a portion of the reported 3%.

Dis-benefits

Distraction

The restrictions to the infotainment system must be designed in a way that they reduce the level of distraction (and hence themselves not become a source of further distraction). Good HMI design can ensure that the driver is only exposed to information that is relevant and in a quantity that does not cause distraction. For example, certain functionalities, such as browsing the web while driving can be simply blocked if the car is in motion. If no information about this is provided to the driver or no confirmation is sought, the restriction would not add to the driver's workload and distraction.

Frustration

With the growth of smartphone usage and high speed mobile data connections, communication and connectivity is becoming ever more ubiquitous. It may therefore become frustrating if a driver is actively restricted from using such functions when driving – even if it is specifically to improve their safety.

By-passing the system

While not a dis-benefit on its own right, it is possible that if the certain functions (such as checking text messages) are blocked on the vehicle's on board infotainment system when the vehicle is in motion, the driver may attempt to access this information on portable electronic devices (such as smart phones). For this reason, is it important that similar functions be also blocked on the portable electronic devices. The technology exists to implement this (e.g. Samsung's DrivelinkApp, Blue&Me™), however currently this is voluntary: the driver (or fleet manager) has to opt to install such apps on their portable electronic devices.

Lack of productivity

Another possible disbenefit of applying infotainment restrictions is the impact on a driver's potential productivity. While driving, the driver is out of communication and is not able to engage in complex and productive tasks. This might be addressed if/when vehicle automation systems reduce the requirement for drivers to attend to the driving task sufficient to allow the driver to engage in secondary tasks. These may include web browsing, sending and receiving emails, reading documents, giving calls, participating in video conferences, and so on. An infotainment restriction system could work well in tandem with vehicle automation systems such that a driver is permitted to use the more complex infotainment systems (such as web browsing) only when the vehicle is safely under the control of automation systems.

F.3.6 Benefit:Cost Ratio

Neutral. The monetary costs of introducing mandatory restrictions to in vehicle infotainment systems are relatively minor considering the size of the vehicle manufacturing industry, which is estimated to be worth over $800 Billion globally and growing at a rate of 4.8% in 2011 (Stone, 2012). However, other costs of introducing restrictions to in vehicle infotainment systems include legislative costs, driver frustration and lack of productivity. The possible opportunity cost of not investing these resources into other measures where more significant benefits can be achieved is also notable.

Collision types related to driver distraction would be reduced if the use of the infotainment systems is appropriately restricted (Lam, 2002;, Stutts et al., 2005). This would mean a reduction of distraction related deaths, injuries, possible infrastructure damage, insurance claim payments and the impact these have on public services (health services, police force, legal system).

The estimated proportion of collisions where distraction is a contributory factor is relatively small (e.g. UK 2012 data – 3%, NSW Australia - 3.8% of all injury accidents have 'Distraction in-vehicle' as a contributory factor.) In addition, only a portion of in-vehicle distraction related serious accidents are caused by an infotainment system. It is not known what proportion of this is due to distraction due to using an infotainment system. It is estimated that serious or fatal crashes due to driver distraction by an on-board infotainment is likely to be a portion of the reported 3%.

In our opinion, while voluntary restrictions to infotainment system exist, these are inconsistently applied and do not go far enough to reduce deaths and serious injures due to in-vehicle distraction. We recommend that a comprehensive and systematic study be conducted to evaluate the impact of infotainment on collision related deaths and serious injuries.

Given the overall cost of introducing these measures, they would result in a relatively small benefit in collision reduction. For this reason, a neutral classification was assigned to this measure.

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F.4 Reducing Driver Distractions

Driver distraction is the diversion of attention from activities critical for safe driving to a competing activity. Competing activities come in an increasing variety of forms and can be within the vehicle or external. Reducing distraction to improve drivers' attention to the activities required for safe driving should reduce collision risk.

F.4.1 Overview

What are the technologies / sub-systems?

Driving distraction originates from sources both inside and outside the vehicle. Sources of driver detraction inside the vehicle include verbal interaction with other passengers, eating, drinking, smoking, children, pets, the vehicle's own infotainment system (such as music players, SatNav systems, eco-driving information, web browsers) and the portable devices the driver or passengers carry (mobile phones and tablets with their own music players, navigation applications, web browsers, as well as incoming calls and text messages). Mobile devices may or may not be paired with the vehicle's system via Bluetooth. Sources of driver distraction outside the vehicle include unexpected behaviour of other drivers or road users, road-side advertising, on-vehicle advertising, etc. Studies have shown that in-vehicle distraction is responsible for the majority of distraction related collisions (e.g. Lam, 2002, Stutts et al, 2005).

To explore the methods currently available to reduce driver distraction, peer reviewed literature (via ScienceDirect), automotive industry publications and relevant company websites were reviewed.

This research indicates that currently there is a three-pronged approach to reducing in-vehicle driver distraction:

- Through good HMI design of existing systems
- Through additional technology
- Legislation, Regulations and Guidelines

Reducing Driver Distraction Through Good HMI design of Existing Systems

Good HMI design of the vehicle's own infotainment system (such as music players, SatNav systems, eco-driving information, web browsers) and the portable devices the driver or passengers carry (mobile phones and tablets with their own music players, navigation applications, web browsers, as well as incoming calls and text messages) can reduce driver distraction.

Birrell and Young (2011) conducted a simulator study to evaluate the impact that two prototype ergonomic designs for a smart driving aid on driver workload, distraction and driving performance. The results showed that real-time delivery of smart driving information did not increase driver workload or adversely affect driver distraction, while also having the positive effect of decreasing mean driving speed in both simple and complex driving scenarios (Birrell and Young, 2011). Subjective workload was shown to increase with task difficulty and revealed important differences between the two interface designs Birrell and Young (2011). Birrell and Young (2011) concluded that the delivery of smart driving information did not adversely affect driver workload or distraction and users showed reduced workload when driving with an ecologically designed HMI.

Reducing Driver Distraction Through Additional Technology

According to the US DOT (2014), technology can help mitigate distraction via:

- Lock-outs (i.e., not allowing incoming calls or while vehicle is in motion)
- Reduce human interaction (visual, manual, cognitive) with on-board systems
- Warn of imminent danger

In a peer-reviewed research study, Roberts and colleagues (Roberts et al, 2012) explored drivers' acceptance of real-time and post-drive distraction mitigation systems using the 'Technology Acceptance Model'. This research found that the real-time distraction warning system was more obtrusive and less easy to use than the post-drive system that provide information about distracted driving after the trip. These results suggested that informing drivers with detailed information of their driving performance after driving is more acceptable than warning drivers with auditory and visual alerts while driving.

Academia and industry collaborations exist to investigate how technology can help reduce driver distraction. The Advanced Human Factors Evaluator for Automotive Distraction (AHEAD) is a consortium of Denso, the Massachusetts Institute of Technology (MIT) AgeLab and Touchstone Evaluations with an aim to develop new perspectives and methodologies regarding distractive driving (Kilcarr, 2014). AHEAD aims to create a quantifiable objective evaluation "toolkit" for the automotive industry to help support new HMI development (Kilcarr, 2014). Its aim is that this toolkit will improve the effectiveness and reliability of data, helping manufactures and portable electronics suppliers offer intuitive, convenient and safe interfaces to the consumer while more effectively meeting industry and governmental guidelines (Kilcarr, 2014).

In addition, there are software products and services in the market today that aim to reduce driver distraction. These include Aegis Mobility's FleetSafer and TeenSafer, and Celcontrol's Fleet and Family solutions.

Aegis Mobility's FleetSafer is equipped with a patent-pending method that automatically places the driver's mobile device in "safe mode" when driving is sensed that also prevents a driver from evading the "safe mode" while driving, excluding emergency calls (Aegis Mobility, 2014a).

Cellcontrol's patented non-pairing Bluetooth-enabled technology is integrated directly with a vehicle's onboard electronics to determine vehicle state, and then linked to driver and/or passenger mobile devices to implement usage policies immediately upon vehicle movement (Cellcontrol, 2014).

Legislation, Regulation and Guidelines

Legislation is a third way of reducing driver distraction. As described in section 1.7 below, both the EU and the US (Federally and at a State level) have created guidelines and principles to limit driver behaviour than may lead to distraction.

In 2006, the European Commission released a set of European Statement of Principles applying to in-vehicle entertainment, which address the issue to driver distraction (EC, 2006). The European Commission requested that vehicle manufactures and the suppliers of portable in-vehicle devices should enter into a voluntary agreement to follow these principles (EC, 2006).

The U.S. Transportation Secretary released distraction guidelines that encourage automobile manufacturers to limit the distraction risk connected to electronic devices built into their vehicles, such as communications, entertainment and navigation devices (NHTSA, 2013).

Going a step further, the following US State regulations are also in place (GHSA, 2014):

- Hand-held Cell Phone Use: 12 states, D.C., Puerto Rico, Guam and the U.S. Virgin Islands prohibit all drivers from using hand-held cell phones while driving.

Beginning in October 2013, all laws are primary enforcement—an officer may cite a driver for using a hand-held cell phone without any other traffic offense taking place.

- All Cell Phone Use: No US state bans all cell phone use for all drivers, but 37 states and D.C. ban all cell phone use by novice drivers, and 20 states and D.C. prohibit it for school bus drivers.

According to a white paper by State Farm (US-based insurance company) US "drivers were more in favour of laws and regulations prohibiting text messaging, emailing and phone calls while driving than they were of technology preventing cellphone usage for these purposes" (State Farm, 2013).

F.4.2 Any potential for sharing tech between measures?

Yes, with the "Driver interface provisions and restrictions for on-board infotainment systems" measure.

The Aegis Mobility and Cellcontrol software products are capable of blocking infotainment on portable devices (but not on the vehicle's inbuilt infotainment system).

F.4.3 When could the measure be introduced?

Both Aegis Mobility and Cellcontrol software products are in the market today (March 2014) in the US and Canada. Similar products could be deployed in Europe subject to commercial agreements with these companies and mobile connectivity providers. Such commercial negotiations could take anywhere from 3-9 months.

Small software modifications to the mobile phone apps or the back office software might be required to get these products ready for the European market. This could take anywhere from 3-6 months and could run concurrently with the commercial negotiation.

F.4.4 Penetration rate / by mileage?

No sources could be found that state the percentage of all cars equipped with a system to reduce driver distraction (such as the Aegis Mobility and Cellcontrol products) today. However, the fact that there a several competing products on the market to fulfil this purpose seems to indicate that at least some vehicles on the roads today (in the US and Canada) are equipped with a system to reduce driver distraction.

It is not likely that the penetration rate of system to reduce driver distraction is higher on vehicles travelling higher than average mileage. Rather, it appears that this rate may be higher on commercial fleets (sales fleets, trucking fleets, delivery drivers, local service fleets, construction fleets) than on personally owned vehicles (Aegis Mobility, 2014a).

F.4.5 Relevant fleets

Both Aegis Mobility and Cellcontrol have software products specifically designed for commercial fleets (sales fleets, trucking fleets, delivery drivers, local service fleets, constriction fleets) and families (teens). As the features of these software products are fully customisable, it is possible to create rules to mitigate driver distraction for other types of fleets (such as long distance delivery drivers vs. short distance delivery drivers, bus drivers, drivers of hazardous materials, drivers of heavy construction machinery, etc.)

F.4.6 Could the measure be over-ridden by the user?

Both the Aegis Mobility and Cellcontrol software products can be overridden by the user in case of an emergency. For example, if phoning while driving is blocked, the driver can make an emergency call. However, this activity is logged and alert about this activity is sent to the fleet manager (in case of commercial fleet applications) or a parent (in case of family applications).

F.4.7 Are there similar measures in legislation in other regions?

Europe

In 2006, the European Commission released a set of European Statement of Principles applying to in-vehicle entertainment, which address the issue to driver distraction (EC, 2006). The European Commission requested that vehicle manufactures and the suppliers of portable in-vehicle devices should enter into a voluntary agreement to follow these principles (EC, 2006).

The design principles are as follows:

- The system supports the driver and does not give rise to potentially hazardous behaviour by the driver or other road users.
- The allocation of driver attention while interacting with system displays and controls remains compatible with the attentional demand of the driving situation.
- The system does not distract or visually entertain the driver.
- The system does not present information to the driver which results in potentially hazardous behaviour by the driver or other road users.
- Interfaces and interface with systems intended to be used in combination by the driver while the vehicle is in motion are consistent and compatible (EC, 2006).

A set of Installation principles also apply, including:

- The system should be located and securely fitted in accordance with relevant regulations, standards and manufacturer’s instructions for installing the system in vehicles.
- No part of the system should obstruct the driver's view of the road scene.
- The system should not obstruct vehicle controls and displays required for the primary driving task.
- Visual displays should be positioned as close as practicable to the driver's normal line of sight
- Visual displays should be designed and installed to avoid glare and reflections (Commission Of The European Communities, 2006).

In addition, all of the 27 EU Member States (all except Sweden), Switzerland and Iceland have adopted specific regulations on mobile phone use while driving (Janitzek et al, 2009).

However, with regards to Personal Navigation Devices (PNDs), music players and TV/video players, the picture is rather varied (Janitzek et al, 2009). Some European countries address the use of these devices through both specific and/or general regulations; however, in other countries there is no legislation applicable to the use of any devices other than mobile phones. 16 out of the countries address the use of PNDs, 13 states have articles in place that concern the use of music players, and 15 countries have legislation adopted that can be applicable to TV/video player use (Janitzek et al, 2009).

US

Federal Level

The U.S. Transportation Secretary released distraction guidelines that encourage automobile manufacturers to limit the distraction risk connected to electronic devices built into their vehicles, such as communications, entertainment and navigation devices (NHTSA, 2013). Issued by the U.S. Department of Transport's National Highway Traffic Safety Administration (NHTSA), the voluntary guidelines establish specific recommended criteria for electronic devices installed in vehicles at the time they are manufactured that require drivers to take their hands off the wheel or eyes of the road to use them (NHTSA, 2013a).

The guidelines include recommendations to limit the time a driver must take his eyes off the road to perform any task to two seconds at a time and twelve seconds total. The guidelines also recommend disabling several operations unless the vehicle is stopped and in park, such as:

- Manual text entry for the purposes of text messaging and internet browsing;
- Video-based entertainment and communications like video phoning or video conferencing;
- Display of certain types of text, including text messages, web pages, social media content.

Recognizing the extent and complexity of the problem, the Department will continue to work with federal, state and local partners, the auto industry, and safety community to address distraction (NHTSA, 2013a).

The recommendations outlined in the guidelines are consistent with the findings of a new NHTSA naturalistic driving study, The Impact of Hand-Held and Hands-Free Cell Phone Use on Driving Performance and Safety Critical Event Risk. The study showed that visual-manual tasks associated with hand-held phones and other portable devices increased the risk of getting into a crash by three times (NHTSA, 2013b).

State Level

In the US, the Governors Highway Safety Association (GHSA) states that the following US State regulations are also in place (GHSA, 2014):

- Hand-held Cell Phone Use: 12 states, D.C., Puerto Rico, Guam and the U.S. Virgin Islands prohibit all drivers from using hand-held cell phones while driving. Beginning in October 2013, all laws are primary enforcement—an officer may cite a driver for using a hand-held cell phone without any other traffic offense taking place.
- All Cell Phone Use: No US state bans all cell phone use for all drivers, but 37 states and D.C. ban all cell phone use by novice drivers, and 20 states and D.C. prohibit it for school bus drivers.
- Text Messaging: Washington was the first US state to pass a texting ban in 2007. Currently, 41 states, D.C., Puerto Rico, Guam and the U.S. Virgin Islands ban text messaging for all drivers. All but 4 have primary enforcement.
- An additional 6 states prohibit text messaging by novice drivers.
- 3 states restrict school bus drivers from texting.
- Crash Data Collection: Nearly all states include at least one category for distraction on police crash report forms, although the specific data collected varies. The Model Minimum Uniform Crash Criteria (MMUCC) guideline provides best practices on distraction data collection.
- Pre-emption Laws: Many localities have passed their own distracted driving bans (GHSA, 2014).

In addition, Aegis Mobility was awarded a contract from the Iowa Department of Transportation in the fall of 2013 to provide a mobile application, called TEXTL8R, to reduce distracted driving fatalities and accidents. Once developed, Iowa will be the first US state to offer text blocking technology for free to teenage drivers (Aegis Mobility, 2014b).

F.4.8 Expected benefits

How does it work?

Aegis Mobility

Aegis Mobility is one of the world's leading providers of patented software for mobile devices to prevent distracted driving. FleetSafer enables employers to proactively promote safe and legal use of mobile devices while employees are driving on the job.

TeenSafer enables parents to ensure that their young drivers are not distracted by texting, tweeting or talking while driving (Aegis Mobility, 2014b).

Aegis Mobility - FleetSafer

FleetSafer is software for corporate fleets that automatically promotes safe, legal and responsible use of mobile devices while driving (Aegis Mobility, 2014a).

Aegis offers the broadest portfolio of products to meet enterprise requirements for the safe and productive use of electronic devices in vehicles. While different products may be desired for different fleet requirements and vehicle situations, the Aegis portal provides a single unified view of policy configuration, administration, management, analytics and reporting across all products (Aegis Mobility, 2014a).

For commercial fleets equipped with telematics systems, FleetSafer Vision is a one-of-a-kind risk-management service that combines cell phone usage data and vehicle trip data, enabling companies to manage employee use of cell phones while driving (Aegis Mobility, 2014).

FleetSafer GPS is a software-only solution, with client software running on the handset and server software running in the cloud. FleetSafer GPS provides industry-leading battery life and detection accuracy.

FleetSafer OBD consists of an add-on OBD-II hardware device that installs simply and easily in the vehicle, providing the driving-state trigger via Bluetooth to client software running on the handset.

FleetSafer Telematics communicates with the fleet's existing telematics system and activates and deactivates safe drive mode accordingly.

SafeDial™ is the first and only safe driving solution to fully foster compliance with new FMCSA cell phone regulations requiring any mobile phone calls made by interstate commercial drivers to be "one-touch" and hands-free in nature. SafeDial™ is a feature enhancement available on any of FleetSafer GPS, OBD or Telematics.

SafeApp™ is the first application manager that allows corporations to selectively allow applications permitted by company policy (ex. navigation) to be used while driving. SafeApp™ is a feature enhancement available on any of FleetSafer GPS, OBD or Telematics.

Aegis Mobility – TeenSafer (TEXTL8R)

Aegis Mobility – TeenSafer software product uses the same technology as the FleetSafer product described above. However, it is customised for parents to set locks on certain activities (such as texting or phoning while driving) and to set thresholds on speed and other driver behaviours.

The TEXTL8R application, which will disable text and phone capabilities when driving (except for emergency calls), is scheduled to be launched in the first quarter of 2014. Planned features include:

- The ability to monitor and receive reports on driver behaviour, including drive time, speeding, fast acceleration and hard braking
- A secure parent portal providing reports on driving behaviours, including route-specific events displayed on maps
- Notifications sent to parents via email for exceeding configurable thresholds

(Aegis Mobility, 2014b).

Aegis Mobility was awarded a contract from the Iowa Department of Transportation in the fall of 2013 to provide a mobile application, TEXTL8R, to reduce distracted driving fatalities and accidents. Once developed, Iowa will be the first state to offer text blocking technology for free to teenage drivers (Aegis Mobility, 2014b).

Cellcontrol

Cellcontrol is one of the world's leading technology to stop distracted driving. The award-winning technology eliminates the temptation to talk, text, email and surf the web while driving and is available for all vehicles ranging from compacts to tractor/transport trailers. Cellcontrol is compatible with over 1,500 mobile handsets, tablets and handheld computers across all the leading domestic and international mobile service providers, as well as all current release MS-Windows business and ruggedized laptops (Cellcontrol, 2014).

Cellcontrol's patented non-pairing Bluetooth-enabled technology is integrated directly with a vehicle's onboard electronics to determine vehicle state, and then linked to driver and/or passenger mobile devices to implement usage policies immediately upon vehicle movement. This approach is unique from other GPS-based distracted driving apps that engage when the "phone" moves (Cellcontrol, 2014).

Cellcontrol - Fleet

Cellcontrol- Fleet protects employees against driver distraction. Cellcontrol- Fleet enables companies to protect their employees from inappropriate or unauthorized use of cell phones, laptops, tablets, and more while driving (Cellcontrol, 2014).

The Cellcontrol solution is purpose ready for fleets of all size, vehicle type, and geographic location, and can be deployed from a few vehicles to many thousands of vehicles at any time. Drivers are protected, whether they are assigned to a single vehicle, or are assigned to a different vehicle at any time - regardless of the number of devices an employee may bring to the vehicle. Cellcontrol automatically ensures compliance with the company's mobile phone and mobile device use policies (Cellcontrol, 2014).

The Cellcontrol-Fleet platform comprised of three elements:

- Policy "triggering" technology for each employee driven vehicle
- Policy software for each employee mobile device
- Web-based management portal for policy administration, reporting, and exception management (Cellcontrol, 2014).

Cellcontrol - Family

Cellcontrol - Family makes smart phones smarter and take away the temptation to text, email, or play a game on a mobile phone while driving.

- Supports Apple iPhone, Android, Blackberry, Brew and Microsoft Windows Mobile
- Can be configured to enforce policy only on driver, leaving passengers free to use their mobile phones (devices)
- Because Cellcontrol accesses the car's driving metrics, it works even at speeds as slow as 1 mph. (Cellcontrol, 2014)
- The vehicle tells the system instantly when in motion and it locks certain features on the mobile devices (pre-determined by the customer).
- Regardless of vehicle location, wireless access, or GPS availability – Cellcontrol works.
- Customizable, the customer determines how the phone is to be used when the vehicle is in motion
- Flexible, the customer can adjust settings to allow for specific applications like navigation and music. The customer can vary policies from most restrictive to most permissive based on the teen driver's needs. (Cellcontrol, 2014)

Where does it work?

According to Cellcontrol (2014), their fleet solution can be deployed in any geographic location. Cellcontrol's patented non-pairing Bluetooth-enabled technology is integrated directly with a vehicle's onboard electronics to determine vehicle state, and then linked to driver and/or passenger mobile devices to implement usage policies immediately upon vehicle movement. Celcontrol's Fleet solution does not require a mobile coverage or GPS reception to restrict devices.

Based on information in the public domain, it is not possible to determine whether there are any geographical limitations to the Aegis Mobility system.

Which collision types are influenced?

Collision types related to driver distraction would be reduced if the use of portable devices is appropriately restricted.

Non-collision benefits?

Non-collision benefits may include reduced CO2 emissions, the driver's increased awareness of own driver behaviours promoting safety.

F.4.9 Possible disbenefits

F.4.10 Distraction

Systems to reducing driver distractions must be designed in a way that they themselves not become a source of further distraction. Good HMI design can ensure that the driver is only exposed to information that is relevant and in a quantity that does not cause distraction.

For example, certain functionalities, such as sending text messages or browsing the web while driving can be simply blocked if the car is in motion. If no information about this is provided to the driver or no confirmation is sought, the restriction would not add to the driver's workload and distraction.

Lack of productivity

Another possible disbenefit of applying infotainment restrictions is the impact on a driver's potential productivity. While driving, the driver is out of communication and is not able to engage in complex and productive tasks. This might be addressed if/when vehicle automation systems reduce the requirement for drivers to attend to the driving task sufficient to allow the driver to engage in secondary tasks. These may include web browsing, sending and receiving emails, reading documents, giving calls, participating in video conferences, and so on. A system to reduce driver distraction could work well in tandem with vehicle automation systems such that a driver is permitted to use the more complex systems on portable electronic devices (such as web browsing) only when the vehicle is safely under the control of automation systems.

Frustration

With the growth of smartphone usage and high speed mobile data connections, communication and connectivity is becoming ever more ubiquitous. It may therefore become frustrating if a driver is actively restricted from using such functions when driving – even if it is specifically to improve their safety.

F.4.11 Training required?

Minimal to none. For people with basic computer literacy and smart phone use experience, minimal to no training is required if the software product designed to reduce driver distraction follows good HMI principles.

F.4.12 Acceptability to the public

There are likely to be some regional and cultural variations to the acceptability of restricting specific in-vehicle activities that may cause driver distraction.

In Europe, given existing regulations limiting the use of hand held mobile phones while operating vehicles, it is reasonable to assume that the public has a good level of understanding and acceptance of the need to limit the use of portable electronic devices while driving.

In the US, according to a white paper by State Farm (US-based insurance company) "drivers were more in favour of laws and regulations prohibiting text messaging, emailing and phone calls while driving than they were of technology preventing cellphone usage for these purposes" (State Farm, 2013).

When asked if they agreed or disagreed with a measure that would prohibit people in general from texting/emailing while driving, 91% of respondents "strongly" or "somewhat" agreed. When asked if they agreed or disagreed with a measure that would prohibit young drivers from texting/emailing, the same percentage (91%) "strongly" or "somewhat" agreed (State Farm, 2013).

At the same time, "Auto executives and industry trade groups have said that consumers are going to use mobile phones in their cars regardless of what legislators or manufacturers do. Robert Strassburger, vice president of vehicle safety and harmonization at the Alliance of Automobile Manufacturers, said, 'We live in a society where we demand to be connected, 24/7, 365 days a year. We have to design systems so people will want to tether their devices to their vehicles'" (The Truth About Cars, 2014).

To fully assess the acceptability of restricting specific in-vehicle activities that may cause driver distraction, public opinion surveys and user trials could be run.

F.4.13 Privacy issues

If it was legislated that all portable electronic devices are fitted with software to reduce driver distraction (similar to the Aegis Mobility and Cellcontol products), privacy issues may arise as some motorists may not want their actions or location monitored so closely. Privacy concerns may extend to what other parties may gain access to that driver data, how these data are stored, transmitted, shared and protected (Sedgwick, 2013).

F.4.14 Standardisation issues?

The systems designed to reduce driver distraction due to portable electronic devices are designed to be compatible with a range of portable electronic devices.

Cellcontrol's system is compatible with over 1,500 mobile handsets, smartphones, tablets and handheld computers across all the leading domestic and international mobile service providers, as well as all current release MS-Windows business and ruggedized laptops (Cellcontrol, 2014).

Aegis Mobility's FleetSafer application is also compatible 1000s of different devices using the Apple iO, BlackBerry and Android, and Kyocera feature phones (Aegis Mobility, 2014a).

F.4.15 Expected costs

Likely fitment costs

Given that both Cellcontrol and Aegis Mobility only offer bespoke scalable enterprise solutions, quotes for the systems are only available following a customer meetings. For this reason, it was not possible to obtain an exact price for these systems from the public domain. It is estimated that an enterprise solution for a small to medium enterprise would be in the £10,000-£25,000 range. The price of a larger system for thousands of vehicles would likely be much higher. The systems designed for families are estimated to be in the £150 - £500 range. Mobile connectivity charges and yearly renewal charges are likely to be additional.

Any infrastructure costs?

None. Existing infrastructure (such as existing satellite navigation and mobile communications infrastructure) is used by the software products designed to reduce driver distraction.

Any exploitation costs?

By exploitation costs, back-office servers for congestion/accident avoidance navigation system are meant. No additional exploitation costs would be needed.

Legislation costs

There will likely be legislation costs associated with introducing products designed to reduce driver distraction, which are difficult to estimate at this stage. There would also be additional costs associated with testing and validating the restrictions. These would depend on European legislative rules and the complexity of legislation required.

F.4.16 Possible Benefit:Cost Ratio

Table F-7:

Neutral	The monetary costs of introducing a system to reduce driver distraction are relatively minor considering the size of the vehicle manufacturing industry, which is estimated to be worth over $800 Billion globally and growing at a rate of 4.8% in 2011 (Stone, 2012). However, other costs of introducing a system to reduce driver distraction include legislative costs, driver frustration and lack of productivity. The possible opportunity cost of not investing these resources into other measures where more significant benefits can be achieved is also notable. The benefits of introducing a system to reduce driver distraction include reducing accident rates, reducing collision related deaths, injuries, reducing collision-related insurance claim payments and potentially reducing CO_2 emissions. However, the estimated proportion of collisions where distraction is a contributory factor is relatively small (e.g. UK 2012 data – 3% of all injury accidents have 'Distraction in-vehicle' as a contributory factor). In addition: • It is difficult to legislate specifically to reduce driver distraction • Various standards committees and working groups are active in this topic already • There are existing products and services in the marketplace today that are designed to reduce driver distraction • Work on vehicle automation is supporting safety, thereby enabling drivers to engage more readily with potentially distracting tasks It is estimated that, given the overall cost of introducing these measures, they would result in a relatively small benefit in collision reduction. For this reason, a neutral classification was assigned to this measure.

F.4.17 References

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F.5 Driver Distractions and Drowsiness Rcognition

Sensor technology is advancing such that it is becoming possible for technology to provide a reasonably accurate estimate of driver alertness in relation to distraction or fatigue, with some vehicle manufacturers already offering systems that deliver warnings if they detect that the driver is showing signs of fatigue. This measure relates to the effectiveness of potential interventions for measuring driver distraction or drowsiness.

F.5.1 Driver distraction and drowsiness

'Driver drowsiness' is widely considered a sub-component of 'driver fatigue'. In the context of devices that detect driver drowsiness, it is arguably more common for such devices to target 'driver fatigue' as a broader classification of a driver's tendency to disconnect from the driving task.

Fatigue in the context of the driving task—or indeed any operational task—has been assigned multiple definitions. Brown (1994) describes fatigue as an inability or disinclination to continue an activity, generally because the activity has, in some way, been going on for 'too long'. This rather simple definition has been elaborated in several ways.

A mental component

In a review of fatigue detection literature, fatigue is defined as a 'mental state' that reflects a gradual and cumulative process associated with a disinclination for any effort, sensations of weariness and inhibition, with reduced efficiency, alertness and mental performance (Grandjean, 1979, as cited by Borghini et al., 2012). Zhao et al. (2012) further allude to fatigue having a mental component by describing fatigue as a change in the psychophysiological state that people experience during and after the course of prolonged demanding cognitive activity that requires sustained mental efficiency. Driving is considered to be an example of the long-term, continuous and repetitive performance of a mental task that can lead to fatigue.

Fatigue and drowsiness

Many use the terms fatigue and drowsiness interchangeably: for example, Dinges (1995) states that he uses both terms interchangeably to describe the neurobiological processes regulating circadian rhythms and the drive to sleep. This is somewhat misleading. Indeed, fatigue is not reported to be the same as drowsiness because a fatigued person may not necessarily feel sleepy and a sleepy person may not feel fatigued (Xu et al., 2011).

Khushaba et al. (2011) expand on this distinction. They state that fatigue is considered as one of the factors that can lead to drowsiness and it is a consequence of physical labour or a prolonged experience. They define fatigue as a disinclination to continue the task at hand. They further this distinction by stating that fatigue does not fluctuate rapidly over periods of a few seconds, as drowsiness does—a view shared by Borghini et al. (2012). In addition, rest and inactivity usually relieves fatigue; however, it makes drowsiness worse (Khushaba et al., 2011).

Driver drowsiness

If drowsiness is to be considered as a distinct sub-component of fatigue, it is useful to define these states. Driver drowsiness has been described as:

- A state of progressive impaired awareness associated with a desire or inclination to sleep (Khushaba et al., 2012).

- A process of gradually declining alertness from a normal state to the onset of sleep through several indistinct stages (Tsai et al., 2009).
- A transition state between awakening and sleep during which a decrease in vigilance, i.e. the capacity of keeping one's attention on a task, is generally observed (Picot et al., 2008).

Common across these definitions is a progression towards sleep, which is a step further than the general disinclination for effort and weariness that defines 'fatigue'. At this level there appears to be a performance component to fatigue, as noted by several researchers in this field who have recorded:

- The unconscious acceptance of lower standards of performance, impairments in the capacity to integrate information, and narrowing of attention that can lead to forgetting or ignoring important aspects of a task (Perry, 1974, cited by McKinley et al., 2011).
- Reduced vigilance, and deficits in information processing, all of which lead to an abnormal driving behaviour (Dinges & Kribbs, 1991; Dinges et al., 1997).
- Degradation in reaction times (Hu et al., 2013; Hanowski et al., 2008) and response accuracy and speed (McKinley et al., 2011).
- Impaired performance defined by a loss of attentiveness, slower reaction times, impaired judgement, poorer performance on skilled control tasks and increased probability of falling asleep (DfT, 2010).

Driver distraction

Definitions of 'driver distraction' are arguably even more diverse than those for driver drowsiness and fatigue. Pettitt et al. (2005) claim that driver distraction has become an imprecise, everyday term that lacks precision for scientific purposes. Regan et al. (2011) provide a comprehensive review of the different definitions of driver distraction. They concluded that driver distraction has several key elements, specifically:

- There is a diversion of attention away from driving, or safe driving;
- Attention is diverted toward a competing activity, inside or outside the vehicle, which may or may not be driving-related;
- The competing activity may compel or induce the driver to divert attention toward it; and,
- There is an implicit, or explicit, assumption that safe driving is adversely effected.

Regan et al. (2011) subsequently report that there is substantial consensus across the literature to suggest that driver distraction is simply a type of 'driver inattention'. The definition of driver inattention is beyond the scope of this document but it is worth noting that Regan et al. define drowsiness as a type of driver inattention, too (specifically 'Driver Restricted Attention' due to biological factors).

Summary of definitions

Fatigue is a transitional state that progresses from alertness through to sleep. Fatigue can first emerge as a general disinclination for the task at hand, which may be characterised by weariness and cognitive inefficiencies. Drowsiness is typically a progression of the fatigued state (although fatigue is not a necessary precursor to drowsiness). Drowsiness is characterised by a desire to sleep, hypovigilance, and degradation in global task performance.

Driver distraction is defined as the diversion of attention towards a competing activity and away from activities critical for safe driving. It can encompass a wide range of activities both internal and external to a vehicle. The distraction may be confined to internalised mental activities or may divert a driver's visual attention (and possibly other faculties) at the same time.

It is notable that distraction and drowsiness are both considered types of driver inattention and, for the purpose of this document, it is assumed that the key shared feature is the absence of visual attention on the driving task, either due to fatigue or due to some activity that competes for a driver's visual attention.

Road safety implications

Statistics relating to the proportion of road accidents attributable to driver fatigue vary between country and reporting body. However, figures tend to suggest that fatigue is a contributory factor in approximately 20% of accidents. The European Union summarises that fatigue is involved in 10–25% of crashes based on a synthesis of the literature (EC, n.d.). The European Transport Safety Council (ETSC) reported that research showed driver fatigue was a significant factor in approximately 20% of commercial transport crashes (McDonald, 2001). The UK Department for Transport estimates that fatigue is factor in 10% of all collisions, and 17% of those killed or seriously injured in crashes on motorways and major trunk roads (Maycock, 1995). This suggests that fatigue may be a greater risk factor in highway-based driving. In Australia, it was reported that 16.6% of fatal crashes in 1998 involved driver fatigue (Dobbie, 2002).

There is general agreement in the research community that any percentages based on crash data underestimate the true magnitude of the problem, since the evidence for fatigue involvement in crashes is questionable, as it is often based on criteria that exclude other factors rather than identifying definite involvement of fatigue. Indeed, assigning fatigue as a contributory factor in a crash situation is likely to be a subjective assessment by investigators rather than an admission from the driver involved.

F.5.2 What are the technologies / sub-systems?

A wide range of technology may be used to identify fatigue (and drowsiness) in drivers in order to minimise related accidents. Drowsiness monitoring systems typically employ one or more of the following approaches:

- Physiological measures: Some physiological measures have been shown to correlate with sleepiness, for example ocular parameters, brain activity, heart rate, or electrical activity on the surface of the skin. Such devices may use cameras to monitor the eyes, or sensors attached to the operator to measure other physiology.
- Physical measures: Activity and body movement can be measured to provide an indication of fatigue. Cameras or sensors may be fitted in the operating environment and/or sensors may be worn by the operator to monitor physical indicators of drowsiness, such as head and body movements (tilt, droop).
- Behavioural indices: Activities directly related to the driving task can be measured; for example, steering wheel movements, accelerations, gear change patterns, lane keeping and headway. Rather than detecting drowsiness physiologically, these approaches seek evidence of performance decrements to indicate when drowsiness occurs. If behaviour deviates from 'normal' or safe parameters, such systems can alert the operator that they may be drowsy.
- Biomathematical models of fatigue: Predictions from prior sleep patterns, circadian rhythm factors, time of day and working patterns can be used to estimate future fatigue. Such data may be self-reported or provided by technology such as accelerometers worn by operators continuously to report periods of sleep, restfulness and activity. These systems use biomathematical modelling to predict the probability of fatigue affecting an individual at certain times of the day, rather than identifying the onset of fatigue. The efficacy of these systems will be affected by individual differences between drivers that in turn could be influenced by a broad range of factors (e.g. exercise, diet, emotional state).

Some of these measures may also detect distracted drivers. In particular, systems that monitor physiological measures (e.g. eye features) may also recognise signs that a driver has diverted their visual attention from the driver task for a certain period of time. Systems that use behavioural indices (e.g. looking at manifestations in driving performance) may also detect distracted drivers as the behaviours may be similar (e.g. poor lane keeping or erratic steering inputs).

F.5.3 How does it work?

Systems to detect driver drowsiness (and in some cases, driver distraction) typically use camera-based systems directed at the driver for eye, face and head feature detection. The next most common type of system is based on vehicle control measures (typically the primary controls such as steering, braking and acceleration). Camera-based systems are more likely to be available as aftermarket options whereas systems that utilise data on vehicle control inputs are more often found as original equipment on vehicles. There are further examples of systems that can detect driver inattention using physiological measures such as heart and brain wave feature detection. How these different approaches work is explained in the following subsections.

Eye feature detection

PERCLOS (percentage eyelid closure)

Several studies have found that blink duration increases with fatigue, due to a slower opening and closing phase (e.g. Lobb & Stern, 1986). PERCLOS (percentage eyelid closure) is a measure of blink duration, and measures the percent of time that eyes are more than 80% closed over one minute. This metric has the highest correlation with driving fatigue (Xiong, Xie & Wang, 2012). PERCLOS is a measure of slow eyelid closure (i.e. 'droops'), as opposed to blinks. Slow eyelid closures can be a physiological indicator of drowsiness and interruption in visual information gathering (Wierwille et al., 1994).

PERCLOS has also been shown to have a strong relationship with lane departures and subjective drowsiness (Dawson et al., 2013) and with the Psychomotor Vigilance Task (PVT) (e.g. Rau, 2005), which has been shown to be sensitive to sleep loss (Dinges et al., 1997).

PERCLOS has some disadvantages, specifically:

- It measures just a single aspect of physiology, and can be affected by eye, head and body movements—for example mirror or blind spot checks—and by the driver wearing glasses.
- Friedrichs and Yang (2010) stated that a major weakness of the PERCLOS measure is that it "detects fatigue too late and fails to detect participants that are drowsy with eyes wide open" (i.e. staring).
- Johns (2003a) stated that "there is evidence that drowsy subjects who are trying to stay awake can keep their eyelids open voluntarily for some time…in the drowsy state, visual suppression may possibly occur without eyelid closure or saccadic eye movements" (p.1). Under such circumstances, the PERCLOS technique would not detect drowsiness in a driver.
- PERCLOS monitoring may also be affected by the driver performing secondary tasks (such as looking at the speedometer) that could be misread as an eye closure (Hanowski et al., 2008), although this may also detect moments of distraction.
- Severe sleepiness does not result in increased lid closure in all people (Schleicher et al., 2008).
- No early warning is given; it is only once the driver's eyelids are closed for a large proportion of time that fatigue is detected, and so an additional problem (but not one unique to PERCLOS) is deciding on the point at which the driver is deemed to be in an 'unsafe' state, and when to apply a warning(s).

Several alternative eye feature measures have been explored for drowsiness detection. Of these, the most effective appears to be amplitude-velocity ratio of blinks (AVRB). Johns (2003b) developed the AVRB measure of drowsiness. This takes into account two blink parameters which are not measured in PERCLOS: peak closing velocity (PCV) and amplitude. The ratio of amplitude to PCV (i.e. the AVRB) can be used as a measure of drowsiness, as blinks become relatively slower for the same amplitude in drowsy subjects.

Face features and head movements have also been incorporated in some camera-based systems as a supplementary measure of drowsiness and/or distraction alongside eye feature detection. The algorithms on which detection of these driver inattention states is calculated often utilises the same technology and simply requires further image processing.

Eye features: summary

Several ocular parameters have been shown to be related to fatigue. PERCLOS (percentage of eyelid closure) is widely used to measure fatigue in drivers, either in isolation or in combination with other measures, and has been shown to have a strong relationship with fatigue indicators such as lane departures, PVT and subjective drowsiness, but it is not without its disadvantages. A number of other blink measures exist but there tend to be large inter-individual differences in the way that drivers respond to fatigue.

Eye features are a well-established fatigue metric and have been incorporated into a number of fatigue monitoring systems. The main advantage of eye measures is that they are non-invasive, and they have high face validity and some strong supporting evidence, but this varies between eye feature measure; all measures have associated disadvantages.

One group of researchers has evaluated in the laboratory a number of eye measures including eye gaze, pupillary change and blink rate, as well as head position (Heitmann, Guttkuhn, Aguirre, Trutschel & Moore, 2001). These studies led to the conclusion that no single eye feature is sufficiently sensitive or reliable as a measure of alertness, and that

> Our view: Eye feature measures have a strong presence in the literature with clear evidence of effectiveness for drowsiness detection, and many existing aftermarket systems employing this measure. Some OE systems from automotive manufacturers also use camera based systems for eye feature detection.
>
> Most systems are non-invasive and suitable for use in vehicles to monitor fatigue in real time. Some systems are limited by factors such as ambient light and use of sunglasses or prescription lenses. The field has been a focus of extensive research for decades; future focus is likely to be on miniaturisation of effective research-oriented systems and overcoming limitations such as low light and adaptation to eyewear.

multiple measures need to be considered for a robust method of monitoring drowsiness and potentially distraction.

F.5.4 Heart rate feature detection

Human heart rates can be measured using a range of devices, the most common of which is the electrocardiogram (ECG). In more recent years, several studies have demonstrated the application of heart rate measures (and in particular, heart rate variability) as a potential measure of driver drowsiness and some other types of driver inattention.

Heart rate (HR) and specifically heart rate variability (HRV) are established measures of changing physical and cognitive states. HRV is defined as the variability in the time interval between heartbeats. Egelund (1982) found that HRV at a certain spectral frequency was significantly associated with distance driven and was reported to indicate the onset of drowsiness. De Rosario et al. (2010) cite findings from Oron-Gilad et al. (2008) that showed it was possible to detect a lack of attention from HRV, with focused attention characterised by a regular HR and an increasing lack of focus characterised by a more irregular HR and an increase in HRV. De Rosario et al. (2010) verified in their own study that HRV did indeed increase in participants who were fatigued. More promising findings emerged from metrics associated with respiration: respiration amplitude was significant when used to differentiate between alertness and incipient fatigue/drowsiness. There were also indications that parameters measured by seat pressure sensors could differentiate between states of alertness if noise in the signal was sufficiently filtered.

Zhao et al. (2012) and Apparies et al. (1998) suggest that HRV might serve as an early indicator of drowsiness. Specifically, they claim a decrease in high frequency HRV and an increase in low frequency HRV represented the sympathetic nervous system asserting dominance in place of the parasympathetic nervous system (which corresponds with an increase in 'mental tension'). Other studies have summarised findings that demonstrate similar changes in HRV that are associated with a shift from alertness to drowsiness and then sleep (e.g. Hu et al., 2009, Yu, 2012b). Yu (2012b) reported that, in a simulated driving study, the low frequency/high frequency ratio of HRV was a high variability parameter and therefore was more effective at detecting the onset of driver drowsiness when combined with other physiological measures such as EEG as well as vehicle control measures. Yu concluded that a long-term decrease in the low frequency/high frequency ratio of HRV was associated with subsequent driving errors and bursts of EEG activity were indicative of drowsiness, suggesting that HRV activity was a potential precursor to drowsiness.

Nakano et al. (2009) demonstrated drowsiness detection via HRV to an accuracy of approximately 80% whilst experimenting with an ECG steering wheel sensor (a capacitive-type sensor with electrodes in the steering wheel and the driver's seat to enable signal detection even when using only one hand on the wheel). Whilst HRV measurements were effective at detecting general changes in alertness, they were less effective indicators of sudden drowsiness for which the authors recommended a hybrid approach of ECG and eyelid detection.

The range of technology used for heart feature detection includes contact sensors embedded in vehicle control surfaces (e.g. the steering wheel) and non-contact sensors fitted in the seat or elsewhere in the vehicle (e.g. Yu, 2012a). Only one fatigue detection system suitable for drivers that utilises ECG sensors appears to be available on the commercial market. It is an aftermarket detector that uses ultra wideband radar to detect HRV through non-contact sensors. However, the market may be set to widen as interest in real-time ECG monitoring in the driving context appears to have gathered momentum in recent years. It is currently the focus of a European Commission funded project entitled 'HARKEN'. HARKEN is a European consortium of research centres and enterprises that has collaborated to research and develop an in-vehicle system for non-contact sensing to monitor a driver's physiological and mechanical activity related to the cardiac and respiration cycles.

The HARKEN concept is to develop sensors that can be embedded in the seat cover and safety belt of a driver's seat to monitor HR and HRV, and respiration rate. The consortium propose to achieve this by manufacturing seat covers and belts from smart textile materials with electrical properties, as well as designing optimal anchorage points for a safety belt that will enable it to provide data on respiration rate to the tensors by capturing the change in pressure exerted by the body during the respiration cycle. The consortium proposes to produce a sensing and signal processing unit that can then provide a driver fatigue status to vehicle systems or any other aftermarket monitoring device.

ECG monitoring: summary

There is substantial evidence that heart rate feature detection is a valid and reliable indicator of fatigue. In the driving context, recent studies have focused on metrics calculated from HRV (especially high frequency bands) because of the physiological association with the parasympathetic division of the autonomous nervous system (which provides unconscious physiological control over key body functions when progressing towards sleep). The accuracy of fatigue detection using ECG-based measures has been shown to increase if a composite index is created (e.g. Xu et al. (2011) included respiration rate). There are some concerns regarding the ability of ECG-based measures to detect sudden changes in alertness; however, there is some evidence that combining respiration rate metrics may improve accuracy in such situations. It is interesting to note that the latest fatigue-related collaborative study funded by the European Commission is focused on ECG and respiration rate non-contact sensors: this would suggest a shift in focus from earlier EC studies of driver fatigue that predominantly explored eye feature detection and vehicle control measures as indicators of fatigue. Indeed, De Rosario et al. (2010) comment that respiration rate specifically is an understudied parameter in the field of fatigue detection and that both ECG and respiration-based parameters yield substantial potential in future fatigue detection systems that are truly nonintrusive.

Our view: ECG monitoring has a strong presence in the literature with strong evidence of effectiveness for drowsiness detection and some other forms of inattention.

Current focus is on non-contact sensors and this is expected to develop further in the near future. One existing commercial system demonstrates the possibilities.

F.5.5 EEG

The electroencephalogram (EEG) measures electrical activity that originates in the brain by using electrodes attached to the scalp to record electrical impulses that are present on the surface. The literature support that components of the EEG signal can be used to identify changes in alertness that correspond with driver fatigue.

Borghini et al. (2012) reference several studies that demonstrate how different characteristics of EEG waveforms can be used to identify states of alertness. However, they conclude that, "no device or convincing algorithm has been published or practically applied for a robust online recognition of the mental states investigated by this review" (p.13). The authors state that the online processing of EEG data and its collection via a reduced set of 'dry' electrodes (i.e. electrodes that can be applied without conductive gel) are areas of research that are expected to be a prominent focus in the near future. Our own review of the literature suggests that developments in this direction are still tentative but there is evidence of substantial progress in several key areas, such as algorithm development, EEG component extraction, electrode reduction and prototype development.

The technology used for EEG detection currently relies on scalp electrodes embedded into headwear (e.g. the rim of a cap). These electrodes monitor brain wave activity and then, depending on the processing modules that are used, can provide alerts on real time of driver drowsiness and potentially other forms of inattention. Commercial applications in the driving domain are not common; only one system has been identified.

EEG monitoring: summary

There is still debate over which components of the EEG signal are most suited to drowsiness detection. Traditionally, there has been most focus on spectral power in certain frequency bands (or metrics derived from relative spectral power); however, there have been trends towards detection of localised shifts in the EEG signal and attention to the details of specific fluctuations, such as alpha spindles. These techniques have shown promising gains in accuracy over spectral power alone for fatigue classification, and have also shown significant predictive power by detecting fatigue in advance of its onset.

Algorithm development shows promise for electrode reduction, classification of alertness in real time and even scope for pre-emptive drowsiness detection in comparison to other methods. Typically, algorithms are efficient enough to enable high temporal resolution, enabling classification of fatigue using a signal of just a few seconds.

EEG studies have indicated that EEG signals are powerful classifiers of fatigue, with reported accuracy of classification ranging upwards of 75%. Alone, EEG is a powerful tool for fatigue classification (more so than EOG and ECG alone or in combination) but EEG can be further improved if combined with other physiological signals (EEG and ECG is a particularly powerful combination for fatigue classification). EEG also has a demonstrated capacity for closed-loop feedback, being able to evaluate instantaneous effects of countermeasures on alertness.

Real world applications of EEG for fatigue detection are limited by the potential for signal noise and by the intrusiveness of the sensor technology (although use of a reduced set of dry electrodes can minimise this problem). However, prototype systems have attempted to overcome these limitations with miniaturised and wireless componentry, and efficient on-board data processing. There appears to be merit in pursuing commercialisation of this technology, as demonstrated by the launch of at least one aftermarket system.

Our view: Strong presence in the literature with strong evidence of effectiveness for drowsiness detection.

Technology currently lacks portability and is potentially intrusive but is expected to remain a focus of future research and development. One existing commercial system demonstrates the possibilities.

F.5.6 EDA

Electrodermal activity (EDA) is a common term used to describe all electrical phenomena in the skin. Boucsein (2012) provides a comprehensive review of EDA, which has been a dominant measure in psychophysiology since the 1960s. Electrodermal recordings can be captured in conditions that are either endosomatic or exosomatic (without or with the application of an electrical current to the skin surface, respectively). Boucsein describes how EDA can either be 'tonic' (i.e. a level response that is not in reaction to a specific stimulus and is typically recorded as skin potential, or admittance/impedance if a current is applied) or 'phasic' (i.e. a reaction to a stimulus). Phasic electrodermal reactions (EDR) that occur without a specific stimulus are classified as 'nonspecific' (Boucsein, 2012). Further classification of EDA and EDR is possible by calculating additional metrics from the signals.

Clarion et al. (2009) state that EDA is subject to substantial intersubject variability so monitored EDA values must be referenced against average mean values captured during a 'relaxed state' time window. The metrics commonly captured might include mean, standard deviation and number of EDRs. Specifically for EDRs, the amplitude, duration, half recovery time, latency and slope are all feasible metrics.

The physiological basis for EDA is not fully understood; Dorrian et al. (2008) cite Miró et al. (2002, p.105) who state that EDA "is an accepted vigilance index used in diverse psychophysiological fields". Miró et al. (2002) are also cited to report that EDA is associated with self-reported sleepiness, performance errors and EEG changes that are indicative of drowsiness. However, Dorrian et al. (2008) cite contrary evidence from Wright and McGown (2001), who failed to find a specific relationship between EDA and drowsiness, with a general EDA pattern underlying the transition to sleepiness but in such a way as to be too broad a measure to detect the point of transition or predict when it would be likely to occur.

Technology used to monitor EDA requires skin contact sensors. These sensors can be embedded in vehicle control surfaces (such as the steering wheel) or worn by the driver (e.g. as a ring or wristband) with wireless transmission of the monitored EDA signal. There are several aftermarket EDA sensors available across the price spectrum. All utilise sensors that are worn by the driver.

Summary of EDA monitoring

EDA is firmly established as a psychophysiological indicator yet there is no consensus in the literature regarding its relationship with drowsiness. Of the commercial systems that use EDA, only two have a theoretical evidence base. There is reasonable evidence from two sources that a decrement in EDA is associated with a reduction in alertness. However, the specific relationship between EDA and drowsiness is unclear and an independent evaluation of one system failed to find a significant association between the increase in drowsiness as indicated by the system when compared with other measures of drowsiness.

Our view: Low presence in the current literature with poor evidence of effectiveness for drowsiness detection. EDA does seem to correspond with drowsy events but it is not sufficiently clear how to interpret the signal so that it can be used as a precursor.

Systems are likely to always require skin contact which could be a limiting factor for future applications. It is unclear whether this will be an active area of research in the driver drowsiness domain, although there is scope for further understanding. Current commercial systems vary in cost and practicality.

F.5.7 Vehicle control measures

Vehicle control measures are a direct reflection of how a driver is interacting with a vehicle relative to the demands of the environment. It is generally accepted that inattention (either from drowsiness or distraction) will show a corresponding change in control inputs. Detecting this change requires measurement of direct inputs to controls and/or control surfaces (e.g. steering wheel movements, grip force on the steering wheel rim) or measurement of vehicle metrics related to these control inputs (e.g. vehicle speed, accelerations, yaw angles).

The majority of evidence in the literature for drowsiness monitoring using vehicle control measures is focused on steering wheel inputs and lane keeping. Indeed, Forsman et al. (2013) demonstrated that the transfer function between steering input and change in lateral lane position can be used effectively to estimate the relative change in lateral lane position based solely on the steering wheel angle. Lane variability is a metric of drowsy or otherwise unsafe driving (Åkerstedt et al., 2010; Anund et al., 2008; Sandberg et al., 2011) and has been a focus of several OEM-type systems to monitor driver alertness (e.g. by Bosch, Bendix, Volvo). However, lane tracking typically requires camera-based equipment and complex video signal processing, and is prone to data loss when it is not possible for the camera to observe lane markings (due to weather or poor quality markings). Deriving lane keeping from steering wheel control is therefore a viable and potentially more reliable alternative.

Forsman et al. (2013) demonstrated two driving metrics (steering variability and lane variability) that seemed to account for most of the variance in performance when drivers were moderately drowsy. Yu et al. (2012b) identified (from a simulated driving study) that the rate of steering wheel reversal and a parameter based on steering wheel position and speed of movement were significant indicators of driving errors that occurred concurrently to EEG indicators of driver drowsiness. Krajewski et al. (2009) were able to classify slight and severe drowsiness with an accuracy of 86.1% using metrics of steering wheel behaviour. McDonald et al. (2012) claimed that steering-angle can be used to predict drowsiness-related lane departures six seconds before they occur. The positive predictive value for lane departures was also greater when computed for steering angle than for PERCLOS suggesting that this vehicle control measure was more accurate at predicting a drowsiness-related event.

Malta et al. (2014) found an overall positive effect on a number of potentially safety-related measures when the evaluated functions (ACC+FCW) were made available to the driver. "In both cars and trucks, when drivers were following a lead vehicle while using ACC+FCW, time-headway increased significantly, and the relative frequency of harsh braking events and incidents decreased. In terms of changes in driver behaviour, car drivers using ACC+FCW were three times more likely to engage in visual secondary tasks during normal driving (e.g., reading maps, looking at passengers or objects in the car), but this difference was not found during incidents. These results imply that drivers seem to abort secondary tasks and focus on the road ahead when the traffic situation requires it. In addition, ACC+FCW presence does not seem to affect the amount of drowsy driving. For trucks, no particular side effects on driver behaviour were observed."

Vehicle control measures: summary

Steering inputs and lane deviation are two (related) vehicle control measures that have evidence of their effectiveness for monitoring different states of alertness. A variety of metrics have been proposed and refining the most relevant metrics for fatigue monitoring is likely to be a focus of future research for aftermarket system development. However, OEM-type systems using vehicle control measures (especially those produced by vehicle manufacturers and offered as driver monitoring safety systems on new vehicles) appear to have developed sufficiently robust algorithms to make these systems available to the mass market. This may well restrict further development of aftermarket systems using vehicle control measures as such systems are likely to filter into vehicle fleets as standard equipment when they are renewed.

Nevertheless, some manufacturers appear to be pursuing CAN-based[40] drowsiness monitors using a wide range of vehicle control measures. These systems may have a place in the market as an OEM offering to be used by automotive manufacturers and as an aftermarket option to fleets. Monitoring devices that are integrated with vehicles as OEM fitment are less likely to provide telemetric links to control centres to warn of alerts (although it is feasible that this could be detected by an in-vehicle monitoring system), in which case an aftermarket system becomes an attractive and configurable option for fleets that wish to have more insight into how their operators are affected by drowsiness.

One of the limitations of using vehicle control measures is that they may not apply in all operating environments. For example, monitoring steering inputs and/or lane keeping for signs of fatigue typically requires operators to be using a highway route and travelling above a certain speed, which may not cover all types of operations where fatigue is a concern. Such measures are also not transferrable to control room situations, unlike physiological measures.

[40] Controller Area Network (CAN) refers to the electronic system of data transfer between vehicle components

Our view: Moderate presence in the literature with moderate evidence of effectiveness for fatigue detection. Often poor vehicle control emerges as a product of fatigue at a point where it may be considered 'too late' to issue an alert. In the literature, such measures are often used to 'verify' physiological indicators of fatigue.

Future focus is likely to be on CAN-based integrated systems that use a range of measures.

F.5.8 Summary of measures used to monitor for driver drowsiness and/or distraction

Overall, the literature indicates that eye feature detection is the most established measure for drowsiness monitoring and has the strongest evidence base for real-time detection. It is non-invasive and the latest (aftermarket) systems seem to be overcoming limitations associated with operator compatibility such as different eyewear and problems with low light. It can be combined with wider face and head detection methods using the same camera technology for improved accuracy.

EDA has inconclusive evidence of the nature of its link with drowsiness, it always requires skin contact and it is sensitive to ambient temperatures. EEG and ECG are the two technologies that warrant close attention in the near future. Both have a strong evidence base for drowsiness detection. EEG is potentially more intrusive than ECG monitoring, which is currently the focus of research to develop non-contact methods of monitoring.

Of the other methods, vehicle control measures are typically most suited to highway environments as they are often based on steering inputs and lane keeping behaviour. For drowsiness monitoring they are more reactive than predictive. They perhaps have most relevance as part of a composite monitoring system that includes physiological measures. However, vehicle control measures are the most established method of drowsiness monitoring fitted by automotive manufacturers as original equipment.

F.5.9 Sharing technology

There is scope for sharing technology between the measures used for drowsiness and/or distraction monitoring. For example:

- Camera based systems with a driver view can be used to monitor a range of eye, face and head features for multiple purposes including drowsiness and distraction. Such systems can be expanded to have a forward facing camera (e.g. to monitor lane deviation and provide alerts, to record collisions, to monitor headway).
- Systems based on vehicle control measures can monitor drowsiness by utilising existing vehicle sensors for steering, braking, acceleration and metrics derived from these inputs. This is why such systems are favoured by automotive manufacturers.
- Systems can also utilise existing safety features of vehicles, such as lane keeping devices, to identify whether drivers appear distracted or drowsy according to the consistency with which they remain in a lane, the number of deviations and the rate of correction.
- Systems can integrate with other vehicle telematics to transfer information about driver state and the number of alerts (e.g. to a fleet operator).
- Some camera based products can utilise the cameras and hardware in mobile phones to provide drowsiness monitoring without the acquisition of additional hardware dedicated to this purpose.

F.5.10 Availability and relevant fleets

Systems for monitoring driver drowsiness and distraction are available now as both aftermarket and original equipment in vehicles. There are a multitude of systems using cameras and vehicle control measures in both types of market. Systems that are fitted by automotive manufacturers are more commonly of the lane keeping type (even when based on vehicle control measures such as steering inputs) and are therefore suited to highway driving only above a certain speed. Such systems are known to be offered by a wide range of manufacturers in existing car fleets and are also offered in truck cabs by some manufacturers.

Aftermarket systems, which are predominantly camera-based for eye feature detection, can be fitted to a wide range of vehicle types and used in a wide range of environments. Some systems, especially those that use physiological measures exclusively, such as EEG, ECG or EDA are portable and can be taken with drivers for use in other vehicles.

Interest in drowsiness monitoring has initially come from industries that require some protection from inattentive operators. Examples include the mining and oil and gas sectors. Early adopters have been businesses operating vehicle fleets where drivers are subject to long hours or demanding conditions. Monitoring devices can be one way in which a company can exercise appropriate duty of care for its driving workforce.

F.5.11 System overrides

Many of the systems available for monitoring driver drowsiness can be overridden by the driver. Systems fitted by automotive manufacturers are believed to be exclusively optional and such assistance can be switched off if the driver chooses to do so. Aftermarket systems can be configured to be mandatory; often, if they are used across a fleet of vehicles, the fleet operator may choose to use telemetric links with each equipped vehicle to monitor drowsiness remotely, receive reports of each drowsy alert to a driver and to receive alerts if the system is switched off or not activated before a drive.

F.5.12 Expected benefits

The expected benefit of using systems to monitor for driver drowsiness and distraction is a reduction in the number of collisions where these issues are a causal factor. However, no controlled scientific studies appear to have identified whether such systems have achieved a reduction in the rate of collisions. However, commercial systems that have been developed to monitor driver fatigue claim varying rates of collision reduction when implemented in specific vehicle fleets. More commonly, claims are made regarding a reduction in drowsy events that are recorded by businesses that opt to use such systems.

There are other expected benefits to systems that monitor drowsiness and distraction. A dearth of published, peer reviewed evidence for commercial devices means that the claimed benefits are invariably unsupported. However, they include:

- Potential for real-time monitoring of drowsiness and other states of inattention, with systems providing alerts using audible, visual or sometimes haptic feedback to the driver to restore attention.
- Potential for telemetric transfer of data on drowsy or inattentive states to a control centre to enable businesses (or indeed other organisations) to monitor the frequency and severity of such events and take corrective action.
- Potential to alert other road users to a vehicle that is not controlled by a driver that is attentive (e.g. through use of hazard warnings).
- Potential to exercise autonomic control over a vehicle in the event of inattention by slowing or stopping the vehicle, or engaging active safety features that may enable the vehicle to avoid a collision.
- Offer organisations a system by which those who drive for work purposes can be monitored to check for recurrent drowsiness. If this occurs, other management measures can be implemented to mitigate the risk (e.g. changes to shifts or tasks, training, disciplinary measures).

F.5.13 Possible disbenefits

There are several limitations to systems that monitor for driver drowsiness and distraction. Common to all types of systems that provide drivers with alerts, there is the potential for the system itself to be a distraction. There are several ways in which a system may distract a driver:

- The alert interface (be it audible, visual or haptic) may be a distraction in itself. Systems with visual displays can require that a driver divert their attention to attend to the display. Some alerts have to be silenced using a button press. These secondary tasks can distract from the driving task.
- Some systems require drivers to undertake reaction time tasks while driving to confirm that they are attentive. Again, this is a secondary task that may distract drivers.
- Systems with low specificity may have a high false positive rate. This may trigger alerts for inattention when the driver was actually attentive. As well as undermining the system, this is a potential distraction and source of driver frustration.

A further disbenefit that may occur is related to an increased dependence on effective monitoring systems. Drivers that use an effective system may regard it as a 'safety net' that enables them to drive for longer when tired, and may discourage taking regular breaks or maintaining a healthy cycle of rest and wakefulness. The net benefit may therefore be reduced and there may even be a cost to safety.

Systems that utilise cameras or other physiological sensors may be regarded as an invasion of privacy by some drivers. Procedures for data handling and processing will be a consideration, particularly when there is a telemetric link to a device.

Some devices are more intrusive than others and require drivers to wear equipment (e.g. hats, glasses, wristbands) or maintain contact with control surfaces. For some drivers this may be impractical, for others it may be considered a nuisance.

Other disbenefits include:

- System calibration can be required, at installation, to accommodate different drivers or at the start of each journey. This varies across systems.
- System maintenance may be required at regular intervals.
- Training may be required to install, operate and maintain a system. This is more relevant to aftermarket systems than OEM devices.
- Systems with wireless components (e.g. sensors that are worn by drivers) may require regular battery charging.

Finally, it is notable that there are a wide range of systems that have adopted very different approaches to monitoring driver inattention. This does make standardisation of monitoring devices and protocols difficult to achieve at this stage. Even across those devices that utilise similar principles (e.g. PERCLOS as a type of eye feature detection), there are different approaches to camera technology and image processing, as well as the algorithms used to identify when an inattentive state has occurred. When considering other systems, such as those using EEG signals, there is greater divergence in the literature on what data patterns are indicative of different states of inattention. The ways in which different systems' suppliers have approached the task of monitoring drowsiness and distraction are almost always proprietary and therefore not made public to retain a commercial advantage.

F.5.14 Costs

The costs associated with driver drowsiness and distraction devices vary substantially. In a recent review of such systems by TRL (commercially confidential), the costs ranged from under €100 per device to in excess of €10,000.

The lower cost devices are typically camera based systems for eye feature detection, ECG monitors, and EDA monitors. The higher cost devices are typically managed systems targeted at high risk fleets. These are also often camera based, although the single EEG based commercial offering falls into the higher price range.

F.5.15 Benefit:Cost Ratio

The benefit:cost ratio for devices that monitor driver drowsiness and distraction depends critically upon the user group for which the intervention has been applied. For the general public, the implementation of such a system would address a prevalent contributory factor in approximately 20% of collisions (although statistics are generally considered to underestimate the actual contribution of driver inattention to crashes). Whether the costs would outweigh the benefits depends entirely on the type of system implemented and the method of implementation. Fitting aftermarket devices for the general public is expected to have a negative benefit:cost ratio (Benefit:Cost ratio <1). Mandating a standardised system for new vehicles is an alternative route to implementation and this is expected to have a positive benefit:cost ratio (Benefit:Cost ratio >1) as automotive manufacturers are already offering such systems as optional equipment in many mass market vehicles. The benefit:cost ratio of this approach may be higher still if the system can be made compulsory and if mitigating safeguards can be initiated for drivers who ignore alerts.

For commercial and public service fleets, there is a greater potential benefit. The risk of injury to passengers, damage to freight and/or reputational harm that may accrue from a crash where a company driver is found to be drowsy or distracted may be very damaging for the vehicle fleet operator. Implementation in such fleets is more practicable when considering aftermarket systems than it is for the general public. In addition, fleet operators can be better equipped to initiate management strategies to act upon instances of drivers continuing to operate vehicles when they are inattentive. Consequently, it is suggested that the cost:benefit ratio of opting for OEM devices or aftermarket installations for commercial fleet operators is positive (Benefit:Cost ratio > 1). This claim appears to be supported by the voluntary adoption of such systems by fleets already, and the burgeoning commercial market for such systems.

F.5.16 References

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F.6 Alcohol interlock devices

Alcohol interlock devices prevent the vehicle ignition from operating if alcohol above a pre-defined threshold is detected. Application of this measure is intended to reduce collision risk by restricting the opportunity for drivers to operate vehicles when under the influence of alcohol.

F.6.1 Description of the Problem

- Consumption of alcohol affects driving ability at strategic (mode, route choice etc), tactical (speed choice, gap acceptance etc) and control (instantaneous interaction with controls) levels as well as affecting the visual and auditory senses involved in driving. It can also affect other safety-related behaviours such as the propensity to wear a seatbelt.
- The European research project DRUID (Driving Under the Influence of Drugs, Alcohol, and Medicines) provides much information on the prevalence and risk of driving whilst under the influence of alcohol:
    - Houwing et al. (2011) conducted a prevalence study across drivers in European traffic, estimating that 1.65% are driving with a blood alcohol concentration (BAC) of 0.05% or higher. For alcohol levels above 0.01% the estimated prevalence was 3.85%.
    - Hels et al. (2011) conducted a population based case-control study showing that:
        - the highest risk of getting seriously injured or killed is associated with driving with very high BAC (above 0.12%) and alcohol combined with other psychoactive substances. Risk of death or serious injury for these drivers was estimated to be 20-200 times that of sober drivers.
        - Drivers with high BAC (0.08%-0.12%) were found to have a collision risk estimated to be 5-30 times that of sober drivers.
        - Increased collision risk was also observed for drivers with lower BAC levels (0.05-0.08%), estimated to be 2-10 times that of sober drivers.
- Subject to caveats related to under-reporting and variance in the legal limit, the median of the percentages for alcohol-related road fatalities from 28 European countries in 2010 was 13.5% (ETSC, 2010).
    - Applying this median value to the total number of fatalities across the 28 EU countries for 2012 (28,100 fatalities – CARE, 2014) gives an estimate of the number of alcohol-related road fatalities as 3,794.
    - The European Commission uses an estimate of four permanently disabling injuries and eight serious injuries per fatality (European Commission, 2014). This produces estimates of 15,176 permanently disabling injuries and 30,352 serious injuries associated with alcohol-related traffic collisions.
- A report by Ecorys (2014) estimated the casualty reduction figures for alcohol interlocks deployed across four groups based on 2010 fatality statistics, giving estimated benefit-cost ratios and Internal Rate of Return (IRR)[41] figures:

[41] The internal rate of return (IRR) is the interest rate at which the net present value of all the cash flows (both positive and negative) from a project or investment equal zero and indicates the efficiency, quality or yield of an investment with higher positive IRR values representing a more attractive project.

Table F-8:

Population affected by alcohol interlock scheme	Estimated annual net reduction in fatalities across Europe	Estimated Benefit:Cost ratio	Internal Rate of Return
Offenders	7-137	1.0-2.8	5%-163%
Goods vehicles	125	1.4	25%
Buses and coaches	5	0.3	n.a.
All passenger cars	3,500-5,600	0.8-1.3	-3%-22%

- The Ecorys (2014) report also provided estimates on casualty reduction, benefit:cost ratio and IRR for improving information exchange between member states and for harmonisation of technical and operational aspects of interlock programmes across member states:

Table F-9:

Alcohol interlock measure	Estimated annual net reduction in fatalities across Europe	Estimated Benefit:Cost ratio	Internal Rate of Return
Information exchange	7-137	1.5-2.7	81%-186%
Harmonisation	2-4 first year; 4-8 second year	1.8-3.3	77%-140%

  - It should be noted that the estimates in the Ecorys (2014) report were subject to numerous significant caveats including the percentage conviction rate among offenders, percentage participation rate in alcohol interlock schemes and estimated net effect of the alcohol interlock scheme in reducing in alcohol-related crashes.
- It can be concluded that alcohol interlocks can offer effective and cost-beneficial improvements to road safety in Europe, particularly for offender and commercial vehicle populations. Consideration should also be given to legislative and knowledge sharing activities in relation to alcohol interlocks that could facilitate and enhance the benefits of their use.
  - In particular, if alcohol interlocks are to be deployed as a significant intervention against driving under the influence of alcohol, it is important to implement a standard to which vehicle manufacturers adhere that ensures the feasibility of alcohol interlock fitment in all road vehicles sold in Europe.

F.6.2 Potential Mitigation Strategies

Alcohol interlock devices are designed to prevent a driver from starting the ignition of a vehicle if alcohol above a pre-defined threshold is detected. The most prevalent technique by which a driver's alcohol level can be detected is breath analysis, with a typical threshold alcohol concentration of 20µg/100ml of breath; approximately equivalent to 46mg/100ml of blood (0.046% BAC).

NHTSA (2010) set out minimum criteria for acceptable widespread use of alcohol interlocks, suggesting they should be:

- Non-invasive
- Quick to use (determines breath alcohol concentration in <0.5 seconds from activation and recycle)
- Highly accurate
- Small
- Highly reliable
- Repeatable
- Durable, robust
- Low cost
- Require no or low maintenance
- Virtually invisible to sober drivers

Devices based on breath analysis typically require the driver to exhale into a vehicle dashboard-mounted detector where breath-alcohol is assayed. If the device detects alcohol above the pre-defined threshold, the interlock prevents the engine from being started. Alcohol interlocks feature running retests whereby further breath samples are required at intervals after the vehicle has been started to counteract a) breath samples being provided by a sober confederate which allows the vehicle to be started and a drunk driver to proceed and b) a driver who chooses to consume alcoholic drinks whilst driving. This type of alcohol interlock typically requires periodic recalibration at 30, 60 or 90 day or annual intervals, depending on the particular system used.

Requirements for the development of alcohol interlocks are captured in the CENELEC 50436 standards, currently considered to be among the most rigorous and comprehensive in the world (Ecorys, 2014):

- EN 50436-1: Instruments for drink-driving-offender programs
- EN 50436-2: Instruments having a mouthpiece and measuring breath alcohol for general preventive use
- TR 50436-3: Guidance for decision makers, purchasers and users
- EN 50436-4: Connectors for the electrical connection between the alcohol interlock and the vehicle
- EN 50436-5: Instruments not having a mouthpiece and measuring breath alcohol for general preventive use
- EN 50436-6: Data security

Draft document prEN 50436 - 4 creates a standard for the electrical connection between the alcohol interlock and the vehicle. The draft was put on hold because it was not accepted by car manufacturers. Future deployment of alcohol interlocks may be critically dependent upon adherence to an agreed standard in this area because some new vehicles are coming to market with powertrain ignition systems that do not have the facility to permit alcohol interlock installation (Ecorys, 2014).

F.6.3 Feasibility

- Technical feasibility
    - Breath-based alcohol interlocks have been in use in the United States since 1970. Gradual incremental improvements have been made to their accuracy and calibration requirements.
    - The CENELEC standards provide the basis of how alcohol interlocks should operate. However, as noted, the standard to determine compatibility of vehicle ignition systems has not yet been agreed, raising the risk that cars may come to market with ignition systems that are incompatible with alcohol interlocks.
    - Warm-up time of alcohol interlock systems is an issue, particularly in regions with lower ambient temperatures where this can take several minutes.

  - Systems require (at least) annual calibration.
- Enforcement feasibility
  - Breath sampling includes requirements for volume, flow and exhalation time to deter attempts to falsify breath samples by artificial means.
  - Secure logging of events is covered within the CENELEC standards (EN50436-6: Data security) to enable enforcement by authenticated service personnel.
  - Some systems add a picture of the individual supplying the breath sample to aid enforcement.
  - In setting the threshold for the alcohol interlock, consideration must be given to different BAC limits that apply for different driving populations and different countries. Different limits apply across adjacent European countries – for example, a driver using an alcohol interlock could begin their journey with a legal BAC in Germany (BAC limit 0.05% for all experienced drivers over 21 years of age) and arrive in the Czech Republic (BAC limit 0.00%) with an illegal BAC.
- Acceptability
  - For widespread acceptability, devices must not impede a sober driver from starting their vehicle (Ecorys, 2014). Acceptability is less of an issue in commercial vehicles where use of an alcohol interlock can be made a condition of employment. For offenders, acceptance of an alcohol interlock is requirement to retain access to independent mobility.

While breath-based devices require the driver to exhale into a specific device, other less invasive techniques have been proposed to detect a driver's alcohol level.

Tissue spectroscopy uses the changes in light absorption (typically in the near infrared region of the spectrum) of skin tissues caused by the presence of alcohol to produce an estimate of blood alcohol concentration.

Distance spectroscopy uses an unobtrusive 'sniffer' to detect alcohol in the vehicle. Multiple sensors can be placed within the vehicle (e.g. steering wheel, A-pillar etc.) to identify and quantify the alcohol concentration in exhaled breath as detected within the vehicle cabin.

Transdermal (skin-contact) systems determine alcohol in perspiration through contact with the skin. The lag between the consumption of an alcoholic drink and the translation of that alcohol into sweat (of the order of 30-60 minutes) means that this measure may not be appropriate for instantaneous measurement to govern vehicle ignition.

Although devices based on these techniques produce accurate results, there are significant challenges in adapting the equipment to meet size, cost, measurement time and accuracy parameters to be suitable for in-vehicle use (Pollard, Nadler & Stearns, 2007).

F.6.4 Costs

Basic alcohol interlock systems cost in the region of €1,000. In the Finnish offender programme, costs are spread over the term of the sentence in the range of €110-€170 per month.

Ecorys (2014) provided costs and benefits for six scenarios relating to alcohol interlock adoption:

- Exchange of information – information sharing between EU member states to support the adoption of best practice.
- Harmonisation of technical aspects – relieving operational bottlenecks, easing system introduction and reducing costs.
- Legislation concerning high BAC offenders – offering alcohol interlock programmes as an alternative to licence revocation
- Legislation concerning compulsory fitment of alcohol interlocks in commercial vehicles

- Legislation concerning compulsory fitment of alcohol interlocks in buses and coaches
- Legislation concerning compulsory fitment of alcohol interlocks in all passenger cars

For full information on the methodology applied is available in the Ecorys (2014) report. The summary tables are provided below. In each table, the abbreviation 'AIP' stands for 'alcohol interlock programme'.

Costs and benefits – Exchange of information

Table F-10:

Total costs for EU and Member States in two year period	3.4m Euro
Total annual costs of the AIP in the second year of programme (3,000 participants)	9m Euro
Total annual safety benefits (based on 1-2.5 road deaths saved in year 2 of programme)	14 to 28m Euro
Total mobility benefits in year 2 (3,000 participants)	3m Euro
Benefit:Cost ratio (2 years preparation; 2 years programme)	1.5 to 2.7
Internal rate of return	81% to 186%

Costs and benefits – Harmonisation of technical aspects

Table F-11:

Total costs EU and Member States	9.3m Euro
Total annual costs AIP	12m Euro (yr 1); 24m Euro (yr 2)
Total annual benefits (based on 2-4 road deaths saved) year 1	23–46m Euro
Total annual benefits (based on 4-8 road deaths saved) year 2	46-92m Euro
Benefit:Cost ratio (3 years preparation, 2 years programme)	1.8 to 3.3
Internal rate of return	77% to 140%

Costs and benefits – High BAC offenders

Table F-12:

Total preparation costs	58m Euro
Total annual costs AIP	68m-630m Euro
Minimum annual benefits (based on 7 road deaths avoided in year 2)	88m Euro
Minimum annual benefits (based on 147 road deaths avoided in year 2)	1,600m Euro
Benefit:Cost ratio (4 years preparation, 2 years programme)	1.0 to 2.8
Internal rate of return	5% to 163%

Costs and benefits – Goods vehicles

Table F-13:

Total preparation costs	58m Euro
Total investment costs for alcohol interlocks	5,000m Euro
Total annual costs for alcohol interlocks	250m Euro
Total annual benefits (based on 125 road deaths avoided)	1,500m Euro
Benefit:Cost ratio	1.4
Internal rate of return	25%

Costs and benefits – Buses and coaches

Table F-14:

Total preparation costs	30m Euro
Total investment costs for alcohol interlocks	800m Euro
Total annual costs for alcohol interlocks	40m Euro
Total annual benefits (based on 5 road deaths avoided)	60m Euro
Benefit:Cost ratio	0.3
Internal rate of return	N/A

Costs and benefits – All passenger cars

Table F-15:

Total preparation costs	58m Euro
Total investment costs for alcohol interlocks	242,000m Euro
Total annual costs for alcohol interlocks	12,000m Euro
Total annual safety benefit	42,000-62,000m Euro
Benefit:Cost ratio	0.8-1.3
Internal rate of return	-3% to 22%

F.6.5 Benefits

- Direct benefits
    - Reduction in collisions related to alcohol. This is difficult to estimate as it is not possible to be certain that a collision where alcohol was listed as a contributory factor would not have occurred if alcohol had not been present in the system of the involved driver. Ecorys (2014) made the following estimates:
        - For offenders, the net effect of an alcohol interlock as compared to suspension of the driving licence, in terms of a reduction in traffic fatalities ranges between 18.75 and 37.5%. A Finnish report published in 2013, and based on four years of data, showed a recidivism rate of 6% when interlocks were used compared to the usual 30% rate in Finland (ETSC, 2014).

        - For commercial vehicle drivers, 50% of the alcohol related road deaths can be avoided with an alcohol interlock.
        - For installation in all passenger cars, no figure is given but effectiveness in preventing collisions where alcohol was a contributory factor is presumed to be less than 100%.
    - Re-offence rates of alcohol interlock users are 40-90% lower than those of offenders with a suspended licence (Bax et al., 2001).

Pappas et al. (2008) listed the research that has found the strengths of alcohol interlocks.

    - Reduce recidivism among convicted drunk drivers (Marques et al., 2001).
    - Provides a mechanism by which authorities can track offenders' drink driving behaviour (Marques et al., 2003a).
    - Can combine alcohol interlock use with other forms of treatment (Voas et al., 2002).
    - Can provide user with feedback on drinking behaviour and alcohol metabolism (Freeman & Liossis, 2002).
    - Users can develop strategies to avoid future drunk driving situations (Freeman & Liossis, 2002).
    - Offenders can still participate in society and employment (Marques et al., 2003b).
    - Users report positive experiences with alcohol interlocks (Freeman & Liossis, 2002).
    - Provides a new strategy with which medical/legal authorities can tackle drink driving (Bjerre, 2005)
    - Devices perceived as positive by commercial drivers in Sweden where 75% of respondents in a demonstrator study believed that they should become standard equipment (Bjerre, 2005)
- Indirect benefits
    - As part of a programme of rehabilitation of drink-driving offenders, access to a vehicle is a reward for remaining sober and so may support the health (and social) rehabilitation of alcoholics.
    - By allowing a convicted drunk driver to retain independent mobility, it may permit them to remain in employment and therefore less likely to draw on social support funds.

F.6.6 Benefit:Cost Ratio

- A report by Ecorys (2014) estimated the casualty reduction figures for alcohol interlocks deployed across four groups based on 2010 fatality statistics, giving estimated benefit-cost ratios and Internal Rate of Return (IRR) figures:

Table F-16:

Population affected by alcohol interlock scheme	Estimated annual net reduction in fatalities across Europe	Estimated Benefit:Cost ratio	Internal Rate of Return
Offenders	7-137	1.0-2.8	5%-163%
Goods vehicles	125	1.4	25%
Buses and coaches	5	0.3	n.a.
All passenger cars	3,500-5,600	0.8-1.3	-3%-22%

  - The estimates in this table are based on three factors, resulting the ranges of estimates for some of the values – the factors are:
    - The number of collisions for which the population is responsible
    - The effectiveness of the alcohol interlock in reducing collision likelihood
    - The penetration of alcohol interlocks among the population
- The values given by Ecorys (2014) can be considered as accurate as can be expected given the available information. One factor that is difficult to include within such assessments is the public relations benefit that can be achieved by alcohol interlock fitment in, for example, school buses – even if the benefit:cost ratio is less than one.
- The Benefit Cost Ratio calculations of Ecorys include the estimated value of avoided road injuries and deaths that are based on values from year 2002. They have been updated to level 2012 by taking into account the absolute development in purchase power parity in each Member State. However, the actual updated values for year 2012 are not reported by Ecorys. To give an example, in Finland in year 2010 the Finnish Transport Agency published the value of 1 919 000 EUR for a death, 1 079 000 EUR for a permanent injury, 248 000 EUR for a severe injury and 49 000 EUR for a slight injury.
- ETSC has assessed that the monetary value for ETSC has assessed that the monetary value for 2013 of the human losses avoided by preventing one road fatality to be 1.91 million euro.

F.6.7 References

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F.7 Crash Event Data Recorders (EDR)

To enhance knowledge about accident causes and improve driver behaviour, information to be derived from the DG MOVE study – 'Study on the benefits for road safety resulting from the installation of event data recorders') acting as a possible psychological stimulant to drivers promoting the safe operation of the vehicle under all driving conditions.

F.7.1 Description of the Problem

An Event Data Recorder (EDR) is a device mounted in a vehicle that will record objective data over a short timeframe before, during and after a collision. The data recorded may include the change of velocity of the vehicle (known as delta-*v*), vehicle acceleration, pre-collision brake and throttle application, seat-belt status, airbag deployment status and timing, and the status of active safety systems such as AEBS, ESC, lane departure warning etc. This information enables the Police, accident investigators, manufacturers, legislators and researchers to understand better the causes of collisions and what may be done to mitigate them.

An EDR records only information associated with an event that is, or is suspected to be, a collision. EDR only record information about vehicle systems immediately before during and after a collision; the total recording time is typically less than 30 seconds. An EDR is thus explicitly different to other in-vehicle data recorders such as driver or journey monitoring devices. These latter systems typically record data about the vehicle and its location continuously, typically sending data to a central server via the mobile phone network. Many retrofit systems, particularly in the fleet and insurance markets, include both driver/journey monitoring and EDR functionality.

The application of EDR in modern vehicles is not solely about enhancing the data available about accidents – it is also about replacing traditional data sources that new technologies are eliminating. An example is tyre skid marks, which used to be used to help determine pre-event vehicle speed, but which are often not present for modern vehicles with ABS. Similarly, the implementation of the digital tachograph in heavy vehicles has reduced the amount of information available for reconstructing accidents involving these vehicles.

In the US, CFR 49 Part 563 has since 2006 specified minimum performance requirements for EDRs in US-market light vehicles *if an EDR is fitted*. Part 563 applies to passenger cars, multipurpose passenger vehicles, trucks, and buses with a gross vehicle weight rating (GVWR) of 3,855 kg or less and an unloaded vehicle weight of 2,495 kg or less (known as 'light vehicles') that are voluntarily equipped with an EDR. Part 563 specifies a core data set that must be recorded, including longitudinal delta-*v*, indicated vehicle speed, driver airbag deployment time and engine throttle application. The sampling rate, range accuracy and resolution for these parameters are defined by the regulation. Part 563 also defines the sampling rate etc. for a much large set of data *if recorded* – i.e. if the manufacturer elects to record one of these data items, then recording must be at least to the quality defined in the regulation. It is understood that fitment of an EDR has been mandatory in the US since September 2014, and NHTSA have proposed to convert the Part 563 regulation into a Federal Motor Vehicle Safety Standard (FMVSS 405), which would allow NHTSA to seek greater, civil penalties for failure to provide an EDR or for failure to provide one that performs properly. It is further understood that the Republic of Korea intends to adopt similar legislation and that Japan has proposed similar legislation, albeit with additional parameters being measured. No EDR legislation was identified for other categories of road vehicle.

Historically, many of the major road safety advances have been achieved by improving secondary safety; for example by the improvement of vehicle structures and occupant restraint systems through the implementation of the EC frontal and side impact directives. EDRs provide data that can be used to evaluate the performance of the vehicle and restraint system in a collision. Indeed, this was one of the reasons that manufacturers started recording crash data in their vehicle models. For example, the objective data from the EDR can be used to determine whether the deployable restraint systems (such as airbags and seat-belt pretensioners) were deployed at an appropriate time to optimise protection of the occupants.

In the future, the consensus view is that primary and active vehicle technologies will deliver significant safety improvements. These systems typically act before the accident to either mitigate or avoid the accident and make a decision to activate based on data collected from sensors that monitor the vehicle state as well as the road environment. , However, it is sometimes difficult to quantify the effectiveness of these systems because the precise conditions of the pre-crash phase are not known and judgement is always required, which is inherently subject to error. As well as providing an accurate record of the vehicle state and the functions of the safety systems during an accident, EDR data also provides the prospect of significantly enhancing the accuracy of predicting the effectiveness of active systems. This will allow road safety policies and regulatory actions to be targeted at those systems most effective at realising casualty reductions on European roads. EDR data also provides the prospect of a large and detailed dataset that can be used for on-going monitoring of road safety systems and policies.

This annex summarises the findings of the project '*Study on the benefits for road safety resulting from the installation of event data recorders'* performed for the European Commission, DG MOVE in 2014 (Hynd and McCarthy, 2014). The aim of the study was to assist the Commission in deciding whether the fitting of EDR in all vehicles or certain categories of vehicles could result in an improvement of road safety or have other possible consequences that would justify the costs associated with the adoption of EU legislative measures. The study quantified the costs and benefits for heavy goods vehicles, light goods vehicles, buses and coaches, and passenger cars (for private and commercial use).

F.7.2 Feasibility

Cars (M1)

The most obvious approach to implementing EDRs in cars is to duplicate the US Part 563 requirements. NHTSA estimated the fitment rate of EDRs in new US-fleet light vehicles as 64% in 2006 (DOT, 2006) and 92% in 2013 (DOT, 2012a), and it is expected that this will be close to 100% by the end of 2014. (There are some exceptions to the regulation, e.g. for 'walk-in' vans designed to be sold exclusively to the US Postal Service, so the rate will always be slightly less than 100%.)

The US regulation requires that data from the EDR is 'available'. Most manufacturers have chosen to use the crash data retrieval (CDR) tool from Bosch, which connects to the OBD II port (and which can connect directly to the ACM if the OBD II port is damaged in a collision. Hyundai and Kia each have their own proprietary download hardware.

In Europe, stakeholders to the DG MOVE project acknowledged that almost all new European vehicle models have EDR functionality as part of the ACM, although access to the data is blocked for most models, except Volvo and Toyota vehicles, other than by sending the ACM to the manufacturer or supplier.

The experience in the US and the fitment rate of similar EDR functionality to most current EU-market vehicles demonstrates the technical feasibility of EDR fitment. However, previous EU work such as the VERONICA I and II projects (Schmidt-Cotta et al., 2006; Schmidt-Cotta 2009) indicated several areas where the US specification could be updated to improve knowledge about EU road traffic accidents. For example:

- Many of the parameters that are listed as 'if recorded' in Part 563 were recommended to be treated as 'if equipped' by VERONICA – i.e. if the vehicle has a particular feature or system that is listed, then recording the data should be compulsory, not at the discretion of the manufacturer. Many US-market vehicles already record these parameters voluntarily.
- VERONICA recommended that all the activity of all active safety and driver assistance systems not otherwise defined should be recorded. Some US-market vehicles already record these parameters voluntarily.
- VERONICA defined additional or more sensitive triggering requirements than Part 563, principally to capture car-to-pedestrian/cyclist and HGV-to-car collisions (with low delta-*v*). The VERONICA II project reported an example of a collision that was recorded between a large Chevrolet van-type ambulance in use in The Netherlands and a pedestrian. This event (delta-*v* of 2.53 $km \cdot h^{-1}$ within 130 ms) triggered the EDR in the vehicle, even though an EDR meeting the Part 563 specification would not have been required to trigger. This was considered to demonstrate clearly the feasibility of triggering EDRs in so-called soft collisions.
- VERONICA recommended that fault codes should be flagged, e.g. to exonerate a manufacturer if a car had been driven with a warning light in effect. Many current Part 563 compliant EDRs already record important fault codes, so this would appear to be feasible.

If EDR were to be mandated in Europe, one aspect that would have to be considered is the method of access to the data, i.e. the tools required to download the data from the EDR. The most straightforward approach would be to duplicate the US approach, which would most likely result in the same Bosch, Kia and Hyundai tools being used in Europe as in the US. An alternative would be to require manufacturers to make available the method of access so that any provider could make a suitable tool (i.e. open access). There are pros and cons to each of these approaches that should be considered if mandatory EDR fitment was to be introduced.

Light Goods Vehicles (N1)

Light Commercial Vehicles (LCVs) in Europe typically now have driver frontal airbags, which implies some sort of collision detection sensor(s) and processing capability to make the fire/no-fire decision. The stakeholders consulted during the DG MOVE study indicated that new car-derived vans were probably all fitted with EDRs because they have a system architecture and airbag control unit derived from the car. The stakeholders also considered that other N1 vehicles may not have an EDR if they do not have an airbag control module. However, the majority current LCV models sold in Europe have at least a driver's airbag and airbag control module as standard equipment. Based on the comments at the stakeholder meeting, this would imply that most current N1 vehicle models have EDR capability.

Given that the ACM technology and EDR fitment rates are similar for N1 and M1 vehicles, and that the US regulation applies to light goods vehicles in the US-market, EDR for N1 vehicles can be considered to be feasible using identical technical specifications as for M1 vehicles.

Heavy vehicles (M2-3, N2-3)

Very little information on EDR fitment in European-market heavy vehicles was identified by the study, except that European Scania trucks that are fitted with an airbag have EDR functionality in the airbag module and have done so for the last ten years; however, the fitment rate is not high and an airbag module is not available on all cab variants. There is much more information available on EDRs in US-market heavy vehicles. US vehicles typically record and store information in the engine control unit (ECU) or engine control module (ECM), and have been capable of doing so for some years (Bayan *et al.*, 2009). The primary purpose of this data recording is the monitoring of engine parameters for emissions control and maintenance, but data useful to accident reconstruction is also often recorded. Data storage is triggered by various events, such as acceleration exceeding a certain level, airbag activation, or a hard stop (i.e. a recording is initiated every time the vehicle stops, which was recommended by VERONICA to maximise the chance of recording collisions with VRU). It is suggested that recording is also triggered by the activation of any active safety system.

The fitment of EDR to heavy vehicles would appear to be feasible, and standards specifying heavy vehicle EDR data types do exist; however, these are inconsistently applied even in the US and most vehicles only record a small proportion of the recommended data types. At the DG MOVE EDR stakeholder meeting, the stakeholders advised that the first step would be to develop standards that define what should be recorded in a heavy vehicle EDR (including sampling rates, accuracy etc.) and how the data should be accessed. This would allow manufacturers and suppliers to implement EDR in heavy vehicles most efficiently. Furthermore, at the stakeholder meeting it was strongly indicated that EDR functionality for heavy vehicles should be separate from the digital tachograph. This was considered to be technically more straightforward for manufacturers and suppliers, offered greater design freedom, and was a more secure solution.

Other Considerations

The main feasibility concerns for EDR fitment relate to the legal and privacy issues of the data and who has access to the data under which circumstances. The legal advice provided to the project from six member states showed that EDR data is not personal because it cannot be used to identify an individual; it only becomes personal if it is linked to an individual or is in the possession of someone who may be able to make such a link. The EDR data would therefore seem to be inherently anonymous unless a link to an individual is introduced. This view hinges very much on the exact data that is recorded by an EDR. CFR 49 Part 563 specifies minimum requirements, but does not preclude the manufacturer recording additional, potentially personal, data – although manufacturers tend to state in their Privacy Policies that they will only access and use EDR data with the permission of the owner of the vehicle.

Federal US requirements for EDR fitment have been supplemented by State-level legislation regarding access to the data. For example Section 9951 of the California Vehicle Code permits anonymously made examinations, including extraction and use of EDR data, for improvements to the vehicle’s safety:

> *‘For the purpose of improving motor vehicle safety, including for medical research of the human body's reaction to motor vehicle accidents, and the identity of the registered owner or driver is not disclosed in connection with that retrieved data. … The disclosure of the vehicle identification number (VIN) for the purpose of improving vehicle safety, including for medical research of the human body's reaction to motor vehicle accidents, does not constitute the disclosure of the identity of the registered owner or driver.’*

Negligible legal issues were envisaged for fleet operators, regardless of the vehicle category, because these vehicles are often fitted with after-market systems that continuously record data such as vehicle position and speed, internal and external camera views, driver monitoring and training etc. These fleet systems are less likely to include recording of vehicle accelerations at a sampling rate that is suitable for collision investigations than car EDR, but this is sometimes available as an option. The application of these systems could be considered invasive if mandated for individuals, but are typically covered by contracts of employment for vehicles driven as part of a driver’s job.

For cars, and LGV / heavy vehicle owner-operators, the legal advice to the study identified a degree of uncertainty surrounding the collection and use of EDR data and recommended that, although adequate legal frameworks exist once ownership and access are defined, specific conventions would be helpful to define these fundamental aspects.

F.7.3 Costs

The DG MOVE study based EDR cost information primarily on that previously published by NHTSA (DOT 2006; DOT, 2012a). The cost in Europe was considered comparable, especially since it is known that most M1 vehicles in Europe are already equipped with airbag modules that already contain an EDR that is capable of meeting the Part 563 specification. The purchase price of EDR download tools is published and ranges from €2,200 for the basic download tool that connects to the OBD II port, to €6,500 for a complete kit with all direct-ACM access cables, software subscription etc. The number of EDR units required in Europe was based on total US sales figures adjusted by the ratio of US and EU populations, resulting in an estimate of 4,750 units in Europe.

Costs were also allowed for the time to access and download EDR data (Petersen and Ahlgrimm, 2014). No costs were allocated to the analysis of EDR data due to lack of specific cost information, and because the views collated from the stakeholder meeting and other discussions indicated that it seems reasonable to assume for the central estimate that the net change in cost is zero. This is because the additional EDR data analysis costs replace the costs currently spent trying to estimate the same items of pre-crash information.

Further information should be sought on the accuracy of costs associated with the implementation of an enhanced specification EDR.

F.7.4 Benefits

The potential benefits resulting from the use of EDR data are numerous and relate to many different user groups. The three primary benefits relate to the following:

- Improvement of road safety by improving the data on the performance of current safety systems (which may include occupant restraints, active safety systems, road-side furniture and safety barriers, or road design)
- Access to justice using accurate and verifiable collision and pre-collision data
- Possible effects on driver behaviour

Most of the benefits listed in Table F-17 relate to the provision by an EDR of more objective, reliable and cost-effective evidence of crash severity, pre-collision driver behaviour, vehicle system performance etc. than is currently available via e.g. accident reconstruction, witness statements or CCTV records. In order to deliver the potential benefits, it is therefore important that the measurements made by an EDR are relevant and reliable. This includes both the value of the measurement (e.g. left hand indicator on, accelerator position) and the timing of the measured parameters.

Table F-17: Examples of users of EDR data and their applications/benefits

User	Application/benefit
Manufacturers	Improve the safety of motor vehicles
	Evaluate the correct operation of vehicle systems for development and litigation cover
Governments	Improve vehicle safety standards
	Improve infrastructure safety standards
	Reduce road fatalities, injuries and damage, and the societal costs associated with these
Vehicle owner/driver	Access to justice
Prospective vehicle buyer	Determine if a vehicle has previously been involved in an accident
Fleet operators	Reduced accident (injury and damage) claims
	Reduced fraud
Police	Impartial accident information
Courts	Objective data for civil and criminal legal proceedings
Solicitors and independent forensic road traffic accident investigators	Objective data to support expert witness statement and reduced reliance on (potentially unreliable) witness statements
Insurers	Faster and more accurate settlement of cases (with reduced costs)
Researchers	More accurate association of crash severity and injury outcome, to improve vehicle structures and restraint systems
	Improved understanding of driver involvement in collisions
Emergency responders	Improved triage (NB this benefit would probably require EDR data to be associated with eCall data)

The potential benefits also vary by fleet type. No quantification of an accident reduction benefit (through improved driver behaviour) for private cars was identified in this review. Indeed, NHTSA's preliminary regulatory evaluation for FMVSS 405 (DOT, 2012b) notes that although NHTSA *'believes that the proposal will improve vehicle safety, the safety benefits are difficult to quantify. Therefore the benefits of this proposal are discussed qualitatively'*. Similarly, the EC VERONICA and VERONICA II projects (Schmidt-Cotta *et al.*, 2006; Schmidt-Cotta 2009) assessed benefits only in qualitative terms.

Nevertheless, collision reduction benefits have been demonstrated in a number of different professional fleet types. There is also a generic benefit for most of these users and applications that the time required to investigate an accident may be reduced, resulting in reduced costs, e.g. reduced insurance costs.

The opportunity to enhance typical current EDR specifications to record the status of active safety systems and to trigger in collisions with VRUs (which may not trigger with current EDR) should be considered and would be expected to deliver significant additional benefit, particularly given the current focus on active safety systems and that reductions in VRU fatalities in Europe are lagging those for vehicle occupants.

F.7.5 Benefit:Cost Ratio

Using the assumptions and values identified (with appropriate ranges) the following BCR values were identified. These do not include those benefits that could not be monetised; if these could also be realised, the benefits would be substantially increased towards or exceeding the upper estimates quoted:

- BCR for M1 vehicles was estimated excluding potentially large components of benefit at between 0 to 5.7, central estimate 0.1;
- BCR for N1 vehicles was estimated excluding potentially large components of benefit at between 0 to 6.6, central estimate 1.0;
- BCR for M2/M3 vehicles was estimated excluding potentially large components of benefit at between 0 to 4.0, central estimate 2.0; and
- BCR for N2/N3 vehicles was estimated excluding potentially large components of benefit at between 0 to 4.6, central estimate 2.3.

Central estimate BCRs appear greatest for large vehicles (despite the relatively high costs assumed), although the greatest absolute benefit accrues to M1 passenger cars because of the greater fleet size of this vehicle type.

An enhanced EDR specification has the potential to deliver significant benefits, although the scale of these is not easily predicted with the available data because much of the benefit is difficult to quantify. The main components that cannot be monetised and have not been included in the calculation of the BCRs can be summarised as:

- Improved accident data
- Access to justice

These aspects have the potential to substantially increase the BCRs quoted here such that the upper estimates in Table F-10 5 would become central or even low estimates. If conservative benefits could be achieved in these areas (or if the safety benefits observed for commercial fleets can be realised for private car fleets) the BCRs for each vehicle type would be comparable or above the upper BCR quoted above.

If EDR data provides more robust evidence that leads to improvements in safety measures or regulation at the same level as predicted by Petersen and Ahlgrimm (2014) (i.e. 2%), then further benefits would be realised, although because of the lag between the data becoming available and subsequent action, these benefits would be largely realised outside the assessment period (unless retrospective access to EDR data is enabled by manufacturers). TRL considers substantial benefits are likely because evidence informing on the effectiveness of active safety systems requires robust information on the timing and chronology of events and actions in the pre-crash phase that can be provided by EDR data, especially if combined with sensor data (e.g. time-to-collision) from active safety systems. Furthermore, secondary safety systems and measures to address vulnerable road users could be improved.

Bearing in mind that EDRs (or EDR-like data) is already being recorded in nearly all vehicles, a large proportion (in some cases all) of the cost may have already been spent. Therefore, measures to harmonise specifications in order to realise the potentially substantial benefits from EDR data would have long-term benefits for road safety and access to justice.

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F.8 Hands-free Interlock

There are existing systems that use ignition interlocks to prevent a car from starting until the driver's mobile phone has been placed into a specific cradle. This cradle prevents the driver from interacting manually with the phone and thus prevents hand-held usage while driving. Bluetooth technology, however, enables some functions to be accessed hands-free. The proposed measure is to introduce a system that achieves this same functionality, but without the need for a cradle. The system would therefore need to be able to detect when a driver is interacting with their phone and whether they are holding it at the time.

F.8.1 Description of the Problem

The idea of a hands-free interlock is based on the premise that using a phone hand-held represents a significant increase in risk compared to not using a phone, whereas using it hands-free does not. However, it should be noted at this juncture that this premise is not without controversy and there is some doubt as to the value of encouraging drivers to switch from hand-held to hands-free in any case.

Evidence from simulator-based studies indicate that talking on a phone does indeed represent a significant increase in various measures of potential driving risk, but that there is only a relatively minor difference between hand-held and hands-free usage (Burns et al, 2002). The evidence indicates that it is the act of talking that represents the majority of the distraction to the driver, rather than the holding of the phone itself. This would suggest that any measures to prevent only hand-held phone use may yield minimal safety benefits.

Conversely, naturalistic driving study-data (e.g. Hickman et al, 2010; Olson et al, 2009) suggest that the act of talking on a phone does not increase collision risk. The reasoning is thought to be that when drivers are free to choose when to use their phone they are able to modify their behaviour to adapt, and that talking on the phone may provide a means of fighting the effects of drowsiness. These studies further suggest that it is when the driver is forced to take their eyes off the road (e.g. when reaching for the phone or when writing a text message) that a significant safety risk is introduced. These studies would suggest that preventing physical interaction with the phone (whilst allowing hands-free interaction) may indeed represent a significant safety benefit.

F.8.2 Potential Mitigation Strategies

There are a number of potential ways of achieving a broadly similar result:

- The most extreme application would be to attempt to replicate the existing in-vehicle 'cradle' system. In this case the vehicle would need to be able to detect that a phone is being used, that it is being used by the driver, and that the driver is using it hand-held. If this is the case the vehicle would then penalise the user in some way until they hang up; this would most likely be achieved by sounding an audible alarm, as is the case for existing interlock docking systems (www.consumerreports.org) There remain some safety questions about the practicality and suitability of sounding an alarm whilst the driver is interacting with other vehicles on the open road. (In the case of the cradle the driver cannot start the engine unless the phone is incapacitated, and would need to remove the phone from its cradle to initiate an alarm; without the cradle the driver would presumably simply have to use their phone.)
- A less extreme application would be for the vehicle to detect hand-held phone use by the driver, as above, but rather than sounding an alarm the vehicle would block the phone signal instead. This would seem to be a preferable option as the

desired outcome is to allow the driver to continue driving without distractions, not to potentially add significant additional distractions.

- A different approach would be for phone manufacturers to be responsible for installing sensors and software to allow the phone to detect for itself whether it is being used hand-held by a driver and shut itself down accordingly. This essentially performs the same function and has the same outcomes as for Application 2, but places the burden of responsibility on the phone manufacturers instead. A scaled-down version of this would be to use an App that can be installed post-manufacture, although this would be limited to smartphones, may not have access to suitable sensors to accurately detect hand-held usage, and would presumably need to be installed by the phone vendor with a lock to prevent the user from uninstalling it. It could potentially work for businesses that supply work phones to employees, in which form it would most closely resemble the current in-vehicle docking in terms of effectiveness and market penetration.

F.8.3 Feasibility

Technical feasibility

There are several hurdles relating to how the system would work in practice:

- If the vehicle penalises the driver in some way, there would need to be a standardised form of penalty and a standardised way of alerting the driver to what is happening, the reasons why, and what they need to do to remedy the situation. This would need to ensure minimum distraction.
- If the vehicle is to disable the phone, this would need to ensure that if works for all phones/operating systems/networks. It may be that phone manufacturers would need to design their phones to a certain specification to allow the signal to be blocked, which would require engagement and acceptance from handset manufacturers. Alternatively, it may be that the network provider is responsible for blocking the call or message. This would also require industry-wide agreement on protocols. Furthermore, it would not be possible to prevent a driver from attempting to send a message (even if it is ultimately not actually sent – although once the user had discovered that the system did not permit specific communications activities, they presumably would quickly cease attempting them), nor from preventing a driver from reading a message they’ve already received.
- If the phone is to disable itself, this would also require international buy-in from handset manufacturers and/or software providers, and would require a recognised way of alerting the user as to what is causing the phone to disable itself and why.

The measure would need to be phased in with the introduction of new vehicles of handsets to market. Before this could happen though, there would need to extensive research and development, including safety testing, and legislation may also take time to pass. Perhaps in the region of 5-10 years to get to market, significantly longer to achieve anything approaching saturation (author’s estimate). A smartphone App would likely be able to be produced much more quickly, although with the limitations on system efficacy as discussed above.

Mobile phone usage whilst driving is a widely applicable issue and thus the measure could apply to the majority of drivers. However, issues related to the practicality of implementation could mean that the measure would be best targeted at fleet and commercial drivers (e.g. taxi drivers, HGV drivers etc.), or where people drive for business using a phone or vehicle supplied by their employer.

Enforcement feasibility

There are existing systems that claim to detect automatically when the user is driving (e.g. T-Mobile DriveSmart Plus, engadget.com) and disable the phone accordingly, but are based simply on the phone being in motion and so do not discern between phone-use as a driver or as a passenger. As such the user is always given the option of disabling the feature. In order to be effective the system would ideally not have the potential to be overridden by the user (except perhaps in the specific case of a call to the emergency services). There are difficulties associated with this, particularly if the phone itself is responsible for preventing its use whilst the user is driving, as phones typically give users greater freedoms over software and functionality. Users might therefore be expected to find ways to circumvent the system if they so desired.

An alternative approach could be adopted, whereby the user is required by law to have the system operational, and enforcement measures in place to ensure that this is followed. However, this essentially replicates the current system of policing (given that hand-held usage is already outlawed in many countries) and so would be a redundant measure. Therefore, in order to be useful, the measure would need to prevent the user from overriding the system.

A final option would be an entirely different measure that seeks simply to police the current legislation, perhaps by alerting the authorities to the fact that someone is breaking the law. This has many other issues associated with it and is outside the scope of this review.

Acceptability

Public acceptance could be low, given that it would restrict the driver’s ability to do something they might otherwise wish to do (on the basis that the system would only make a difference for people who currently choose to use their phones whilst driving). If it is to be a car-based system, it would also likely result in additional purchase costs of the vehicle and, during the phasing in of the system, it might also represent a disincentive to buying a new vehicle, where the user could by a second-hand car that did not have the system installed. It seems plausible that the system would be seen by many as an example of excessive regulatory intervention. There would also likely be significant user dissatisfaction in any cases where the system did not perform as intended (e.g. engine cuts out even though user is not on the phone, phone is disabled even though being used hands-free, or phone is disabled when being used by a passenger). There may also be perceptions that users are being spied on in the sense that their phone/vehicle ‘knows’ what they are doing and acts to police their activities.

F.8.4 Costs

Considerable costs involved as technology would need to be researched, developed and given type approval. There would also need to be significant safety research and testing, and there would likely be significant legal costs brought about by sectors of the industry fighting the proposals or seeking damages in cases where the system does not perform as intended. There would also likely be significant costs should any accidents occur as a direct results of the feature (whether behaving as intended or a malfunction).

F.8.5 Benefits

If an effective and reliable system can be implemented, the measure may be expected to reduce the number of crashes due to drivers being distracted.

F.8.6 Benefit:Cost Ratio

The system would be expensive to develop, would face significant hurdles in terms of achieving the required level of performance, would likely face significant user backlash and may pose safety concerns if errors in operation occur. There is also an element of doubt as to the potential safety benefits of preventing hand-held phone use with regards to talking on the phone. The most plausible form that a final system might take is as a smartphone app, which would offer limited functionality and market penetration. (benefit:cost ratio < 1).

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Appendix G. Intelligent Transport Systems (ITS)

G.1 Introductory Remarks on Intelligent Transport Systems (ITS)

G.1.1 Note on Functions and C2V/C2I

C2V (car-to-vehicle) and C2I (car-to-infrastructure) are enablers for functions/applications/services that provide safety and other benefits. There is no universally agreed set of these, so how they are described and how they are bundled together varies between projects and reports.

For example, the Connected Vehicle Reference Implementation Architecture in the US (see www.iteris.com/cvria/html/applications/applications.html) lists over 50 applications. For Europe, an independent overview of the benefits is provided by the iMobility effects initiative (see www.imobility-effects-database.org/applications.html) with the following being identified as priority systems:

- Adaptive headlights
- Blind spot monitoring
- Dynamic navigation systems
- Dynamic traffic management (Variable Message Signs)
- eCall
- Eco-driving assistance
- Emergency braking
- Extended environmental information (extended FCD)
- Lane keeping support
- Local danger warnings
- Obstacle & collision warning (including ACC)
- Real-time traffic information
- Speed alert

It seems reasonable to assume that projects will generally focus on the most realistic services providing the most benefits and that results are more readily available where there are large potential impacts (whereas small impacts will be more difficult to measure).

There is, however a question around how to identify the incremental benefits of cooperative systems where a similar service can be implemented in a non-cooperative way.

G.1.2 Architectural Options

It may well be possible to deliver an application/function/service to the driver in different ways. For example, warning of a hazard ahead may derive from information passed on V2V or V2I channels and then communicated to the driver within their vehicle via V2V, V2I or from an infrastructure sign. Also, the V2I may be through cellular communications or from local beacons (Dedicated Short Range Communications).

As an example of differences in description, the CODIA project describes Local danger / hazard warning as using external signage. SAFESPOT provides similar functionality into the vehicle.

These different architectural choices do not greatly affect the impact of the service (e.g. safety) but are likely to affect the benefit-cost ratio and roll-out feasibility.

G.1.3 New Paradigm in Co-operative Intelligent Transport Systems (C ITS)

It is worth noting that C-ITS offers the possibility of sharing of common resources

The following drawing (from an ERTICO standardisation handbook) summarises the European mandated applications situation:

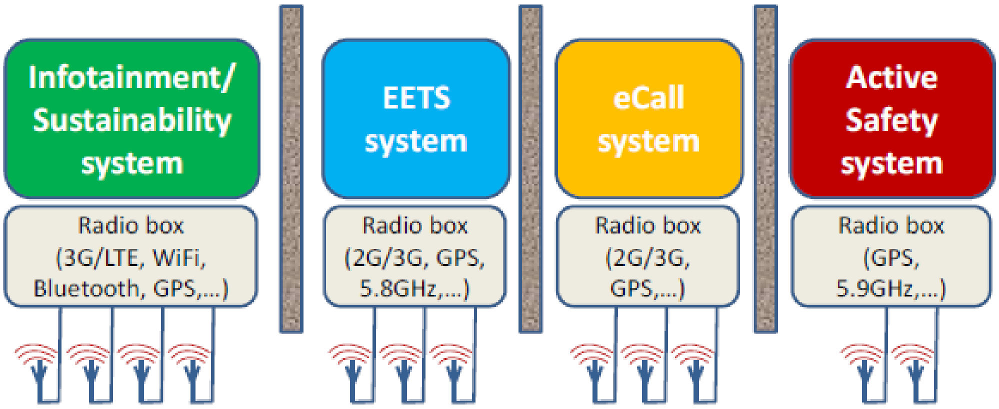

Figure G-1:

However, an architecture for cooperative ITS could look like this:

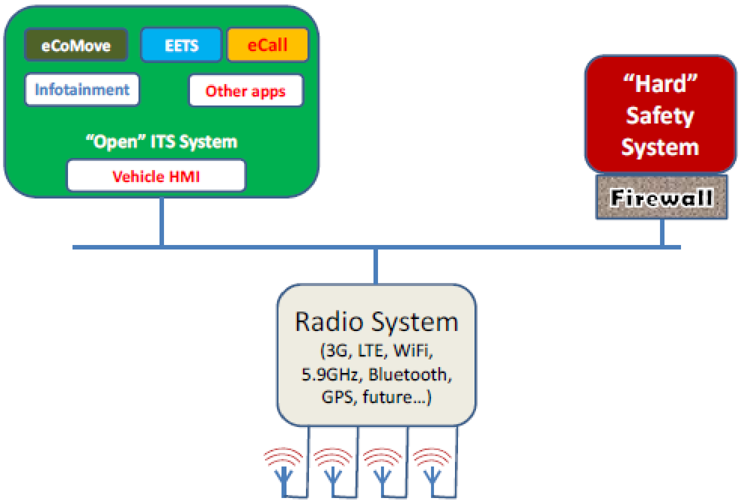

Figure G-2:

G.2 Car-to-Infrastructure communication (C2I)

C2I is a technology that can support many functions/services involving transfer of information from vehicles to the infrastructure (roadside) and from infrastructure to vehicle. Here only cars and light vans are considered as the relevant vehicles. Also, just two functions/services are considered - warning of hazards on the road ahead and warning of speed limits (which might be variable depending on traffic and weather conditions)

G.2.1 Description of Function

C2I is a technology that can support many functions/applications/services involving transfer of information from vehicles to the infrastructure (roadside) and from infrastructure to vehicle.

Just two functions/services are considered (specified by EC) - warning of hazards on the road ahead and warning of speed limits (which might be variable depending on traffic and weather conditions).

Also, only cars and light vans are considered as the relevant vehicles to be fitted with the function (although, of course, a hazard on the road ahead involving another type of vehicle will still be considered as a hazard).

The function relies on the collection of suitable real-time information about speed limits, weather conditions, stopped vehicles or other hazards etc.). How this information is collected (loops, video monitoring, patrol vehicles, feed from sign systems, cooperative vehicles) and how it is evaluated and combined into highway information within a traffic control centre is not considered as part of the function.

G.2.2 Benefits Reported in Literature

CODIA (2008)

CODIA (Co-Operative systems Deployment Impact Assessment) was a joint VTT and TRL project for the European Commission DG-INFSO. It aimed to provide an independent assessment of direct and indirect impacts, costs and benefits of five co-operative systems:

- Speed adaptation due to weather conditions, obstacles or congestion (V2I and I2Vcommunication)
- Local danger / hazard warning (V2V)
- Cooperative intersection collision warning (V2V and V2I)
- Reversible lanes due to traffic flow (V2I and I2V)
- Post-crash warning (V2V)

Concerning the safety impacts, speed adaptation systems was assessed as contributing a 7.2% fatality reduction and local danger warning a 4.2% reduction.

Cooperative intersection collision warning has highest potential (-7%) to reduce injuries.

With regard to benefit to cost ratios, speed adaptation and local danger warning indicate socio-economic profitability (BCR of 1.3 and 1.6 in a 2030 “high penetration” scenario). Cooperative post-crash warning is not socio-economically profitable due to its modest safety impacts, and reversible lane control is not profitable due to its restricted potential use.

The CODIA estimates should be considered as indicative rather than robust for a number of reasons:

- Some of the data on benefits is now dated
- Several assumptions have had to be made about future scenarios
- As time goes on other technology will also contribute to safety (and other) improvements
- The function is not widely implemented and drivers' behaviour has to be surmised
- The in-vehicle implementation and HMI will affect driver reaction

SAFESPOT (2009)

SAFESPOT was an EU project (completed 2009, www.safespot-eu.org/). V2I functions and potential safety benefits were reported in terms of fatality reductions:

- Speed alert 7%
- Hazard and incident warning 2%

SAFESPOT also considered the benefits potentially provided by cooperative intersections (3%). However, this benefit is not one of the EC specified sub-functions for C2I. The SAFESPOT estimates should be considered as indicative rather than robust for the same reasons as given for CODIA above.

SMART 63/64/65 (2010)

These three projects were carried out for the European Commission (DG Information Society and Media) during 2011[42].

SMART 63 looked at what the future infrastructure for supporting cooperative systems will look like. In order to identify infrastructure requirements, the project selected and ranked cooperative systems. Applications were grouped according to their requirements for communications and roadside infrastructure. The project also looked at socio-economic impact assessments and road maps for deployment.

SMART 64 was concerned with what is needed to achieve wide scale deployment of automated driving by 2025. It examined technical issues, policy and other issues, and carried interviews with key players. The conclusions covered three main areas where action is needed for deployment to become a reality: the drivers, the technology and the business models.

SMART 65 – European Services Enabled by the Connected Car identified the needs of both public and private sectors for the services enabled by cars being connected to the internet by 2025. It identified the technologies and services facilitated by the concept of a European Wide Service Platform. The project consulted a range of stakeholders across Europe with different roles in providing and using connected vehicle services on future requirements, priorities and issues. Scenarios and road maps for Future Mobility services enabled by the Future Internet were examined in order to identify future research requirements.

The most quantitative and relevant here is SMART 63. An extract from the impacts table (based on research from previous studies) is provided below:

[42] A summary of key points on these projects is available at:

www.imobilitysupport.eu/imobility-forum/governance-structure/plenary/library/2011-4/1st-meeting-1/25-oct-2011/451-plenary-presentation-13-smarts-kmalone-2-25-oct-2011/file

Table G-18:

Nr.	Name of Service	Safety (Fatality)	Efficiency (Congestion)	CO2 Reduction
1	In-vehicle signage	<+1%[43]	-2…-4%	<-2%
2	Road works warning	<–1%	±0%	<-1%
7	Vulnerable road user warning	<–1%	<-1%	<-1%
9	Hazardous location notification	–4%	-3%	<-1%
10	Traffic jam ahead warning	–4%	-3%	<-1%
11	Post-crash warning	–1%	–1%...+3%	<-1%
12	Enhanced route guidance	<+1%	-2…-4%	<-2%
13	Car breakdown warning	<–1%	–1%...+3%	<-1%
14	Obstacle on driving surface warning	<–1%	<-1%	<-1%

As SMART63 was a desk study of previous work the caveats from CODIA and SAFESPOT on the robustness of these findings also apply here.

COBRA (2013)

COBRA was a European ERA-NET project. It developed a methodology for assessing impact of a bundle of C-ITS services and calculated some expected impacts of (configurations of) cooperative services in terms of optimised vehicle flow, traffic safety and emission reduction, compared to existing Intelligent Transport Systems. It also undertook a cost-benefit analysis of cooperative systems, based on the impact assessment and given investments and maintenance costs.

See: www.eranetroad.org/index.php?option=com_content&view=article&id=109:2011-mobility&catid=31:standard&Itemid=46

Bundles investigated in the COBRA project were:

- Local Dynamic Event Warnings: Hazardous location notification, road works warning, traffic jam ahead warning and post-crash warning (eCall)
- In-Vehicle Speed and Signage: In-vehicle signage, dynamic speed limits and Intelligent Speed Adaptation (ISA)
- Travel Information and Dynamic Route Guidance: Traffic information and recommended itinerary, multi-modal travel information and truck parking information and guidance.

COBRA largely used previous findings (again!) and calculated the effects of the bundles on fatality reductions of 7%, 7% and 4% respectively.

[43] The EasyWay Cooperative Systems Task Force (Task 2.3, Intermediate results, 25 July 2011) has suggested that in-vehicle signage will cause some degree of re-routing onto less safe roads so there could be a marginal decrease in safety

DRIVE C2X

DRIVE C2X (www.drive-c2x.eu/project) is in an early phase so no impacts are provided yet. Deliverable D11.4 on "Impacts of cooperative systems and user perception" is expected in June 2014.

The project website states that "there are no doubts about the potential benefits of C2X communication technology but so far those benefits cannot be quantified because there are no field trials with cooperative systems technology ongoing yet that can provide the data needed for a serious assessment of the benefits".

iMobility Effects (2014)

The iMobility effects database summarises results from a number of published studies on the effects of different ITS applications/services.

See: http://www.imobility-effects-database.org/applications.html

The functions/services that can be implemented using V2I communications (relevant to hazards and speed limits) are reported as having the following safety benefits in terms of fatality reductions:

- Local danger warnings (using VMS signs) 1-5%
- Real-time traffic information – no reliable estimates but certainly <10% (but substantial traffic flow benefits)
- Speed alert. Could be up to 30% for mandatory; less for warnings

The literature is taken mostly from Europe but with some US studies. Some of it goes back more than 15 years. No examination of the original sources has been undertaken at this time (it would be quite a significant undertaking). Overall, the results probably present a "best estimate/consensus" but cannot be considered completely firm.

FOTSIS (2014)

FOTSIS (European Field Operational Test on Safe, Intelligent and Sustainable Road Operation, www.fotsis.com) is undertaking large-scale field testing of seven "close-to-market" cooperative I2V, V2I & I2I technologies in four European test sites (Spain, Portugal, Germany and Greece). Field trials are expected to provide useful data to help clarify estimates of benefits but will of necessity be related to very specific designs of functions and "use cases".

FOTSIS is a member of FOTNET a project coordinating and summarising Field Operational Testing. The following information is based on a review of FOTsis Deliverable D4.2 M29 (Safety impact assessment – Preliminary Report Version number: 0.6). We are grateful to the consortium for sharing this preliminary unpublished information.

The services being considered are:

- S1. Emergency Management (eCall)
- S2. Safety Incident Management
- S3. Intelligent Congestion Control
- S4. Dynamic Route Planning
- S5. Special Vehicle Tracking (e.g. dangerous or valuable goods)
- S6. Advanced Enforcement (on board recording and tutoring)
- S7. Infrastructure Safety Assessment ("black spot" identification from vehicle data)

S2 provides real-time warnings to drivers using I2V of congestion, incidents, speed and weather.

S3 attempts route load balancing using real-time information and predictive algorithms and attempts to affect traffic using VMS.

S4 provides route recommendations to individual drivers (I2V) based on the view of the network from S3.

The Deliverable provides a qualitative indication of the impacts expected from each service. Research questions and indicators are discussed. The difficulty of statistically significant results is presented e.g. for fatalities and therefore the need to consider proxy measures. The proposed trials will by 8 months (4 months without the treatment and 4 months with).

The deliverables conclusion is:

"As of this writing no definitive conclusions with respect to safety impacts are possible. Almost all of the research methodologies require a comparison of the field test results, yet to be conducted, with baseline or reference data".

Further data from deployed Services is expected to be available for evaluation in the coming months.

G.2.3 Potential Disbenefits

Potential disbenefits have not been widely discussed in the literature. Two aspects can be considered for each of the functions:

- Whether the function may provoke some adverse behavioural adaptation of the driver which has negative effects
- Whether the function has an adverse effect on any other road user or stakeholder

Potential disbenefits for the two functions in scope of this work are considered below:

Warning of hazards on the road ahead

Firstly, the HMI of the warning device may be distracting or may alarm the driver causing unsafe driving. This can be minimised by suitable design. Secondly, being warned of hazards ahead may cause a driver to re-route onto roads which are less safe per unit distance travelled thus increasing their risk exposure (this point was noted in the literature above). Thirdly, the driver may execute an unsafe manoeuvre in order to leave the roadway (such as a rapid lane change, illegal turn, reversing or U-turn etc.). This is a general issue of safe driver behaviour.

Other road users are unlikely to be affected save through the mechanisms noted above.

Warning of speed limits

Firstly, the HMI of the warning device may be distracting or may alarm the driver causing unsafe driving. This can be minimised by suitable design. Secondly, the driver may perceive a conflict between information presented within the vehicle and external information or behaviour of other road users. This is not expected to be a large issue as the driver should be in a heightened awareness state. The driver may interpret the speed limit as a "safe speed" and my drive up to this limit even if conditions do not support it.

Other road users are unlikely to be affected save through the mechanisms noted above.

G.2.4 Summary/Conclusions on Benefits and Disbenefits

The two functions considered in the scope of this work appear to be the V2I services which offer the greatest potential benefits. From analysis of crashes and driver behaviour, estimates in the literature suggest about a 7% potential fatality saving from speed advice and between 2 and 7% for hazard ahead warning and with few disbenefits. However, such estimates have been derived from desk study rather than actual field operational tests. Information from such tests should become available over the next year. Some additional points are:

- The actual benefits will also depend on the systems technical performance and the driver HMI

- FOT results should, as well as measuring benefits, provide information about driver acceptance issues and any behavioural changes
- The same communications and hardware could support additional V2I services (providing additional benefits)

G.2.5 Anticipated Costs and Feasibility

In-vehicle Costs

All of the automobile manufacturers interviewed for the US's GAO report (see below) said that it is difficult to estimate in-vehicle V2V component costs. It can be expected that the same is true of V2I. There are probably several reasons for this:

- Bundling - which services would be supported
- Sharing – which in-vehicle components can be shared with existing hardware
- Architecture – in particular which communication channel
- Quantity – how many units of each design are required
- Timescale – when would these need to be available
- Line-fit by OEM/dealer/aftermarket – which channel to the customer
- Regulation - which aspects of the design may be regulated

Vehicle Fitting and Type Approval

The basic components of an in vehicle system (IVS) are:

- Aerial
- Communications equipment
- Processing and storage
- Driver HMI (e.g. screen, audio)

A series of C-ITS standards have been developed and are available for use by system providers. There could be a case for mandating fitment of IVS to support these services. The US government appear to be taking this route, although their timetable is not yet clear. However, experience with eCall (in many ways a "simple" V2I service) has shown that mandating a function has been more complex than anticipated as the IVS is only part of the information chain. Overall, our recommendation is not to seek Type Approval at this time.

Communication and "Back-office" Costs

C2I using cellular communication is relatively low cost and feasible. The actual cost of information transfer will depend on the service package that the customer has with the cellular service providers.

Communications using dedicated short range roadside beacons is initially more expensive due to the necessary beacon deployment.

Back-office hardware/software costs to support these services are one-off costs and relatively low compared with the millions of IVS required for full deployment.

COBRA has investigated costs and benefits. For Bundle 1 (Local Dynamic Event Warnings): If the services are delivered through cellular network communications to smartphone apps, such that there are no additional in-vehicle costs, and communication costs are negligible, then the benefit cost ratio is positive and increases over time. If the service is delivered through beacons, then the costs greatly exceed the benefits, due to the investment in the roadside beacons.

Bundle 2 (In-Vehicle Speed and Signage) achieved a benefit-cost ratio slightly higher than 1 in the examples considered where it is delivered via cellular networks.

Commercial issues

It should be noted that the business case for wide deployment of V2I has not been firmly established.

As stated in Smart 63:

‘There are still a number of challenges to be sorted out by the members of the value chain in cooperative ITS. The responsible stakeholders may vary from member state to member state and even might vary from region to region. The deployment choices may also depend on the legacy systems and the roles chosen by the public and private parties.’

G.2.6 Stakeholders

- National and Regional governments
- Public service providers (including Member States, Road Operators and Road Authorities)
- Commercial service providers and industry (including vehicle and equipment manufacturers, service suppliers (e.g. in-vehicle services))
- Communication suppliers, particularly mobile providers
- Road users (representatives of private individuals, freight industry, fleet managers).

Note: A substantial Stakeholder consultation on connected car services took place in the SMART 65 project.

G.3 Vehicle-to-Vehicle communication (V2V)

Capability for vehicles to rapidly exchange digital messages to support a range of services/function for safety, efficiency and environmental benefits including, importantly, time critical messages to help avoid collisions or mitigate their effects. Called "connected car" in the US. Also V2V although here it is understood that the primary focus is passenger cars and light trucks

G.3.1 Description of function

These technologies facilitate the sharing of data, such as vehicle speed and location, among vehicles to warn drivers of potential collisions. Based on the data shared, V2V technologies are capable of warning drivers of imminent collisions, including some that sensor-based crash avoidance technologies would be unable to detect.

Often included is automatic application of brakes, steering, etc. to avoid "certain" crashes. Other V2V functions could allow "platooning" of vehicles together as a form of automated driving.

The following literature includes "connected vehicles" so has elements of V2I as well as V2V if projects or studies consider both technology options together.

G.3.2 Benefits reported in literature

RITA (2008)

The US DOT Research and Innovative Technology Administration (RITA) had a programme called the "Vehicle-Infrastructure Integration (VII) Initiative". In 2008 a Benefit-Cost Analysis (Version 2.3, 2008) was produced:

152.122.41.186/connected_vehicle/508/Library/Library-RRs-Institutional/VII%20BCA%20Report%20Ver2-3.htm

The report investigated a bundle of V2V and V2I applications with on-board unit equipped vehicles and a five-year roll-out of DSRC beacons. The table below illustrates benefits and calculates an overall BCR. However, the text says for several parts of the bundle that "it is not yet possible to generate meaningful quantitative estimates of safety and mobility aspects"

Table G-19: Summary of Estimated VII Benefits and Costs (Present Values, Billions of 2008 Dollars)

Application / Cost Element	Safety Benefits	Mobility Benefits	Costs
Signal Violation Warning	11.0	0.1	
Stop Sign Violation Warning	2.7	0.0	
Curve Speed Warning	14.6	0.1	
Electronic Brake Lights	13.6	0.2	
Ramp Metering		0.3	
Traffic Signal Timing		0.3	

Application / Cost Element	Safety Benefits	Mobility Benefits	Costs
Winter Maintenance		0.4	
Traveller Information		0.9	
Total Benefits	***41.8***	***2.4***	
Roadside Equipment			9.3
Onboard Equipment			12.4
Network Backhaul, O&M			3.7
Governance & Program			1.0
Application-Specific Costs			0.8
Total Costs			***27.3***
NET BENEFITS: 16.9 B/C RATIO: 1.6			

The recent NHTSA announcement (see below) indicates that more recent work has identified sufficiently robust benefits to support mandatory fitment of this technology.

US Government Accountability Office (2013)

The US Government Accountability Office's report to Congressional Requesters can be summarised as "vehicle-to-vehicle technologies are expected to offer safety benefits, but a variety of deployment challenges exist" (www.gao.gov/assets/660/658709.pdf).

According to NHTSA, if V2V technologies are widely deployed, they have the potential to address 76 percent of multi-vehicle crashes involving at least one light vehicle by providing warnings to drivers. However, the potential benefits of V2V technologies are dependent upon a number of factors including their deployment levels, how drivers respond to warning messages, and the deployment of other safety technologies that can provide similar benefits.

All of the automobile manufacturers GAO interviewed said that it is difficult to estimate in-vehicle V2V component costs. The costs associated with a V2V communication security system also remain unknown but could be significant.

NHTSA (2014)

NHTSA announcement (February 3, 2014) on V2V future requirement/regulation:

www.nhtsa.gov/About+NHTSA/Press+Releases/2014/USDOT+to+Move+Forward+with+Vehicle-to-Vehicle+Communication+Technology+for+Light+Vehicles

The U.S. Department of Transportation's (DOT) National Highway Traffic Safety Administration (NHTSA) announced that it will begin taking steps to enable vehicle-to-vehicle (V2V) communication technology for light vehicles.

V2V communications can provide the vehicle and driver with 360-degree situational awareness to address additional crash situations – "V2V crash avoidance technology has game-changing potential to significantly reduce the number of crashes, injuries and deaths on our nation's roads". In addition to enhancing safety, these future applications and technologies could help drivers to conserve fuel and save time. V2V technology does not involve exchanging or recording personal information or tracking vehicle movements.

In August 2012, DOT launched the Safety Pilot "model deployment" in Ann Arbor, Mich., where nearly 3,000 vehicles were deployed in the largest-ever road test of V2V technology. NHTSA is currently finalising its analysis of the data gathered as part of its year-long pilot program and will publish a research report on V2V communication technology for public comment in the coming weeks. The report will include analysis of the Department's research findings in several key areas including technical feasibility, privacy and security, and preliminary estimates on costs and safety benefits. NHTSA will then begin working on a regulatory proposal that would require V2V devices in new vehicles in a future year, consistent with applicable legal requirements.

PIARC (2012)

PIARC's connected vehicle report (www.piarc.org) was developed by a joint task force of PIARC and FISITA. The reports explores the commercial and public sector perspective and discusses a number of issues and implementation factors. They say that:

'Research suggests that connected vehicles and cooperative systems will bring economic savings in transport …but for most countries (Japan is an exception) the evidence is not yet sufficiently compelling to justify a government investment programme.'

SAFESPOT EU project (2009)

This project (www.safespot-eu.org) has researched V2V functions and potential safety benefits from enhanced driver perceptions in terms of fatality reductions and estimate:

- Longitudinal collision reduction 7%
- Lateral collision reduction <1%
- Road departure <1%
- Combined package ~ 8.3%

iMobility Effects

The iMobility effects database (www.imobility-effects-database.org/applications.html) summarises results from a number of published studies on the effects of different ITS applications/services.

The database does not specifically list any V2V results (presumably because of the dearth of evidence). However, some indication of potential benefits could be gleaned from autonomous systems (i.e. on-vehicle systems involving sensors which automatically activate vehicle systems): For example, emergency braking is expected to provide overall a 7% fatality reduction. This evidence comes from a combination of accidentology with simulator and track testing of equipment. Perhaps a V2V service that also operated the vehicle's brakes would offer a similar benefit.

Blind spot monitoring and lane keeping functions can also be supported through V2V rather than on-board sensors so additional benefits could be expected.

Standards Development/Project Involvement

Two European standards organisations, ETSI (European Telecoms Standards Institute) and CEN (European Committee for Standardization), have confirmed that the basic set of standards requested by the European Commission (EC) to make 'connected cars' a reality, has been fully completed. Connected cars, able to communicate wirelessly with each other (V2V) and with road infrastructures (V2I), are expected to appear on European roads in 2015. The EU has invested more than €180m (US$246m) in research projects on cooperative transport systems, such as Coopers, CVIS, and Safespot, which have delivered results that contributed, under the coordination of the COMeSafety project, to the definition of communication architecture for cooperative systems. This work has been further validated by large-scale pilots such as Drive C2X and FOTSIS. The two European organisations have also cooperated closely with American and Japanese organisations to ensure that the systems are compatible across the globe.

The Release 1 standardisation package covers the norms that have been adopted to ensure that vehicles made by different manufacturers can communicate with each other.

Work on the Release 2 standardisation package has already begun to fine tune existing standards and deal with more complex use cases.

G.3.3 Potential Disbenefits

Potential disbenefits have not been widely discussed in the literature. Two aspects can be considered for each of the functions:

- Whether the function may provoke some adverse behavioural adaptation of the driver which has negative effects
- Whether the function has an adverse effect on any other road user or stakeholder

Potential disbenefits are considered below:

HMI Issues in General

The HMI of the warning device may be distracting or may alarm the driver causing unsafe driving. This can be minimised by suitable design.

Issues Related to Drivers' Response to Information

As with V2I services providing information to the driver, a range of responses and adaptations can be anticipated. Some examples are given below:

- The driver may perceive a conflict between information presented within the vehicle and external information or behaviour of other road users. This is not expected to be a large issue as the driver should be in a heightened awareness state.
- The driver may interpret a speed limit as a "safe speed" and my drive up to this limit even if conditions do not support it.
- Being warned of hazards ahead may cause a driver to re-route onto roads which are less safe per unit distance travelled thus increasing their risk exposure (this point was noted in the literature above).
- The driver may execute an unsafe manoeuver in order to leave the roadway (such as a rapid lane change, illegal turn, reversing or U-turn etc.). This is a general issue of safe driver behaviour.
- Vulnerable road users such as pedestrians and cyclists are unlikely to be equipped with V2V technology and thus may become a relatively disadvantaged road user.

Other road users are unlikely to be affected save through the mechanisms noted above.

Issues Related to Vehicles' Automated Responses

For services that automatically implement vehicle control to avoid collisions or otherwise adapt to the roadway, some additional potential disbenefits can be considered:

- System safety and technical failure
- A change in driving style and/or testing the limits of the technology
- Reduced driver awareness and out-of-loop issues
- Non-response to unequipped pedestrians and other VRU
- Unsafe transfer effects when driving unequipped vehicles
- Hacking and illegal activity towards target vehicles

The extent of these problems and potential effects on other road users is unknown at the present although some information may begin to become available from field operational tests.

G.3.4 Summary/Conclusions on Benefits

Nearly half of the crashes examined by the US's Highway Loss Data Institute involve rear-end collisions. In theory, information-swapping between cars could virtually eliminate such accidents. However, results from field operational tests are still awaited but should become available over the next year. Some additional points are:

- The actual benefits will also depend on the systems technical performance and either the driver HMI or the vehicle actuation of control
- FOT results should, as well as measuring benefits, provide information about driver acceptance issues and any behavioural changes
- The same communications and hardware could support a broad range of V2V and V2I services to and from roadside beacons
- However, the case for V2V benefit is weak until many (most) vehicles are equipped. Whereas autonomous sensing provides immediate and progressively increasing benefits as vehicles are equipped, V2V does not provide benefits until most vehicles are equipped.

G.3.5 Anticipated Costs and Feasibility

In-vehicle Costs

All of the automobile manufacturers interviewed for the US's GAO report (see above) said that it is difficult to estimate in-vehicle V2V component costs. There are probably several reasons for this:

- Bundling - which services would be supported
- Sharing – which in-vehicle components can be shared with existing hardware
- Architecture – in particular which communication channel
- Quantity – how many units of each design are required
- Timescale – when would these need to be available
- Line-fit by OEM/dealer/aftermarket – which channel to the customer
- Regulation - which aspects of the design may be regulated

Vehicle Fitting and Type Approval

The basic components of an in-vehicle system (IVS) are:

- Aerial
- Communications equipment
- Processing and storage
- (optional) interface with vehicle controls to implement manoeuvers

A series of C-ITS standards have been developed and are available for use by system providers which should help to ensure compatibility between vehicles if widely adopted (whether this will happen could depend on the business case).

There could be a case for mandating fitment of IVS to support these services. The US government appears to be taking this route, although their timetable is not yet clear. However, experience with eCall (in many ways a "simple" C-ITS service) has shown that mandating a function has been more complex than anticipated.

Overall, our recommendation is not to seek Type Approval at this time.

Communication Costs

C2C should not have any usage cost associated with communications as the DSRC frequencies and protocols are open.

The GAO report referred to above notes that the costs associated with a V2V communication security system also remain unknown but could be significant. Security would become particularly important when the functionality of the C2C service includes control of the vehicle (e.g. to avoid another vehicle).

Commercial Issues

It should be noted that the business case for wide deployment of V2I has not been firmly established.

As stated in Smart 63:

‘There are still a number of challenges to be sorted out by the members of the value chain in cooperative ITS. The responsible stakeholders may vary from member state to member state and even might vary from region to region. The deployment choices may also depend on the legacy systems and the roles chosen by the public and private parties.’

Car manufacturers can be in control of V2V communications channels without the need to pay third parties for communication costs. This contrasts with cellular networks.

Many V2V services can also be delivered through V2I channels and (although these could use roadside beacons) many can be supported with cellular radio.

There are some time critical services (such as collision warning/avoidance) where the latency of cellular communications would be insufficient and where roadside beacon density would be insufficient. For such services there are two options:

- Use of V2V communications between the vehicles involved in the manoeuver
- Use of on-board sensors

The use of on-board sensors is also a robust solution in the situation of other vehicles not being equipped with V2V services. Thus the case for V2V is weakened by the “roll-out” issue: Autonomous sensing provides immediate and progressively increasing benefits as vehicles are equipped whereas V2V does not provide benefits until most vehicles are equipped. Although ultimately it might be a cheaper solution, the case for deployment is difficult to make.

In the US it must be noted that steps are being taken to mandate V2V. If so, the commercial issues partly disappear as all manufacturers will have to provide at least some minimum functionality.

G.3.6 Stakeholders

- National and Regional governments
- Public service providers (including Member States, Road Operators and Road
- Authorities)
- Commercial service providers and industry (including vehicle and equipment
- manufacturers, service suppliers (e.g. in-vehicle services))
- Communication suppliers
- Road users (representatives of private individuals, freight industry, fleet managers).

Note: A substantial Stakeholder consultation on connected car services took place in the SMART 65 project.

G.4 Dynamic Navigation

Enhanced navigation functionality to a) dynamically route around accidents and congestion hot-spots, b) ensure routes are appropriate for the class of vehicle

G.4.1 Description of Function

The stated function for investigation is:

Enhanced navigation functionality to a) dynamically route around accidents and congestion hot-spots, b) ensure routes are appropriate for the class of vehicle

However, this service needs some "unpacking" before a consideration of benefits:

Levels of Service

Navigation is available as a commercial service in many countries and regions. It is possible to distinguish several levels of sophistication:

- Individual Static route guidance
- Individual Dynamic route guidance
- Collective/Enhanced route guidance

Individual static route guidance using only the theoretical travel times in each road stretch, not taking into account the possible congestion in the route suggested. A range of after-market personal navigation devices (PND) and smartphone apps are available in a range of €10 - €100.

Individual Dynamic route guidance takes account of current (and to some extent predicted) travel times. The route provided is calculated as best for the individual driver. Example commercial services are TomTom HD and Google Maps Navigation.

Collective/Enhanced route guidance is not currently provided as a service. It could be developed (using both implementation architectures described below and for different vehicle classes). It would provide travel times or offer routes in such a way as to seek a system-optimal solution to all vehicle routes through a given network.

Implementation Architecture

The functions of dynamic and collective/enhanced can be implemented in at least two distinct architectural forms:

- "Thick client" where the navigation system on-board the vehicle periodically receives information about travel times and delays and makes its own calculation of route based on the vehicle's current position and destination
- "Thin client" where the system provides current position and destination to an off-board server which periodically returns routing information based on centrally held journey times and delays

These two forms have distinctly different business models and privacy issues.

Thick Client example 1: TomTom IQ, which is available in many countries in Europe, is a PND with a connection to a standard Traffic Message Channel (TMC) FM or DAB radio that decodes broadcast messages to provide current traffic delay information. Information on the congestion status on highways and major roads is used by the PND to re-calculates routes.

Thick Client example 2: TomTom HD, which is available in many countries in Europe, is a PND with an in-built modem and SIM that use the cellular network to connect to

TomTom's internet service that provides up-to-date traffic congestion information. Information on the congestion status on highways, major and some local roads is updated to the PND that then re-calculates routes.

Thin Client Example: Google Maps Navigation is an on-line service which provides maps and satellite views of most part of the world and also permits calculation of the optimal route between two specific points. This service is available for smartphones with the Android Operating system and using the predefined origin as the current position (based on GPS when active) and the user need only enter a destination to get a route.

Type of Vehicle

Depending on the class of vehicle, different routes may be appropriate. For example, high-sided vehicles need to avoid low bridges and long/wide vehicles need to avoid narrow roads and tight turns etc.

Providing appropriate guidance is a matter of:

- Having suitably accurate and refined mapping information
- Ensuring the correct vehicle characteristics are used for calculation (which may depend on the vehicle owner correctly declaring their vehicle or using a suitable service)

Quality of Information

A key factor in realising benefits is good information including:

- Up to date maps from commercial providers
- Real-time journey time information (robust, accurate etc.)
- Algorithms to combine journey time sources with historic data and to predict future effects

Real-time data typically comes from the sensors installed in or above roads and from (anonymous) real time location and speed from service users of certain commercial services such as TomTom HD or Google Maps. This "crowdsourcing" approach helps to improve the overall picture of the road network.

G.4.2 Benefits Reported in Literature

Identification of Benefits

There are several subtle issues to be taken into account when reporting benefits:

Incremental benefits: As static and individual dynamic route guidance are commercially available, these can be taken as the "baseline" and the issue is then the identification the incremental benefits of enhanced functionality.

Benefits for less equipped drivers: As the proportion of users of route guidance increases there are benefits to unequipped drivers whose experience of congestion will be less severe due to more efficient routing of other drivers. (It is probably impractical to measure such benefits; Tom Tom's modelling studies suggest that if 10% of drivers use dynamic routing average journey times for all drivers is reduced by up to 5%.).

Benefits by road and congestion level: The benefits of dynamic and enhanced guidance depend on the road topology and level of congestion. There is no benefit

In very light uncongested traffic. Also there is no benefit when the road system is highly congested and with no re-routing capacity. Thus benefit averages need to take account of actual use.

Individual Static and Dynamic Route Guidance

Some previous European in dynamic route planning have been[44]:

- TRANSLIB (1991): Transport Guidance and Information System for Freight Transport in the City of Berlin.
- CLEOPATRA (1998): City Laboratories Enabling Organisation of Particularly Advanced Telematics Research and Assessment.
- FEEDMAP(2006): Enabling quick and inexpensive map updates
- REACT (2006): Realizing Enhanced Safety and Efficiency in European Road Transport.
- CARGOES: Integration of Dynamic Route Guidance and Traffic Control System.
- I-TRAVEL: (2008): Technologies for travel planning and comprehensive information for travellers en-route.
- IN TIME: (2009) : Real time traffic and Travel Information (RTTI) services

A detailed review of these sources has not been undertaken at this time.

TomTom Dynamic Navigation

Analysis by TomTom of randomly selected trips shows that TomTom users with IQ Routes (a form of dynamic route guidance) can save an average of 2-4% of their journey time relative to static route guidance, depending on the availability of a good alternative route to reduce journey time.[45]

The following table shows the impact of IQ Routes based routing on journey times:

Table G-20:

Region	Trip sample size and time of departure	Route differs IQR vs Std-Route	Journey time savings Percentiles using IQR-MSP (50,75,95)	Average journey time savings Using IQR-MSP	Average absolute journey time deviations Std-ETT vs IQR-MSP
Berlin	8000 (Mo,8am)	51%	2.3%,4.9%,11.7%	3.5%	14.1%
Paris	5000 (Mo,8am)	65%	2.1%,4.8%,11.4%	3.3%	15.6%
Ruhr area	5000 (Mo,8am)	61%	1.4%, 3.8%, 8.4%	2.3%	10.1%
London	2000 (Mo,8am)	53%	2.46%, 5.3%, 12.6%	3.8%	12.6%
London	2000 (Mo,5pm)	52%	2.5%,5.7%, 12.9%	4%	10.2%

Where:

MSP: Measured Speed Profiles based on TomTom Community Trip Statistics

[44] Numerous sources are also listed in the US DOT benefits database:

www.itsbenefits.its.dot.gov/its/benecost.nsf/BenefitTerminators/DAS+Navigation_Route+Guidance

[45] www.tomtom.com/landing_pages/trafficmanifesto/content/pdf/Support%20Document_lid1.pdf

IQR-MSP: IQ Routes Travel Time using measured speed profiles per road stretch

Std-ETT: Standard Estimated Travel Time using speeds derived from road stretch attributes (e.g. Functional Road Class, maximum legal speed limit etc.)

iMobility Effects

The iMobility summary of reviewed sources concerns individual dynamic route guidance.[46]

The summary states that "users reach their destination via a personally optimal route, which means that the whole transport network is being utilised more efficiently"; however, no overall figures are given although a small positive effect of around 2% is recorded in terms of fuel efficiency. It is also stated that "Dynamic navigation is also very likely to have a positive impact on traffic safety as drivers are better informed about hazardous situations such as a tail of congestion, ghost drivers, or the overall high traffic volumes".

Dynamic navigation is also very likely to have a positive impact on traffic safety as drivers are better informed about hazardous situations such as a tail of congestion, ghost drivers, or the overall high traffic volumes.

Smart 63

The Smart 63 project has a concept called "enhanced navigation" although on close reading of the project deliverable's annexes, this appears to be "only" individual dynamic route guidance. The offered benefits from this accord with that from TomTom and iMobility above:

Table G-21:

Nr.	Name of Service	safety (Fatality)	Efficiency	CO2 reduction
12	Enhanced route guidance	<+1%	-2…-4%	<-2%

The source of this estimate has come from the project's literature review (although the exact source used is not immediately clear).

Benefits of Collective Route Guidance

There have been numerous theoretical studies of "system-optimal" routing and how it differs from the individual optimal case.

see Jahn et al. (2003): web.mit.edu/schulz/www/epapers/jmss-or-2005.pdf

Van Vuren et al. (1991): trid.trb.org/view.aspx?id=353793

However, in terms of practical measurements, the need for high usage rates make practical estimates of collective routing difficult. Indeed, a driver accepting a system-optimal route may actually experience an individual dis-benefit.

Because individual dynamic routing also benefits unequipped drivers, the incremental benefit is likely to be smaller than the incremental benefit of individual dynamic routing over individual static routing.

G.4.3 Potential Disbenefits

Potential dis-benefits of re-routing have been discussed in the literature. Two aspects can be considered:

[46] www.imobility-effects-database.org/applications_17.html

- Whether the function may provoke some adverse behavioural adaptation of the driver which has negative effects
- Whether the function has an adverse effect on any other road user or stakeholder

Potential dis-benefits are considered below:

HMI Issues in General

The HMI of the route guidance screen may be distracting causing unsafe driving. This can be minimised by suitable design of the screen and use of auditory guidance. In any case, the issues with "basic" navigation and any form of enhanced navigation are similar.

Issues Related to Drivers' Response to Routing Information

As with V2I services providing information to the driver, a range of responses and adaptations can be anticipated. Some examples are given below:

- The driver may perceive a conflict between information presented within the vehicle and external information or behaviour of other road users. This is not expected to be a large issue as the driver should be in a heightened awareness state.
- Dynamic routing may cause a driver to re-route onto roads which are less safe per unit distance travelled thus increasing their risk exposure (this point has been noted in the literature).

- If not presented at the most appropriate time, the driver may execute an unsafe manoeuver in order to follow routing instructions (such as a rapid lane change, illegal turn, reversing or U-turn etc.). This is a general issue of safe driver behaviour and is also an issue in basic navigation systems.

Other road users are unlikely to be affected negatively save through the mechanisms noted above (and there is evidence that unequipped drivers will benefit from drivers with route guidance).

Privacy Issues

The architectural options were discussed above. The "thick client" option does not have any specific issues of privacy unless users agree to contribute their position and travel times for crowdsourcing agglomeration of congestion information.

For the "thin client" there may be some issues. In order to access this (optional) service, a driver will have to sign a contract and part of the terms of the contract will concern privacy of the location data supplied to the off-board server.

Providing location does not necessarily give away personal information as long as the number of vehicles using the service is high and the location is not so specific (e.g. at the location of one house) but is in a road or area.

There is popular press comment on privacy issues in route guidance, "probe vehicle data" and "crowdsourcing". The concerns of Working Party 29 on eCall are relevant (1609/06/EN WP 125 Working document on data protection and privacy implications in eCall initiative Adopted on 26th September 2006) as they make a distinction between services that are optional (and hence governed by terms and conditions for use of the service) and a service that is mandatory. As long as dynamic and future enhanced guidance is optional, then privacy issues do not seem to be insurmountable.

G.4.4 Summary/Conclusions on Benefits

Route guidance provides substantial individual benefits to drivers (and secondary benefits to other users in terms of reduced congestion). Individual dynamic guidance makes use of real-time congestion information and provides an additional benefit which has been estimated to be 2-4% of travel time and corresponding benefits to environmental performance. The further incremental benefits of enhanced guidance using "collective" (system optimal) routing do not seem to have been practically researched or measured but are probably significantly less than 2-4%. Note also that the actual benefits will also depend on the systems technical performance and the driver HMI.

G.4.5 Anticipated Costs and Feasibility

Collective routing could, in theory, be achieved with both architectural options. The thin client approach can achieve this most readily as it directly provides routes to drivers. The thick client option would need to calculate an array of travel times that would cause the vehicle's routing engine to calculate the required route (although this is relatively indirect might be less efficient).

In-vehicle Costs

In-vehicle implementation can most readily be achieved using a personal navigation device or a smartphone App. Alternatively, it can be viewed as a V2I cooperative system (see also the notes on V2I costs in the above sections).

Costs would be similar to individual dynamic route guidance in terms of any on-vehicle equipment.

Vehicle Fitting and Type Approval

As drivers are familiar with using route guidance as an after-market option through Personal Navigation Devices or Smartphones, it would be a radical (and probably unpopular) initiative to mandate fitting as part of OEM equipment.

Therefore the issue of TA does not arise for such navigation systems.

There are a number of commercial solutions and organisations with different approaches to integration of smartphone apps within vehicles who would become additional Stakeholders in any mandated developments:

- The new Ford Focus features SYNC 2 and AppLink functionality to pair with smartphones, and offers some advanced driver assistance features.
- Renault's R-Link, which was launched late last year, was Europe's first major IVI system based on Android.
- The Car Connectivity Consortium (CCC) is committed to the development of global standards and certification for smartphone in-car connectivity. The responsibilities of the CCC include writing technical specifications, building test tools for certifying products, supporting application developers with user-interface guidelines and conferences, and ensuring a trouble-free experience for users through publicity and trademark enforcement.
- The Open Automotive Alliance (OAA) is a relatively new alliance between technology suppliers and the auto industry; the platform aims to integrate Android based systems into the vehicles and, as such, they are seeking to deliver similar outcomes to the CCC.
- In March 2014 Apple launched CarPlay which ia an iOS7/iPhone-like interface for the car dashboard that provides access to iPhone functionality via a Siri or touch activated dashboard interface. Volvo, Mercedes-Benz and Ferrari have announced CarPlay in their cars with BMW, Ford, Kia, Nissan, Mitsubishi, Toyota and Jaguar soon to follow.
- A commercially neutral forum is provided by the safeAPP working group which is part of the iMobility platform (co-supported by ERTICO and the European Commission).

Communication Costs

Using the model as for dynamic route guidance which makes use of cellular connection to the internet, there would be no additional costs associated with communication.

Back-office Costs

There would be some incremental development cost of "back-office" routing engine algorithms to identify and implement the system optimal routing.

Commercial Issues

There are existing commercial providers with strong market positions providing dynamic route guidance. As noted above, TomTom provides an example of a "thick client" architecture which has and Google Maps Navigation is an example of "thin client" architecture app. These commercial organisations also have value chains involving the mapping and communication suppliers and, increasingly, the OEM car makers.

In addition, there is an installed user base who appear to like the products and find them useful.

Therefore, this would appear to be a market that is working and providing benefits to individual users who wish to make use of the services (and pay for them). At the same time, although there are theoretical incremental benefits available, their magnitude is probably modest and there are practical issues to realize them.

Overall, it therefore seems unlikely that market intervention would be warranted.

G.4.6 Stakeholders

- National and Regional governments
- Public service providers (including Member States, Road Operators and Road
- Authorities)
- Commercial service providers and industry (including vehicle and equipment
- manufacturers, service suppliers (e.g. in-vehicle services))
- digital map providers
- Communication suppliers
- Road users (representatives of private individuals, freight industry, fleet managers).

G.5 Additional General Sources on ITS and C-ITS Benefits

SCOOP@F French project

In France, a common road map of OEMs together with the Ministry of Transport exists. Before starting the real deployment there will be the pilot project Scoop@F with about 1000 vehicles. Applications will be safety relevant. The focus on valuable business models is the unique characteristic of the pilot project. Pilots will not only show use cases, but collect data on performance, cost/benefit and user acceptance.

amsterdamgroup.mett.nl/News/222640.aspx?t=Impression%20&%20Presentations%20 Open%20workshop%20September%2025

US Benefits & costs

www.itsoverview.its.dot.gov

TEMPO (Easyway) evaluation library

www.easyway-its.eu/home

G.5.1 Other Information - eCall Stakeholders

eCall

The potential improvement in safety from eCall (automatic crash notification) depends largely on the current road situation and rescue chain efficiency in the area in which it is being applied. Benefits of up to 5% reduction in fatalities have been estimated in some studies (considerably less in the UK).

In the European eCall impact assessment study, benefit: cost ratios were estimated for EU-25 in 2020 and 2030, under scenarios with three different levels of policy intervention: (Francsics et al 2009). The different levels of policy intervention were assumed to result in different penetration rates for eCall in the vehicle fleet. The cost of in-vehicle units was found to be the most critical factor in assessing the costs. Based on reductions in casualties, congestion and emissions, the cost benefit ratio was greater than one (1.31) by 2030 under the mandatory introduction scenario, but not in the other scenarios.

G.5.2 Service Key Actors and Stakeholders (for eCall but Relevant for V2I)

EU Commission (DG Move & Connect) & EU Parliament

European Commission has adopted several measures to ensure eCall deployment by 2015. These measures have been voluntary in the beginning, but they are currently being implemented as regulatory measures. They address the upgrading of emergency call response centres to receive and process 112 eCalls, including calls from vehicles registered in any EU country and vehicle type approval measures. The Commission's aim is to have a fully functional eCall service in place all over the European Union and other European countries such as Iceland, Norway and Switzerland. The commission works in cooperation with Russia in matter related to in-vehicle emergency call services. Also the European parliament supports the aim to have eCall operational in 2015.

Standardisation bodies

eCall standardisation is part of ITS standardisation and made by the European standards organisations CEN and ETSI. They formally accepted the Mandate M/453 in January 2010. The Mandate included a list of minimum set of standards for interoperability and the split of responsibility between these two European standards organisations (ESO).

The ESOs have initiated the standardisation activity, and a number of standards have been developed and published as European Norms (EN) or Technical Specifications (TS) in the typical process towards EN approval as requested in the Commission Mandate. The ITS Coordination Group (ITS-CG) between CEN and ETSI has been established to ensure ongoing coordination of the standardisation activities within the ESOs (1st joint CEN/ETSI-Progress Report to the European Commission, 3.4.2011).

EENA

The European Emergency Number Association is dedicated to promoting high-quality emergency services based on the common European emergency number 112 throughout the EU. EENA serves as a discussion platform for emergency services, public authorities, decision makers, associations and solution providers in view of improving emergency response in accordance with citizens' requirements. EENA is also promoting the establishment of an efficient system for alerting citizens about imminent or developing emergencies. The EENA membership includes about 800 emergency services representatives from 43 European countries, 60 solution providers, 9 international associations/organisations as well as 26 Members of the European Parliament.

EeIP

The European eCall Implementation Platform (EeIP) is the coordination body bringing together representatives of the relevant stakeholders associations representing technology providers together with the National Platforms supporting the implementation of a pan-European in-vehicle emergency call in Europe. It aims to guide, coordinate and monitor the progress of the implementation of the eCall service across Europe to ensure a timely, effective and harmonised deployment of the eCall service in Europe.

eSafety eCall Driving group

The Driving Group on eCall was one of the Working Groups established by the European Commission under the eSafety Forum. eSafety was a joint industry/public initiative for improving road safety by using new Information and Communications Technologies. The overall objective was to join forces and build up a European strategy to accelerate the research and development and deployment and use of Intelligent Integrated Safety Systems. The eCall Driving Group has finalised its activities with the release of the "Recommendations of the DG eCall for the introduction of the pan-European eCall" in 2006.

National bodies

National bodies of member states relevant in the context of eCall include Ministries and agencies such as Public Safety Answering Points and Centres (PSAPs), Rescue Forces, Police, Health Care Road Authorities and Vehicle Inspection Agencies.

Mobile Network Operators

Mobile Network Operators are responsible of handling eCall voice and Minimum Set of Data delivery in the same order of priority to the Public Service Answering Points as normal 112 emergency calls. They have to upgrade their systems for monitoring and mediating eCall indicators in their communication networks.

Vehicle Industry

Vehicle industry has to equip vehicles with standardized eCall In-Vehicle Systems (IVS). They have to find eCall products operating with high performance and reliability over the whole life span of the vehicle or to find a way to update the in-vehicle system.

In-Vehicle system manufactures

Device and system manufacturers have to produce high-quality products according to standards. Preferably, they have to test their products in national or Pan European interoperability test-beds and “plug-tests” well before the devices get the certificate for approved eCall service.

Service and Maintenance Providers

eCall related services can be provided in development of software, device production, facilitating tests, consulting different decision makers etc.

Certification bodies

Mandatory devices, like the eCall IVS, must be certified before releasing to the market. Certification bodies can national or international.

Satellite Navigation Systems and Services & Digital Map Providers

eCall is dependent on accurate positioning provided by global navigation satellite services. The location information provided by eCall to the PSAP is presented using a digital map. The operation of eCall has to be based accurate and updated maps.

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