Improvements of vehicle-related safety measures

Deliverable 6.5

Identification of Vehicle related safety measures

Work package 6, Deliverable 6.5

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Executive summary

The present Deliverable (D6.5) describes the expected effects of different levers on the improvement of vehicle safety measures. These were described in the D6.2 that outlines the results of Task 6.2 of WP6 of SafetyCube: identification and evaluation within the scientific literature for each identified safety measure. Task 6.5 aimed at listing improvement levers for these measures. To reach this objective, a working group of vehicle safety experts was built with the purpose of setting a common methodology aimed at identifying improvement levers and their effects. Levers ranged from cost-improvements, regulation settings to interventions linked with non-vehicle-related domains in Safety Cube.

For a better coherence, the classification of the safety measures from task 6.2 was used. Categories are as follows: Crashworthiness, Active safety/ADAS and Tertiary safety.
Each vehicle-related safety measure is introduced by an abridged abstract (excerpt from D6.2) containing its description and then possible improvements are listed. These were classified in seven categories ("levers") that the group of experts agreed upon :
Technology – What technology improvements would increase effectiveness?
Standardization – What could the standardization of the measure bring in terms of improvement? How beneficial would it be that regulations are harmonized around the world? How could consumer test protocols be harmonized?
Regulation –Would the adoption of a regulation on the measure increase road safety and if a regulation is already existing, would an update improve it's the measure's effectiveness?
Consumer test – This lever is quite similar to the "regulation" but deals with the adoption or update of consumer test protocols.
Cost reduction – How could the cost of the measure be reduced?
Interaction with other safety domains – How is the measure linked with other safety domains and, in the opinion of vehicle-related measures experts, how could these domains contribute to improving the effectiveness of the measure?
Transferability and transposability - How could the measure be transferred to other countries or geographical areas, be used in other road safety domains or transposed to different vehicle types?

It is possible that other levers can be applied to some safety measures but only the 7 we just described were considered in the present document.

For each measure and each lever, a colour code was determined in order to visually indicate if the safety measure can be improved. The ones used for the efficiency of the safety measures have been kept but the definition has been adapted to the context of task 6.5.

The attribution of the colour codes is of course subject to interpretation. It is depending on one hand of the expertise of each person attributing a colour and on the other hand of knowledge of the different road safety contexts in which the safety solution could be implemented. Additionally, the authors wish to remind the future readers that the present deliverable is based on the state of the art of publications on road safety measures existing at the time of writing of the deliverable D6.2 on which it is based. Therefore, it is not to be considered as a truth for decades, and certainly a revision will be necessary in the coming years. The mobility changes are for the moment so big and so quick that it is a real challenge to try to indicate which ways seems the most promising to improve the global road safety situation even in the near future.

A detailed analysis of the effect of the 7 levers was synthetized for each of the measures that was deemed relevant for the present document.

A global analysis was also performed and results show that all the measures studied can be improved; that all the levers chosen are relevant, showing some potential benefit of improvement to measures: 48% (lowest percentage) of the safety measures could be improved by using the "cost reduction" and 78% (lowest percentage) of the safety measures could be improved by using the regulation and transferability/transposability levers.

One of the aims of this deliverable was to rank safety measures and relevant improvement levers. This task is not possible at a global stage and for different reasons. First of all, the priorities for road safety are highly dependent on local political and economic contexts: for example, some measures, even if apparently very efficient, would not be suitable for some countries, because of their immediate cost. The same safety measure in another area is may be not a priority because it is already in use. The prioritisation also depends on the state of the art of regulation in a given area and on other safety domains such as infrastructure or local cultures and human behaviour. The social acceptance rate of a non-regulated measure – on which its effectiveness depends - is linked with the road safety awareness in the geographical area in which its deployment is planned.

Globally speaking, the logical way of progressing on vehicle-related measures is, in our view, as follows:

1. Test new measures (or alterations of previous measures) on representative subsets of road users in order to ensure that any subsequent decision is not seen as an individual constraint but as a benefit for public health
2. Have interaction with the industry, in order to make sure than any required technical improvements (such as a new feature becoming mandatory) would be feasible in the time interval required
3. Issue regulations when necessary
4. Make sure regulations are enforced

The standardization of regulations and of safety systems would at the same time increase the global protection of rod users and decrease the price end users have to pay for each of them. Consumer tests and technological improvements can then lead to improvements of the system performance through ratings or new technical solutions.

During the analysis per categories of road users, it was clearly seen that the interaction with other safety domains such as infrastructure and education is very strong for vulnerable road users. Dedicated spaces for pedestrians, cyclists, or even Powered Two-wheelers can have a very large impact on their safety, and even if already considered in this analysis in the lever "interaction with other safety domains", their impact can be larger than the global vehicle safety measure they are included in. Safety culture (helmet wearing, respecting road rules,...) and human behavior are also very important when talking about safety measures for vulnerable road users as they often think that other road users have to take care of them or that rules are only for 4 wheelers or more.

Concerning vehicle (light and heavy) passengers, measures pertaining to protection by the vehicle were found to have less improvement potential than other measure or occupant categories. It is mainly because the systems are already well developed, regulated, rated and economically optimized. Concerning systems in which the vehicle is making an automatic intervention (transparent to drivers), they are all showing potential ways or progress concerning technology, regulation, consumer testing and cost reduction. Their interaction with the other safety domains is high, as they could be interacting directly with the infrastructure as surrogates to the drivers, which can cause acceptability issues. Some systems are just helping drivers by giving them information or safety alerts. Most of these vehicle safety systems are belonging to the active safety domain and may be improved by using a variety of levers such as technical improvements, regulation, transferability or transposability.

For all safety systems that could be useful for rescue teams (all types of vehicles), the improvement is possible but as some are already properly working and are implemented on new vehicles in Europe, their transferability to other regions and transposability to other types of vehicles seem to be the most promising way of improvement.

It is important to remind here that no prioritisation in the safety systems is proposed for this deliverable first of all because very few Cost Benefit Analyses are available for the vehicle-related measures studied in the task 6.2. All the potential levers are not independent from the local context and it is necessary to include legal requirements (regulations, enforcement, respect of the law,…), technical status of the car fleet (e.g. level of active or passive safety equipment), infrastructure-related issues (quality of roads, technical and safety equipment,…), local road safety awareness and the global social acceptance of each measure at all levels (states, consumers, industry,…) in any attempt at prioritisation. This means that according to geographical areas, safety culture, awareness of road users, what could work and what could not is totally different and not only depending on the vehicle safety solutions, but also of the economic situation of the considered country, the global human behavior and many other components that are difficult to target (including the need of road user, the sources of interest and distractions,…).

It is noteworthy that strong links with other domains of safety domains have been highlighted in the context of the present document, so using a lever to improve the efficiency of one of the vehicle-related safety measure can have a direct impact in some other safety domains (need of education, infrastructure requirements,…). In other words, some decision in another road safety domains can influence the efficiency or the potential benefit of levers to be applied on vehicle-related safety measures. Vehicles-related safety measures are one way to improve the road safety policy, and their improvement is a major step in the benefit for final users, but they are not the only ones and have to be accompanied by other road safety decisions.

1 Introduction

1.1 SAFETYCUBE

SafetyCube aims at:

1. developing new analysis methods for (a) Priority setting, (b) Evaluating the effectiveness of measures (c) Monitoring serious injuries and assessing their socio-economic costs (d) Cost-benefit analysis taking account of human and material costs
2. applying these methods to safety data to identify the key accident causation mechanisms, risk factors and the most cost-effective measures for reducing fatally and seriously injured casualties
3. developing an operational framework to ensure the project facilities can be accessed and updated beyond the completion of SafetyCube
4. enhancing the European Road Safety Observatory and working with road safety stakeholders to ensure the results of the project can be implemented as widely as possible

The core of the project is a comprehensive analysis of accident risks and the effectiveness and cost-benefit of safety measures focusing on road users, infrastructure, vehicles and injuries framed within a systems approach with road safety stakeholders at the national level, EU and beyond, having involvement at all stages.

Work Package 6

The purpose of work package 6 was to analyse data and to implement developed methodologies (WP3) concerning accident risk factors and road safety measures related to the vehicle point of view. It examines accident risks and safety measures concerning all types of road users (passenger cars, heavy goods vehicle, powered two wheelers ...) including Vulnerable Road Users (VRU). Personal as well as commercial transportation aspects are taken into account.

Therefore, various data sources (macroscopic and in-depth accident data) and knowledge bases (e.g. existing studies) were used in order to:

- Identify and rank risk factors related to the road use
- Identify measures for addressing these risk factors
- Assess the effect of measures

The work on vehicle-related risks and measures in road traffic was done according to the methodologies and guidelines developed in WP3 (Martensen et al., 2017) being thus consistent with work packages dealing with human (WP4) and infrastructure (WP5) related risks and measures.

All main results of WP6 were integrated into the DSS and linked with each other (risk factors and measures) and with outcomes of other work packages (WPs 4, 5, and 7).

1.2 PURPOSE AND STRUCTURE OF THIS DELIVERABLE

The overall aim of Task 6.5 was to identify the possible improvements of the vehicle-related safety measures presented in the SafetyCube project. This addresses one of the main objectives of the SafetyCube project and was done through an analysis by road safety. The outcomes of this task will be the basis for stakeholders and vehicle manufacturers to prioritize their developments and initiatives towards improved road safety.

This deliverable is based on the version of WP6's other deliverables (1 through 4) available at the time of redaction. The following steps were taken towards achieving the common purpose of SafetyCube and are described in detail in this deliverable:

- List of vehicle related counter measures (D6.2)
- Identification of the possible levers for improvement
- Feasibility of applying the different levers on every vehicle related safety measure
- Analysis of the expected effect (improvement) of each lever if applied on a given safety measure
- Analysis per category of safety measures of the potential of each lever.

The main results of deliverable 6.5 consist in a broad variety of possible actions aimed at improving vehicle-related safety measures that were identified and ranked by effectiveness in task 6.2, linked to corresponding road safety risk factors (identified in task 6.1) and analysed in terms of cost-benefit-an (task 6.3) whenever possible. Results are presented for each measure in a synthetic table but transversal analyses of the possible effect of levers and analyses by categories of measures are also proposed in a dedicated chapter. All the synopses corresponding to the safety measures treated in this deliverable are available separately via the project website **(www.safetycube-project.eu/)** and on the DSS. However, an abridged version of the synopses' abstracts is reproduced in this document as an introductory text. Task 6.2 colour codes are also provided in the present deliverable. For a more detailed description of the measure, readers should refer to the complete synopses that they can get by browsing through the DSS.

This document and the methodology therein are unique in the context of the Safety Cube project, as neither road users (human behaviour) nor infrastructure working groups were asked to produce this kind of analysis.

D6.5 and D6.2 are similar in terms of structure. In both documents, vehicle-related measures were analysed for each of the following vehicle categories – Bicycles, Powered Two Wheelers (PTW), Passenger Cars (PC), Light Goods Vehicles (LGV), trucks and buses. The pedestrian category was added to this list in order to gather the dedicated counter measures instead of analysing them separately for each of the different vehicle types.

Chapter 2 summarises the methodologies and procedures used in the identification and prioritization of vehicle-related counter measures. This includes a definition of all possible (in our expert group's opinion) improvement levers.
Chapter 3 consists of all the improvement tables (organized by lever) corresponding to each individual measure.
Finally, chapter 4 presents the general conclusions and gives a hint on the next steps.

2 Assessing improvement levers of safety measures

This chapter provides an overview of the methodology we developed to evaluate the possible improvement of safety measures identified in task 6.2.

In the organization of the Safety Cube project, all work packages dealing with safety issues are organized in a similar way, and their deliverables are also following similar patterns. Nevertheless, only in the context of vehicle-related WP6 was it required to highlight possible improvements of the safety measures, as a conclusion to the research program, and to gather the results in a synthetic document, based on the other WP6 deliverables (as available at the time of redaction). We mostly made use of D6.1 (vehicle-related risks) and D6.2 (synopses or abbreviated synopsis for existing safety measures). Both of them are based on available publications, so it is possible that some systems have not been considered because no eligible scientific papers were found during the literature review. D6.3 that deals with the cost benefit analysis of vehicle-related safety measures was not consolidated at the time of the writing and D6.4 was still in progress so none of them was included in the analysis performed for D6.5.

The aim of our work was to review and analyse information for each vehicle safety measure in as standardized a way as possible. Three institutes being contributors in this deliverable, devising a common methodology was necessary. The approach and 'coding template' we developed were designed to be flexible enough to allow entering data on a variety of measure types while investigating on possible common levers.

2.1 PRIOR TO ANALYSE

2.1.1 Classification of safety measures

As previously mentioned, the aim of this work is to determine the levers that could be used to improve the safety measures present in the Decision Support System (DSS). "Improving" must be understood as "improving the benefit-cost ratio", which can be done in two ways: improve measure effectiveness or reduce measure costs. Measures identified in task 6.2 were reviewed with this in view, regardless of their present level of effectiveness, as found in the literature.
The definition and the classification of measure was recovered from task 6.2, in a first step. Categories were set as follows:

- **Crashworthiness**, divided in nine sub-categories: Frontal Impact; Side Impact; Rear Impact; Rollover; Heavy Good Vehicles (HGV); Cyclists; Powered Two wheels (PTW); pedestrian and child
- **Active safety/ADAS** consists of six sub-categories: Longitudinal control; Lateral control; Driver assistance; Visibility enhanced, Technical defects and Connected vehicles.
- **Tertiary safety** only contains the post-crash category.

2.1.2 Work organisation

Three institutes were involved in the writing of the document and the team was composed of six road safety experts. Most of them being close geographically, the work was initiated during face to face meetings in order to define a common work methodology, analyse some safety solutions together to see if this methodology yields satisfactory results and improve it if necessary. We defined six steps for our work:

1. Define potential levers that could be used for the improvement of measures,
2. Analyse **green** (effective) measures in view of step 1,
3. Analyse **light green** (probably effective) measures in view of step 1,
4. Analyse grey (effect unclear) measures in view of step 1,
5. Analyse **red** (adverse effect) measures in view of step 1,
6. Perform a global analysis of the systems.

2.1.3 Definition of the levers for improvements of safety measures:

Each vehicle-related measure was introduced by a description (recovered from D6.2) and then potential improvement levers were investigated.

Lever 1: Technology – Most of the safety solutions are based on one or more technologies. This lever is considering how the technology could be improved in order to make the solution more effective. (e.g. by addressing known technical limitations)

Lever 2: Standardization – This lever is based on three perspectives:

- What could the standardization of the considered system bring in terms of improvement?
- If a safety measure is already regulated, how harmonized are the regulations around the world, and would it be beneficial to harmonize them?
- If the safety measure is part of consumer test protocols are those harmonized across the different consumer test organisations? This issue can be important because it can lead OEM to create diversity in design or process, in order to comply with one consumer test protocol or another. And diversity has a cost that consumers somehow pay for.

Lever 3: Regulation – This lever is based on two perspectives:

- Would the adoption of a regulation on a given measure be beneficial for road safety?
- If a regulation already exists, would a full or partial update be beneficial for road safety?

Lever 4: consumer test – This lever is similar to lever 3 but concerns adoption or update of consumer tests protocols.

Lever 5: cost reduction – In this one, experts have tried to anticipate how the cost of given safety measures could be reduced. This is a tricky point because:

- Most of the time the generalization of a safety system on all vehicles of a given category is making the price of the system lower because of the volume effect but is also making the price of the vehicle higher if not equipped previously.
- Some safety solutions are sold as packages by vehicle manufacturers and they make use of common sensors or units. It is therefore difficult to indicate how to reduce the cost of a safety solution if it has an impact on another one that is not analysed at the same time. This is one of the reason why a transversal analysis per category of safety measures was undertaken in the context of task 6.5.

Lever 6: interaction with other safety domains – This lever contains interactions with other safety domains and expert opinion on how other road safety domains could contribute to improve the effectiveness of vehicle –related measures. Not surprisingly, two domains are often linked to the vehicle safety measures: the environment in which the vehicle is evolving and the road users. So most of the time, the approach was to check if the infrastructure can have a role, for example the separation of road user categories or communication between vehicles and the infrastructure. Of course, very often the efficiency of a safety measure is depending on human behavior, so experts have kept this in mind for their analysis. The items considered are as follows:

- How is the system/safety measure limited by one of the other safety domains?
- Is the solution well accepted by road users?
- If not, how we could improve on this?
- Is there some possibility to misuse the systems for things that they were not designed for and could that limit effectiveness or become a new source of road safety issue?
- What are the involuntary and voluntary errors possible in using the system? What are their consequences for the different road users?

Lever 7: Transferability and transposability - Finally, the experts have checked how the vehicle safety solution could be transferable to other countries or geographical areas, usable in other road safety domains or transposable to different vehicle types, not only limiting to the road safety areas.

When one of the lever is not applicable to the safety solution, the experts simply reported it, but in most cases, this classification resulted in satisfactory assessments.
It is possible that some other levers can be applied to safety measures. Nevertheless, only the 7 described before have been considered in task 6.5.

2.2 DISPATCH AND VALIDATION PROCESS

2.2.1 Work dispatch

The number total of safety measures defined in D6.2 is 46. 36 of them were considered as effective (colour code=green) or potentially effective (colour code=light green) and 10 were coded as unclear (colour code=grey). The list of these measures and the corresponding colour codes are given in Appendix 1 of this deliverable.
Measures were distributed among partners, as far as possible according to their domains of expertise in the different subjects.
Table 1 is giving the repartition of the safety measures among the three partners.

Name of organization	Nb of safety measures addressed	Fields covered in the analysis	Nb experts in D6.5
CEESAR	14	Active safety/ADAS,	2
CIDAUT	8	Crashworthiness, Active safety/ADAS	1
GIE PSA RENAULT (LAB)	24	Active safety/ADAS, Crashworthiness, Tertiary safety	3

Table1: work and manpower distribution

2.2.2 Validation of results

Cross validations were performed done during progress meetings, occurring twice a month. For some "difficult" safety solutions, the analysis was done by the group, so individual experience could be shared for better team work efficiency, which always resulted in relevant proposals aimed at improving the measure.
Once ready, partners provided the template containing their analysis. A first review was done by the expert responsible of the deliverable to ensure consistency between partners and to make sure that all levers were analysed as deeply as possible. A second reviewer checked all the templates. All of them were returned to authors so they could take comments into account. Once this done and

checked, the templates were merged into the Deliverable. When all required analyses were gathered, a draft of the D6.5 underwent the SAFETY process for content and quality checks.

It is important to recall here that no prioritisation in the safety systems is proposed for this deliverable because the adoption of safety measures is highly dependent of the road safety context. This means that according to geographical areas, safety culture, awareness of road users, what could work and what could not is totally different and does not depend on the vehicle-related measure only, but also on e.g. the economic situation of the considered country, the global human behavior and many other components that are difficult to target (including the needs of road user, distractions etc.…).

2.3 DEFINITION OF THE POTENTIAL BENEFITS OF LEVERS

2.3.1 Colour codes

In order to visualize the effect of each lever on each safety measure, a colour code was attributed by our group of experts, for each measure-lever combination. The colour code used in task 6.2 for the efficiency assessment of measures was kept but the definition was adapted to the context of task 6.5.

Four levels of potential improvement were defined:

- **Green**: This lever can clearly bring improvement to the measure.
- **Light Green**: This lever can have an effect on the improvement of the measure but with a limited benefit, or in a limited number of situations.
- Grey: Whether or not the lever can be used to improve the measure remains unclear.
- **Red**: This lever is not relevant or cannot bring any improvement to the measure.

For instance, if a measure is **Green** for some levers, it means that it is possible to improve the measure effect on road safety through using these levers, either individually or in combination.

2.3.2 Limitations

The attribution of the colour codes for the possible improvement of measures is of course subject to interpretation. It is depending on the one hand on the expert opinion of each person attributing a colour and on the other hand on the knowledge of the different road safety contexts in which the safety solution could be implemented. In addition, it has to be reminded that the present study is based on the state of the art of publications on road safety measures existing at the time of writing of the deliverable D6.2 on which it is based. Therefore, it is not to be considered as a truth for decades, and certainly a revision will be necessary in the coming years.
The mobility changes are for the moment so big and so quick that it is a real challenge to try to indicate which ways seems the most promising to improve the global road safety situation even in the near future.

3 Improving vehicle-related safety measures

This chapter provides an overview of the possible ways of improvements of the vehicle-related measures as included in deliverable D6.2 in June 2017 and available in the Safety Cube Decision Support System (DSS). The analysis in this chapter is based on the colour coding of the 7 studied levers for each safety measure. However, for a more detailed perspective on a given measure, it is necessary to look at section 4 where a detailed form is given for each measure.

3.1 GLOBAL ANALYSIS

As mentioned previously, the list of levers for improvement of the vehicle safety measures is not exhaustive and not independent from other road safety domains. The levers considered in task 6.5 were built by a group of vehicle technical experts, possibly in some other domains other levers could be useful. The attribution of a colour code corresponding to an expected benefit is also subject to the interpretation of the expert in charge, therefore differences are possible. Results of the analysis are summarized in Table2 for which the definitions and colour codes have been already described in section 2.

The main findings are as follows:

- All measures can be improved using an array of levers. The minimal number of active (**green** or light green) levers found for a given measure is **3**. For 9 of the vehicle-related measures, all levers are active.
- All levers show some potential in improving measures with **green** colour code ranging between 48% of measures for lever5 (cost reduction) and 78% for levers 3 (regulation) and 7 (transferability/transposability).
- The **green** colour code was attributed to 65% of the measure-lever combinations, the light green colour in 14%.

One of the aims of this deliverable was to prioritize the safety measures and the levers to improve them. This exercise is not possible at a global stage and for different reasons: first of all, the priorities for road safety depend on local political and economic contexts. For instance, some apparently very efficient measures would not be suitable for low income countries because of their immediate cost. The same safety measure transferred in some other country or territory area may not be a priority because it is already applied. What is also difficult is to evaluate side effects arising from misuse of a given measure, that can lead to new situations for which no countermeasures exist to this day. The prioritisation is also depending on the state of the art of regulation of the area and on other safety domains such as infrastructure or human behaviour. A large part of a measure's social acceptance depends on the road safety awareness prevailing in the geographical area in which it could be deployed.
Globally speaking, the logical way of progressing on vehicle-related measures is, in our view, as follows:

1. Test new measures (or alterations of previous measures) on representative subsets of road users in order to ensure that any subsequent decision is not seen as an individual constraint but as a benefit for public health
2. Have interaction with the industry, in order to make sure than any required technical improvements (such as a new feature becoming mandatory) would be feasible in the time interval required
3. Issue regulations when necessary
4. Make sure regulations are enforced

The standardization of regulations and of safety systems would at the same time increase the global protection of rod users and decrease the price end user has to pay for each of them. Consumer tests and technological improvements can lead then to improvement of the performance of the systems through ratings or new technical solutions.

Topic	*Counter-Measures / Safety Systems*	*Technology*	*Standardization*	*Regulation*	*Consumer tests*	*cost reduction*	*interaction*	*Application*
Crashworthiness	Directive 96/79/CEE et ECE.R94							
Crashworthiness	EuroNcap (Frontal impact)							
Crashworthiness	Frontal airbag							
Crashworthiness	Seat belt (effectiveness)							
Crashworthiness	anti-submarining							
Crashworthiness	Directive 96/27/CEE et ECE.R95							
Crashworthiness	Regulation UN R135							
Crashworthiness	EuroNCap (side impact)							
Crashworthiness	Side airbag							
Crashworthiness	Anti Whiplash							
Crashworthiness	Rollover protection systems							
Crashworthiness	Pedestrian 'active technology'							
Crashworthiness	Pedestrian 'vehicle shape'							
Crashworthiness	Pedestrian regulation							
Crashworthiness	Child Restraint System							
Crashworthiness	Booster seats for children							
Crashworthiness	PTW protective clothing							
Crashworthiness	PTW helmet							
Crashworthiness	PTW Airbag							
Crashworthiness	Cyclist protective clothing							
Crashworthiness	Cyclist helmet							
Crashworthiness	Underrun protection							
Active safety	Emergency Braking Assistance system							
Active safety	AEB (City, interurban)							
Active safety	AEB (Pedestrians & cyclists)							
Active safety	Emergency Stop Signal (ESS)							
Active safety	Braking system PTW							
Active safety	Collision Warning							
Active safety	ISA + Speed Limiter/regulator							
Active safety	Adaptive Cruise Control							
Active safety	Electronic Stability Control (ESC)							
Active safety	LDW + LKA + Lane Centering System							
Active safety	Alcohol Interlock (ALC)							
Active safety	Enhanced Headlights							
Active safety	Daytime running lights							
Active safety	Night Vision							
Active safety	Reversing Detection or Camera systems							
Active safety	Blind Spot Detection							
Active safety	Tyre Pressure Monitoring and Warning							
Active safety	Vehicle inspection							
Active safety	AEB for trucks							
Active safety	Vehicle to Vehicle communication							
Tertiary Safety	eCall							
Tertiary Safety	Rescue Data Sheet & Rescue code							
Tertiary Safety	ECE R100 (electric vehicle)							
Tertiary Safety	Event Data Recorder							

Table2: Synthesis of results for measure-levers combinations.

3.2 ANALYSIS BY CATEGORY OF SAFETY MEASURE

In this section, safety measures were regrouped by category of safety domains in a first step and then by category of road users to which they could be beneficial. Results are presented in tables, briefly commented in order that if for example some road safety actions for the improvement PTW riders are decided the tables gives an overview of the possible safety measures and the possible ways to make them possibly even more efficient. Of course, since only vehicle-related measures were dealt with in the present task, it might be useful to check what complementary safety measures from other road safety domains could be applied in parallel to this category of road users. It is also important to remind that all the safety measures of the SafetyCube's deliverable are based on published data, which means that for some of the most recently developed safety measures, results were not available and could change part of the analysis or bring in new ideas for improvements.
Table3 shows the repartition of the colour codes according to the three domains of the vehicle safety. Active safety shows the highest rate of green colour code with 70% followed by passive safety with 63% and tertiary safety with "only" 54%. When combining green and light green colour codes, passive safety is the domain in which the highest number of actions with a positive effect is recorded with 81%, close to primary safety that scores 79%. Tertiary safety has the highest rate of red codes with 21%, which doesn't mean that these safety measures are not effective but that they are may be more difficult to improve than others (a perfect safety measure would score 100% of red codes as it would not possible to improve it!)

	GREEN	*LIGHT GREEN*	*GREY*	*RED*
ACTIVE	70%	9%	11%	10%
PASSIVE	63%	18%	8%	12%
TERTIARY	54%	18%	7%	21%

Table3: Synthesis colour codes for the 7 levers for safety measures per vehicle safety domains

The following analysis was performed for each category of final users to which they could be beneficial. Their repartition is as following: Vulnerable road users (pedestrians, cyclists, PTW riders, children in vehicles), light vehicle occupants, heavy vehicle occupants and rescue teams.

- **Vulnerable Roads users**
  Here, and may be much more than for other road users groups, interaction with other safety domains such as infrastructure and behaviour are very strong. Dedicated spaces for pedestrians, cyclists, or even PTW can have a big impact on their safety, and even if already considered in this analysis in the lever6 (interaction with other safety domains) their impact can be larger than the global vehicle safety measure they are included in. Safety awareness (wearing helmet, respecting traffic rules,...) is also very important when talking about safety measures for vulnerable road users as they often think that other road users have to take care of them or that rules are only for 4 (or more) wheelers.

  - *Vehicle-related* ***measures beneficial to pedestrians***
    Table4 shows potential improvements of vehicle-related measures that could be beneficial to pedestrians. Generally speaking, crashworthiness measures can all be improved but not by the cost reduction. Visibility or detection of both pedestrians and vehicles can improve, so could also Automatic Emergency Braking.

Topic	Counter-Measures / Safety Systems	Technology	Standardization	Regulation	Consumer tests	cost reduction	interaction	Application
Crashworthiness	Pedestrian 'active technology'							
Crashworthiness	Pedestrian 'vehicle shape'							
Crashworthiness	Pedestrian regulation							
Active safety	AEB (Pedestrians & cyclists)							
Active safety	Daytime running lights							
Active safety	Night Vision							
Active safety	Reversing Detection or Camera systems							

Table 4: Potential improvements of vehicle-related measures beneficial to pedestrians

- *Vehicle-related* ***measures beneficial to cyclists***
  As shown in table 5, pedestrians and cyclists can benefit from the same vehicle-related measures. Two major items are cyclist specific: the first one is cyclist **body protection** through protective devices or systems avoiding being overpassed by heavy vehicles, and the second one is **enhanced cyclist conspicuity** either through cyclists wearing highly visible clothes or ADAS such as Blind Spot Detection being installed on cars or trucks. Most of these safety measures exhibit green codes for possible improvements. Relatively few red codes were found, the one on the transferability for helmet wearing is mainly due to the fact that some experts argue that making helmets mandatory would deter people from engaging into cycling activities.

Topic	Counter-Measures / Safety Systems	Technology	Standardization	Regulation	Consumer tests	cost reduction	interaction	Application
Crashworthiness	Cyclist protective clothing							
Crashworthiness	Cyclist helmet							
Crashworthiness	Underrun protection							
Active safety	AEB (Pedestrians & cyclists)							
Active safety	Daytime running lights							
Active safety	Night Vision							
Active safety	Reversing Detection or Camera systems							
Active safety	Blind Spot Detection							

Table 5: Potential improvements of vehicle-related measures beneficial to cyclists

- *Vehicle-related* ***measures beneficial to Powered Two Wheelers***

  Table6 deals with vehicle-related measures for powered two wheels. Helmets and protective clothing are much more critical for PTW users, owing to high riding speeds. Technical improvements in PTW braking and PTW detection by car or truck drivers are the main technical levers. A lot of green colour codes were found so many improvements are possible. Concerning protective devices, acceptability is a major culture-related issue, so full transferability, even if making sense it terms of protection, seems difficult to achieve, specifically into low income countries with hot climates.

Topic	***Counter-Measures / Safety Systems***	***Technology***	***Standardization***	***Regulation***	***Consumer tests***	***cost reduction***	***interaction***	***Application***
Crashworthiness	PTW protective clothing							
Crashworthiness	PTW helmet							
Crashworthiness	PTW Airbag							
Active safety	Braking system PTW							
Active safety	Blind Spot Detection							

Table 6: Potential improvements of vehicle-related measures beneficial to PTW riders

- ***Vehicle-related measures beneficial to children in vehicles***

  Specific in-vehicle measures exist in order to accommodate children needs as car passengers: restraint systems and booster seats, the latter an effective solution to the problem of adapting safety belts positioning to children bodies. Improvements can be reached through a variety of levers. Cost reduction appears as light green for CRS, as the pricing array for these systems is already very wide.

Topic	***Counter-Measures / Safety Systems***	***Technology***	***Standardization***	***Regulation***	***Consumer tests***	***cost reduction***	***interaction***	***Application***
Crashworthiness	Child Restraint System							
Crashworthiness	Booster seats for children							

Table 7: Potential improvements of vehicle-related measures beneficial to children in vehicles

- **Passenger cars, Light Goods Vehicles (LGV) or Light Commercial Vehicle (LCV)**
  The following tables deal with measures aimed at protecting light vehicle passengers. Those were grouped by category: in-vehicle protection devices, vehicle automated interventions, and information systems for the drivers.

  - ***Vehicle protection***
    This part of the analysis is focused on safety systems or test programs designed to protect light vehicles occupants. As shown on table8, the colour green is less present than in the table dealing with vulnerable road users, as many relevant measures have already been optimized, in terms of technology and costs. As they are passive safety systems, their interaction with other domains of the road safety is often very limited or non-existent. Nevertheless, anti-submarining, anti-whiplash systems and rollover protection systems show the largest potential of improvement, while progress seems possible on seatbelts (with a generalization of advanced devices) and limited for systems such as airbags, their high level of effectiveness notwithstanding.

Topic	***Counter-Measures / Safety Systems***	***Technology***	***Standardization***	***Regulation***	***Consumer tests***	***cost reduction***	***interaction***	***Application***
Crashworthiness	Directive 96/79/CEE et ECE.R94							
Crashworthiness	EuroNcap (Frontal impact)							
Crashworthiness	Frontal airbag							
Crashworthiness	Seat belt (effectiveness)							
Crashworthiness	anti-submarining							
Crashworthiness	Directive 96/27/CEE et ECE.R95							
Crashworthiness	Regulation UN R135							
Crashworthiness	EuroNCap (side impact)							
Crashworthiness	Side airbag							
Crashworthiness	Anti Whiplash							
Crashworthiness	Rollover protection systems							

Table 8: Potential improvements of vehicle-related measures for light vehicle occupants – vehicle protection

  - ***Vehicle automated intervention*** ("independent of driver reaction")
    Table 9 illustrates the synthesis of possible progress levers for vehicle safety systems that alter the vehicle's course when given events occur, driver reaction notwithstanding. These systems are nearly all relate to active safety. Technology, regulation, consumer testing and cost reduction were identified as progress levers for nearly all of them. Their interaction with other safety domains is high, as they could be interacting directly with the infrastructure and replace the driver in given situations which can be a source of social acceptability issues. The only measure relating to tertiary safety can be improved through nearly all levers.
    What is important on these vehicle safety systems is that they are all in interaction with other safety domains, possibly with each other and that their transposability is possible. Concerning transferability, most of these systems only work correctly in the

context of a healthy road infrastructure, which can be a problem for low income countries.

Topic	*Counter-Measures / Safety Systems*	*Technology*	*Standardization*	*Regulation*	*Consumer tests*	*cost reduction*	*interaction*	*Application*
Active safety	Emergency Braking Assistance system							
Active safety	Emergency Stop Signal (ESS)							
Active safety	AEB (Pedestrians & cyclists)							
Active safety	AEB (City, interurban)							
Active safety	Electronic Stability Control (ESC)							
Active safety	Adaptive Cruise Control							
Active safety	LDW + LKA + Lane Centering System							
Tertiary Safety	eCall							

Table 9: Potential improvements of vehicle-related measures for light vehicles – vehicle automated intervention

- ***Information/assistance to drivers***

  As shown on table 10, most of the vehicle safety systems belonging to this category relate to active safety, the only passive safety system involved being the seatbelt, through the seatbelt reminder.

  The alcohol interlock stands between the present category and the "automated intervention category" as it works twofold. There is a large potential for improvement on this system, mainly in terms of acceptability and in the procedure to use it as it could cause public health issues, especially in shared car fleets.

  All systems are showing possibilities of improvement. Most of them on technical issues, some others on regulation and all of them in transferability or transposability.

Topic	*Counter-Measures / Safety Systems*	*Technology*	*Standardization*	*Regulation*	*Consumer tests*	*cost reduction*	*interaction*	*Application*
Active safety	Alcohol Interlock (ALC)							
Crashworthiness	Seat belt (incl. Seatbelt reminder)							
Active safety	Collision Warning							
Active safety	Tyre Pressure Monitoring and Warning							
Active safety	Blind Spot Detection							
Active safety	Night Vision							
Active safety	Reversing Detection or Camera systems							
Active safety	Vehicle to Vehicle communication							
Active safety	Daytime running lights							
Active safety	ISA + Speed Limiter/regulator							
Active safety	Enhanced Headlights							
Active safety	Vehicle inspection							

Table 10: Potential improvements of vehicle-related measures for light vehicle occupants – information/assistance

- **Truck or Heavy Goods Vehicles (HGV) and Bus & Coaches**
  This section presents the possible ways to improve existing measures targeting heavy vehicles.

  - ***Vehicle protection***
    Table 11 highlights measures aiming at protecting drivers of heavy vehicles. Their number is lower than the number of equivalent measures aiming at protecting light car drivers and most of them are present because of the transposability of the systems from light vehicle to heavy vehicles. What is also remarkable is the absence of consumer tests on heavy vehicles which does not encourage manufacturers to equip their vehicle in order to obtain high ratings. All the passive safety equipment listed can be improved in many ways, technology being arguably the less promising lever as these systems are already working on light vehicles.

Topic	*Counter-Measures / Safety Systems*	*Technology*	*Standardization*	*Regulation*	*Consumer tests*	*cost reduction*	*interaction*	*Application*
Crashworthiness	Frontal airbag							
Crashworthiness	Seat belt (effectiveness)							
Crashworthiness	anti-submarining							
Crashworthiness	Side airbag							
Crashworthiness	Rollover protection systems							
Crashworthiness	Underrun protection							

Table 11 Potential improvements of vehicle-related measures for heavy vehicle occupants – vehicle protection

  - ***Vehicle automated intervention*** (“independent of driver reaction”)
    Some systems present in the Table12 are dedicated to heavy vehicles only but most of them are transposed from light vehicles. Nevertheless, very few red colour codes are present in this table, meaning that most of the systems can be improved using many levers, especially AEB for trucks and Line Keeping Assist.

Topic	*Counter-Measures / Safety Systems*	*Technology*	*Standardization*	*Regulation*	*Consumer tests*	*cost reduction*	*interaction*	*Application*
Active safety	Emergency Braking Assistance system							
Active safety	Emergency Stop Signal (ESS)							
Active safety	AEB for trucks							
Active safety	Adaptive Cruise Control							
Active safety	LDW + LKA + Lane Centering System							
Tertiary Safety	eCall							

Table 12 Potential improvements of vehicle-related measures for heavy vehicles – vehicle automatic intervention

- ***Information/assistance to drivers***

  Table13 highlights almost the same situation as table 12, as most of the systems are derived from light vehicles transposability. Blind Spot Detection and Tyre Pressure Warning could have more effectiveness on heavy vehicles than on light ones, but the way to improve these systems are similar.

Topic	***Counter-Measures / Safety Systems***	***Technology***	***Standardization***	***Regulation***	***Consumer tests***	***cost reduction***	***interaction***	***Application***
Active safety	Alcohol Interlock (ALC)							
Crashworthiness	Seat belt (incl. Seatbelt reminder)							
Active safety	Collision Warning							
Active safety	Tyre Pressure Monitoring and Warning							
Active safety	Blind Spot Detection							
Active safety	Night Vision							
Active safety	Reversing Detection or Camera systems							
Active safety	Vehicle to Vehicle communication							
Active safety	Daytime running lights							
Active safety	ISA + Speed Limiter/regulator							
Active safety	Enhanced Headlights							
Active safety	Vehicle inspection							

Table 13 Potential improvements of vehicle-related measures for heavy vehicles – driver's assistant/information

- **Rescue teams** (all vehicles)

This part of the document highlights the possible levers aimed at improving vehicle-related safety measures designed to help rescue teams. Only four measures were found in the literature in that category: one records the history of the accident (Event Data Recorder); one automatically calls rescue and gives information on the calling vehicle's location; one highlights hard car sub-structures, airbags and high voltage locations in order to prevent rescue teams from taking unnecessary risks; the last one consists of a regulation on electric vehicles, which could sound may be less important today but looks to be more and more useful in view of tomorrow's vehicle fleet.

As shown in Table14, all systems can be improved but some of them are already correctly working and are implemented on new vehicles in Europe, so their transferability to other regions and transposability to other types of vehicles is the most significant improvement we could think of.

Topic	*Counter-Measures / Safety Systems*	*Technology*	*Standardization*	*Regulation*	*Consumer tests*	*cost reduction*	*interaction*	*Application*
Tertiary Safety	eCall							
Tertiary Safety	Rescue Data Sheet & Rescue code							
Tertiary Safety	ECE R100 (electric vehicle)							
Tertiary Safety	Event Data Recorder							

Table 14 Potential improvements of vehicle-related measures for rescue teams

3.3 ANALYSIS BY LEVER TYPE

In this section, vehicle-related measures were analysed per lever.
Table15, is synthetizing the results in terms of colour codes. Almost all types of levers can be applied on more than half of the vehicle-related measures, the only exception being "cost reduction" that is "only" scoring 48%, and if cumulating green and light green colour codes, levers apply on 71% to 89% of the measures.

	GREEN	*LIGHT GREEN*	*GREY*	*RED*
TECHNOLOGY	54%	17%	13%	15%
STANDARDIZATION	67%	11%	11%	11%
REGULATION	78%	7%	4%	11%
CONSUMER TESTS	65%	11%	9%	15%
COST REDUCTION	48%	24%	15%	13%
INTERACTION	65%	15%	11%	9%
APPLICATION	78%	11%	2%	9%

Table 15 – Colour codes of safety measures per relevant lever

- **Technology**: This lever exhibits one of the highest rates of red colour codes. One of the reasons it is not relevant for measures consisting in regulations, as those cannot impose technical solutions, but only criteria to be respected.
- **Standardization**: This lever is green or light green for all the vehicle passive safety systems. A worldwide harmonization of regulations is an old dream, but making it actually happen would be highly beneficial. Most of the grey or red colours are coming from the active safety systems for which less literature is available, so it is more difficult to see what could be the benefit of a harmonization of the systems.
- **Regulation**: Two kind of levers are assembled under this: one is the adoption of a regulation aiming at making a given measure mandatory; the other consists in improving an existing regulation in order to make it more relevant, more comprehensive or more adapted to some new system. This is why this lever gets the highest proportion of green colour. Red colour codes are mostly coming from safety measures such as consumer testing (that are normally complementary to regulation) or from regulations that do not seem to need an update.

-
- **Consumer tests**: About 2/3 of the vehicle-related measures could be consequently improved by using this lever. This may depend on the type of target vehicles, but, generally speaking, a large proportion of passive safety measures could still be improved through an update of consumer test protocols. Benefits from this lever are not relevant for all of the active safety systems, but only for some of them that can be easily tested.
- **Cost reduction**: A good example of this would be the active safety devices eco-system, where a combination of ADAS could use the same sensors or other common electronic equipment and in the same time improve the safety benefits for the end-users. This lever exhibits the lowest number of potentially beneficial vehicle-related measures. For most of the systems already mandatory on vehicles, the cost reduction lever has already been applied in order to limit end user spending on a highly competitive market.
- **Interaction**: Many vehicle-related measures are linked with other domains in road safety, with the exception of some passive safety systems, such as airbags, that are less sensitive to the vehicle occupant's driving or passenger position and behaviour. Most of the time, education and/or improvement of safety awareness play a critical role, when new measures are introduced (e.g. new regulations, new mandatory equipment,…). Road infrastructure has a deep impact on measures addressing vulnerable road users safety, but will also be of utmost importance in the near future when communicating vehicles are made available. Most of the present active safety systems already interact with infrastructure itself (e.g. quality of road surface, quality of horizontal markings, …) or use the information on potential dangers given by other vehicles or dedicated infrastructure spots.
- **Transferability & Transposability**: This lever is one of the most promising with 78% of measures ranking green and 11% light green. **Transposing** a measure might seem relatively easy, but it is still necessary to investigate technical obstacles that may arise from its application to another type of vehicle. For instance, AEB for Trucks must be adapted to account for varying payload mass or trailer length, hardly an issue for passenger cars. In addition, it is also important to check the acceptability of measures in everyday use by different types of road users. For example, alcohol interlocks may be well accepted by school bus drivers or other types of civil servants; but this does not mean that all private drivers are ready to accept it regardless of driving circumstances.

  Transferability, is also a very promising part of the lever, but here again, social acceptance is a critical issue. For example, making costly helmets and thick leather protective clothing mandatory for PTW riders is easily accepted by high income societies living in temperate climates, where riding is more of an individual leisure – but less so in some hot climate, low income Asian countries where motorbikes are commonly used as convenient heavy goods or multiple persons means of transportation, thus replacing missing public transportation or unaffordable cars or light trucks. Road safety awareness has a strong link with local cultural backgrounds and the general attitude towards cars and traffic: measures could be seen locally as an impediment to "freedom" or as a way to "draw money" from people instead of being accepted as an improvement of road safety. This lever is most of the time linked with behavior or education related levers.

4 Detailed analysis of potential levers per vehicle-related measure

4.1 CRASHWORTHINESS – FRONTAL IMPACT

4.1.1 Directive 96/79/CEE, ECE.R94 & EuroNCAP

Colour Code: Light Green

Crashworthiness	Frontal Impact	
Directive 96/79/CEE et ECE.R94		
Summary	In 1996, in order to reduce the number of road accident fatalities in frontal impact, a new regulation text named ECE94 (EEC96/79 in Europe) was introduced. The benefits of this regulation text for Europe were estimated to be about 2.0% of car occupants killed and seriously injured. It is important to note that it is not possible to isolate the benefits due only to the adoption of a dynamic test similar to ECE R94, because the safety measures developed also depend on other safety regulatory requirements (different types of impacts, different severity or crash configurations,…) and the EuroNCAP rating program .It should also be remembered that the study does not consider active safety devices in general, and therefore a possible migration of the proportion of types of impacts. Another study has been kept in the synopsis but not coded. It is a prediction of what would be the effect for emerging markets of adopting basic secondary safety measures such as seatbelt standards, UN regulation 94 and 95 and NCAP ratings. The country chosen in the study is Malaysia. It aims to quantify how many car users' fatalities are likely to be prevented. The study is also based on the renewal of the car fleet with different timing scenarios. The study has not been coded because expected benefits are not only caused by the improvement of the frontal impact situation, but also a more general change in the car generation with changes in frontal impacts (ECE R94), side impacts (ECE R95 and R135) and in parallel, an increase in the equipment of cars with active safety systems (due to regulations and consumer testing). Nevertheless, the study was sufficiently close to our objective: frontal impacts are globally still the major car crash configuration observed on the road so a large part of the benefit could be achieved by the adoption of ECE R94 by emerging markets. As for global results, it is estimated that about 1200 to 4300 car users' fatalities could have been prevented between 2014 and 2030 by the adoption of new rules in Malaysia, depending on the motorisation rate considered.	

Lever 1: Technology	In theory, like all the other regulations, frontal regulation does not aim to impose a precise technology, but rather to set goals to achieve. This is particularly true in synthesis crash where many criteria have to be achieved. Therefore, this is why this lever is not very convenient to improve this regulation.
Lever 2: Standardization	There is many frontal regulation tests around the world. Some of them existing since a so long time that they become a brake to the evolution in terms of car safety. Others have antagonistic requirements such as full lap test and offset deformable barrier test. Worldwide standardization would bring consistency in the development of new technologies. This would also avoid having significant disparities depending on the geographical regions.
Lever 3: Regulation	To improve this regulation, 2 ways are possible. The first one is to make the criteria more severe. Which will be the case for the chest deflection. The limit will become 42mm in 2018 instead of 50mm now. The second one is to enlarge the number of countries where this regulation is applied. Apart its diffusion to more countries, this measure being already regulatory for Europe, it is not possible to go further on this lever. Nevertheless, in order to improve safety in the event of a frontal collision, a new regulation (ECE137) is going to be introduced in 2018. This test will be a full lap at 50 kph with the same criteria as the ECE94.
Lever 4: consumer test	NCAP tests already provide an important lever in this area. Indeed, although the test configurations may be different, they rely on similar criteria to be respected. NCAP tests can be found on many geographical area and then strongly encourage the manufacturers to achieve a minimum of safety in each market. The EuroNCAP frontal impact has also been considered as a safety measure and included in the deliverable (next safety measure). As governments and EuroNCAP organization have different targets in road safety it is hardly feasible to harmonize those 2 frontal test configurations.
Lever 5: cost reduction	Since regulation is by its nature mandatory, there is little to be done on the cost of such a test procedure. Nevertheless, switching to simulation approval could greatly reduce the cost of such a procedure. This transition would also enable to test several variants of a vehicle.
Lever 6: interaction with other safety domains	Harmonization of the criteria to be respected between all the synthesis regulations would be very difficult to achieve because, the dummier used are not the same in frontal and side impact. Add to this the criteria are the translation of biomechanics mechanisms that are different according to the type of impact sustained. The harmonization could be in the injury risk level covered by each criterion.
Lever 7: Application	This regulation can be transposed on all the geographical areas in order to improve the road safety since it applies as well for Left Hand Drive and Right-Hand Drive vehicles.

4.1.2 EuroNCAP (Full Width & ODB)

Colour Code: Green

Crashworthiness	Frontal Impact	
EuroNCAP (Full width & ODB)		

Summary	There are no studies in the literature reviewed which assess the efficiency of the EuroNCAP frontal configurations in terms of improvement of road safety. Attention must be drawn to the fact that it is not possible to isolate the benefits associated with the introduction of new consumer tests from those associated to new regulations, as design improvements on vehicles are usually trade-offs between a variety of requirements (including safety). EuroNCAP tests are complementary to regulatory crash tests and are more severe. The tests are published on the EuroNCAP webpage and are used by manufacturers to improve the marketing of their products through good performance rating. There are two configurations for the frontal tests, one with a full width barrier and another one with 40% overlap and a deformable barrier. The results from the literature review were diverse. Based on the Swedish data analysed, Lie and Tingvall (2000) indeed found that EuroNCAP tested vehicles rated four stars had a lower average serious injury risk in real crashes than those rated three stars. The three-star vehicles had a correspondingly lower average risk than vehicles rated two stars. Newstead et al., 2005 found a general trend of improvement in the new crashworthiness measure based on real world accidents with increasing EuroNCAP star rating, in line with the findings of Lie and Tingvall (2002 and 2010). However, Seguí-Gomez et al. did not find any statistically significant relationships between the EuroNCAP safety scores and real-world death or severe injury outcomes for frontal impacts. Fildes et al., studied the estimated benefit of introducing the ODB test in Australia and they found a potential benefit above regulation between 24% and 36% in reduced Harm in frontal crashes.
Lever 1: Technology	Introduction of new technologies such as ADAS in consumer testing is already part of the EuroNCAP roadmap. This lever is also emphasized through the folder of excellence proposed by the manufacturers themselves regarding the overall safety. For example, systems improving anti-submarining for rear occupants.
Lever 2: Standardization	Today, there are several rating NCAP in the world. The standardization of the test protocols for each configuration would provide customers a very good way to compare the performance of their vehicle compared to other ratings. This, regardless of the number of tests proposed by each NCAP.

Lever 3: Regulation	The EuroNCAP roadmap takes into account future regulatory developments by adding them before the application date of the regulation itself. Add to this the EuroNCAP criteria are always more severe than the regulation requirements. As a result, the regulations can hardly bring more to these tests already more demanding than in regulation.
Lever 4: consumer test	Since NCAP tests are already customer tests, this lever has no potential action apart from the introduction of new tests in the current protocols or the introduction of NCAP in geographical area that do not yet have them.
Lever 5: cost reduction	Apart from the introduction of numerical tests, it is difficult to apply a cost reduction to synthesis tests. One of the few ways of improvement would be to group the EuroNCAP tests with the Regulations ones for the tests with comparable protocols.
Lever 6: interaction with other safety domains	Initially, NCAPs were used to classify vehicles based on their secondary safety performance. Since 2010, the arrival of primary security has changed the game. More and more NCAPs take into account the level of equipment as well as the performance of ADAS in their overall rating. Thus, interaction with infrastructure will become more and more important. We can also imagine in a more or less near future the assessment of the level of autonomy of future vehicles and give a qualitative estimation for each level.
Lever 7: Application	NCAP tests already exist on most geographical areas. These levers can therefore be applied for each of them. We could even more imagine sharing the test results between the whole NCAP regarding the vehicle definition. The transferability could also apply to other vehicle categories like LGV, and to develop other protocols for trucks, public transport and PTW.

4.1.3 Frontal airbag

Colour Code: Green

Crashworthiness	Frontal Impact	
Frontal airbag		
Summary	When analysing the effectiveness of airbags, one needs to consider that accidents without airbag deployment are normally less severe than those with airbag deployment (the airbag does not deploy below a certain impact severity). However, literature has shown a clear effectiveness to reduce injuries and mortality with the availability of an airbag in a frontal collision. E.g. Lackner et al. (2007) found that the airbag reduced the early mortality rate (first 24 h) decidedly, from 29.3% to 8.0% and Williams et al. (2008) found that airbags are associated with reduced in-hospital mortality and with decreased injury severity and also the probabilities of sustaining evident and disabling injuries are reduced when vehicles with airbags are involved in crashes (Obeng 2008). For airbags especially in frontal impact situations the protection level depends also on the seat belt usage. Indeed, the use of seatbelt being mandatory in European countries, developments and performances of airbags in this part of the world are linked to the use of seatbelt. All following studies are based on US data for which in some states the use of seatbelt is not mandatory. Donaldson et al (2008) found that the drivers using the airbag-only had a significantly higher rate of cervical fractures than those using both airbag and a seatbelt and that other severity indexes were significantly worse in patients who used an airbag-only. Furthermore, there are different generations of airbag systems. Especially with the introduction of the second airbag generation the associated risk for car occupants in non-optimal positions was reduced by depowering the airbag and improving the inflation process. And MacLennan et al. (2008) found that there was no significant difference in the protection of front-seated occupants in vehicles equipped with first-and second-generation airbags, while Jernigan et al. (2005) found that occupants exposed to a depowered airbag deployment were significantly more likely to sustain a severe upper extremity injury (3.9%) than those occupants exposed to a full-powered airbag deployment.	
Lever 1: Technology	Little technology progress is expected for frontal airbag as it seems to work quite well already. But in the possible way of improvement, some safety solutions are developed in direct relation with the airbags. Volume, pressure for inflating, hot gas control,..., there is certainly some possible technical improvements and some minimum requirements for the development of such a protecting device.	

Lever 2: Standardization	The surface covered by the frontal airbag is not defined and standardized. It could cover the head or head+thorax. Therefore, a minimum coverage of the system could be an added value. As there is no requirement of frontal airbag to approve a vehicle, the fitting of cars is highly depending on the consumer test programs.
Lever 3: Regulation	The frontal impact test is included in the global approval of a vehicle. Criteria have then to be respected, but the frontal airbag itself, is not mandatory. There is no reason to do so as it would simply impose a technical solution.
Lever 4: consumer test	Most of the consumer organizations, like EuroNCAP, require for their frontal crash test, a front airbag to achieve the maximum rating for head injury criteria as well as for the thoracic criteria. It is therefore naturally a powerful lever of improvement for this safety device.
Lever 5: cost reduction	No cost reduction seems possible if the technology remains as it is today. Vehicle manufacturers have optimized the cost of this safety device.
Lever 6: interaction with other safety domains - human behavior, infrastructure)	As the other safety devices, it has been optimized for in-position occupants. The fact of being out of position can lead to unsafe situations, but globally the systems has been rated as effective, which means that in a large majority of cases no issue has been noted. The awareness on the danger of being out of position (feet on dashboard for example) needs to be increased, so the human behavior of some car passengers can be modified. Frontal airbags can be an issue for rearward facing child restraint systems. That is the reason why the installation of such a system is forbidden at a seating position if an active frontal airbag is present. Most of the car manufacturers are proposing a solution for the inhibition of the frontal airbag in order to allow the installation of the rearward facing child restraint system at the front passenger position. No interaction with other safety domains than the passive safety is expected.
Lever7: acceptability	Frontal airbag seems already implemented in all types of vehicle that need to insure a minimum of safety in frontal collision.

4.1.4 Seat belt (effectiveness) SBR and Load limiter included

Colour Code: Green

Crashworthiness	Frontal Impact	

Seat belt (effectiveness) SBR and Load limiter included	
Summary	Seatbelts are an effective safety countermeasure in road vehicle crashes. The seatbelt restrains the occupant during a crash and reduces the risk of violent contact with vehicle interiors as well as protecting against the risk of ejection from the vehicle. Seatbelts have been proven effective in a global distribution of studies.
Lever 1: Technology	Possible technological developments would be to generalize the pretension and load limitation to all places. This would have the same benefit effect as for the front places. Another new technology improvement could be to install expanded safety belts in the rear seats for vehicles that do not have front airbag at rear places (Air Belt device). This would apply the load effort during a crash on a greater surface and then reduce the injury risk for the chest. More than the belt itself, the pretensioner could also be generalized in other crash configurations like Rollover for example, where the seat belt is the more efficient safety system.
Lever 2: Standardization	There are 2 ways of improvement here regarding standardization. The first would be to have the same Belt+Load Limiter for each place. The second, a more basic one, could be to have 3 points anchorage belt for each seat. This also improve significantly the child safety where 3 pts belts are also necessary/used for the attachment of a large number of child restraint systems. Standardization in terms of seatbelt characteristics is a need worldwide (done in Europe but still a lack in a lot of areas)
Lever 3: Regulation	The 3-point belt is mandatory in Europe. The next step could be to make world wild's mandatory 3pts belt with a belt wearing regulation at all places. Concerning the SBR (Seat Belt Reminder), mandatory for driver since November 2014 in Europe, the lever is already on the way. In 2019 this safety system will be mandatory for all front seats with a load detection implemented in the seats. This regulation will be in the ECE regulation agreement in 2019 and EEC regulation in 2020 for all new vehicle types (M1). For all new cars, this will be applicable in 2021 for ECE and 2022 for EEC.
Lever 4: consumer test	Nowadays, in frontal crash test, most of the consumer tests do not have thoracic criteria for adults installed on rear seats. An improvement could be to generalize it for dummies on rear seats equivalent to those in the front seats (to encourage the installation of load limitation for the rear seats). Another point that could be mentioned here, even if not specific to consumer testing is the submarining effect. A significant progress would be to improve the quality of belting to limit the risk of submarining and have a better level of protection for

	the abdomen. This could be done by improving the implementation of the belt or the combination of the belt with another security system such as a seat airbag and knee, or the use of a pretensioner.
Lever 5: cost reduction	The seatbelt being the cheapest safety device in terms of protection, it is difficult to see how to reduce its cost.
Lever 6: interaction with other safety domains	It is not about interaction with other security domains that we could improve the efficiency of these systems because they have almost no interaction with other security domains. Beside this, passenger could be more aware of the risk of being unbelted through training or informative advice spots. This will then influence their behavior and motivate them to wear their seatbelt more often with a clear positive influence on road safety. In addition, it has to be noticed that the seatbelt route and seatbelt adjustments are important. Teach people how to route the seatbelt on their body (and why) could be beneficial. It also has to be reported that the use of some devices aiming to give additional slack (for comfort?) has to be forbidden as it is contrary to the safety prescription. Some of them are dedicated for small size people or children and completely re-route the seatbelt in places on the body that cannot stand high loads (abdomen, ribs,…)
Lever7: Application	The transferability focuses on the way to promote the belt wearing toward countries where there is no regulation or incitation to wear it. The implementation of a SBR on vehicles of these markets would be the second step. Another way of improvement could be to promote the belt wearing on other vehicle types, like truck and buses or to encourage particular road users (taxis, firemen, paramedics' drivers) to wear their seatbelt through awareness campaign.

4.1.5 Anti-submarining (airbags, seat bossage, knee airbag, seatbelt pretensioner…)

Colour Code: Grey

Crashworthiness	Frontal Impact	

anti-submarining (airbags, seat bossage, knee airbag, seatbelt pretensioner,…)

Summary	Several systems have the aim of preventing or limiting the submarining process (sliding of the pelvis under the lap belt). Knee airbags are designed to reduce leg injuries and to stop the road user submarining. They can be mounted on both the driver and passenger sides. A seat ramp is part of the occupant seat. An anti-submarining ramp is a ramp located in the seat base which is inclined so that the front edge points upwards. This ramp is designed to prevent the seat occupants from sliding underneath the lap belt when they are pushed deep into the seat cushion in a collision. Pretensioners aim at clamping the driver and passengers to their seats in case of accidents. Knee bolster position and physical characteristics can also reduce occupants' likelihood of sliding under the seat belt. None of the articles studied assess the effectiveness of these systems in preventing or mitigating injuries due to submarining. Indeed, occupants submarining during a crash could cause abdomen and lower extremities injuries. But abdominal and lower extremities injuries can be caused either by direct contact with a vehicle component (car door, steering wheel, armrest, console …) or by direct contact with passive safety components (seatbelt, seatbelt anchor, airbags …) or generated by a mechanism called submarining. That is probably why there is no study assessing the effectiveness of anti-submarining systems. Many articles are derived from biomechanics research and aim at understanding the accident characteristics which cause the occupant to slide under the seat belt. Articles can be sorted into three categories (Uriot et al. 2006). The first category is composed of the studies where the means to prevent or limit the submarining process are investigated. The second category of studies consists of research works dealing with the technology available to measure submarining or its consequences on dummies. The third category contains the papers where the authors focused on the description and the characterisation of submarining as a physical phenomenon.
Lever 1: Technology	It seems that the global kinematics of dummies (children and adults) is a limit to reproduce the submarining behaviour. This is may be one of the major reason why efficiency is difficult to evaluate, as the standard measurement devices are not sensitive to the phenomenon. The use of human body finite element models would bring a clearer view but no publication on the subject is available with them at this time.

Lever 2: Standardization (system, regulation, consumer testing)	As there is no efficiency of the systems available, it seems difficult to tell which one works better than another for the moment. The standardization of the best one would be beneficial by reducing its cost and to make all vehicles at the same level of protection of the abdominal area.
Lever 3: Regulation (adoption of a regulation improvement of the existing one)	Only for children restraint system, the regulation is considering the penetration of parts of the restraint systems into the abdominal area and impose some dummy criteria to be respected. Therefore, it would be good to extend this to all vehicle occupants.
Lever 4: consumer test	Consumer organizations are interested in the protection of the abdominal area but the lack of good device to evaluate it is still a blocking point. Most of the anti-submarining devices have been developed for the front occupants positions, the consumer test organisations are imposing some test configurations that lead to the extension to other seating positions.
Lever 5: cost reduction	This point is not relevant until one of the systems is chosen as being the best solution. But the globalization of one solution would lead to a lower price per unit.
Lever 6: interaction with other safety domains - human behavior, infrastructure)	First these systems are only developed and evaluated only for restrained occupants. The benefit can only be seen if the use of the seatbelt is mandatory. Secondly, to be properly restrained, it's important that people are taught how to use the restraint systems available in the cars, and what are the postures not allowed (e.g. foot on the dashboard,...) while being in a vehicle.
Lever7: Application	Submarining devices can only be effective in situations in which the occupant is seated like in a passenger car so could be transferable to light vehicles, truck, coaches drivers/passengers but not to other road users situations.

4.2 CRASHWORTHINESS – SIDE IMPACT

4.2.1 Directive 96/27/CEE, ECE.R95 & EuroNCAP

Colour Code: Light Green

Crashworthiness	Side impact	
Directive 96/27/CEE et ECE.R95		
Summary	UN ECE Regulation No. 95 (also referred to as R95 or 96/27/CEE specifically in Europe) addresses the safety requirements to be complied with in a side impact crash test for vehicles fulfilling the application conditions of this regulation. It was initially published on 20 May 1996 and has been amended several times since then. This summary is based on a short review of the literature on expected benefits after the application of this regulation in Europe. It should be noted that the studies mentioned in this document were all carried out prior to the introduction of the regulatory pole side impact test in 2015. That is why although they are still interesting in terms of accident study; these publications have become partly obsolete. Nevertheless, certain points raised, such as the mass of the impacting vehicle, are still valid. Added to this, it is difficult to dissociate in accidentology the proportion of the effect attributable to the regulation and the potential influence of the EuroNCAP test in to which car manufacturers have invested a lot of energy to be awarded the best rated. This document mainly presents the coverage of this regulation through the study of accidents and its limits. Indeed, although these studies agree that this law brought an improvement in accident outcome, the latter remains limited because of its low representativeness of automobile accidentology. The studies quoted indicate coverage of 45 to 63% of side impact crashes, all levels of force and all configurations against a particular vehicle. On the other hand, when we look at lateral impact mortality, the configuration against a particular vehicle represents only 25 to 37% depending on the country studied. The pole/tree side impact represents 24 to 30% of fatal lateral accidents, which is almost equivalent to the proportion of the configuration of the ECE95. All the studies agree to develop the regulation text, with one or more test configurations, towards an up to date situation closer to our European accident situation.	
Lever 1: Technology	In theory, like all the other regulations, Side impact regulation do not aim to impose a precise technology, but rather to set goals to achieve. This is particularly true in synthesis crash where many criteria have to be achieved. Therefore, this is why this lever is not very convenient to improve this regulation.	

Lever 2: Standardization	There is many side impact regulation tests around the world. Depending on the geographical area, the test configurations can vary significantly as well as the criteria to comply. Harmonization of test configurations and criteria would be a first step towards a global regulation that would simplify the development of new vehicles and bring more homogeneity in terms of safety between each geographical area.
Lever 3: Regulation	Regulation requirements, although not very reactive over time, feed on accident data. This is how a pole test regulation (R135) has been set up in 2015 highlighting a frequent configuration of accidents not covered by the R95. The subject that is now pushing the regulation of side impact is the far side topic. In fact, the proximity of occupants side by side can generate an increased risk in side impact and therefore must be brought under control. Finally, an accident study showed that the mass and ground clearance of cars having evolved, it could be necessary to update the R95 test procedure.
Lever 4: consumer test	Consumer tests are already largely based on regulatory tests. The roadmaps of organizations such as EuroNCAP are generally more advanced than the regulatory one, they often foreshadow future developments. We can therefore consider that this lever is already very active for road safety and does not require any particular effort for its improvement in Europe. Beside this, in other areas could import this type of requirement in their countries to impose a safety threshold. We could also imagine spreading this rating to other type of road user like light goods vehicles.
Lever 5: cost reduction	Since regulation is by its nature mandatory, there is little to be done on the cost of such a test procedure. As just said before the test procedure need an update, it could be an opportunity to see how prices of devices/solutions could be decreased and still fulfil protection criteria. Nevertheless, switching to simulation approval could greatly reduce the cost of such a procedure. This transition would also enable to test several variants of a vehicle.
Lever 6: interaction with other safety domains	This is not on interaction with other safety domain that we could improve the efficiency of these system because, they have nearly no interaction with other safety domains. Beside this, passenger could be more aware of the efficiency of the side protection devices. This will then influence their choice when buying a new car, which could have a clear positive influence on road safety. Finally, we could think that a mitigation of this type of impacts could come from active safety devices. Then even if not influencing the protection offered itself, it could be that the side airbag protection devices are seen as less important because the crash configuration is becoming less common. The level offered by the regulation could be then sufficient even without any revision.
Lever7: Application	This regulation can be implemented on all the geographical areas in order to improve the road safety and extend its application range to other vehicle types such as light goods vehicles.

4.2.2 Regulation UN R135 (Pole side-impact protection)

Colour Code: Light Green

Crashworthiness	Side impact	
Regulation UN R135 (Pole side-impact protection)		
Summary	UN ECE Regulation No. 135 addresses the safety requirements to be complied with in a side impact crash test for vehicles fulfilling the application conditions of this regulation. It was initially entry in to force on the 15th of June 2015 and has been amended one time. This analysis is based on a short review of the literature on expected benefits after the application of this regulation in Europe. It is important to note that it is not possible to isolate the benefits due to the adoption of a dynamic test similar to ECE R135, because the safety measures developed also depend on other safety requirements and regulations. Added to this, it is difficult to dissociate in accidentology the proportion of the effect attributable to the regulation and the potential influence of the EuroNCAP test in to which car manufacturers have invested a lot of energy to be awarded the best rated. Two studies have been coded because they estimate the benefits in terms of reduction of fatalities and injury severities but none considers the generalisation of active safety devices and therefore a possible migration of the proportion of types of impacts. One is based on UK data and gives the potential benefit of the reduction of injury severity through comparison of AIS values of occupants involved in side impacts with a fixed object in cars compliant with R95 with cars developed before the regulation involved in the same type of impacts. Results show a benefit of 5% of all car occupant fatalities and of 2% of all severely injured car passengers. The other study is French study based on data from 2009. The study sampled the distribution of fatalities and serious injuries for passenger cars (M1 vehicles) and light commercial vehicles (N1 vehicles) involved in side impact. Regarding M1 vehicles, after 14 years French fleet renewal, stiffness and protection upgrade have contributed to a reduction of 4,150 severely injured people and an avoidance of 1,326 fatalities. Regarding N1 vehicles, for a similar renewal period, the safety benefits should be avoidance of 241 severely injured people and 73 fatalities.	
Lever 1: Technology	In theory, like all the other regulations, side impact regulations do not aim to impose a precise technology, but rather to set goals to achieve. This is particularly true in synthesis crash where many criteria have to be achieved. Therefore, this is why this lever is not very convenient to improve this regulation.	

Lever 2: Standardization (system, regulation, consumer testing)	There are many side impact regulation tests around the world. Depending on the geographical area, the test configurations can vary significantly as well as the criteria to comply. Harmonization of test configurations and criteria would be a first step towards a global regulation that would simplify the development of new vehicles and bring more homogeneity in terms of safety between each geographical area.
Lever 3: Regulation (adoption of a regulation improvement of the existing one)	Regulation requirements, although not very reactive over time, feed on accident data. The subject that is now pushing the regulation of side impact is the far side topic. Regulation could improve by adopting new pole-side configurations with different angles or speed.
Lever 4: consumer test	Consumer tests are already largely based on regulatory tests. The roadmaps of organizations such as EuroNCAP are generally more advanced than the regulatory one, they often foreshadow future developments. However, there are some consumer tests which could improve by introducing side pole impact tests.
Lever 5: cost reduction	Since regulation is by its nature mandatory, there is little to be done on the cost of such a test procedure. Nevertheless, switching to simulation approval could reduce the cost of such a procedure, but still need to have calibration test. This transition would also enable to test several variants of a vehicle.
Lever 6: interaction with other safety domains - human behavior, infrastructure)	There is not a clear interaction with other safety domain that we could improve the efficiency of these system because, they have nearly no interaction with other safety domains. Beside this, passenger could be more aware of the efficiency of the side protection devices. This will then influence their choice when buying a new car, which could have a clear positive influence on road safety. The regulation its self has no interaction, but the V2I communication could improve the safety on side impacts.
Lever7: Application	This regulation can be implemented on all the geographical areas in order to improve the road safety. It also, could be extended to other types of vehicles.

4.2.3 Side impact measure – EuroNCAP (MDB & Pole)

Colour Code: Light Green

Crashworthiness	Side impact	
EuroNCAP (MBD & Pole)		
Summary	There are no studies in the literature reviewed which assess directly the efficiency of the EuroNCAP side impact configurations in terms of improvement of road safety. It is important to note that it is not possible to isolate the benefits of the EuroNCAP rating program from obligation of manufacturers to comply with similar regulation tests. EuroNCAP tests are complementary to regulatory crash tests and are more severe. The tests are published on the EuroNCAP webpage and are used by manufacturers to improve the marketing of their products through good performance rating in the consumer test. There are two configurations for the side impact tests, one with a Moving Deformable Barrier (MDB) and another one which is a pole impact to represent a vehicle sliding sideways off the road and striking a tree or pole. A literature search on the effectiveness of EuroNCAP in side impacts did not yield any epidemiological studies. One paper provided information on the earlier effects of EuroNCAP including the MDB side impact (Segui-Gomez, Lopez-Valdes, and Frampton 2007) and one study provided the benefits of the US consumer rating for side impact provided by the Insurance Institute for Highway Safety (IIHS) (Teoh and Lund 2011). The evaluation of EuroNCAP (Segui-Gomez, Lopez-Valdes, and Frampton 2007) was not able to produce meaningful results. The authors commented that many new vehicles have good (green) ratings for many categories making it difficult to discriminate between vehicles with statistical tests. The US study by (Teoh and Lund 2011) was able to show a 70% reduction in fatality risk for drivers when struck on the left (driver) side of the vehicle if the vehicle had a good rating vs a poor rating. The study also indicated that occupants on the non-struck side of the vehicle (far side occupants) also were less at risk in vehicles with good ratings vs poor ratings. The fatality rate was 68% lower. The results of the selected studies are consistent although no recent evaluations of EuroNCAP for side impact were obtained.	
Lever 1: Technology	Introduction of new technologies such as ADAS in consumer testing is already done regularly in the EuroNCAP roadmap. This lever is also emphasized through the folder of excellence proposed by the manufacturers themselves regarding the overall safety.	

Lever 2: Standardization	Today, there are several NCAP ratings in the world. The standardization of the test protocols for each configuration would provide customers a very good way to compare the performance of their vehicle compared to other ratings. This, regardless of the number of tests proposed by each NCAP.
Lever 3: Regulation	The EuroNCAP roadmap takes into account future regulatory developments by adding them before the application date of the regulation itself. Add to this the EuroNCAP criteria are always more severe than the regulation requirements. As a result, the regulations can hardly bring more to these tests already more demanding than in regulation. EuroNCAP is monitoring the far side impact in 2018 and 2019 and it would be mandatory in 2020.
Lever 4: consumer test	Since NCAP tests are already customer tests, this lever has no potential action apart from the introduction of new tests in the current protocols or the introduction of NCAP in geographical area that do not yet have them.
Lever 5: cost reduction	The introduction of simulation tests would reduce the costs and increase the configurations to be proved. Nevertheless, still need to have calibration tests. One of the few ways of improvement would be to group the EuroNCAP tests with the Regulations ones for the tests with comparable protocols.
Lever 6: interaction with other safety domains	Active safety systems like the Lane Departure warning will help to reduce the side accidents. Also, the V2I systems could reduce the number of accidents or minimize their consequences
Lever 7: Application	NCAP tests already exist on most geographical areas. These levers can therefore be applied for each of them. Share the test results between the whole NCAP regarding the vehicle definition would be ideal for transferability.

4.2.4 Side airbag (Head only Head + Thorax, Thorax + Abd + Pelvis, Farside airbag, curtain)

Colour Code: **Green**

Crashworthiness	Side impact	
Side airbag (Head only Head + Thorax, Thorax + Abd + Pelvis, Far-side airbag, curtain, ...)		
Summary	Side airbags are passive safety systems which function as an energy-absorbing barrier between the occupant and potentially injury-inducing structures to protect the vehicle occupant from injuries in a crash with a lateral direction of force (side impacts). Most commonly, there are two different types of side airbags available for cars. One airbag which is usually installed in the vehicle doors or seats serves to reduce thoracic and pelvic injuries and one airbag which deploys as a curtain in front of the vehicle's side windows serves to reduce head injuries. While the side airbag for the protection of thorax and pelvis is often only available for the front car occupants in the actual car fleet, the window curtain airbag also serves to protect the rear seat passengers. As it is expensive to have side airbags in every car as a standard, especially those systems protecting more than one body region, it is important to find out whether they can reduce the risk of injury or death significantly. Also, their deployment could lead to further injuries, so the risks, costs and a vehicle's occupants' protection must be weighed against each other. One study provides a general description of the most common side impact crashes, finding they mostly occur at intersections or left turns with a moderate change in velocity with head, thorax and pelvis being the body regions injured most often. Therefore, airbags are needed that protect not only one region but both the torso and the head. Studies comparing single to dual airbags could confirm these findings as dual airbags were shown to be the statistically significantly more efficient systems. Whether a single airbag provides sufficient protection or is of minor relevance could not be determined, as results on that topic are contradictory. Additionally, two other studies concentrated on the direct comparison of vehicles where side airbag systems were installed to those without side airbags. Both studies came to the conclusion side airbags are very important in the prevention of injuries. McGwin et al. (2007) found there even was a reduction in risk of head injury of approximately 75%. One study reviewed the influence side airbags had on injuries of the upper extremity. The forces generated by the deployment of side airbags led to more serious injuries in the named body region, such as the dislocation of shoulders. The author though points out these are not life-threatening injuries in contrast to those that occupants could suffer from when no side airbags had been installed. These cases are often found when vehicle occupants are seated out of position, meaning not seated in the optimal posture.	

	All the studies faced certain limitations concerning the data worked with. The studies were of a retrospective nature, the authors had to rely on the objectivity and accuracy of police and insurance company reports. Moreover, in some cases there was no certainty as to which vehicles had side airbags installed as the companies only sold them optionally for some models?
Lever 1: Technology	No progress in technology is expected as it seems to correctly work. But regarding the protection area covered by the side airbags, some standardization could be possible. The coverage area could be extended to include a larger part of the population. We could also imagine a way of improvement of the gas used to inflate the airbags (toxicity, quantity needed, characteristics, etc.).
Lever 2: Standardization	The surface covered by the side airbag is not defined and standardized. A minimum coverage of the system could be a benefit. The fitting of vehicles in terms of side airbag is not necessarily the same according to the geographical area. As there is no requirement of side airbag to approve a vehicle, the fitting of cars is highly depending on the consumer test programs as well as the safety policy of each car manufacturer.
Lever 3: Regulation	The side impact test is included in the approval of a vehicle if the R point is lower than 700mm. Criteria have then to be respected, but the side airbag is not mandatory. There is no reason to do so as it would simply impose a technical solution.
Lever 4: consumer test	In most of the consumer tests around the world, side impact are found which strongly encourage car manufacturers, who target a highs safety score, to implement side airbags. In EuroNCAP, for the moment, consumer test are done in side impact according to two different crash configurations: mobile deformable barrier into the side of the vehicle, and sliding vehicle into a pole. The far side protection is not yet considered but could lead to the introduction of additional side airbags in vehicles.
Lever 5: cost reduction	No cost reduction seems possible if the technology remains are they are today. Vehicle manufacturers have optimized the cost of this safety device.
Lever 6: interaction with other safety domains	The curtain airbags, originally developed for the side protection, can be used in frontal impact to limit head impact against rigid part of the vehicle during the rotation phase. In rollover, the side airbag can be beneficial for the protection of occupants. As the other safety devices, it has been optimized for in-position occupants. The fact of being out of position can lead to unsafe situations, but globally the systems has been rated as effective, which means that in a large majority of cases no issue has been noted. No interaction with other safety domains than the passive safety is expected.
Lever 7: Application	Side airbag and their validation (consumer tests) could be extended to light utility vehicles and even to trucks as well in case of tip over.

4.3 CRASHWORTHINESS – REAR IMPACT

4.3.1 Anti-Whiplash (Seat, active headrest …)

Colour Code: Green

Crashworthiness	Rear impact	
Anti-Whiplash (Seat, active headrest, …)		
Summary	Over 90% of the injuries sustained by occupants whose vehicles are struck in rear-end collisions are to the neck region. More than 200,000 people suffer such injuries annually. There are different theories on the mechanism for whiplash injuries. The maximum rotation of the neck, relative acceleration between the head and torso, or spinal fluid pressure gradients are among the different explanations for the cause of the injury. All are based on the assumed motion of the head and neck during a crash, most notably rear impacts. During a rear impact the struck vehicle is accelerated forwards. The forward motion of the vehicle causes the occupants to be loaded by the seat back as the vehicle moves relative to the occupant. The loading of the occupant's torso causes the body to move forward while the head's inertia holds it in space as the torso moves under it. The relative motion of the head and torso causes an extension of the neck until the head contacts the seat back/head restraint. Anti-Whiplash seat designs try to reduce the relative motion between the head and torso by using passive or active seat designs. Active seat designs will cause the head restraint to move forward (relative to the seatback) when the torso begins loading the seatback. Passive systems attempt to minimise the head-torso relative motion by positioning the head restraint closer to the head during normal operation or controlling the collapse of the seatback. Controlled seatback motion minimises the relative loads on the neck. Several studies have assessed the effectiveness of anti-whiplash systems by comparing the injury risk between identical, or similar, vehicle models, either equipped with an anti-whiplash system or equipped with an older conventional seat design. Concerning the safety benefit of Anti-Whiplash Systems based on field accident data, Farmer et al (2003) found that new seat designs, such as active head restraints that move upward and closer to drivers' heads during a rear impact, give added benefit, producing about a 43% reduction in whiplash injury claims. According to Kullgren et al (2013) the proportions of drivers with permanent medical impairment dropped by approximately 51% in rear-end crashes (62% for males and 44% for females). Regarding drivers with symptoms lasting longer than one month, the reduction was approximately 27% in rear-end impacts (33% for males and 26% for females).	

	Concerning expected injury risk reduction in vehicles with good whiplash rating in EuroNCAP, Kullgren et al. (2015) found that the EuroNCAP whiplash protocol score appeared to have strong meaningful association with the advent of Permanent Medical Impairment. J-NCAP and IIWPG were also evaluated and showed very similar results. There was no statistical difference between the effects of the protocols, based on the data available. No precise number of the risk reduction was presented, only the trend. Farmer et al (2008) reported that driver neck injury rates were 15% lower for vehicles with seats rated good compared with vehicles with seats rated poor. Rates of driver neck injuries lasting 3 months or more were 35% lower for vehicles with seats rated good compared with vehicles with seats rated poor.
Lever 1: Technology	Improvement in technology is expected through sensor-based systems or fluid-based head restraint systems.
Lever 2: Standardization	There are only a few consumer tests which include specific tests for Anti Whiplash. It would be necessary a common regulation to improve the head restraint systems.
Lever 3: Regulation	Only the USA has a regulation through the FMVSS 202. Is necessary to implement regulations worldwide concerning whiplash to improve safety in these type of accidents, specially knowing that 90% of the injuries sustained by occupants whose vehicles are struck in rear-end collisions are to the neck region
Lever 4: consumer test	At the moment, only a few consumer tests have protocols to assess whiplash in rear-end accidents. EuroNCAP evaluates three configurations (static, dynamic and AEB city), C-IASI and K-NCAP evaluate two configurations (static and dynamic) and C-NCAP and J-NCAP evaluate only the dynamic configuration. Some dynamic tests are performed for insurance companies, by independent test laboratories. They assess the risk of cervical injuries using crash test dummies, these are leading to a better design of the backrest and headrest of the vehicles. They could be performed worldwide to improve the situation of whiplash injuries in all geographical areas.
Lever 5: cost reduction	Some costs reductions could be achieve if there is a standardization of the regulation and the consumer tests. Each manufacturer have create their own solutions at their own costs.
Lever 6: interaction with other safety domains -	Active safety systems as AEB or EBA could reduce the number of rear-end collisions and finally have an effect on the need of rating cars in this configuration in the future. V2V systems could avoid this type of accidents.
Lever 7: Application	Head restraint systems could be extended to other types of vehicles (bus, truck) and to the rear passenger seats.

4.4 CRASHWORTHINESS – ROLLOVER

4.4.1 Rollover protection system

Colour Code: Grey

Crashworthiness	Rollover	
Rollover protection systems incl. ECE R66		
Summary	Rollover accidents often come with serious injuries to the head and spine. This is because often the roof of the vehicle is crushed which results in an intrusion of the roof into the passenger cabin and the occupant has contact with the roof during the rollover event. This could also be observed when the passengers don't wear their seatbelt and are projected in the passenger compartment. By a reduction of roof intrusion and the wearing of the seatbelt at rollover accidents a substantial reduction in injuries can be achieved. Using expected costs for the treatment of spinal cord injuries it was calculated that in the USA over 97 million dollars can be saved annually if the maximum roof intrusion in rollover crashes were limited to 8-15 cm for belted occupants. Dobbertin et al. (2013) found a direct association between roof crush and head, neck and spine injuries. Using the NASS CDS accidents data, he found a 44% increase in the odds of sustaining any injury to the head, neck or spine with every 10 cm increase in roof crush. Measures against injuries from rollover accidents can be found in both active and passive safety. Active safety measures to avoid rollover accidents can be found in the scope of ESP/ESC systems which to a certain extent avoid the vehicle's lateral (yaw) movement in case of loss of control and thus reduces the chance of a lateral rollover. By increasing the stability of a vehicle's roof structure, roof crush due to the rollover event is reduced and thus injuries can be decreased. In Europe the applied regulation for roof strength is the UN-ECE R66. This relates to the approval of large passenger cars (M2 or M3 buses) with regard to the strength of their superstructure to ensure that the residual space during and after the rollover test on the complete vehicle is uncompromised (Liang et al, 2010).	
Lever 1: Technology	For the 2 identified mechanisms leading to occupant injuries in case of rollover, each has its own type of countermeasure. For the first, which consists in minimizing the passengers' displacement during a rollover, we can play with the safety devices already implemented in the vehicle such as the seat belts with pretensioners and the side protection through the presence of side airbags. For these two systems, the technological aspect has already been mentioned in the "belt" and "side airbag" measurements. For the second mechanism, we have to reduce intrusions into the passenger compartment during the rollover. The first way of improvement would be to work on the strength of the car, working on alloy and shape of the reinforcements of the vehicle's structure. The second way would be to trigger a safety device that would make incompressible passengers compartment. This	

	system would be similar to that existing on convertible vehicles. This type of system already works properly, it just have to be implemented on all vehicle types.
Lever 2: Standardization	One of the most important risks in the case of rollover is the ejection. This risk is real in all type of vehicle. To limit it, wearing a seatbelt is the most efficient protection. It should be compulsory in all type of vehicle. Add to this, in passenger cars, in order to improve its efficiency, it may become mandatory to have a belt pretensioner system but also lateral protection systems. That would reduce the risk of ejection during rollover. Up to now, no consumer testing is reported in this field of accidentology and if it was the case, it would only apply to passenger car and maybe light goods vehicles. But this will not concern coaches or bus.
Lever 3: Regulation	Today there is only one regulation in Europe (R66) and it concerns only vehicles of category M2 and M3. This regulation could be adapted and applied to all vehicle types less than or equal to M3 and to LCV <3.5T. Regulation of this kind exists in USA under FMVSS 216 and apply to passenger cars. The use of laminated windows could also bring a significant gain in case of rollover or overturning, preventing ejection in buses and coaches. We could also imagine to impose some requirement for other types of vehicle like motorcycles.
Lever 4: consumer test	Nowadays, there is no consumer organization interested in this type of crash configuration. Indeed, rollover represents only about 15% of traffic accidents. The introduction of a rollover test in the NCAP tests would bring a big boost in this safety area. These tests could be inspired by the FMVSS2016 regulation for the criteria or/and set up a dynamic rollover test. As the rollover crash mainly concerns the superstructure of the vehicle, it would be quite possible to make validations through simulations, which would greatly simplify the implementation of a new regulation and reduce the associated cost.
Lever 5: cost reduction	As this field of accidentology is still not very widespread in Europe, it is difficult to talk about Cost Reduction. Better consideration in the design of new vehicles and the use of stronger materials could be a good lever for cost control. However, standardization of side airbags and pretensioners could lead to a reduction in terms of cost, due to the volume effect.
Lever 6: interaction with other safety domains)	For passenger vehicles, although the accident time scale between a side impact and a rollover is quite different, the safety devices used in these two types of accident are the same. A synergy between those 2 domains could allow to use the same device for these two distinct types of crash. Regarding public transport the requirement to wear a seatbelt would significantly reduce the risk of injury. Roll-overs are often resulting from a previous impact, and the safety devices have sometimes already been activated and are less or even not efficient at the time of the roll-over. The avoidance of the first impact or of the loss of control of the vehicle could be (partially) managed with active safety devices.
Lever 7: Application	This regulation could be applied to all types of vehicles of 4 wheels and more.

4.5 CRASHWORTHINESS – PEDESTRIAN

4.5.1 Pedestrian protection – Active Technology

Colour Code: Light Green

Crashworthiness	Pedestrian	
Pedestrian protection - 'active technology'		
Summary	Active Technology relates to two broad measures, often working in conjunction: Pop-up Bonnet technology (often called Active Hood Lift System – AHLS) and Pedestrian Airbags. AHLS works by lifting up the rear of the vehicle bonnet to obtain space to absorb the impact energy of a pedestrian's head and prevent it from hitting rigid components in the engine compartment if necessary due to limited space between hood and engine. This technology uses pedestrian impact sensors, located on the front of the vehicle, and actors which lift the rear edge of the bonnet away from the scuttle area, typically by around 10cm. Only some of these systems are not reversible and consequently there is a need of a careful management of the deployment to ensure protection only if a pedestrian is involved. AHLS can work independently but is more efficient when working in conjunction with Pedestrian Airbags. These airbags deploy externally from the gap made by the pop-up bonnet at the base of the windscreen and are typically designed to cover the scuttle/rear of the bonnet, the A-pillars and the base of the windscreen.	
Lever 1: Technology	AHLS would greatly benefit from any technology allowing it to be reversible - at a reasonable cost. Using shape memory alloys for design or piezoelectricity might be long term solutions, depending on feasibility	
Lever 2: Standardization	This topic, that is mainly operated with by computer simulation, will benefit for any improvement in biomechanics computer science methods standardization - the lack of which today being one of the obstacles to relevant vehicle design comparisons.	
Lever 3: Regulation	Extend (e.g. NCAP) protocols for pedestrian safety testing to classes of vehicles such as commercial or public service vehicles that not have to fulfil such detailed pedestrian protection testing/legislation which can lead to a disparity in real world pedestrian protection.	
Lever 4: consumer test	Publicize consumer information on vehicle test results relevant to pedestrian safety, by make and model of car, for example, results of New Car Assessment Programs. In doing so, make clear whether any active technology present has an effect on pedestrian safety. For this purpose, tests such as NCAP should be realized with and without active technologies.	

Lever 5: cost reduction	Nothing much can be done in this line : * AHLS is hampered by its non-reversibility * Pedestrian airbags are more expensive than classical airbags because of the size of the area that they are supposed to cover
Lever 6: interaction with other safety domains	Reduce pedestrian exposure to vehicle traffic by altering road infrastructures, e.g. : * Install and/or upgrade traffic and pedestrian signals * Provide sidewalks and enforce vehicle/PTW parking laws * Install "pedestrian only" underpasses or covered overpasses * Reduce traffic volumes by switching journeys from the car to public transport, walk and cycle for distances and purposes when possible Car to X technology could also be beneficial for pedestrian equipped with a smartphone, they could be alarmed of a car coming (in rural areas) or a communication to the vehicle could be done.
Lever 7: Application	The protection of pedestrians could be transferred to other types of vehicles for which existing technical solutions could be applied

4.5.2 Pedestrian protection – Vehicle Shape

Colour Code: Light Green

Crashworthiness	Pedestrian	
Pedestrian protection - 'vehicle shape'		
Summary	Vehicle shape relates to two broad measures; the first is the overall 'silhouette' of a vehicle, ignoring the 'micro' or detail design elements of the design, and instead looking purely at the overall or 'macro' shape of the vehicle. Commonly shape in this context is classed in a number of broad groups such as SUVs (passenger vehicles with raised suspensions in the mould of an off-road vehicle), saloon vehicles (the traditional vehicle type commonly seen on EU roads) and 'one box' which covers everything from minivans to MPVs. Secondly vehicle shape considers a number of detailed geometry measures and the effect that changes to these have on pedestrian protection; for example, details such as small changes to bumper height, bumper leading length, hood edge height and hood stiffness measures.	
Lever 1: Technology	Due to the nature of vehicle design and the diversity of human size, it is not always possible to state that a certain design change or vehicle shape will provide benefits for all pedestrians. Only one vehicle design change does appear to provide uniform benefits for pedestrians: lower bonnet (hood) stiffness This topic, that is mainly dealt with by computer simulation, will benefit for any improvement in computer science in conjunction with biomechanics. Fields that come to mind include : * Increasing computer capacity in order to assess a wider variety of vehicle general design parameters, impact speeds and human shapes in crash simulations * Developing realistic and reliable human body numeric models, fit for vehicle-pedestrian crash simulation	
Lever 2: Standardization	This topic, that is mainly deled with by computer simulation, will benefit for any improvement in biomechanics computer science methods standardization - the lack of which today being one of the obstacles to relevant vehicle design comparisons. Standardization of existing pedestrian safety related test methods would also be greatly beneficial, for the same reason	
Lever 3: Regulation	Extend (e.g. NCAP) protocols for pedestrian safety testing to classes of vehicles such as commercial or public service vehicles that not have to fulfil such detailed pedestrian protection testing/legislation which can lead to a disparity in real world pedestrian protection. Most of the region with a lot of fatal pedestrian accidents do not have regulation for the vehicles. High benefit would be expected once the regulation is in place and that the car fleet has been renewed.	

Lever 4: consumer test	Pedestrian safety relevant testing is now part of the Euro NCAP protocol. Information on test results should be widely made available to consumers, by make and model of car. Most of the region with a lot of fatal pedestrian accidents do not have consumer test ratings for the vehicles for pedestrian protection. High benefit would be expected once the regulation is in place and that the car fleet has been renewed.
Lever 5: cost reduction	Carmakers to improve the vehicle design for pedestrian safety will be more inclined to join in the race if progress is made in : * Increasing computer capacity in order to assess a wider variety of vehicle general design parameters, impact speeds and human shapes in crash simulations * Developing realistic and reliable human body numeric models, fit for vehicle-pedestrian crash simulation
Lever 6: interaction with other safety domains	Reduce pedestrian exposure to vehicle traffic by altering road infrastructures, e.g. : * Install and/or upgrade traffic and pedestrian signals * Provide sidewalks and enforce vehicle/PTW parking laws * Install "pedestrian only" underpasses or covered overpasses * Reduce traffic volumes by switching journeys from the car to public transport, walk and cycle for distances and purposes when possible
Lever 7: Application	Not relevant in this context except a transferability to other vehicle types when possible.

4.5.3 Pedestrian regulation

Colour Code: Light Green

Crashworthiness	Pedestrian	
Pedestrian regulation		
Summary	Powered vehicles may be aggressive to pedestrians due to their mass and design, as the high amount of energy transferred to the pedestrian during a crash could possibly lead to severe and even fatal injuries. Pedestrian regulations aim at providing better protection for pedestrians in the event of crash with a powered vehicle, by regulating vehicle designs in order to reduce the amount of energy transfer. This transnational concern has given birth to a variety of legislations, of which three groups emerge: Japanese, European (Reg. 78/2009) and US/Australia (Global Technical Regulation n°9). Each of these requires given groups of vehicles to comply with impact tests, focusing on pedestrian head and leg impacts.	
Lever 1: Technology	In theory, regulations do not aim at imposing a precise technology, but rather set goals to achieve. In this case, however, technology and regulations cannot be treated separately. Pedestrian impact areas (windshield, hood, bumper, and ground as a secondary impact locus) and speeds have been shown to intimately depend on whether active safety systems such as Automated Emergency Braking are present on the impacting powered vehicle. In order not to be misleading, regulations and compliance tests should not be thought of without taking vehicle technology evolutions into account, e.g. should be adapted depending on whether AEB systems are made mandatory or not.	
Lever 2: Standardization	At this stage, there is no worldwide pedestrian regulation standard, even though European and US/Aus test results have been shown to exhibit a good level of correlation. In a context where carmakers increasingly sell worldwide and not only on their domestic market, worldwide standardization would make vehicle compliance to pedestrian regulations more cost effective and is therefore highly desirable.	

Lever 3: Regulation	Adoption of a pedestrian regulation by formerly non-regulated countries has a global positive effect as it favours the introduction of vehicles more compliant with pedestrians in case of accident. Improvement of the current regulations include: * The regulation considered in the synopsis is only dealing with passenger cars. The extension to other types of vehicles (PTW, Trucks, buses, tramways,...) * Taking SUV and other vehicle with a high ground clearance (risk of pedestrian being dragged under car body after impact) into account * Taking the windshield area - an important impact area at high speed - into account * Day running light is not mandatory in all regulated areas, as it increases the visibility of vehicles, it should limit the number of impacts due to non-detection of an in-coming car. (see specific form in this document related to that system) * Better assessment of the potential pedestrian second impact on the ground.
Lever 4: consumer test	Publicize consumer information on vehicle test results relevant to pedestrian safety, by make and model of car, for example, results of New Car Assessment Programs Extend the pedestrian protection protocols to all geographical areas, especially the countries in which the number of pedestrian killed is high (Asia, US, Latin America,...).
Lever 5: cost reduction	Regulation is only based on physical tests; the selection of the points to be tested is made using simulations. Introduction of virtual testing in the regulation could lead to a cost reduction, or to the increase of the number of impact points tested (=global increase of safety)
Lever 6: interaction with other safety domains	Reduce pedestrian exposure to vehicle traffic by altering road infrastructures, e.g. : * Install and/or upgrade traffic and pedestrian signals * Provide sidewalks and enforce vehicle/PTW parking laws * Install "pedestrian only" underpasses or covered overpasses * Reduce traffic volumes by switching journeys from the car to public transport, walk and cycle for distances and purposes when possible *The behavior of pedestrian is a key-point in its protection. The newly developed source of distraction (phones, music players,...) are often isolating the pedestrians in their world while they are in the middle of a traffic flow. Education and recommendations are necessary on this point.
Lever 7: Application	A regulation for the protection of pedestrians could be adopted for other types of vehicles for which Safety Cube deliverable D6.1 underlines a need of protection.

4.6 CRASHWORTHINESS – CHILD

4.6.1 Child Restraint System – 'CRS'

Colour Code: **Green**

Crashworthiness	Child	
Child Restraint System – "CRS"		
Summary	Child restraint systems (CRS) aim to reduce injuries to children in motor vehicle crashes by providing both additional impact protection and optimal restraint geometry to a child passenger. Typically, countries regulate the use of child restraint systems through safety laws with most developed countries stipulating the use of a CRS up to the age of 2 or more. Studies on child restraint performance are normally derived from the analysis of real world collision data, hospital information and public health data and can therefore form large samples and robust results. The results found that the use of an appropriate and correctly used child restraint can reduce the risk of death and injuries compared to a child either using a CRS incorrectly, using a standard seat belt or completely unrestrained. Despite the overall positive effect on road safety, there is evidence in some instances, such as comparing a correctly used child restraint to a standard seatbelt, that fatalities and very serious injuries are not significantly reduced for infants involved in higher speed motor vehicle crashes or where intrusion into the interior space is present.	
Lever 1: Technology	Reduction of misuse possibilities, innovative protection in frontal and side impact (airbag integrated in CRS, harness strap retractor, load limitation,…)	
Lever 2: Standardization	User manual available as QR code could help in the installation of the CRS in the car and of the child in the CRS. The integration of ISOFIX connectors in every car is a benefit for the CRS that can be installed at the equipped seating positions. In some geographical area such as Latin America, it seems necessary to harmonize the regulations. Some countries (e.g. Israel) are allowing the use of CRS of different standards that do not give a homogeneity to the proposed systems on the market and make the consumers confused.	

Lever 3: Regulation	The adoption of a regulation for the transportation of children in vehicles is a starting point for the improvement of the child safety in vehicles. Most of the developed countries have adopted such a regulation and some of the "motorizing countries" have their own rules. The second step that is not uniform across the world is the enforcement of the regulation. A new regulation for CRS approval (ECE R129) is on the point to be adopted by UNO. Its application in the countries with vehicles equipped with ISOFIX anchorage would improve the global protection of children on the following points: reduction of misuse of installation of CRS, side impact, appropriateness of the restraint (centimetric approach), use of Rearward facing at minimum until 15 months of age, integral systems to a minimum height of 100cm.
Lever 4: consumer test	Consumer tests both for CRS and car products can rapidly improve the availability of compatible products on the market. ADAC tests for CRS and EURONCAP for vehicles would initiate both the awareness of consumers and the disponibility of ISIZE products.
Lever 5: cost reduction	CRS range of price is very large and can vary from 5 to 500 euros according to the technology used and the safety requirements of the CRS manufacturer. Nevertheless, if approved according to a European regulation every system has been tested to guaranty a minimum level of safety to its occupant.
Lever 6: interaction with other safety domains	Acceptability, can sometimes be a problem. It can occur from the child itself (difficulties to restrain some of them in car) and ability to create misuse situations (e.g. to put their arms out of the harness once the journey is started) that can affect their level of protection. Education (belonging to Human behavior WP) becomes there an important point and the awareness of parents on the need for a given system to be correctly used to be fully efficient too. In some cases, parents are refusing to restraint their children in cars. About 6 to 10% of children are travelling unrestrained, enforcement being there the only lever.
Lever 7: Application	Regulation of transportation of children in CRS is applied all over Europe for children in cars, and in light vehicles. Some countries have recommendations for children in coaches (and buses), and for other types of vehicles, the number of children transported is too low to impose requirements on it.

4.6.2 Child Restraint System – 'booster seats'

Colour Code: **Green**

Crashworthiness	Child	

Child Restraint System – "Booster seats"

Summary	The injury outcomes for child occupants involved in vehicle collisions can differ significantly depending on whether a child is restrained in the vehicle and if they are, how they are restrained. Child restraint system design and regulation has changed markedly over the last decade with many different seat types and designs currently available; one of these types of restraint, belt positioning booster seats, are designed to provide optimal belt geometry for forward facing child occupants between 15 and 36kg (broadly 4 to 10 years of age) who use the standard, 3-point adult belt fitted to passenger vehicles. Typically for this age group a standard three-point belt will not sit across a child body in a way which enables the restraint to work effectively, this can lead to problems such as abdominal or spinal injuries through the upper body 'jack-knifing' over the belt webbing or the child 'submarining' under the webbing. Additionally, a poorly located belt can lead to head injuries through contact with interior vehicle components or contact with their own knees/legs. Analysis of large scale, real world collision data shows that belt positioning booster seat designs are effective in mitigating injuries in child passengers. Most research has been conducted in the US where the child seat laws are broadly representative of the EU situation.
Lever 1: Technology	Many technologies are possible to construct a booster system, and it is important that the resulting product is following certain rules: First the booster system aims to position the child's body into the seatbelt geometry as close as possible as an adult's body. This means that rerouting completely the seatbelt is not the main point, and when it is necessary to change the seatbelt route it is important that the rigidity of the seatbelt guides is sufficient. This is to ensure that the loads applied on the belt will not change its geometry during the crash, otherwise, the booster has not efficiency at all. Secondly, it is important that the booster itself cannot be deformed too much during the crash, with eliminates inflatable systems, and structure less systems on which it is not possible to ensure that the belt load path will remain in the same geometry as before the crash. Improvement on guiding the seatbelt, adjustments of the parts of the boosters are still a point on which many systems could be improved. The main technological improvement for the future systems high quality systems will be to combined an optimum level of protection and ensure a good comfort for the child, so it will not conduct to voluntarily misused situations.

Lever 2: Standardization	As for Child Restraint Systems in general, booster systems can be developed according to different regulations with completely different criteria to respect. It is important to harmonize this point and to consider the real protection of children in the setting of the criteria to be fulfilled before a system is put on the market. Another issue which is linked at the same time to standardization of systems and to regulation is the fact that some add-on systems are sold most of the time without any approval. Their main goal is to improve the comfort of the child, and manufacturers are producing sled test results showing that it does not decrease the protection of children. Accident data and tests made with more advanced dummies than the ones of the ECE R44 have shown that the abdominal part of the child is at risk using such systems that are simply de-routing the seatbelt from its original place by putting down its thoracic part and pulling up the lap part of the belt onto the child's belly.
Lever 3: Regulation	The adoption of a regulation for the transportation of children in vehicles is a starting point for the improvement of the child safety in vehicles. Most of the developed countries have adopted such a regulation and some of the "motorizing countries" have their own rules. The second step that is not uniform across the world is the enforcement of the regulation (see standardization item). To ensure that the systems sold as booster systems provide a minimum of safety, it is important that a regulation exists to check that protection criteria are respected during a series of crash tests. In Europe, the ECE R129 has been recently adopted and for booster systems, it shows major differences compared to the previous regulation (ECER44). In the past, boosters were commonly approved from 15 to 36 kg even if they had no backrest. In ECE R129, the use of backless boosters is only allowed for children taller than 125cm. This means two things: 1- the seatbelt is guided on the child's clavicle by the system until the child is 125cm, which should avoid the fact that the seatbelt is located in the child's neck area (that leads often to misuse situation due to discomfort). 2 -the booster system has to fulfil the side-impact test requirements and criteria, which is of course an improvement of the global protection offered to the child. For children taller than 125cm, it is assumed that using a simple booster is positioning the head of the child in the same area as the one of a small adult, which means that the protection in side impact is covered by the car approval regulation.

Lever 4: consumer test	Both car and CRS consumer tests are performed on boosters in Europe. The first ones are leading to high quality systems that are improving the child protection in a given number of crash situations, but the tested systems are not the one that are the most commonly used in cars by parents. The second ones are testing a larger panel of CRS, and produce results in wild spread media (newspapers, websites,…) and make the informal easily available for parents looking for information. It seems that test protocols being different between the cars and the CRS rating tests, it is difficult to have products that are good at the same time in both consumer test categories and that fully respect the regulation. The danger being to have CRS designed to reach the higher scores in the largely diffused rating results (that is completely criteria depending) and that are not offering the protection expected in all in real life conditions.
Lever 5: cost reduction	The price of a booster system is largely depending on its conception. Some of them are really low cost to produce and some others are more expensive. Nevertheless, they are all approved which means that they guarantee a minimum of safety level to be respected. With the entrance in force of the new regulation in Europe, it is expected that the price of booster seats will be higher than the one of booster cushions. Nevertheless, the fact that all booster systems for children between 105 and 125 cm will be only with backrest will increase the number of these systems and by the way could lead to a reduced price of each of them.
Lever 6: interaction with other safety domains	The use of child restraint system is strongly linked with the fact that the driver of the car is using or not a seatbelt, and more generally of its sensitivity to the road safety. The use of booster systems, is also depending on the child's sensitivity to its protection. Very often, children of 6 or 7 years of age consider that such a system is only for babies, and that using it is a shaming in front of the other children. In the same idea, parents are often using booster systems while their children could still fit in the integral system he was using before. It is important that users understand that using a system too early is not the optimum protection they can offer to their children. In addition to this problem of choosing the right system for the child, the quality of use is of first order! First, parents have to correctly understand how it works, and the importance of using the system correctly. Secondly, the permissivity of parents regarding their children to change the situation during the journey is also a key-point. If the issue is a comfort one, then the system is not the appropriate one or it is not correctly adjusted in a large number of cases. To resume, child safety education is needed to improve the situation and it has to be done both for parents and children.
Lever 7: Application	The use of child restraint systems in other transport modes than cars is always a subject leading to experts' discussions. For boosters, the situation seems to be clearer: In light utility vehicles, in trucks and in coaches, if the seating position is fitted with a three point belt then the use of a booster system is a plus for the protection of the child. It has to be reminded that the use of a booster with a two point belt is not allowed and it is dangerous (abdominal penetration of the seatbelt and lack of restraint of the upper part of the body leading to a high head forward excursion). For city buses, train, airplanes, ships, the use of booster systems do not seems to add any safety to the child.

4.7 CRASHWORTHINESS – PTW SPECIFICITIES

4.7.1 Protective clothing

Colour Code: **GREEN**

Crashworthiness	PTW	
PTW protective clothing		
Summary	Collisions involving powered two wheelers (PTWs) often involve the rider of the motorcycle coming into contact with another vehicle, the road surface or other items of street furniture. These interactions vary enormously depending on a wide range of crash characteristics; However, it is likely that the rider is exposed to injury during the contact with other objects. Powered two wheeler protective clothing is designed to mitigate the risk of injury from these interactions by providing protection in a number of ways, either through impact resistance, abrasion resistance or by containing and controlling damage to body parts, for example, the stiffness of the ankle protection provided by a motorcycle boot. PTW protective clothing cover a wide range of different items. For this topic, the following types of clothing were considered: motorcycle jackets, trousers, gloves and boots.	
Lever 1: Technology	All the technological items linked with airbag integrated in the motorcyclist jacket are treated in the dedicated chapter on the safety measure PTW Airbag. Potential improvement of PTW protecting clothes could be done through the use of new materials for their conception.	
Lever 2: Standardization	The European Personal Protective Equipment (PPE) Directive requires that any clothing or personal equipment sold as providing protection from injury must comply with the relevant European Standard. The list of standards relevant to our topic is as follows: EN 1621-1:1998 Impact protective clothing. Requirements and test methods for impact protectors EN 1621-2:2003 Back impact protective clothing. Requirements and test methods. EN 13595-1:2002 Protective clothing. General requirements. EN 13595-2:2002 Protective clothing. Test method for determination of impact abrasion resistance. EN 13595-3:2002 Protective clothing. Test method for determination of burst strength. EN 13595-4:2002 Protective clothing. Test methods for the determination of impact cut resistance. These texts remain an exception even though efforts have been made in Australia & New-Zealand to enter similar texts into local regulations and US's ANSI is considering following the same path. Worldwide standardization of European regulations and test should be seen as a great step towards global PTW safety.	

Lever 3: Regulation	Regulation on the resistance of PTW clothings exist in Europe to guarantee a certain level of protection of the rider in case of fall. These regulations could be extended to other geographical areas. What is not mandatory is to wear such safety equipments while riding a PTW. This could be very beneficial in term of injury severity reduction.
Lever 4: consumer test	Regarding clothing, a label ("CE") already exists at European level, for those clothing which have successfully passed the mandatory tests and are thus allowed on the market. There is no consumer test program on these safety equipments. Rating their efficiency would be a great help for the riders awared of the need of being protected.
Lever 5: cost reduction	Reducing the price of PTW clothing will increase the rate of use and by the way the protection of riders in accidents. Generalization of approved PTW protective clothing will decrease the price. Financial efforts could also be made by insurance companies as the use of them would decrease the money that have to spend for the recovering of the rider if involved in an accident.
Lever 6: interaction with other safety domains	Any effort to physically separate motorcycle and powered vehicle traffics would be a great improvement for motorcyclist safety. In a transitory state where this is not achieved, any educational effort aimed at making motorcyclists understand that: 1) They are ordinary road users who must comply to general road rules - including respecting traffic lights, avoid car blind spot overtaking, signaling direction changes, avoid speeding and riding under the influence 2) Aside from pedestrians and cyclists, they are the most vulnerable road users - prone to falling in bad weather conditions and easily overseen by car drivers - even when not concealed by heavier vehicles - who often underestimate the pace of their approach. As a consequence, they should consider adopting any measure increasing their safety e.g. wearing proved protective equipments such as helmets or protective clothing, making themselves more conspicuous - especially at dusk or in the nighttime - by wearing reflective clothing, even if laws do not make it compulsory.
Lever 7: Application	It does not seems possible to impose to other road users to wear protective clothes.

4.7.2 PTW helmet effectiveness

Colour Code: GREEN

Crashworthiness	PTW	
PTW Helmet effectiveness		

Summary	PTW helmets aim to reduce injuries to the wearer in the event of a PTW crash by providing additional impact and abrasion protection to the head. A helmet meeting or exceeding the required standard can reduce the risk of blunt or direct trauma to a PTW users head or face. The injury types covered are typically to the head including; extradural and subdural injuries; skeletal (skull fractures and facial bone fractures); extracranial injuries (lacerations and contusions) and brain injuries (subdural haematoma, subarachnoid haemorrhage).
Lever 1: Technology	Any design improvement aimed at making helmet lighter (without any loss of protective properties) would be beneficial for social acceptation in hot climate countries. Design improvements for oblique impact test compliance should be beneficial as well.
Lever 2: Standardization	Helmet construction and test standards vary between continents however the primary standards available are US Federal Motor Vehicle Safety Standard (FMVSS) 218, The European UN ECE 22.05 regulation, The Snell M-2015, the UK British Standards BS 6658 and the Australian and New Zealand AS/NZS 1698:2006 standard (and amendments) Regarding helmets, even though there is a high quality international helmet standard (UNECE regulation 22), relevant test conditions and assessment criteria are still an open field of research, the outcome of which will set the frame for future regulations. The Helmet Standard Test method - proposed by the International Motorcycle Federation (FIM) in 2017 - includes improvements such as taking into account oblique impact test and should play a major role in the near future.
Lever 3: Regulation	While regulations about wearing helmets exist in many countries, they not always enforced and are rarely comprehensive : they allow exceptions for given categories of age, say nothing about the motorcycle passengers or are defined at provincial or state level with no global harmonization. An effort in those directions would also be very beneficial. Many countries regulate the use of PTW helmets through safety laws although large areas of Africa, The Middle east and South East Asia do not have helmet wearing laws despite high levels of PTW use.
Lever 4: consumer test	Setting up a standard test protocol aimed at checking whether wearing any given helmet leads to better safety and make the results widely available to the general public would be greatly beneficial.

Lever 5: cost reduction	UNECE regulation 22 complying helmets are still scarce and very expensive on emerging markets, thus putting the general public's acceptance of helmet wearing laws in jeopardy. Any program aimed at lowering costs for low-income populations in these countries would be greatly beneficial.
Lever 6: interaction with other safety domains)	Any effort to physically separate motorcycle and powered vehicle traffics would be a great improvement for motorcyclist safety. In a transitory state where this is not achieved, any educational effort aimed at making motorcyclists understand that: 1) They are ordinary road users who must comply to general road rules - including respecting traffic lights, avoid car blind spot overtaking, signaling direction changes, avoid speeding and riding under the influence 2) Aside from pedestrians and cyclists, they are the most vulnerable road users - prone to falling in bad weather conditions and easily overseen by car drivers - even when not concealed by heavier vehicles - who often underestimate the pace of their approach. As a consequence, they should consider adopting any measure increasing their safety e.g. wearing proved protective equipments such as helmets, even if laws do not make it compulsory.
Lever 7: Application	

4.7.1 PTW airbag

Colour Code: Light Green

Crashworthiness	Frontal Impact	

	PTW Airbag
Summary	There are two different kinds of airbag for motorcyclists. One kind is mounted on the motorbike itself, the other is fitted in the motorcyclist's garments. Both are passive safety systems, designed to mitigate injuries derived from PTW accidents. The inflation of the devices mounted on the motorbike is activated by one or more accelerometers on the motorbike's body or even on the wheel mount, to get earlier information when a frontal impact occurs. These devices have with very short reaction times and are inflated fast, through a pyrotechnic inflator. Airbag devices intended to be fitted into motorcycling equipment are very small in comparison. Their inflation is achieved via compressed gas and can be triggered electronically or by mechanic wire. The in-vehicle airbag has been proved (both by tests and simulation) to be very efficient in a given set of scenarios, defined by ISO 13232. Its implementation is a very complex task due to the limitations of physical space in the PTWs to fit the airbag (type of motorcycle), the reaction structure and the point of impact of the rider, and requires lots of research and development effort. On the other hand, there are no studies proving strongly the efficiency of airbag jackets. The evaluation of these systems has been carried out through computer simulation and only in a very limited number of scenarios.
Lever 1: Technology	The integration of an airbag in a PTW is still a field of research. Technical issues such as managing the secondary impact injuries and the airbag / rider area of contact must be thoroughly addressed prior to marketing the device as a reliable road safety device.

Lever 2: Standardization	European Standard EN 1621-4 covers requirements and test methods for mechanically activated inflatable protectors for motorcycle riders. It specifies the minimum level of protection, the minimum intervention time of inflated bag, and the minimum coverage to be provided by motorcyclists' protectors worn by riders. Inflatable protectors covered by this standard may be incorporated in motorcycle garments or equipped with by appropriate restraint systems and worn on their own. The standard contains the requirements for the performance of the system during an accident and details of the test methods, requirements for sizing, ergonomics, innocuousness, labelling and the provision of information. Inflatable protectors other than mechanically activated are not covered by this standard. Worldwide standardization of this document would be highly beneficial in regulating the market and providing guidelines to customers.
Lever 3: Regulation	Not relevant in this context
Lever 4: consumer test	Consumer testing is not relevant for the time being for motorbike fitted airbags, as more efficiency tests in real situations must be carried out prior to reaching a sufficient level of social demand and acceptance. Results of existing garment fitted airbag tests (e.g. prescribed by EN 1621-4) could be made available to the public either exhaustively or through a quality tag.
Lever 5: cost reduction	Garment fitted airbags are mainly used in sport racing (compulsorily after 2018), so production remains at low levels and prices remain high. Democratization, e.g. made compulsory by regulations, would certainly be cost-effective for that type of equipment. Regarding motorbike fitted airbags, cost is not relevant, since more efficiency tests in real situations must be carried out prior to reaching a sufficient level of social acceptance.
Lever 6: interaction with other safety domains	Any effort to physically separate motorcycle and powered vehicle traffics would be a great improvement for motorcyclist safety. In a transitory state where this is not achieved, any educational effort aimed at making motorcyclists understand that: 1) They are ordinary road users who must comply to general road rules - including respecting traffic lights, avoid car blind spot overtaking, signaling direction changes, avoid speeding and riding under the influence 2) Aside from pedestrians and cyclists, they are the most vulnerable road users - prone to falling in bad weather conditions and easily overseen by car drivers - even when not concealed by heavier vehicles - who often underestimate the pace of their approach. As a consequence, they should consider adopting any measure increasing their safety even if laws do not make it compulsory.
Lever 7: Application	Technology transfer to quads (all types of airbags) or two-wheeled, Segway-like scooters (garment fitted airbags) seems feasible. Transfer to cyclists would presumably not meet social acceptance.

4.8 CRASHWORTHINESS – CYCLIST PROTECTIVE CLOTHING

4.8.1 Reflective equipment + lighting (usage + performance)

Colour Code: Green

Crashworthiness	Cyclist	
Cyclist protective clothing		
Summary	Cyclist protective clothing is not 'protective' in the common sense of the word (i.e. protects the body during an impact or fall). This difference is particularly clear if comparing it to motorcyclist protective equipment, which often includes padding, abrasion resistance or other 'armour' within the clothing. Due to the physical exertions required to ride a bicycle, the flexibility required and the need for the clothing to be light and comfortable, protective equipment in the traditional sense does not exist for cyclists. Instead the definition of protective equipment for cyclists for this topic is anything that cyclist can wear that could reduce their risk of collisions or the consequences of collisions. The most obvious form of this is bright, light coloured or high visibility clothing.	
Lever 1: Technology	Due to recent progress in terms of lightning, it is relatively easy now to make some clothes that includes LED. Cyclists could be offered such possibilities.	
Lever 2: Standardization	To this day, no international effort has been done towards setting up a standard test protocol aimed at checking whether wearing any given clothing leads to better conspicuity for cyclists. Setting up such a protocol would be greatly beneficial, helping lawmakers and consumers to sort out the safety best fit or fits from a wide variety of clothing options.	
Lever 3: Regulation	To this day, no international standard defines whether wearing any given fit-for-cyclists clothing leads to better conspicuity. This can be seen as an obstacle for protective clothing regulations. Lifting it would be greatly beneficial. The wide array of existing regulations for road workers (e.g. construction site workers) could be a source of inspiration.	
Lever 4: consumer test	Setting up a standard test protocol aimed at checking whether wearing any given clothing leads to better conspicuity and make the results widely available to the general public would be greatly beneficial.	
Lever 5: cost reduction	Not relevant in this context	

Lever 6: interaction with other safety domains	Any effort to physically separate cycle and powered vehicle traffics would be a great improvement for cyclist safety. In a transitory state where this is not achieved, any educational effort aimed at making cyclists understand that: 1) They are ordinary road users who must comply to general road rules - including respecting traffic lights, avoid car blind spot overtaking, signaling direction changes 2) Aside from pedestrians, they are the most vulnerable road users - prone to falling, slow and cumbersome. As a consequence, they should consider adopting any measure increasing their safety e.g. making themselves more conspicuous - especially at dusk or in the nighttime - by wearing reflective clothing even if laws do not make it compulsory (e.g. reflectors on the frame).
Lever 7: Application	Scooters, seg-ways, … and « walking buses" (children going to school as a group) would be better protected if more visible when in the road traffic. Devices designed for cyclists could be also used by them.

4.8.1 Helmet (usage + performance

Colour Code: Green

Crashworthiness	Cyclist	

Cyclist Helmet effectiveness	
Summary	Cycle helmets aim to reduce injuries to the wearer in the event of a bicycle crash by providing additional impact protection to the head. Real world collision data, hospital information and public health data show that the use of a cycle helmet can reduce the risk of death and serious injuries to the head or face compared to not wearing a cycle helmet. The injury types covered are typically to the head including; extradural and subdural injuries; skeletal (skull fractures and facial bone fractures); extracranial injuries (lacerations and contusions) and brain injuries (subdural haematoma, subarachnoid haemorrhage). It is also worth mentioning that there is evidence in some instances that injuries to the neck or severe brain injuries may not be reduced by using a cycle helmet.
Lever 1: Technology	Any effort in the way of improving designs or making storage easier would be beneficial for social acceptance of the cyclist helmets
Lever 2: Standardization	Helmet construction and test standards vary between continents however the primary standards available are US Consumer Product Safety Commission (CPSC) standard, the European EN 1078 regulation, the Snell B-95 (and addendums) and the Australian and New Zealand AS/NZS 2063 standard.
Lever 3: Regulation	A few countries regulate the use of cycle helmets through safety laws, however the use of legislation is not widespread or necessarily representative of high cycle use, i.e. the countries with higher cycling levels do not typically legislate for cycle helmet use. As it has a lot to do with the general attitude of given societies towards cycling, this concern cannot be dealt with without changing educational policies and human behavior/attitude towards cycling (see lever 6).
Lever 4: consumer test	Standard test results should be made widely available to the general public wherever they exist (US, Europe, Australia&New Zealand) would be greatly beneficial. Labelling compliant US, EU or OZ&NZ helmets would be help consumer make their choice in countries or areas where no such consumer tests exist.
Lever 5: cost reduction	Helmet construction and test standardization would greatly help to make cyclist helmet a more cost-effective measure

Lever 6: interaction with other safety domains	Any effort to physically separate cycle and powered vehicle traffics would be a great improvement for cyclist safety. In a transitory state where this is not achieved, any educational effort aimed at making cyclists understand that: 1) They are ordinary road users who must comply to general road rules - including respecting traffic lights, avoid car blind spot overtaking, signaling direction changes 2) Aside from pedestrians, they are the most vulnerable road users - prone to falling, slow and cumbersome. As a consequence, they should consider adopting any measure increasing their safety e.g. wearing proved protective equipments such as helmets even if laws do not make it compulsory. Social acceptation of cyclist helmets is a specific issue, that has given cause to bitter conflicts in countries with high cycling activity, over recent years. Whereas helmets are widely accepted by e.g. cross-country cyclists, many urban users see it as an ugly and cumbersome device and cycling associations regularly complain that any regulation aiming at making helmets compulsory would deter people from adopting the bicycle as a mean of transportation, thus hampering its extension in over-polluted city centers. In the aforementioned transitory state, this must be addressed urgently, through educational policies or tax incentives.
Lever 7: Application	Due to social acceptation issue, the transferability seems only case by case study, and the transposability is not relevant for this safety measure.

4.9 CRASHWORTHINESS – HGV SPECIFICITIES

4.9.1 Underrun protection (Front / Side + Lateral Side Guards / Rear)

Colour Code: Light green

Crashworthiness		HGV	
	Underrun protection (Front / Side + Lateral Side Guards / Rear)		
Summary	Underrun protection of heavy goods vehicles (HGV) includes lateral side guards to provide protection to vehicles and vulnerable road users involved in collisions with the side of the HGV and a rear underrun protection (RUP), which aims to reduce the injury severity for the occupants of passenger cars that collide with the rear end of a heavy goods vehicle (HGV). The fitment of RUP to HGVs was made mandatory by the directive 70/221/EC, however these RUP's are often not sufficiently dimensioned in terms of rigidity and position to withstand severe car impacts. In 2006, the directive was amended (2006/20/EC) to increase two of the test loads from 25kN to 50kN and to allow for interruptions in the RUP for tail lifts. Even with this amendment a test has shown that a RUP that passed the higher test loads was still not sufficient to withstand the impact of a small family car at 56km/h. The percentage of the target population that can benefit from such a structure lies between 22.6–34.1% for fatalities, and 52% for serious casualties, based on (Smith et al., 2008). On the other hand Lateral Side guards are meant to reduce casualties by deflecting pedestrians, cyclists, motorcyclists and also cars off the guard from the sides of the HGV rather than falling or driving under the HGV. Thus the reduction of injury frequency and severity is achieved because the probability of being overrun by the HGV is reduced. Thomas et al. (2015) found that at least in cities fatalities of cyclists are often linked to a crash where a cyclist is next to a truck that is turning at a junction. In these cases cyclists are often overrun by the rear axle(s) of the turning HGV because the rear part of the truck moves on a smaller curve radius than the front and thus cuts the curve into the path or position of the cyclist. The study also showed that protection by lateral side guards in these types of accidents is limited because the cyclist often has his initial contact with the front side of the truck, the cyclist then falls to the ground and passes underneath the side guards between the axles and is then run over by the following axle. Negative impacts for both types of underrun protection area reduction of the vehicle functionality or its off-road capability due to the added structures under the HGV's body as identified by a document produced by TRL in the scope of a GSR-2 report (TRL, 2016). Due to the increased mass of the underrun protection structures the payload of the HGV may be decreased and fuel consumption and emissions are likely to increase.		

	In Great Britain approximately 45% of killed or seriously injured (KSI) road users in impacts with HGVs were car occupants and in Europe between 7.2% and 14.3% of car to HGV accidents were relevant to RUP (Smith et al., 2008). Furthermore British data indicates that if the rear of an HGV can be designed to ensure that the crash structure at the front of the car is engaged by an effective RUP and that the car provides protection to the occupants at speeds up to 56km/h, then approximately 50% of the fatalities could be prevented. For these RUP, next to the stiffness of the structure, the ground clearance has been identified as one of the most critical factors in producing an effective underrun device.
Lever 1: Technology	When collisions with the rear end of an HGV occurs, the crash structure of the smaller vehicle tends to pass underneath the stiff structures of the HGV, thus bypassing the safety systems of the car and often resulting in extensive passenger compartment intrusion and serious or fatal injury. RUP systems are intended to provide a stiff structure like a bumper underneath the stiff structures of the HGV to prevent this underrun and to provide a stable surface for the front of the car to interact with the HGV and to allow the frontal crush zone of the car and restraint systems of the car to work as they were designed to. By achieving this, the protection offered to occupants can greatly be increased (Smith et al. 2008). This literature review by Smith et al.,(2008) found that occupant compartment displacement of a crash opponent reduced when the ground clearance of the RUP was reduced from 560mm to 400mm and that there was still 30mm reduction in displacement when ground clearance was changed from 480mm to 400mm. Subsequently, there is margin to improve the technology.
Lever 2: Standardization	Extend the standardization of the system to other type of vehicles.
Lever 3: Regulation	The fitment of RUP to HGVs was made mandatory by the directive 70/221/EC. In 2006, the directive was amended (2006/20/EC). However, this regulation sometimes is not sufficiently dimensioned in terms of rigidity and position to withstand severe car impacts, so it can be improved
Lever 4: consumer test	This lever does not seem appropriate for this safety measure. There are no consumer tests for these systems.
Lever 5: cost reduction	Improving the technology and setting up standard systems that could be used in all type of HGVs would reduce the costs.
Lever 6: interaction with other safety domains	The underrun protection might have no interaction with other safety domains but V2V systems, Blind spot detection, AEB for trucks and other ADAS systems could reduce this type of accidents. Another essential aspect could be the education and behavior of VRUs regarding their interaction with HGV.
Lever 7: Application	Transferability to other countries should be considered given the potential of this measure.

4.10 ACTIVE SAFETY – LONGITUDINAL CONTROL

4.10.1 Emergency Braking Assistance system

Colour Code: **Green**

Active safety / ADAS	Longitudinal	
Emergency Braking Assistance system		
Summary	Emergency Brake Assist (EBA) is an active safety system which provides extra braking power when the driver attempts to perform an emergency stop. A sensor attached to the brake pedal allows the system to detect when the driver attempts an emergency stop and apply maximum braking force (depending on the road friction coefficient that can be mobilised) in order to avoid the collision. This system is not automatic and operates only when an emergency braking maneuver is initiated by the driver. A systematic literature search has been conducted and four relevant studies have been selected and analysed. The studies were executed using data sets from European Member states, two from France, one from Germany and one from Spain. The safety benefits of the EBA combined with other features (Antilock Braking System, warning system, cars rated by EuroNCAP) have been studied using retrospective and prospective methodologies. A case – control study was conducted to estimate the effects of the EBA systems on the accidents' outcomes in the retrospective studies. And within the framework of prospective studies, the EBA's efficiency was calculated by simulating the effect of the systems and estimating their effects on the outcomes of injuries and accidents. In general, the findings show that the EBA is efficient in reducing the accident numbers and injury severities.	
Lever 1: Technology	EBA system would have benefits for the crashes where braking performance is a factor. In fact rear-end and head-on collisions, merging and intersection collisions, as well as collisions with vulnerable road users and obstacles could be concerned by the system. Studies show that in emergency situation about 50% of drivers do not press the brake fast enough or hard enough to make full use of their vehicle's breaking power. Hence, during an episode of emergency braking, EBA could assist the driver by avoiding the crash or by mitigating the injury severity by reducing the impact speed. No improvement in technology is expected as it seems to work correctly, but the effectiveness of the EBA should be improved by combining with driver monitoring system, in addition to assist the driver during the emergency situation, the system identifies the driver's activity and warn the driver according to his driving behavior (speeding, distracted driving,…). This would help to have an effective braking.	

Lever 2: Standardization	Extend the standardization of the system to other type of vehicles.
Lever 3: Regulation	The mandatory fitting of Emergency Brake Assist for new vehicles in the European Union has been established by Regulation (EC) 78/2009 for the motor vehicles of categories . The Regulation should be extended to other category of vehicles (e.g PTW).
Lever 4: consumer test	This lever does not seem appropriate for this safety measure.
Lever 5: cost reduction	The Cost Benefit Study conducted within the SafetyCube project shows the benefits tend to exceed the costs for the EBA system and hence the cost reduction should be a positive lever to increase the fitment of the EBA in the vehicles. The democratization of the system will be a lever of cost reduction, in order to increase the fitment of EBA on the vehicles.
Lever 6: interaction with other safety domains	For the EBA combined with driver monitoring system, driver should be informed on the presence, the performance and the functioning of the system.
Lever 7: Application	Transferability to other countries can be considered but one should be very careful of the fact that the efficiency of EBA may be sensitive to driver characteristics (age, gender, …) and infrastructure (road conditions).

4.10.2 Autonomous Emergency Braking AEB (City, interurban)

Colour Code: Green

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Active safety / ADAS	Longitudinal	

Autonomous Emergency Braking AEB (City, interurban)

Summary	Autonomous Emergency Braking (AEB) is an in-vehicle system that can avoid a crash with another vehicle or mitigate its consequences by automatically applying the brakes. The term AEB is usually followed by the words "city" or "interurban" which designate the environment where it is supposed to be the most efficient. AEB city can work only at low speeds (below 30 or 50 km/h) while AEB interurban can work only at high speeds. Depending on the system supplier or manufacturer, the system may give a warning to the driver and apply the brakes only in case of no driver reaction. Results are based on a literature review of the benefits of AEB city and interurban systems in terms of reduction in accident numbers and injury severity. A systematic literature search has been conducted and relevant studies have been analysed. No relevant study was found dealing with AEB interurban while five relevant studies were found for AEB city. Four of them undertook retrospective analyses and only one prospective analysis was found. The latter consists of a study of the potential benefit of AEB systems in reducing injuries in frontal crashes between heavy goods vehicles and passenger cars, if the system was designed to work in this configuration. The other studies demonstrated that AEB city is efficient in reducing rear-end crashes and injuries in different environments and on different car models

Lever 1: Technology	AEB technology usually uses a combination of sensors (camera & radar, or camera & LIDAR) in order to detect and classify objects, and estimate trajectories of and collision probabilities with these objects. Most of AEB effectiveness studies were based on Volvo's "City Safety" system (low speed AEB) and demonstrated good rate of accident reduction even for zones where speed limit was higher than the system speed range. However, future AEB systems will tend to take account of a wider range of accident scenarios (front-to-front, front-to-side, ...) by increasing the speed range, the sensors field of view, and the amount of braking deceleration. These new settings could lead to higher activation frequency of the system and probably to a higher amount of false activations. In the cases where the system braking deceleration is increased, the consequences of false activations would be probably more serious, as the driver behind the AEB equipped vehicle wouldn't have enough time to brake efficiently. Vehicle-to-vehicle communication systems (V2V) could be a solution for mitigating the consequences of false activations, but while waiting for large scale implementation of V2V systems, more studies and tests should be undertaken in order to determine the effects of false activations before the implementation of the new generation AEB systems.
Lever 2: Standardization	Few years ago, AEB was only fitted on high-end (luxury) vehicle models. Today, many vehicle manufacturers offer AEB as part of a safety pack and other manufacturers have even included it as standard equipment on many of their new models. No standard AEB model is known. AEB parameters and use domain could vary from one manufacturer to another and from one vehicle model year to another. The effect of the standardization of AEB on vehicle is at this day not known both for cost reduction and effectiveness.
Lever 3: Regulation	No regulation actually exists for AEB that equip light passenger vehicles. In the US automobile manufacturers voluntarily committed to make AEB standard on all new light vehicles by 2022. The implementation of a regulation on this item could lead to a large adoption of AEB which could be of safety benefit.
Lever 4: consumer test	AEB was introduced in the Euro NCAP rating of 2014. The ability of avoiding and mitigating rear-end crashes was first tested. In 2016, AEB pedestrian systems were added to the tests and AEB cyclists will be added in 2018. In its roadmap, Euro NCAP reveals that it plans on testing AEB systems in other scenarios by 2020 to address cross-junctions, head-on and reversing accidents. Testing false positive cases could improve the effectiveness of the system and limit the crashes (if any) due to a false activation. It would improve the acceptance and confidence of drivers in the system. Some Ncaps protocols are planning to do such tests. As no regulation exists for implementation of such systems in passenger cars, the only lever existing at this day is the consumer test programs.

Lever 5: cost reduction	As AEB technology tends to get more sophisticated (use of a combination of advanced sensors), the only lever of cost reduction of this technology is its democratization. However, as future AEB will address more accident scenarios, the target population of this technology will be much larger. The AEB sensors could also be shared with other systems like, for example, the Lane Keeping Assist system. This will help reducing the cost-benefit ratio.
Lever 6: interaction with other safety domains	Just like many ADAS systems, AEB should be of ergonomic use and drivers should be educated to the use of these systems to get the most benefit. Standardization of the technology and the development of standard HMI could be of great help in this domain. Today, many drivers think that automatic functions are not safe and tend to turn off these systems. Some deviant behavior could also happen as drivers could be overconfident and drive dangerously while counting on AEB to stop the vehicle when there is a collision probability.
Lever 7: Application	AEB systems are already mandatory in Europe since 2015 on trucks (see corresponding safety measure sheet) and other heavy vehicles and could also be added to powered two wheelers.

4.10.3 Autonomous Emergency Braking AEB (Pedestrians & cyclists)

Colour Code: Green

Active safety / ADAS	Longitudinal	
Autonomous Emergency Braking AEB (Pedestrians & cyclists)		

Summary	Autonomous Emergency Braking (AEB) for pedestrian and cyclist is an in-vehicle system that can avoid a crash with a pedestrian or a cyclist or mitigate its consequences by automatically applying the brakes. Depending on the system supplier or manufacturer, the system may give a warning to the driver and apply the brakes only in case of no driver reaction. Other parameters may vary from one system to another, depending on the sensing and braking technologies that were used by the manufacturer, thus influencing the outcome in terms of accident avoidance and mitigation. Results are based on a literature review of the benefits of AEB pedestrian and cyclist systems in terms of reduction in accident numbers and injury severity. A systematic literature search has been conducted and relevant studies have been analyzed. Certainly due to the fact that the system is relatively recent and that the market penetration is still weak, most of the studies consisted of prospective analyses of the system's effectiveness by simulating the effect an AEB system would have had on the accidents' outcomes. Only one study comprises a retrospective analysis but the results were not statistically significant due to the small sample size. However, all results seem to agree that AEB is efficient in reducing pedestrian and cyclist accident numbers and severities. Effectiveness can vary from 2.2% to 84%. This is subject to the outcome definition and to the system parameters that were taken into consideration.
Lever 1: Technology	When vehicle speed is low, AEB should be easily able to avoid a crash by automatically applying the brakes and stopping the vehicle. However, due to the low speed of the vehicle, crossing pedestrians and cyclists may not be detected if the field of view of the sensor is not wide enough. This is typically the case of urban areas where accident scenarios include many vehicles going at relatively low speeds and crashing with crossing VRUs. The installation of more sensors is one solution to improve the detection of cyclists and pedestrians in a number cases that seems to be not negligible. The combination of AEB VRU with vehicle to vehicle and vehicle to infrastructure systems may improve significantly the efficiency by detecting some VRU that are not easily visible or masked. Automatic Emergency Steering could be also combined with AEB VRU to avoid accidents that are only mitigated if the vehicle is only equipped with AEB VRU.

Lever 2: Standardization	AEB pedestrian and cyclist is not yet a standard feature but had begun to equip more and more vehicles (especially AEB pedestrian). While some manufacturers are just beginning to equip their vehicles, some others have made the step to make it standard on some of their models or on all their new models. The effect of the standardization of AEB on vehicle is at this day not known both for cost reduction and effectiveness.
Lever 3: Regulation	No regulation actually exists for AEB that equip light passenger vehicles. The implementation of a regulation on this item could lead to a large adoption of AEB which could be of safety benefit.
Lever 4: consumer test	More scenarios should be added to the Euro NCAP tests like situations in which the vehicle is turning and scenarios to test false activations. As no regulation exists for implementation of such systems in passenger cars, the only lever existing at this day is the consumer test programs.
Lever 5: cost reduction	As AEB technology tends to get more sophisticated (use of a combination of advanced sensors), the only lever of cost reduction of this technology is its democratization. However, as future AEB will address more accident scenarios, the target population of this technology will be much larger. The AEB sensors could also be shared with other systems like, for example, the Lane Keeping Assist system. This will help reducing the cost-benefit ratio.
Lever 6: interaction with other safety domains	Just like many ADAS systems, AEB should be of ergonomic use and drivers should be educated to the use of these systems to get the most benefit. Standardization of the technology and the development of standard HMI could be of great help in this domain. Today, many drivers think that automatic functions are not safe and tend to turn off these systems. Some deviant behavior could also happen as drivers could be overconfident and drive dangerously while counting on AEB to stop the vehicle when there is a collision probability. What is not yet analyzed in the effectiveness studies is the interaction of such safety measures with the environment and the other road users using vehicles not equipped.
Lever 7: Application	AEB systems are already available on trucks and on some other heavy vehicles but it is not clear if the pedestrian and cyclist detection is covered. Nevertheless, the system could also be added to powered two wheelers.

4.10.4 Emergency Stop Signal (ESS)

Colour Code: Grey

Active safety / ADAS	Longitudinal	

Emergency Stop Signal (ESS)	
Summary	Rear-end crashes account for a substantial share of all road crashes. Often these crashes occur because the driver of the following vehicle is not fully focused on the lead vehicle and then fails to react in time when the lead vehicle performs a sudden emergency brake maneuver. The emergency stop signal is a vehicle measure to reduce the response times of the following vehicle in this situation. The signal is displayed either by flashing direction-indicator lamps (hazard warning lights) in addition to the lit brake lights or by the brake lights flashing instead of just lighting up.
Lever 1: Technology	Concerns have been raised that the use of ESS in a fleet that is not completely fitted with it might lead to no or negative effect on road safety (e.g. following vehicle n°1 will perceive ESS fitted lead vehicle's lights, but not following vehicle n°2 if n°1 is not fitted with ESS itself). In this transitory state where no regulation mandates ESS, V2V communication could help supplement ESS and makes its social acceptance easier.
Lever 2: Standardization	Today, there is no agreement on what should be the most relevant way to gain attention from the following vehicle: UNECE R28 prescribes that the emergency stop signal be given by the simultaneous operation of all the stop or direction-indicators present on the vehicle; recent research suggests that direction indicator flashing should be more efficient than brake flashing; and a handful of carmakers actually advertise having set hazard light rapid flashing for the purpose. Standardization in this domain would be highly beneficial - both in terms of cost-effectiveness for carmakers and of social acceptance.
Lever 3: Regulation	ESS technology - like many ADAS - can only reach its true potential for road safety when either combined with other technologies (such as V2V communication) or made mandatory in all vehicles, be it by regulation or under the pressure of consumer demand. Regulation is not only a lever for this measure, but it is a part of its efficiency.
Lever 4: consumer test	V2V communication will provide drivers with the information they need in order to anticipate potential crashes. Euro NCAP roadmap 2020-2025 plans to set V2X technology testing but the exact protocol is not decided yet. ESS could be included in this package.
Lever 5: cost reduction	Only by mandating ESS we will reach both efficiency and cost reduction as the need to couple ESS with V2V for efficiency will disappear.

Lever 6: interaction with other safety domains	V2V communication could help supplement ESS and makes its social acceptance easier
Lever 7: Application	This system could be proposed for all types of motorized vehicles

4.10.5 Braking system PTW (ABS, Combined braking system …)

Colour Code: Green

Active safety / ADAS	Longitudinal	

Braking system PTW (ABS, Combined braking system, …) ABS (PTW)	
Summary	In the category of Powered two wheeler (PTW) braking systems, devices designed to increase braking features and stability control of motorcycles have been included. The PTW braking systems have evolved during the last decade but unfortunately not as rapidly as passenger car safety systems. The PTW braking systems have the potential to considerably reduce motorcycle accidents and to reduce their consequences. There are some systems that have been proved to be very effective in certain configurations i.e. PTW Active Braking Systems, and others that are not fully developed but have a great potential to contribute to PTW safety e.g. Electronic stability control. The literature reviewed provides insights of the effectiveness of the multiple systems and indicates that the newer technologies and systems need more development and/or conclusive studies to determinate their efficiency.
Lever 1: Technology	No technological enhancement levers were identified for ABS and CBS systems. For electronic stability control system, current research is being focused on the design of activation and deactivation logic to ensure that the system intervenes only in the face of dangerous situations and to develop the system to be helpful in more accident critical events. Moreover, the sensitivity to the actuators' bandwidth has to be investigated. Finally, a robustness analysis of the proposed control strategies has to be performed. ESC for motorcycles needs further investigation to help with more safety critical events.
Lever 2: Standardization	ABS is standard on motorcycles above 125 cm^3. It can also have a positive impact in the crash risk for less powerful bikes. However, it will be challenging, in the short term, for this technology to quickly penetrate this market, unless it becomes mandatory. For light motorcycles (< 125 cm^3), CBS could be a useful alternative for a much lower cost.
Lever 3: Regulation	International and European regulations require PTWs to be fitted with independent controls for the front and rear brakes. As of 2016 in Europe, ABS has been mandatory on new motorcycles above 125 cm3. The adoption of a regulation making ABS mandatory on all types of motorcycles could be beneficial for rider safety.
Lever 4: consumer test	No consumer test actually exists for PTW safety systems. The adoption of a consumer test could be beneficial to promote the equipment of more PTWs with such systems.

Lever 5: cost reduction	The use of CBS instead of ABS could be a lever of cost reduction. However, CBS is not as efficient as ABS in preventing brakes from locking. Thus the benefit would not be the same. Standardization of ABS could be a lever for cost reduction.
Lever 6: interaction with other safety domains	Riders should be made aware of the importance of such systems. They should also be educated on the way these technologies help avoiding crashes and how they should be used correctly without overconfidence.
Lever 7: Application	The benefits and limitations of the various Advanced Braking Systems vary significantly per type of vehicle. The weight, weight distribution, the center of gravity and the rider braking behaviour have an influence on the braking capacity of the system.

4.10.6 Collision Warning system

Colour Code: Grey

Active safety / ADAS	Longitudinal	
Collision warning		

Summary	In-vehicle systems related to collision warning assist drivers to react in time in order to avoid a collision. Collision warnings have the potential to reduce the number of rear-end collisions. These systems inform drivers to use the brakes to reduce speed. Thus, drivers react to the warning signal. The intention is to make drivers immediately look forward and assess the threat to make an important safety decision: either to hit the brake pedal or to continue driving at the same speed. Simulator and field experiments showed that this measure has mixed and unclear effects on the level of road safety, and more specifically on road safety outcome indicators like travel speeds, reaction time, force on brake etc. Five high quality studies consisting mainly of simulator experiments were coded. The effects of collision warning systems in cars on road safety tend to have mixed and unclear effects. Usually the various study findings report improved driving performance indicators stemming from simulator studies. However, there are many cases where non-significant or negative results (deterioration of road safety) are also observed (Bueno et al., 2014; Wege et al., 2013). With regard to vehicle speed there are inconclusive results. Other common road safety indicators such as reaction time and distance to lead vehicle are improved after implementation of collision warning systems. A major drawback observed in some studies is the lack of statistical tests, since only before-after differences are reported and they lack standard errors.
Lever 1: Technology	Concerns have been raised that the use of Collision warning systems due they can produce a negative response or an overreaction. However there is no sufficient filed data to assess these systems. There are studies considering Improved Cooperative Collision Warning System (ICCWS) which take into account the curvature of the road. Another way of improved these systems is through intervehicle communication or V2V communication, Intelligent speed adaptation, Adaptative Cruise Control and any other ADAS helping to maintain a safe distance with the other vehicles.
Lever 2: Standardization	There is no standardization of these systems. Each manufacturer uses their own product.
Lever 3: Regulation	Collision warning system can only reach its true potential for road safety when either combined with other technologies (such as V2V communication) or made mandatory in all vehicles, be it by regulation or under the pressure of consumer demand. Regulation is not only a lever for this measure, but it is a part of its efficiency.

Lever 4: consumer test	Collison warning could improve if there is a set protocol to assess their effectiveness in consumer tests.
Lever 5: cost reduction	If the collision warning systems are mandatory and they are standardized then they will be efficient and more affordable
Lever 6: interaction with other safety domains	These systems should interact with other in-vehicle systems like ABS, LDW or AEB and with infrastructure systems to be more efficient. The acceptability of such a systems, and the adaptation of the driving of the user needs to be increased by safety campaigns promoting the potential benefice of such devices.
Level 7: Application	These systems could be developed for all types of motorized vehicles

4.10.7 Intelligent Speed adaptation, Speed Limiter & Speed regulator

Colour Code: Light Green

Active safety / ADAS	Longitudinal	

Intelligent speed adaptation + Speed Limiter + Speed regulator	
Summary	In-vehicle systems assist drivers to maintain a safe speed or prevent them from driving above the speed limit. Observational and field experiments showed that this measure affects the level of road safety, causing a reduction in travel speeds, an improvement of safety performance indicators and a reduction in fatal crashes. Six high quality studies regarding field experiments were coded. On the basis of both studies and effect numbers, it can be argued that speed adaptation systems create a generally positive impact on road safety. There were cases, however, where results did not include any statistical tests, and therefore conclusions cannot be strongly supported. The results seem generally transferable with caution.
Lever 1: Technology	Speed adaptation and speed limiter systems check if vehicles are complying with the speed limit on roads and warn the driver or prevent him from excessive speeding by applying a counter pressure to the accelerator pedal. There are various such systems and each one might be considerably different from the other, but in general, the systems are based on a GPS receiver, which continuously identify the position of the vehicle, and a digital map containing all the current speed limits within this area. A lever of technological enhancement would be to include dynamic speed limits that take account of the actual circumstances at a particular moment in time. This could happen for example by adding information from traffic sign recognition systems to adapt to certain circumstances like speed limit reduction due to public works. This is actually the case of warning systems that are equipping the latest vehicle models. Weather information could also help to give advisory speed limits.
Lever 2: Standardization	ISA and speed limiter systems are only found in premium luxury cars and may be part of safety packs for other kinds of passenger cars. Standardization of the system is recommended in order to get the best benefit for road safety.
Lever 3: Regulation	No regulation actually exists for this system. The implementation of a regulation on this systems could lead to a large adoption of ISA which could be of safety benefit.

Lever 4: consumer test	No consumer test actually exists for ISA. In its roadmap, Euro NCAP mentions that speed assistance systems could be tested by 2020, but no more information is given on the type of test and systems to be tested. The implementation of consumer tests for ISA would be a good incentive to manufacturers to equip more vehicles with this system.
Lever 5: cost reduction	Democratization of the system and sharing the GPS and/or camera with other safety systems could be a lever for cost reduction.
Lever 6: interaction with other safety domains	ISA is based on the interaction with the driver and the infrastructure. The speed limits should be given by the infrastructure to the system so that by its turns it would give a warning to the driver and/or a counter pressure on the accelerator pedal if he exceeded the speed limit. V2X systems should help getting real-time information from infrastructure in order to adapt speed limits to real-time environment. Driver feedback is also important and more studies should be carried out in order to find the effects ISA would have on driver behaviour. Some concerns have been reported like: 1- Drivers tend to compensate by driving faster on road segments where ISA is not active. 2- Drivers diminished attention and over reliability on the system. 3- Drivers feeling frustrated and turning off the system.
Lever 7: Application	ISA is suitable to equip all types of motor vehicles.

4.10.8 Adaptive Cruise Control (ACC & ACC Stop & start)

Colour Code: Grey

Active safety / ADAS	Longitudinal	

Adaptive Cruise Control (ACC & ACC Stop and start)	
	Adaptive Cruise Control (ACC & ACC Stop & start)
Summary	Adaptive cruise control (ACC) is an active technology that constantly monitors and adapts a vehicle's throttle and braking systems to maintain a safe distance to a vehicle ahead. ACC uses a range of sensing technologies to identify and measure the gap to a vehicle ahead while simultaneously automatically commanding the release of the throttle pedal and, potentially, by automatically commanding braking. The most advanced Radar ACC systems can provide information for forward obstacle warning (FCW) or Advanced Emergency Braking (AEB) systems enabling them to be integrated fully into the ADAS vehicle capability. Overall adaptive cruise control affects road safety as it can provide support to drivers in maintaining a safe speed and distance to a vehicle ahead. ACC predominantly affects road safety through management of the longitudinal control of vehicles travelling on roads where non-motorised vehicles and pedestrians are restricted or limited (highways for example) and under free-flowing traffic conditions.
Lever 1: Technology	Drowsiness and distraction recognition systems, when coupled with ACC, would be beneficial for ACC social acceptance - by suppressing risks of involuntarily going out of ACC. Coupling ACC with LDW, FCW and AEB would provide drivers with a self-contained safety package, thus enhancing the consumers' interest for this technology. To this day, ACC technology is prone to errors when used in bad weather conditions, exposed to a consequent level of blinding light (from traffic or infrastructure) or when infrastructure contrast in e.g. markings is poor or confusing. Progress in this direction is an important step towards social acceptance of this technology.
Lever 2: Standardization	Not relevant in this context

Lever 3: Regulation	ACC technology - like many ADAS - can only reach its true potential for road safety when either combined with other technologies (such as FCW, AEB or V2V communication) or made mandatory in all vehicles, be it by regulation or under the pressure of consumer demand. Regulation is not only a lever for this measure, but it is a part of its efficiency.
Lever 4: consumer test	Testing the efficiency of the ACC does not seems to be relevant in this context, but rewarding its presence in a vehicle could be a good way to increase the number of models on which the system is proposed.
Lever 5: cost reduction	Coupling ACC with other ADAS in a global safety package would certainly be very cost effective
Lever 6: interaction with other safety domains	In a context where ACC technology is still prone to errors when exposed to a consequent level of blinding light from the road infrastructure or when infrastructure contrast in e.g. markings is poor or confusing, any progress in upgrading the road network in order to make it more "readable" by a non-human sensor would be beneficial. Concerns have been raised that the use of ACC in a fleet that is only partially fitted with it might lead to no or negative effect on road safety (e.g. aggressive traffic would immediately fill in the headway left by ACC vehicles).
Lever 7: Application	This safety measure can be adapted to other types of vehicles.

4.11 ACTIVE SAFETY – LATERAL CONTROL

4.11.1 Electronic Stability Control (ESC)

Colour Code: Green

Active safety / ADAS	Lateral control	

Electronic Stability Control (ESC)	
Summary	Electronic Stability Control (ESC) is a system that prevents a vehicle from understeering or oversteering. It aims at reducing the risk of vehicle loss of control. ESC was introduced in the European and American markets in the nineties. Since 2000, more and more passenger cars are being fitted with ESC and it became mandatory for all new cars after 2010. From 2000, many studies focused on ESC and its effectiveness. As a significant number of vehicles were equipped with ESC, researchers conducted retrospective studies based on accident data. The evaluation methodology relied on a comparison between two groups of crashes: the case group and the control group. The case group concerns accidents sensitive to ESC and in the control group, it is expected that ESC would have no effect on the accidents. In both groups, it is necessary to identify vehicles equipped or not with ESC. The first challenge was the identification of vehicles equipped or not with ESC as ESC was not a standard safety system. So they used different vehicle criteria to identify them. The second challenge was to choose the control group. Several accident situations were identified as ESC non-sensitive situations. Then, several accident parameters were studied that make it difficult to compare the results. Nevertheless, we can easily conclude that all these results confirm the great effectiveness of ESC.
Lever 1: Technology	No need for technological enhancement is detected or reported for ESC
Lever 2: Standardization	It is shown that it could be of great benefit to make ESC as standard equipment.

Lever 3: Regulation	In Europe, Regulation (EC) No 661/2009 foresees mandatory fitting of ESC on all vehicles from November 1st 2011 for new types of vehicles and from November 1st 2014 for all new vehicles. In the US, legislation passed in 2007 making ESC mandatory standard equipment for all passenger cars, multipurpose vehicles, trucks and buses with gross vehicle mass of 4,536 kg or less from model year 2012. In November 2007, the United Nations announced it would require trucks and heavy vehicles to be fitted with ESC from 2010. Many countries (Australia, Canada, Israel, Japan, New Zealand, the Republic of Korea, the Russian Federation, and Turkey) have been adopting diverse legislations on making ESC mandatory on parts of their motor vehicle new fleet. Global NCAP and Latin NCAP are pushing to make ESC legislation adopted by even more countries and for all vehicles new fleet.
Lever 4: consumer test	Since 2009, Euro NCAP started rewarding vehicles with ESC fitment. Between 2011 and 2013, additional functionality tests on all cars equipped with ESC were performed. Since 2014, Euro NCAP has stopped testing ESC as fitment of the system was made mandatory. Latin NCAP actually performs ESC tests, thus pushing to a large adoption and legislation of the system in Latin America. The system is assessed by performing a series of "sine-with dwell" tests, based on a double lane change maneuver.
Lever 5: cost reduction	No levers for cost reduction have been identified.
Lever 6: interaction with other safety domains	Some aspects of ESC interactions with experienced drivers should be studied. Experienced drivers tend to compensate by themselves for skidding by classical maneuvers and maybe reduce the effectiveness of the system?
Lever 7: Application	When it's feasible, ESC should equip all types of vehicles.

4.11.2 Lane Departure Warning (LDW), Lane Keeping Assist (LKA) & Lane Centering System

Colour Code: Grey

Active safety / ADAS	Lateral control	

Lane Departure Warning (LDW) + Lane Keeping assist (LKA) + Lane centering system	
Summary	Lane keeping assist systems (LKA) and lane departure warning systems (LDW) are drivers' assistance systems for vehicles intended to prevent crashes which occur due to an unintentional lane departure. The systems do so by utilizing cameras to detect the lane by its lane markings and road edge lines and warn the driver about a lane departure when no turn signal was used by an acoustic signal or by a haptic signal (e.g. vibrating steering wheel). LKA systems not only warn the driver but help the driver to stay in lane usually by actively applying torque to the steering wheel in to the opposite-direction thus LKA systems provide a higher level of assistance to the driver and the benefit is likely to be higher than that of a LDW.
Lever 1: Technology	Drowsiness and distraction recognition systems, when coupled with Adaptive Cruise Control (ACC), would be beneficial for LDW/LKA social acceptance - by suppressing risks of involuntarily going out of ACC. Coupling LDW/LKA with ACC, FCW and AEB would provide drivers with a self-contained safety package, thus enhancing the consumers' interest for this technology. To this day, LDW/LKA technology is prone to errors when used in bad weather conditions, exposed to a consequent level of blinding light (from traffic or infrastructure) or when infrastructure contrast in e.g. markings is poor or confusing. Progress in this direction is an important step towards social acceptance of this technology.
Lever 2: Standardization	NCAP protocols for LDW/LKA exist in Europe, Australia/New-Zealand and Japan whereas no such thing exist in Korea or the Americas. ASEAN NCAP status is in between as no field test exists to assess LDW/LKA performance, but manufacturer may have to prove the compliance of their system to a package of "Functional Definitions". Standardization here would certainly be beneficial, giving consumers a clearer picture when comparing systems.
Lever 3: Regulation	UNECE regulation R79 was updated in December 2017 to take active systems such as LKA into account. Transcription of this document into local regulations would certainly be beneficial.
Lever 4: consumer test	No consumer test presently exists for LKA. The implementation of consumerist tests would be a good incentive to manufacturers to equip more vehicles with this system.

Lever 5: cost reduction	Coupling LDW/LKA with other ADAS in a global safety package would certainly be very cost effective
Lever 6: interaction with other safety domains	In a context where LDW/LKA technology is still prone to errors when exposed to a consequent level of blinding light from the road infrastructure or when infrastructure contrast in e.g. markings is poor or confusing, any progress in upgrading the road network in order to make it more "readable" by a non-human sensor would be beneficial.
Lever 7: Application	This safety measure could be transferred to other types of vehicles.

4.12 ACTIVE SAFETY – DRIVER ASSISTANCE

4.12.1 Alcohol Interlock (ALC)

Colour Code: Light Green

Active safety / ADAS	Driver assistance	
Alcohol interlock (ALC)		
Summary	Field experiments showed that this measure has clear effects on the level of road safety in terms of engine stops when the blood alcohol concentration is high. Two high quality experimental studies were coded. On the basis of both studies and effect numbers, it can be argued that alcohol interlock systems have a mixed impact on road safety. There were also cases where results did not include any statistical tests, and therefore conclusions cannot be strongly supported. The results seem generally transferable but this should be done with caution.	
Lever 1: Technology	Alcohol interlock technology could include sensors for breath pressure and breath temperature so that drivers would not bypass the system by blowing compressed air into the breath analyser. Face recognition technology would also help so that ignition of the vehicle would not happen if someone other than the driver blows into the breath analyser.	
Lever 2: Standardization	Alcohol interlock systems are not yet standard, but different organizations are urging for legislation in order to make it mandatory on all new vehicles. No voluntary standardization could be envisaged as this could be considered by car owners as an enforcement measure and thus reduce the appeal for vehicles equipped with the system.	
Lever 3: Regulation	Few countries have adopted legislations and these mostly concern installing interlocks on cars of drivers that have already been controlled or convicted for driving while having a certain amount of alcohol in their blood. Sweden and Finland have implemented the technology in both government and non-government services, including commercial transport vehicles, taxis and child transport. In France, such a system is mandatory for coach and bus drivers since the 1st of September 2015. Its installation for private light vehicle users remains very low and the acceptability of the system is really bad for multiple reasons. The adoption of a regulation could be of great benefit as high proportions of crashes (especially high severity crashes) are due to alcohol.	

Lever 4: consumer test	No rewarding in NCAP programs actually exists for vehicles equipped with alcohol interlock systems. In its roadmap, Euro NCAP mentions driver monitoring for 2020 but no precision if alcohol monitoring would be part of the program. Rewarding with NCAP points the vehicles that have alcohol interlock systems, could be a good incentive that leads to consumer acceptance and to fitment of more vehicles with the system.
Lever 5: cost reduction	Democratization of the system could be a lever for cost reduction.
Lever 6: interaction with other safety domains	One of the biggest challenges for this technology is its widespread acceptance by the drivers. On one hand, it could be considered by many as a repressive measure and on the other hand, there are many rumors and real facts that can mix-up and in terms of reliability of the technology. For example, eating some kind of food may alter the results, so it is recommended to wash their mouth out with water before blowing into the breath analyser. Driver education and awareness campaigns should be carried out in order to introduce drivers to the relevance of this system, its benefits, and the exact way to use it.
Lever 7: Application	Alcohol interlock systems could be applied to all vehicle types.

4.13 ACTIVE SAFETY – VISIBILITY ENHANCED

4.13.1 Enhanced headlights

Colour Code: Grey

Active safety / ADAS	Visibility enhanced	

Enhanced Headlights (automated, adaptive, advanced system, …)	
Summary	Adaptive headlights rotate in the direction of steering and are intended to improve visibility on curved roads. There is a lack of studies that can quantify the safety benefits of adaptive headlights. Jermakian (2011) estimated that adaptive headlights could prevent 2% (142 000) of the annual passenger vehicle crashes in the US.
Lever 1: Technology	Adaptive headlights use different technologies in order to adapt the lighting to the road and traffic conditions. Earlier systems (since 2004 in the United States) used electromechanical control of headlights that rotates the light source in order to ensure optimum illumination of the lane on curved roads. They usually used the Xenon High Intensity Discharge (HID) lamps as light source. In order to control the system, input data such like vehicle yaw rate and steering wheel angle can be used. These inputs, combined to the complexity of design and installation of the mechanical actuator, make the system relatively expensive and difficult to adapt to situations like preceding or oncoming traffic. This may generate glare to the other drivers. Today, new vehicles often use LED lighting technologies. These technologies are more adaptable and don't need the use of complex mechanical installations as the light source can be designed to control the direction of the beam without moving the source itself. This gives the possibility to simply design light beams that give the driver the best possible visibility without the risk of glare to other drivers. While both technologies could be beneficial to road safety, it is evident that the adaptive headlight using LED may have an advantage on the one using HID.
Lever 2: Standardization	Adaptive headlights are not yet standard but a US study estimated that 95% of the fleet would be equipped with this technology by 2044. LED headlights actually equip expensive vehicles but they are getting more popular as, in the mind of the public, they are associated to beautiful designs. As LED is easier and less expensive to modulate, most vehicles equipped with LED headlights would be equipped with adaptive headlights.
Lever 3: Regulation	No regulation exists on adaptive headlights. The adoption of a regulation would speed up the process of making the technology standard, but it is not clear if this could be a safety benefit, as there are not enough studies mentioning the direct impact of this technology on road safety.

Lever 4: consumer test	As safety benefits of this system are still not clear, consumer testing organizations like Euro NCAP give a reward to vehicles equipped with enhanced headlights without including it in the general safety rating of a vehicle.
Lever 5: cost reduction	The use of LED headlights and the democratization of such lighting systems could be the levers for cost reduction.
Lever 6: interaction with other safety domains	The extent of road safety impact of such a system will obviously rely on the interaction with other safety domains such like infrastructure and human behaviour. For example, in places where the traffic is relatively dense, the benefits of enhanced visibility could be outweighted by the drawbacks of the glare it generates to other road users. On the other hand, the benefits will also rely on how drivers will adapt their behaviour to the increased visibility conditions.
Lever 7: Application	Adaptive headlights can equip all types of vehicles.

4.13.2 Daytime running lights

Colour Code: Green

Active safety / ADAS	Visibility enhanced	

Daytime running lights	
Summary	Daytime running lights (DRL) refers to headlights that are switched on while driving in daylight. The main purpose of daytime running lights is to make vehicles more conspicuous and easier to detect in any light condition, thereby reducing daytime multi-party accidents. Results provide consistent support that the cars using daytime running lights are involved in fewer multiple-party accidents than cars not using DRL. Studies evaluating the effect of mandatory use of DRL show smaller safety effects. Three out of three meta analyses and another individual study showed a reduced accident rate. There are several potential influencing factors, but in most cases, there are too few studies to make any conclusions.
Lever 1: Technology	The Daytime running lights could increase the fuel consumption there for therefore the costs. The system should be improved on this area in order to increase the use and the acceptability of the system by the drivers. LED daytime running light should be an alternative solution.
Lever 2: Standardization	Not relevant for this safety measure.
Lever 3: Regulation	EU Directive 2008/89/EC requires all passenger cars and small delivery vans to be equipped with daytime running lights. The mandate was extended to trucks and buses in August 2012. Vehicles produced before don't have to be retrofitted. The mandatory fitting should be extended to PTW and bicycle. Geographical areas where it is not mandatory should adopt a regulation.
Lever 4: consumer test	This safety measure could be integrated in the evaluation of a safety pack of driver assistance in the consumer test ratings in order to evaluate the DLR in terms of visibility on one hand and on the fact that it is not an issue (too bright for example) on the other hand.
Lever 5: cost reduction	The democratization of the system will be a lever of cost reduction. Progress in the optical area can lead to systems that are costless and are consuming very few energy (LED technology for example)

Lever 6: interaction with other safety domains	The safety effect of DRL depends on a series of factors : - Geographical latitude - DRL effects increase the further away from the Equator - Accident types - adverse safety effects on rear-end collisions - Accident severity - greatest effects on most severe accidents - Season - greater effects in winter compared to summer For vehicles equipped with DRL, by night, it is noticeable that some users think that they have the vehicle lights on, so they just drive with DRL, which is not lighting the rear of the car and makes it more difficult to detect for the other drivers circulating behind.
Lever 7: Application	Mandatory fitting of the DRL should be set up worldwide for all vehicles.

4.13.1 Night vision

Colour Code: Grey

Active safety / ADAS	Visibility enhanced	
Night vision		

Summary	Night vision enhancement systems (NVES) are designed to supplement the visibility provided by standard headlights. NVES support the driver during driving at night, reduced visibility, and occasional glare from headlights of oncoming vehicles. There are two main technologies behind NVES systems. The Near infrared (NIR) technology, which requires an IR source and gives a complete picture of the front scene, and the Far infrared (FIR) technology, without an external IR source and which therefore only enhances relatively warm objects (such as people and animals). There are three main display alternatives: a head-up display (HUD) superimposed on the windscreen, a HUD just above the dashboard, and a conventional display somewhere in the dashboard (Rumar 2003). The primary potential safety benefit would be associated with crashes that frequently occur in dark driving conditions. Typical such crashes are crashes between motor vehicles and VRUs as well as animals, single-vehicle crashes and rear-end crashes. Quantitative estimates of traffic safety effects of NVES have a large range and vary from 1% to -25%, partly because of potential risk factors (Rumar 2003). While the safety benefit of NVES in theory could be large, there are concerns that drivers would compensate the increased visibility by for example increasing the driving speed so that the potential safety benefit is diminished (Rumar 2003). Another term for this compensatory driver behaviour is "behavioural adaptation" (BA), and is defined as "unintended behaviour that arises following a change in the road traffic system that has negative consequences on safety". Some empirical evidence indicates that NVES lead to BAs such as increased driving speed, reduced attention to the peripheral field and increased exposure at night and in bad weather conditions. Negative BA may be moderated with adaptive design of HMI interfaces (Rudin-Brown 2010). Regarding NVES, experiments have indicated that if the full display is lit up (or if safety critical object is lit up within the display) when safety critical events are detected, then BA and variance in reaction times can be reduced (Kovordanyui et al., 2006; Tsimhoni et al. 2007).

Lever 1: Technology	The main issues with existing Night vision system are: - The effectiveness of the Near infrared technology fall off in fog, snow or rain. - The Far infrared technology works poorly in warmer weather conditions and doesn´t detect the white or yellow pavement edge markings. - For the system which emit an audible alert to prevent driver, false positive should be a distraction. The Night vision enhancement systems should be improved.
Lever 2: Standardization	Since 2000, Night vision enhancement systems are offered by some car manufactures as optional equipment on certain premium vehicles. No standard model is known at this time. Before any standardization of this safety measure, it is necessary to first have a phase for technological improvements.
Lever 3: Regulation	No regulation actually exists for Night Vision system and it doesn't seem necessary to get one
Lever 4: consumer test	This lever does not seems appropriate for this safety measure, but the system could be integrated in the evaluation of a safety pack of driver assistance in the consumer test ratings, in order to evaluate the performance.
Lever 5: cost reduction	The system is expensive, the price varies between 1000$ and 2000$. The democratization of the system will be a lever of cost reduction.
Lever 6: interaction with other safety domains	Night vision enhancement systems lead to increase driving speed, reduce attention to the peripheral field and increase exposure at night and in bad weather conditions. Therefore, some actions in the learning of use of these systems and their limits is necessary.
Lever 7: Application	Transferability to all types of vehicle (Trucks, PTW,…) can be considered but one should be very careful of the fact that the efficiency of NVES may be sensitive to driver behavior, infrastructure (road conditions) and weather conditions.

4.13.2 Vehicle backup camera - Reversing Detection or Camera systems (REV)

Colour Code: Grey

Active safety / ADAS	Visibility enhanced	

Vehicle backup camera – Reversing detection or camera systems (REV	
Summary	Collisions with a reversing vehicle are particular dangerous for pedestrians and other vulnerable road users (VRU). Mainly in order to protect the car owner from property damage ultra-sonic based reversing assistant systems were introduced and further developed to reversing camera systems. The reversing camera systems were believed to especially contribute additional benefit to protection against property damage by VRU detection and thus protection against injuries. According to Decker et al. (2016) in most of the accidents involving reversing vehicles pedestrians and cyclists are injured (e.g., Germany: 30% cyclists and 60% pedestrians). Most of the victims are either children or elderly people (Fildes et al. 2017). In addition a considerable large number of unreported accidents are expected because police reported accident studies do not normally include accidents happening on private land. According to Austin (2008) only 22% of the insurance reported accidents happened on public roads. Reversing cameras and other reversing assistant systems are capable of either informing or warning the driver when pedestrians or cyclists are passing in the way of the reversing vehicle. In addition, they offer the potential to automatically stop the vehicle.
Lever 1: Technology	Back-up camera systems are considered to be 3 to 4 times more effective than ultrasonic based (or similar) assistant systems. The technology works properly, however, cost benefit analysis did not suggest that the monetary benefit exceeds the costs.
Lever 2: Standardization	Extend the standardization of the system to all type of vehicles.
Lever 3: Regulation	There is no regulation in Europe but reversing camera systems are mandated in the US by May 2018. The adoption of regulations should be extended to other geographical areas.
Lever 4: consumer test	This lever does not seem appropriate for this safety measure.
Lever 5: cost reduction	The democratization of the system will be a lever of cost reduction.

Lever 6: interaction with other safety domains	There could be an interaction with other systems as Collision warning or AEB. An algorithm based on the images could detect the proximity of an obstacle or other vehicle and interact with the Collision warning to send a signal to the driver or interact with the AEB and brake autonomously to avoid the collision.
Lever 7: Application	These systems could be developed for all types of motorized vehicles that can possibly be driven if equipped with a rear gear.

4.13.3 Blind Spot Detection

Colour Code: Light Green

Active safety / ADAS	Visibility enhanced	

Blind spot detection	
Summary	The Blind Spot in a vehicle is becoming a danger when an intended action will be done without recognising another road user or an object which is in danger of coming into contact with the driven vehicle. An intended action could be a lane change, turning maneuver or reversing. The blind spots of a passenger car and a heavy goods vehicle are different. The blind spot of a passenger car can be mainly eliminated with the aid of mirrors or a glance over the shoulder. The limitation of visibility due to vehicle structure is small and no other road user is completely obstructed by it. So blind spot detection for passenger cars means a driver assistance system, that supports the driver in a lane changing event, if he carries out an inadequate glance over the shoulder or does not look at all. The blind spot of a HGV is a major problem, because the limitation of visibility due to vehicle structure is bigger and areas around the driver's cabin are completely obstructed. These limitations can be overcome with the aid of mirrors, camera-monitor systems, new window designs and other measures. Also a driver assistance system, like the one for cars that recognises vehicles in the parallel lane, can prevent accidents on motorways or during overtaking.
Lever 1: Technology	HGV should be equipped with the Camera-Monitor System (CMS) or driver assistance system in addition to mirrors. CMS can be used everywhere on the vehicle, for example to eliminate the rear blind spot of a HGV. HGV cabin design, window designs should also be improved to increase driver visibility. Blind Spot Monitoring systems are designed to alert the driver when a vehicle encroaches into their blind spot by using cameras or sensors to monitor areas to the side of a vehicle. BSM would be most useful in preventing or reducing the severity of lane change crashes. The blind-spot monitors were less sensitive to motorcycles and to detect fast-moving vehicles which are quickly approaching in an adjacent lane. The system should be improved on these two areas.
Lever 2: Standardization	Standardization of the Blind spot mirrors should be extended to other vehicle types as made for the trucks. No standard Blind Spot Monitoring system model is known for the passenger cars.

Lever 3: Regulation	Under EU law, **blind-spot mirrors** have been mandatory for new lorries since 2007, and older lorries have had to be fitted with them since 2009. (The relevant EU Directives don't apply directly but require national governments to pass legislation making the mirrors mandatory). No regulation actually exists to equip passenger cars or PTW with blind - spot system (mirror or monitoring system). The implementation of a regulation could lead to accident reduction due to the blind-spot.
Lever 4: consumer test	The system could be integrated in the evaluation of a safety pack of driver assistance in the consumer test ratings.
Lever 5: cost reduction	The democratization of the system will be a lever of cost reduction, in order to increase the fitment of the Blind - Spot systems on the vehicles.
Lever 6: interaction with other safety domains	Driver should be informed on the performance of the system. Indeed the lack of information and improper use of the system could lead to accidents.
Lever 7: Application	Blind - Spot mirror should be added to the passenger cars and PTW. For the trucks, it could be profitable in terms of safety to adopt a similar regulation as implemented in Europe in other countries.

4.14 ACTIVE SAFETY – TECHNICAL DEFECTS

4.14.1 Tyre Pressure Monitoring and Warning

Colour Code: Grey

Active safety / ADAS	Technical defects	

Tyre Pressure Monitoring and Warning	
Summary	A Tyre pressure monitoring system (TPMS) is a system that monitors the inflation pressure of the vehicle's tyres and informs the driver about a low tyre pressure. Two different technological solutions are available for TPMS: Direct TPMS (dTPMS), which relies on direct measurement via additional pressure sensors in the wheels, and indirect TPMS (iTPMS), which analyses rotational wheel speed patterns measured via existing ABS/ESC sensors to determine underinflation. iTPMS can be used on cars and most vans, but not on vehicles with more than four wheels or twin-wheels. Tyre inflation pressure seems to be mainly related to fuel efficiency. There is also an effect of tyre inflation pressure on road safety but the effects on road safety are not clear (Jansen et. al. 2014). It is known that severely underinflated tyres can lead to bad vehicle handling and increased stopping distances due to a reduced friction coefficient (Choi 2012).
Lever 1: Technology	No progress in technology is expected as it seems to correctly work.
Lever 2: Standardization	Extend the standardization of the system to other type of vehicles.
Lever 3: Regulation	UN regulation R64 Tyre pressure monitoring systems are mandatory for all M1 vehicles since 2014. This should be extended to other types of vehicles and other geographical areas.
Lever 4: consumer test	There is not consumer test, and it is probably not necessary
Lever 5: cost reduction	Not relevant
Lever 6: interaction with other safety domains	The indirect TMPS measures the rotation speed via existing ABS/ESC sensors of the wheels, there is therefore an interaction with some primary safety devices.
Lever 7: Application	The system could be added to other types of vehicles.

4.14.2 Vehicle inspection

Colour Code: Light Green

Active safety / ADAS	Technical defects	
Vehicle inspection		

Summary	The description "Technical Defect" (TD) is used in different domains. Depending on the areas the meaning of these defects is different. There are three different ways to detect TD. ● Periodical technical inspection (PTI) ● Roadside inspection (RSI) ● Inspection after an accident (AI) All types of inspections are carried out by certified people. There is a special type of certification for every kind of inspection. The three types of inspection have different intentions. Here, the periodical technical inspection and the road side inspection are presented as countermeasures for technical defects. The road side inspection shows a clear positive effect on road safety, with an increase of 100 % in the frequency of RSIs reducing the accident rate of HGVs by 7.2 %. The periodical technical inspection reduces the relative accident frequency of the main causing party of an accident by around 2 %. But this effect often starts before the PTI, because many people get their vehicles repaired before the PTI. The results of the PTI from Norway are inconsistent, because it clearly shows a reduction of technical defects due to PTI and thereby an increase of the roadworthiness of the passenger cars. On the other hand the analysis with negative binomial regression models shows a slight increase of the accident rate after the PTI.
Lever 1: Technology	Only periodical technical inspection is involved in the technical part of vehicle inspection. Vehicle fleet will be composed of more and more vehicles equipped with new electronic systems. Technical inspection should take into account the inspection of these systems.

Lever 2: Standardization	Periodical technical inspection are compulsory in most European countries. A European directive has been adopted in 2014. The Directive 2014/45/EU applies to passenger cars, buses and coaches and heavy goods vehicles and their trailers, but for the scooters and motorbikes PTI will be mandatory from January 2022. The Directive 2017/47/EU provides the requirement to control the technical state of commercial vehicles. The standardization of the technical inspection centers could ensure a similar level of control across the European countries.
Lever 3: Regulation	The current EU law on roadworthiness checks could be extended by: - Increasing the inspection frequency of older vehicles - Taking into account the inspection of new electronic systems (ABS, Airbags, ESC: these systems are widely fitted in vehicles). In motorizing countries, very few of them have compulsory law on vehicle inspection. Adoption of regular technical control could reduce the accidents due to technical issues.
Lever 4: consumer test	This lever does not seems appropriate for this safety measure
Lever 5: cost reduction	The price can be a positive lever to have vehicles inspected with success. The introduction of insurance discounts could be used to encourage the drivers the adoption of good maintenance practice.
Lever 6: interaction with other safety domains	Awareness –raising activities could be conducted on the safety benefits of periodical technical inspection to sensitize the drivers on the importance of periodical inspection.
Lever 7: Application	In Africa, Asia and South-America few countries have compulsory law on vehicle inspection. Adoption of regular technical control could reduce the accidents due to technical issues.

4.14.3 Automatic Emergency Braking (AEB) for trucks

Colour Code: Light Green

Active safety / ADAS	Technical defects	

Autonomous Emergency Braking for trucks	
Summary	The autonomous emergency brake system was first introduced by Daimler for HGVs in 2006. This system was mainly developed to reduce crashes between HGVs and the rear end of traffic jams. Due to the big mass of the HGV and the high speed differential, this accident scenario has serious consequences for the vehicles in the traffic jam. EU Regulation No. 347/2012 specifies the technical requirements and test procedures for advanced emergency braking systems and the fitting of "Level 1" systems is mandatory for all new vehicles since 01.11.2015. The AEBS should warn the driver of risk of collision and if the driver does not react appropriately, the system itself should initiate an emergency brake. Modern AEBs in trucks can not only detect moving or stationary vehicles in front of them, even pedestrians and cyclists during turning maneuvers can be detected. Since these systems are relatively new, there is not much data available about the benefits of the AEB. But there are some in-depth analyses of HGV accidents with regard to avoidability if the HGV had been equipped with an AEBS. These analyses show the great potential of these systems, because around 52 % of all rear-end collisions could be avoided and fatalities in accidents with HGVs on motorways could be reduced by up to 50 %.
Lever 1: Technology	For the HGV, AEB can influence road safety positively, especially in rear-end collisions on motorways. Depending on the type of AEB, such systems could prevent many heavy rear-end collisions or at least reduce the accident severity The performance of the AEB technology could be improved by adding additional sensors to improve by increasing the speed range, the sensors field of view, and the amount of braking deceleration

Lever 2: Standardization	In EU, since 2015 the fitment of AEB is mandatory for the new heavy vehicles over 7.5 tons. In United States it's planned that manufacturers will commit to make AEB on standard on all trucks a gross vehicle weight between 3,8 tons and 4,8 tons beginning no later than 1st September 2025. It could be profitable in terms of safety to adopt a similar standardization in Europe and even better Worldwide.
Lever 3: Regulation	From November 1st 2015, EU legislation will mandate the fitment of Autonomous Emergency Braking (AEB) systems on most newly registered Heavy Goods Vehicles (HGVs) over 7.5 tons. The AEB system should warn the driver of risk of collision and if the driver does not react appropriately, the system itself should initiate an emergency brake. The existing regulation could be improved by extending the AEB technology: - to detect pedestrians, cyclists and PTW - to back-over or reversing maneuvers. Lack of visibility due to vehicle structure could lead to the crashes. This technology could be benefit in particular to detect vulnerable road users. - Crossing and turning maneuvers
Lever 4: consumer test	Not applicable for this safety measure as long as trucks are not part of consumer test programs. Rating trucks could be a major step in the offer of ADAS and safety systems as standard equipment of trucks.
Lever 5: cost reduction	The democratization of the system will be a lever of cost reduction.
Lever 6: interaction with other safety domains	Driver should be trained to use the system in order to reduce the misuses. The lack of the information and improper use of the system could lead to accidents.
Lever 7: Application	The system could be added to the PTW.

4.15 ACTIVE SAFETY – CONNECTED

4.15.1 Vehicle to Vehicle communication

Colour Code: Light Green

Active safety / ADAS	Connected	

Vehicle to vehicle communication	
Summary	Vehicle to Vehicle communication is an emerging technology that has the theoretical potential to reduce vehicle to vehicle collisions. Using radio communication, vehicle positions are communicated to neighbouring vehicles to reduce collision risk. This feature is not limited to line-of-sight conditions in order to work and thus can be effective in more scenarios than existing collision avoidance systems. There are no quantitative results for vehicle to vehicle systems as they are not commercially viable but preliminary analyses indicate positive effects for safety. **The system is currently only operational in small test sites and is not yet commercially available.**
Lever 1: Technology	At this time, the system is not yet commercially available. Nevertheless, many different technologies are under estimation, with different prices and efficiencies.
Lever 2: Standardization	In order to establish communication protocols (frequency, message format, security, etc), important standardization efforts are needed. These activities are part of ongoing ITS (Intelligent Transportation Services) activities. Mobile data services currently available are under constant development and recent research suggests that with the coming 5G network are options to provide the speed and bandwidth needed to support large scale deployment of V2V systems.
Lever 3: Regulation	Currently United States has proposed legislation for vehicle equipment that will facilitate V2V technology, it could be profitable in terms of safety to adopt a similar and compatible legislation in Europe and even better Worldwide. Indeed NHTSA (National Highway and Transportation Safety Agency) has launched a proposal to create a new Federal Motor Vehicle Safety Standard (FMVSS) in 2017, in order to mandate vehicle-to-vehicle (V2V) communications for new light vehicles and to standardize the message and format of V2V transmissions. If the proposal is approved, the regulation would require to equip light vehicles with DSRC (Dedicated Short Range Communication) equipment that allows the reception and transmission of Basic Safety Messages (recent braking, vehicle size, emergency electronic brake lights ...). This will facilitate V2V warnings and interventions within a range of approximately 300 m.

Lever 4: consumer test	The connected vehicle technologies will provide drivers the information they need to anticipate potential crashes. In Euro NCAP roadmap 2020- 2025, it is planned to test V2X technology, and the protocol is not currently available.
Lever 5: cost reduction	As the system is not yet standardized and regulated, it is difficult to give indication to reduce the price as so many possibilities are still offered today.
Lever 6: interaction with other safety domains	There is a strong link of this safety measure with the communication of Infrastructure to vehicle (and vice-versa), in terms of regulation, standardization and technical solutions on the vehicle to ensure that they are fully compatible. V2V technologies can potentially provide safety benefits, but consumers are more likely to accept V2V technologies if they understand how vehicles with this technology can be safer. Consumers could be reluctant to accept V2V technologies if they cannot clearly see the benefits of the system. To improve consumer acceptance, awareness –raising activities could be conducted on the safety benefits of V2V technologies (technology demonstrations with V2V, media ...).
Lever 7: Application	Possibly usable for all vehicles. With the limit of being able to have sufficient power supply to make the system active. Portable solutions could also be made possible using interfaces such as mobile phones applications. The communication could be then extended to all new mobility light vehicles such as scooters, segways and also to the pedestrians.

4.16 TERTIARY SAFETY – POSTCRASH

4.16.1 ECall

Colour Code: Light Green

Tertiary Safety	Post-Crash	
eCall		

Summary	The eCall system is intended to automatically contact emergency rescue services in the event of a motor vehicle crash. The system is implemented on certain brands and some commercial implementations are in use. A number of studies have investigated the potential for these systems using an ad-hoc analysis of crash data. All studies are in agreement that eCall could reduce the fatality rate by 1-15% depending on the type, location, and severity of the crash. Almost all studies use an expert panel to reassess the crash outcome if an eCall system was present and are thus only indicative of the actual benefit. The international distribution of papers and analyses confirms the transferability of the results.
Lever 1: Technology	Previously, some systems were integrated into the radio system of the vehicle and need an intervention of the user (inclusion of a SIM card into the system) but thanks to new technology, dedicated and autonomous systems has been developed. This technology seems to be sufficiently reliable and correctly working to use it with any improvement, nevertheless, in the coming years new communication technologies will certainly allow a better service.
Lever 2: Standardization	The system has been standardized and it is going to be mandatory for all new vehicles of M1 and N1 categories in April 2018 in Europe. Other geographical area could use this standard but it is of course limited by the technical possibilities in the concerned area.
Lever 3: Regulation	At European level, the decision to make the system mandatory is already taken. As the system has been recognized having a positive effect on the fatality rate (up to 15%), it would be beneficial to adopt such regulations in countries with rural areas; low traffic flow and for which the localisation of the accident is sometimes difficult to be made.
Lever 4: consumer test	In Europe, as the system is becoming part of the approval of the cars, no consumer test is expected. For other vehicles or geographical areas, consumer testing that are for the moment focusing on active safety are starting to look at the tertiary systems that they could evaluate or reward in the next generation of vehicles. E-call could be one of them.

Lever 5: cost reduction	With the time, the cost of the equipment will certainly decrease (increase of the number of system, simple technology) but the system is also composed of a platform that is able to receive and treat the emergency call. The variation of the price of this part is difficult to evaluate but can represent in the end a large part of the global price of the system.
Lever 6: interaction with other safety domains	There is a technical requirement on the vehicles: they need to be equipped with GPS to forward exact coordinates of the accident. To be efficient the technology of this system has to be linked with an efficient platform to dispatch the emergency call to the safety teams. The main limits are the coverage of the area with communication satellites, and it seems that there is no issue of acceptability nor bias with use of the system that is not initially planned.
Lever 7: Application	This system could be applied to all domains of motor vehicles equipped with GPS. The call is today made when airbag inflatement is detected, which means that for vehicles such as motorbike or HGV, another trigger need to be found, but the system itself and the platform used to send emergency teams on the accident scene are transferable. For cyclists and pedestrian, the transferability seems to be more problematic, but one of the solution could be to use a cell-phone application using the GPS of the phone. The main issue being then to find a way of triggering the ecall in a reliable way.

4.16.2 Rescue Data Sheet & Rescue code

Colour Code: Light Green

Tertiary Safety	Post-crash	
Rescue data sheet and rescue code		
Summary	The rescue data sheet provides the emergency services at the scene of an accident with detailed information to help them rescue the patient from the vehicle in an appropriate manner. This includes a diagram of the vehicle with various components marked on it (tank, battery, airbag, belt tensioners, structural reinforcements, high voltage components and cables, etc.) and possibly additional information. At present, almost all car manufacturers offer a rescue data sheet for each of their new models. Some, however, have to draft it again for older models or develop it with standardized information. Most of these sheets are available on each manufacturer's website (Audi , Mercedes , Renault , ...) but some associations (ADAC, FIA foundation , VDIK , VDA , ACL , ...) or official government agencies (French ministry) or rescue departments themselves make these sheets public in the appropriate language. To avoid difficulties relating to the language, a sheet provides pictures of the vehicles and schemes with different views of the vehicle (lateral and top view) giving the location of some relevant elements such as structure of reinforcements , pyrotechnic safety systems, battery or cable with strong voltage. The ISO 17840-1:2015 document defines the content and the layout of the rescue sheet providing necessary and useful information about a vehicle for supporting rescue teams. These definitions concerned at that time passenger cars and light commercial vehicles (Part1). An extension for buses, coaches and heavy commercial vehicles is in progress (Part2).	
Lever 1: Technology	QR codes are readible by most of the cell phones, therefore, the technology itself seems to be efficient as it is.	
Lever 2: Standardization	An ISO format of the necessary data on the rescue sheet has been set up. So there is no other work than to keep it updated with new technologies appearing on vehicles. No regulation on this point is existing, if some countries are adopting one, it should be could that they use the same one, to harmonize data so rescue teams have the same level of information everywhere. There is no consumer organization award for the provision of such rescue sheet, but some digital platforms have been developed by them to help rescue teams. It should be good to have one single entry point for rescue teams guaranteeing that the most update data is available.	

Lever 3: Regulation	To include this point into the process of the vehicle approval makes sense. Rescue teams would then be sure to get an official document available.
Lever 4: consumer test	Not relevant in this context
Lever 5: cost reduction	The cost of the QR code is not large, the work that is necessary to build the rescue data sheet is for the moment large but this would become less and less time consuming as from one vehicle to another a lot of similarities are shown.
Lever 6: interaction with other safety domains	Not relevant in this context
Lever 7: Application	This kind of safety system can be extended to most of road vehicles with 4 wheels and more.

4.16.3 ECE R100 (Battery electric vehicle safety)

Colour Code: Light Green

Tertiary Safety	Post-crash	

ECE R100 (Battery electric vehicle safety)	
Summary	UN ECE Regulation No. 100 (also referred to as R100) addresses the safety requirements specific to the electric powertrain of road vehicles including rechargeable battery systems. It was initially published on 23 August 1996. Since then, the market for electric vehicles has changed considerably. This text has therefore had to evolve in order to adapt to changes in the automobile market and the introduction of new technologies. However, applications for R100 type approval were limited exclusively to entire vehicle assemblies and evaluations of vehicle component safety were conducted as part of a total vehicle assessment and limited in scope. As a result, vehicle manufacturers were also restricted from changing individual systems or components or to substitute components from one sub-manufacturer with those from another, without requiring a new type of approval application for the complete high voltage electrical powertrain. In 2013, the second revision of R100 implementing significant changes in the type approval process applicable to motor vehicles and Rechargeable Energy Storage Systems (RESS) was published. The regulation provided a separate approval path for RESS (most often, rechargeable battery packs), and introduced a number of tests exclusively applicable to these systems. With the introduction of these new testing requirements, which took effect in July 2014 and became mandatory in July 2016, the responsibility for obtaining type approval for a rechargeable battery may also shift to the RESS manufacturer. Therefore, the second revision of R100 modifies the current type approval scheme, a change that is likely to increase competition in the RESS marketplace. The second revision of R100 also requires that electric vehicles complying with R94 (frontal crash regulation test) and R95 (side impact regulation test1) ensure a high level of electrical integrity through criteria to be fulfilled during these tests. Although no study appears to be a measure of the effectiveness of this regulation it seems evident that the requirements of the second revision ensure at least an electrical safety level equal to the one provided by the safety elements of the car concerned.
Lever 1: Technology	The regulation is not defining any technology.
Lever 2: Standardization	Due to different technologies used for the rechargeable batteries, no standardization is expected at this day. Nevertheless the intervention of safety teams is highly depend of the type of battery. Some have to be drawn in water, for some other the use of water is increasing the risk of explosion.

Lever 3: Regulation	Adoption of this regulation is a guarantee of a minimum of safety for the people (occupants, safety teams) intervening on the electric vehicle during and after crash. It should be good to extend the use of such a regulation for all countries in which electric vehicles are allowed.
Lever 4: consumer test	As it is mandatory in Europe since 2016 to respect this regulation, no point in consumer test is dedicated to this point. Consumer tests in other areas could consider such point (US, China,…).
Lever 5: cost reduction	Optimization of technologies used to guarantee the respect of the regulation are possible, but it is highly depending on the technology used.
Lever 6: interaction with other safety domains	The labelling on the vehicles is very important in order first, to clearly indicate that it contains a rechargeable battery, and that before any intervention on it, it is necessary to check the RQ code to get instructions of interventions.
Lever 7: Application	This regulation could be transferred to electrical PTW.

4.16.4 Event Data Recorder

Colour Code: Light green

Tertiary Safety	Post-crash	

Event Data Recorder	
Summary	An Event Data Recorder (EDR) is a device mounted in the motor vehicle that records vehicle dynamic and occupant information. There are two types of EDRs. The first that works under an accidentology context, only saves the data in case of an accident. This type of EDR captures vehicle dynamic and occupant information for a brief period of time before, during and after a crash. The second, called "driver behavior tracking device" is used to monitor the behavior of the driver throughout the whole driving activity. Currently this type of system is used to monitor the behavior of drivers in order to reduce road accidents. A systematic literature search has been conducted on EDR effectiveness and two relevant studies have been selected and analyzed. Only two studies were found at this time in the literature. One of them is based on an experimental study in which the effect of the data recorders on driver behavior was studied. The results show that the systems improve driver safety through reducing accidents or safety incidents by impacting driving behavior.
Lever 1: Technology	As the progress today in terms of electronic/miniaturization of recording systems/data storage are increasing very rapidly, the technology on which is based the safety benefit analysis is certainly already from another time. It is important to check this point if considered in a global road safety program.
Lever 2: Standardization	Standardization of the data coming from the different systems is an important plus-value and would allow to develop research works on a large scale. The event data recorder is not mandatory.
Lever 3: Regulation	Safety benefits announced in the studies are promising, but include such a system in the approval process is may be not the best way to get it accepted. People would have the impression that everything they do can be checked and used against them. Instead of this, adopting a positive approach of the system and reward the "good" drivers/riders on social networks or on dedicated application could have the same benefice with a better acceptance of the system that is not necessarily in place to punish the "bad" drivers/riders.

Lever 4: consumer test	For this particular safety measure, no consumer tests are possible, except to add points if the vehicle is providing such a device, but for that major works of communication with the public in order to make sure that the system is well accepted. This is where consumer organizations could have a role by putting in place such virtual platforms with rewards, or diagnostics for drivers that would like to improve their driving/riding.
Lever 5: cost reduction	A generalization of the system will decrease the price of each unit, the progress in electronic equipment will also make them cheaper year after year.
Lever 6: interaction with other safety domains	To put such a system in a vehicle cannot be done without a large safety campaign explaining on one hand the safety benefit expected, and on the other hand how the recorded data are stored, treated and can be used. In a second step, it seems that if the vehicle is a communicating with its environment, it is important that the event data recorder is collecting the data received from the outside and the message that the vehicle is sending to the others.
Lever 7: Application	All kind of motorized vehicle can be fitted with an event data recorder, the recording possibilities are of course depending of the vehicle itself and of its equipment.

5 Conclusion

The analysis of all vehicle-related measures contained in Safety Cube's Decision Support System was performed and reported in the present document. This allowed to identify improvement potentials for each of them, using combinations of an array of levers.

This work also showed that any measure ranking or prioritisation is best set at local (country) level. This is because many improvement levers depend on the local contexts. Legal requirements (regulations, enforcement, respect of the law,...), age and composition of the vehicle fleet, road infrastructure context (quality of roads, technical and safety equipments,...), road safety awareness and social acceptance of road safety measures at all levels (state, users, industry,...) are just a few instances of local constraints, having effects on road safety measures priority ranking.

Strong links with other domains of safety domains have been highlighted, so using a lever to improve the efficiency of one of the vehicle-related safety measure can have a direct impact in some other safety domains (need of education, infrastructure requirements,...). In another perspective, decision making in other road safety domains can influence the efficiency or the potential benefit of levers to be applied on vehicle-related measures.

Vehicles-related measures are one way to improve road safety, and their improvement is a major step that will bring benefit to all road users and the society at large. But improving vehicle-related measures has to be a subset of a global road safety decision making process.

5.1 NEXT STEPS

Vehicle-related measures are of course strongly linked with all the other domains of road safety such as infrastructure and human behaviour. Therefore, methodologies developed and used in this document can be reused if some new vehicle-related measures are introduced in the DSS in the near future. It could be beneficial to conduct a similar work on other domains of road safety in order to set guidelines for the future research works and have a clearer view on the potential ways of improvement considering the complete picture of road safety.

References

Hermitte T. and al. (2016), Identification of Vehicle Related Risk Factors, Deliverable 6.1 of the H2020 project SafetyCube.

Jaensch M., Leopold F. and al. (2017), Identification of Vehicle Related safety measures, Deliverable 6.2 of the H2020 project SafetyCube.

Appendix 1: Vehicle-related measures by colour codes

Vehicle-related measures by colour code (excerpt from of D6.2)

Green	Light Green	Grey
! **Seat belt (effectiveness) SBR and Load limiter included**	! Directive 96/79/CEE et ECE.R94	? Anti-submarining (airbags, seat shape, knee airbag, seatbelt pretensioner, …)
! **Frontal Airbag**	! Directive 96/27/CEE et ECE.R95	? Collision Warning
! **Side Airbag**	! Regulation UN R135 (Pole side-impact protection)	? Adaptive Cruise Control (ACC & ACC Stop & start)
! **Anti-Whiplash**	! EuroNCap (MBD & Pole)	? Enhanced Headlights (automated, adaptive, advanced system, …)
! **Child Restraint System – 'CRS'**	! Vehicle inspection	? Night Vision
! **Child Restraint System – 'Booster seats'**	! ECE R100 (Battery electric vehicle safety)	? Tyre Pressure Monitoring and Warning
! **PTW protective clothing**	! PTW Airbag	? Emergency Stop Signal (ESS)
! **PTW protective clothing - Helmet**	! Underrun protection	? Rollover Protection system
! **Cyclist protective clothing**	! Pedestrian protection - 'active technology'	? Lane Keeping systems
! **Cyclist protective clothing - Helmet**	! Pedestrian protection - 'vehicle shape'	? Vehicle Backup Camera
! **Emergency Braking Assistance system**	! Pedestrian regulation	
! **Autonomous Emergency Braking AEB (City, interurban)**	! Blind Spot Detection	
! **Autonomous Emergency Braking AEB (Pedestrians & cyclists)**	! AEB for trucks	
! **EuroNCAP (Full Width & ODB)**	! Vehicle to Vehicle communication	
! **Electronic Stability Control (ESC)**	! Event Data Recorder	
! **Daytime running lights**	! Alcohol Interlock (ALC)	
! **Braking system PTW (ABS, Combined braking system, …) ABS (PTW)**	! Intelligent Speed adaptation + Speed Limiter + Speed regulator	
	! eCall	
	! Rescue Data Sheet & Rescue code	