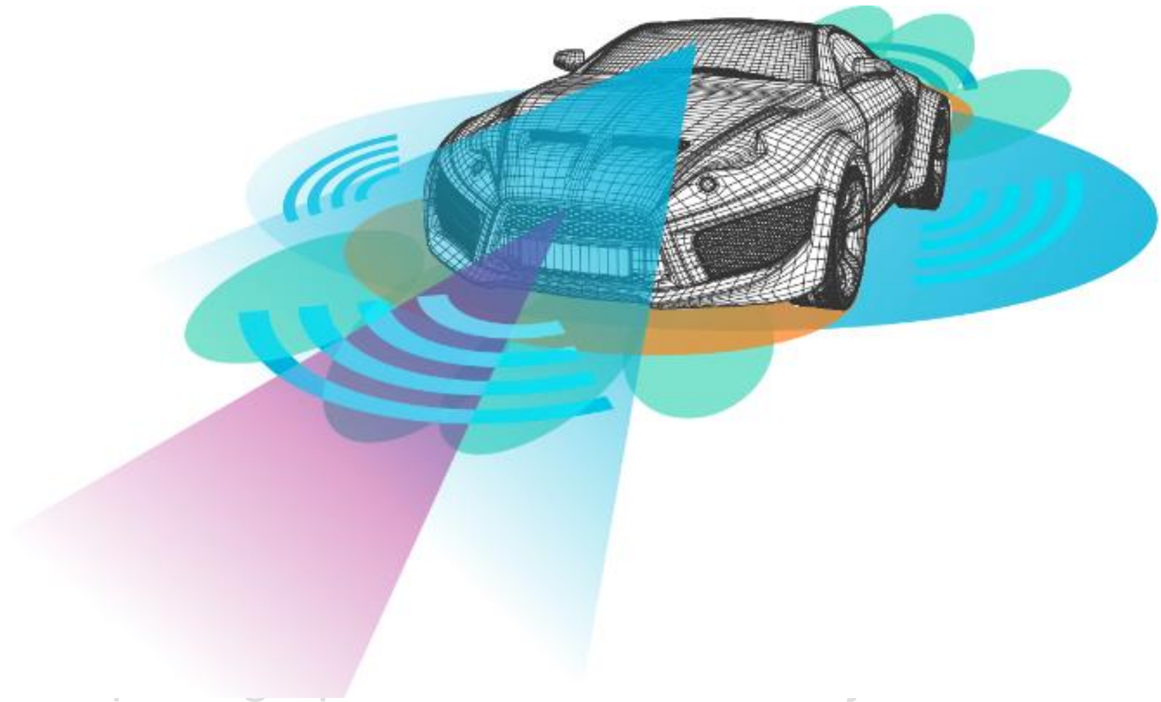

Identification of vehicle related safety measures

Deliverable 6.2

SafetyCube

Identification of Vehicle related safety measures

Work package 6, Deliverable 6.2

Please refer to this report as follows:
Jaensch M., Leopold F. and al. (2016), Identification of Vehicle Related safety measures, Deliverable 6.2 of the H2020 project SafetyCube.

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Table of contents

Executive summary

The present Deliverable (D6.2) describes the identification and evaluation of vehicle safety systems. It outlines the results of Task 6.2 of WP6 of SafetyCube, which aimed at identifying and assessing vehicle-related countermeasures by (i) presenting a taxonomy of dedicated safety systems, (ii) identifying "hot topics" of concern for relevant stakeholders and (iii) evaluating the effectiveness illustrated within the scientific literature for each identified safety measure (target population, casualty reduction, injury mitigation, ...). To reach this objective, Task 6.2 has initially exploited current knowledge (e.g. existing studies), existing accident data (macroscopic and in-depth) in order to quantify target population from scenarios (defined in WP8) related to vehicles. This information helped further on in WP6 to perform cost-benefit analyses on countermeasures so as to highlight cost-effective countermeasures.

The first level of countermeasure taxonomy was based on the main categories of road safety: crashworthiness (passive safety), primary security (active safety) and tertiary safety (post crash safety systems). The second level was established from the various types of road users, i.e. vehicles, pedestrians, cyclists…, but also from the main accident scenarios (frontal, side, rear impact…). The following relevant subcategories were used:

- **Crashworthiness (passive safety):** Frontal impact, side impact, rear impact, rollover, pedestrian protection, child protection, protection of riders of powered two-wheelers, cyclist protection and protection of other roaduser when in conflict with a heavy goods vehicle.

- **Primary safety (active safety):** Longitudinal control of the vehicle, lateral control of the vehicle, driver monitoring, visibility enhancement, warning about technical vehicle defects, vehicle to vehicle communication.

- **Tertiary safety**: Post crash safety systems.

The last taxonomy level was dedicated to the individual countermeasures.

To evaluate the scientific literature, a methodology was developed in Work Package 3 of the SafetyCube project. WP6 has applied this methodology to vehicle countermeasures. This method included a literature search strategy, a 'coding template' to record key data and metadata from individual studies, and guidelines for summarising the findings (Martensen et al, 2017). The main databases used in the WP6 literature search were Scopus, with some countermeasures utilising additional database searches. Where a high number of studies were found, further selection criteria were applied to ensure the best quality studies were included in the analysis (e.g. key meta-analyses, recent studies, country of origin, and importance).

Once the most relevant studies were identified for a countermeasure, each study was coded within a template developed in WP3. Information coded for each study included vehicle types, basic study information, road user group information, study design, measures of exposure, measures of outcomes and types of effects. The information in the coded templates will be included in the relational database developed to serve as the main source of the Decision Support System (DSS) being developed for SafetyCube.

Once all studies were coded for a countermeasure, a **synopsis** was created, outlining the main findings. Each synopsis consists of three sections: a summary (including abstract, overview of effects and analysis methods); a scientific overview (short literature synthesis, overview of studies, analysis methods and analysis of the effects) and finally supporting documents (e.g. details of literature search and comparison of available studies in detail, if relevant). Besides this, it was decided, for safety measures of great interest but with not enough material available in the literature, to write an **abbreviated synopsis** with all the knowledge available and an expert point of view.

At the start of each synopsis, a section states which **colour code is assigned to the safety measure** addressed, as a synthetic mean to view the synopsis content. The code can be **Red** (inefficient), **Grey** (unclear results), **Light Green** (probably effective) or **Green** (very efficient).

46 synopses (abbreviated or not) on vehicle-related safety measures are available in the DSS. A total of **17** countermeasures were given a **Green** code, **19** were given a **Light Green** code and **10** have received a **Grey** code. No countermeasure with **Red** colour code was found.

Safety measures by colour code

Green	Light Green	Grey (Unclear)
! **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	

Scientific literature shows that most measures from the category of crashworthiness have proven effective in mitigating injuries in road crashes and thus protecting road users. Systems such as seatbelt and airbags offer good protection in case of a frontal or side impact, if used in combination. When it comes to protecting vulnerable road users, protective clothing and helmets are capable of effectively mitigating injuries. The protection of children in cars is proven to be enhanced when child restrains systems and booster seats are appropriately used.

Concerning active safety systems most systems are available for cars and have proven effective in terms of reducing crashes by intervention or driver warning. For longitudinal control braking systems like EBA (Emergency Braking Assistance) or AEB (Autonomous Emergency Braking) for cars or trucks have proven most effective and for lateral control ESC (Electronic Stability Control) is effective in terms of crash reduction or mitigation. In terms of visibility enhancements studies have found that vehicles using daytime running lights are involved in fewer multi-party accidents.

Many of the most advertised ADAS features were classified in the "unclear"section. This requires some explanations:

- Mosts studies related to these systems only state the associated *stakes*, in terms of accident avoiding potential.
- These systems are still scarce on the markets and scarcer yet is the literature addressing real-life effectiveness. Additionnally, many of these systems can be switched off by drivers if they e.g. do not feel confident enough to use them or get annoyed by warning messages. An even touchier topic is whether the use of these systems would generate new kinds of accidents by over-confident or insufficiently informed drivers, e.g. on self-switch off operating conditions.
- In short, the actual effectiveness of these measures depends of their availability on the market but even more of their social acceptance and actual use by drivers. This is hard to assess and has not made its way in the scientific literature to an extent that it could have been recorded in the DSS.

One more fact about ADAS and V2X systems is worth mentioning: it is increasingly clear that they will have to work together in order to reach full effectiveness. Adaptive Cruise Control (ACC) is an efficient longitudinal control on vehicles travelling on (e.g.) highways in flowing traffic conditions. Only when ACC is augmented with other capabilities, such as Frontal Collision warning (FCW) or Advanced Emergency Braking (AEB) does it reach its full potential as a part of a road safety package. ABS+ESP, Traffic Sign Recognition + ISA are other examples of efficient cooperation.
This kind of effects is hardly captured within the current Safety Cube approach, in which measures are assessed individually. The scientific literature in a broader sense also has to come to terms with this kind of "safety ecosystems".

For these reasons, some of the "hot topics" questions mentioned by stakeholders interested in vehicle-related issues will not find a full answer in the DSS. Especially, the following questions come to mind in that line:

• How effective are vehicle safety countermeasures (and under which circumstances)?
• What is the effect of the new vehicle technology on road safety (autonomous vehicles, connected vehicles, ADAS …)?
• A priori evaluations of effectiveness of new ADAS: how to harmonise methodologies?
• Acceptability of ADAS: balance between false and missing detection

Although some knowledge regarding these questions exists in the road safety field, it is quite common that it is not made public for reasons related to industrial strategies or by general agreement between stakeholders.

Another surprising result is the classification of regulations, which mostly appears in the "probably effective" section. This certainly doesn't mean that regulations are a weak link in the array of vehicle-related countermeasures. . It only means that the progresses in vehicle design are regulated by so many factors, consumer and competitor pressure not the least, that assessing the effects of an individual regulation becomes a difficult task. Not to mention the fact that this kind of assessment hardly makes its way to the scientific literature and mostly remains confined within the individual stakeholder's design departments.

Some **limitations** were identified mainly due to difficulties in finding relevant and published studies. It was not possible to evaluate the effects on road safety of all topics listed in the taxonomy.

1 Introduction

1.1 SAFETYCUBE

Safety CaUsation, Benefits and Efficiency (SafetyCube) is a European Commission supported Horizon 2020 project with the objective of developing an innovative road safety Decision Support System (DSS) that will enable policy-makers and stakeholders to select and implement the most appropriate strategies, measures and cost-effective approaches to reduce casualties of all road user types and all severities.

SafetyCube aims at:

1. developping 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. developping 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 6.2 was to identify and present all the vehicle related safety measures. This addresses one of the main objectives of the SafetyCube project by contributing towards the creation of an inventory of all the measures put in place to reduce the risk of accident and the gravity of injury for all road users. The outcomes of this task will be the basis for the next step which will be to perform a cost benefit analysis.

This deliverable is dedicated to presenting the process of identifying, selecting, analysing and assessing road safety measures related to vehicles as well as its outcomes. The following steps were taken towards achieving the common purpose of SafetyCube and are described in detail in this deliverable:

- Identification of vehicle related countermeasures – creation of a taxonomy
- Coding of studies
- Synopses creation
- Vehicle related crash scenarios using accident data
- Synopses of countermeasures

The main results of deliverable 6.2 was an array of countermeasures effectiveness analyses, documented in countermeasures 'synopses' which were incorporated into the Safety Cube DSS and linked to corresponding road safety risk factors and cost-benefit-analyses of certain measures. As the synopses are comprehensive, they form individual documents appended to this one and will be made available separately via the project website **(www.safetycube-project.eu/)** and on the DSS when it is launched. However, the abstract of each countermeasure synopsis can be found in this deliverable as well as a colour code which points to the estimated effectiveness of each countermeasure.

The approach of this work differs slightly from the work on road users (human behaviour) and infrastructure. Instead of starting from the countermeasure and analysing it for all vehicle types, it makes more sense to start with the vehicle type. Indeed vehicle-related safety measures are dedicated to a specific road user typer (e.g.: seatbelt for cars and trucks, helmet for cyclists...). Therefore vehicle-related countermeasures were been 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 countermeasures instead of analysing them by adverse vehicle types.

Chapter 3 summarises the methodologies and procedures utilised in the identification and prioritisation of vehicle-related countermeasures. This included developing a taxonomy of countermeasures, identifying hot topic priorities in road safety and the implementation of the SafetyCube methodology for vehicle-related countermeasures.
Chapter 4 includes the abstract of each synopsis and an indication of the estimated effectiveness for each safety measure through a colour code (Green to Red).
Finally chapter 5 consists of a general conclusion.

2 Identification of safety measures

Within the SafetyCube project 'countermeasure' refers to any system that contributes to reducing the consequences of road accidents or even avoiding them. Safety measures can have immediate influence on the accident occurrence, on the injury severity or have an effect on a Safety Performance Indicator (SPI). All elements of the road system (Vehicle, Human, Environment ...) can hold an accident mitigation device. WP6 deals with those that are related to the vehicle point of view in road traffic.

2.1 TAXONOMY OF SAFETY MEASURES RELATED TO VEHICLES

The identification of a comprehensive taxonomy of vehicle-related to countermeasure has not been as difficult as for the risk factors. Initially, it was intended to code and implement each countermeasure. But after the first phase of research, it turned out that each system did not have sufficient documentation to be coded and therefore included in the DSS. As a result, several systems had to be grouped together. The taxonomy then evolved to a more general naming which can be linked to several road users.

Nevertheless, a specific taxonomy based on expertise and some well-known safety systems has been identified. As recommended by the project, the taxonomy for the countermeasures related to the vehicle is based on a three level structure.
The first level of this taxonomy is based on the main categories of road safety:

- Crashworthiness
- Primary safety (Active Safety)
- Tertiary safety

Because every vehicle type has its own characteristics (size, weight, agility ...), different uses and moves on different types of infrastructure (roadway, pavement, path ...), the second level of this taxonomy was established from various types of road users in addition to the main accident scenarios (frontal, side, rear impact...).

The 3rd and last level was dedicated to the countermeasure itself.

The category Pedestrian was added to the initial list composed of vehicle types. The first reason was to complete the countermeasures studied in WP4 of the contribution from the point of view of the vehicle. WP4 did consider the point of view of human behaviour, yet the specific accidentology connected to the pedestrian and its interaction with the other road users (vehicles) was not tackled. The second reason was to gather in the same category the pedestrian countermeasures that would have been studied in every category of vehicle and especially for vulnerable road users.

Table 1: Taxonomy of vehicle countermeasure related to crashworthiness.

Topic	Subtopic	Countermeasure / Safety System
Crashworthiness (Passive Safety)	**Frontal Impact**	Directive 96/79/CEE et ECE.R94
		EuroNcap (Full width & ODB)

		Frontal airbag
		PTW Airbag
		Seat belt (effectiveness) SBR and Load limiter included
		Anti-submarining (airbags, seat shape, knee airbag, seatbelt pretensioner…)
	Side Impact	Directive 96/27/CEE et ECE.R95
		Regulation UN R135 (Pole side-impact protection)
		EuroNCap (MBD & Pole)
		Side airbag (Head only Head + Thorax, Thorax + Abd + Pelvis, Farside airbag, curtain, …)
	Rear Impact	Anti Whiplash (Seat, active headrest, …)
		EuroNCap (whiplash)
	Rollover	AirBag protection (Roof, curtains, …) – combined with side airbag.
		RollOver protection system
	Pedestrian	Pedestrian protection - 'active technology'
		Pedestrian protection - 'vehicle shape'
		Pedestrian regulation
	Child	Child Restraint System – 'CRS'
		Child Restraint System – 'Booster seats'
	Powered Two Wheels	PTW protective clothing
	Cyclist	Cyclist protective clothing
	Heavy Goods Vehicle	Underrun protection (Front / Side + Lateral Side Guards / Rear)

Table 2: Taxonomy of vehicle countermeasure related to Active Safety / ADAS.

Topic	Subtopic	Countermeasure / Safety System
Primary safety (Active Safety)	**Longitudinal Control**	Emergency Braking Assistance system
		Autonomous Emergency Braking AEB (City, interurban)
		Autonomous Emergency Braking AEB (Pedestrians & cyclists)
		Emergency Stop Signal (ESS)

		Braking system PTW (ABS, Combined braking system, …)ABS (PTW)
		Collision Warning
		Intelligent Speed adaptation + Speed Limiter + Speed regulator
		Adaptive Cruise Control (ACC & ACC Stop & start)
	Lateral Control	Electronic Stability Control (ESC)
		Lane Departure Warning (LDW) + Lane Keeping Assist (LKA) + Lane Centring System
	Driver Assistance	Alcohol Interlock (ALC)
	Visibility Enhanced	Enhanced Headlights (automated, adaptive, advanced system, …)
		Daytime running lights
		Night Vision
		Vehicle backup camera - Reversing Detection or Camera systems (REV)
		Blind Spot Detection
	Technical Defects	Tyre Pressure Monitoring and Warning
		Vehicle inspection
		AEB for trucks
	Vehicle Connected	Vehicle to Vehicle communication

Table 3: Taxonomy of vehicle countermeasure (related to Tertiary Safety)

Topic	Subtopic	Countermeasure / Safety System
Tertiary Safety	**Post-Crash**	eCall
		Rescue Data Sheet & Rescue code
		ECE R100 (Battery electric vehicle safety)
		Event Data Recorder

3 Methodology for evaluating effectiveness of selected countermeasures

This chapter provides an overview of the methodology developed to evaluate the scientific literature related to vehicle risk.

The aim was to collect information for each countermeasure in as uniform a manner as possible. Therefore, a standard methodology was developed within the methodology Work Package of the SafetyCube project (WP3). This included developing a literature search strategy, a 'coding template' to record key data and metadata from individual studies and guidelines for summarising the findings per countermeasure. Collating information from a variety of studies each of which may use different underlying theories, designs and methods represented a big challenge. Therefore, the approach and 'coding template' developed was designed to be flexible enough to capture important information but also facilitate the comparison between studies. Copies of these documents and the associated instructions and guidelines can be found in Martensen et al (2017).

3.1 STUDY SELECTION (OVERALL APPROACH)

3.1.1 Literature Search

For each of the identified countermeasure topics, a standardised literature search was conducted in order to identify relevant studies to include in the Decision Support System (DSS) and to form a basis for a concluding summary (synopsis) and further analyses. A standardised procedure was developed (led by WP3) and applied for each examined safety measure in SafetyCube (within Wp4, 5, 6, 7). The literature search was documented in a standard template to make the gradual reduction of relevant studies transparent. This documentation of each search is included in the corresponding supporting documents of the synopses.

The **main databases used** in WP6 are the following:

- Scopus
- Google Scholar
- Science Direct
- Web of Science

3.1.2 Prioritising studies to be coded

The aim was to find studies that provided an estimate of effectiveness of the studied countermeasure. Therefore, studies considering crash data were designated the most important. ....

The criteria for prioritising studies to be selected for further analysis and eventual inclusion in the DSS were based on the following guideline:

- Key meta-analyses (studies already included in the key meta-analysis were not coded again)
- Most recent studies
- High quality of studies

- Country of origin: Europe before USA/Australia/Canada before other countries
- Importance: number of citations
- Language: English
- Peer reviewed journals

According to the level of detail of the topic and the history of research in the field, the number of studies that were eligible for 'coding' varied.

3.2 STUDY CODING

Following the patterns of risk factors assessment, a database was created with all the countermeasures studied in WP4 (human behaviour), WP5 (infrastructure) and WP6 (vehicle). A template was developed within WP3 to capture relevant information from each study in such a manner that this information could be uniformly reported and shared across topics and WPs within the overall SafetyCube project. Guidelines were also made available for the task of coding with detailed instructions on how to use the template. The coding template was designed to accommodate the variety and complexity of different study designs. At the same time its complexity required partners to learn how to use it.

For each study the following information was coded in the template and will ultimately be presented in the DSS:

- Road system element (Road User, Infrastructure, Vehicle) and level of taxonomy so that users of the DSS will be able to find information on topics they are interested in.
- Basic information of the study (title, author, year, source, origin, abstract, colour code, etc.)
- Road user group examined
- Study design
- Measures of exposure to the countermeasure
- Measures of outcome (e.g. number of injury crashes)
- Type of effects
- Effects (including corresponding measures e.g. confidence intervals)
- Biases
- Summary

For the full list of information provided per study see Martensen et al (2017).

Completed coding files (one per study) were uploaded to the DSS relational database.

3.3 COLOUR CODE

At the start of each synopsis, **the measure is assigned a colour code, which indicates how effective this measure is** in terms of the amount of evidence showing its impact on crash reduction. The code can be one of the following:

• **Green**: **Clearly reducing risk**. Consistent results showing a decreased risk, frequency and/or severity of crashes when this measure is applied.

• **Light Green: Probably reducing risk but results not consistent**. Some evidence that there is a decreased risk, frequency and/or severity of crashes when this measure is applied but results are not consistent.

• **Grey: Unclear results**. Studies report contradicting effects. There are few studies with inconsistent or not verified results.

• **Red: Not reducing risk**. Studies consistently demonstrate that this measure is not associated with a decrease in crash risk, frequency or severity.

3.4 SYNOPSES CREATION

The DSS provides information for all coded studies (see above) for various risk factors and measures. The synthesis of these studies are made available in the form of a 'synopsis' indicating the main findings for a particular risk factor derived from meta-analyses or another type of comprehensive synthesis of the results (e.g. vote-count analysis).

The synopses aim at accomodating different end users: decision-makers looking for global estimates vs. scientific users interested in results and methodological details. Therefore, they contain sections for different end user groups that can be read independently. The structure of each countermeasure synopsis, including the corresponding sub items (uniform for human, vehicle, and infrastructure related risk factors), is based on the following:

1. **Summary**
    i. Colour code
    ii. Abstract
    iii. Overview of effects
    iv. Analysis methods
2. **Scientific overview**
    v. Short synthesis of the literature
    vi. Overview of the available studies
    vii. Description of the analysis methods
    viii. Analysis of the effects: meta-analysis, other type of comprehensive synthesis like vote-count table or review-type analysis
3. **Supporting documents**
    ix. Details of literature search
    x. Comparison of available studies in detail (optional)

3.5 FINAL SYNOPSES

The full taxonomy of counter-measures for vehicles can be found in Chapter 2.1. In applying the method outlined in this chapter it was initially intended that each of the 47 safety measures would have a synopsis. However, following completion of the search and coding procedure it became apparent that for some specific measures there were insufficient code-able studies to justify the preparation of a complete synopsis. In these cases an abbreviated synopsis has been created in order to include some knowledge. These abbreviated synopses do not rely on a literature review.

4 Safety measures synopses - abstracts

This chapter provides an overview of all safety measures synopses related to the vehicles that have been written as of June 2017 and these will be available through the DSS when it is launched in 2017. However, since these are very comprehensive documents, only the abstracts and the corresponding colour code - which indicates the level of evidence for a given measures - will be provided in this chapter. The synopses are intended to be periodically updated to reflect new research or in some cases to expand their scope. The full text of the synopses in their current form (v1.0) can be found in Appendix C and any future updates or additions will be available on the project website (http://www.safetycube-project.eu/) and the DSS.

Full list of Synopses: [1]

Because WP6 focuses its analysis on studies related to measures for avoiding accidents and mitigating injury outcome from the vehicle, we decided to base our 1st level of the taxonomy on the type of vehicle safety (active, passive or tertiary). This 1st taxonomy level for WP6 is the following:

- Crashworthiness (passive safety)
- Primary Safety (Active safety: Driver assistance systems)
- Tertiary safety (post crash measures)

In the following parts the safety measures related to the following themes will be presented:

- Accident type
- Road user category
- Active safety
- Tertiary safety

Nevertheless, it should be noted that, due to the availability of studies, each risk factor could not be linked to a countermeasure. In addition, not all countermeasures initially identified in WP6 will be presented here. Indeed, only measures having enough studies (a minimum of 5 eligible articles) were consistently coded in the DSS.

[1] The titles of the synopses are not always in line with the wording of the corresponding topics in the taxonomy. Some specific topics have been summarised in one synopsis. Sometimes a synopsis title corresponding to the content and literature was chosen.

4.1 CRASHWORTHINESS – FRONTAL IMPACT

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

Colour Code: Light Green

Studies generally estimate the safety benefits caused by a car generation change or focus on specific types of impacts or safety systems (e.g. airbags, seatbelts), but they do not isolate the effects of specific regulations or the effect of consumer test being introduced, and/or their results made available to the general public. It can be observed that most of the studies found concerning the ECE R94 frontal test procedure are dedicated to its improvement when compatibility between cars issues was being discussed. Eventually, only two studies are of sufficient interest to be reported in the synopsis. Among them, only one has been coded which means that the statements in this synopsis are based on this single study data. This study uses two different sets of data that are both nationally representative. Data from the United Kingdom and from Germany are used with the objective of making a cost-benefit analysis of the different options to improve the frontal compatibility between cars. One of the proposed options is "no change", which implies a complete renewal of the car fleet with R94 compliant vehicles.

In addition to the previous comments, attention must be drawn to the fact that it is not possible to isolate the benefits associated with the standardization of ECE R94 from those associated to e.g. the introduction of new consumer tests, as design improvements on vehicles are usually trade-offs between all regulations requirements (including safety).

Active safety devices will certainly be more and more present in the future generations of car fleet. Their effect - both on the frequency and the typology of road crashes - is difficult to predict for the time being. Estimations coded for this measure in the present document certainly do not take this effect into account.

Abstract

Although the number of road accident casualties in Europe is falling, the problem still remains substantial. In 2011, over 30,000 road accident fatalities occurred in EU27. Approximately half of these were car occupants, of which 60% were killed in frontal impacts. Lots of studies have focussed on this issue, but design solutions were proposed in order to make vehicles compliant to both NCAP frontal dynamic tests and ECE R94, so the isolated effect of the latter is difficult to grasp. Only one study dealing with the safety benefit due to cars becoming compliant to the ECE R94 frontal test procedure was found in the peer reviewed literature (Edwards M. J, & al.), and only part of it deals with the subject of this synopsis. The main focus of this study is the improvement in compatibility of cars involved in a frontal crash (FIMCAR project). National data from Great Britain (STATS 19) and from Germany (German Federal Statistical Office) were used for the purpose of analysis, in addition with in-depth real word crash data from CCIS (Great Britain) and GIDAS (Germany). To estimate the benefit, a generalised linear model, an injury reduction model and a matched pairs modelling approach were applied. The benefits for Europe were estimated to be about 2.0% of car occupants killed and seriously injured.

Another study (Lloyd L. & al.) was included in the synopsis but was 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 was Malaysia. The purpose of the study was to quantify how many car users' fatalities are likely to be prevented, using different timing scenarios for the renewal of the car fleet.

4.1.2 EuroNCAP (Full Width & ODB)

Colour Code: Green

The scientific literature contains positive evaluations of EuroNCAP's contribution to improved frontal impact protection. The introduction of the consumer test programmes and the regulations have caused manufacturers to compete and improve their vehicles' safety features.

Abstract

Frontal crashes are responsible for more deaths and serious injuries than any other accident type. Around 30% of all road fatalities are car occupants involved in a frontal collision. In 1996, the European New Car Assessment Programme (EuroNCAP) was introduced with the aim of providing objective information for the consumer and encouraging manufacturers to improve their vehicles beyond the demands of legislation. After 21 years EuroNCAP, most of the car fleet has incorporated passive safety elements to improve their safety features and to obtain a good rating score in the EuroNCAP crash test.

However, there are no studies in the literature reviewed which assess the efficiency of the EuroNCAP frontal 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 programme. 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 reviewed were diverse. Based on Swedish data, Lie and Tingvall (2000) 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). However, Seguí-Gomez et al. (2010) 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. (2000) studied the estimated benefit of introducing the Offset Deformable Barrier test in Australia and they found a potential benefit above regulation between 24% to 36% in reduced Harm in frontal crashes.

4.1.3 Frontal airbag

Colour Code: Green

Sufficient studies are available. The results show that there is a significant reduction in injury severity in frontal crashes when a frontal airbag was available. Even though some studies show that an airbag can also cause injuries in specific situations, the measure consisting in the installation of a frontal airbag can be classified as effective in mitigating injuries.

Abstract

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 clearly shown the effectiveness of an airbag in reducing injuries and mortality in the event of a frontal collision. For instance, Lackner et al. (2007) found that the airbag greatly reduced the early mortality rate (first 24 h) - 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.

For airbags, especially in frontal impact situations, the protection level depends also on seat belt usage. Donaldson et al (2008) found that 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.

4.1.4 PTW airbag

Colour Code: Light Green

Powered Two Wheeler (PTW) airbags and motorcyclist's airbag jackets are effective countermeasures to minimise the injuries for certain types of PTW road accidents. Both have been proven to be effective in reducing the risk of having major injuries, especially in frontal collisions. However, there are some concerns about the potential for these countermeasures to increase head and neck injury upon deployment, to increase injuries coming from the second impact (motorcyclist-ground), and for not being able to function properly for some types of accidents.

Abstract

Powered Two Wheeler (PTW) accidents and injuries are still one of the main problems in road safety. One of the strategies to reduce PTW road accidents and the severity of injuries suffered by motorcyclists is through passive safety devices. Passive safety measures are designed to help protect riders in the event of an accident and can therefore improve motorcycle safety. Motorcycle airbag research began in the 1970s with the exploratory work of Bothwell (Bothwell and Peterson, 1973). However, only recently these systems started to appear and were implemented in real production vehicles and garments. Initially, research predominantly followed the successful path already paved for cars, mainly focusing on vehicle-mounted airbags. In recent years, the focus has moved to airbags mounted in the motorcyclist's garments. In the usual design, motorcycle airbags are the most effective in those cases where the motorcycle hits a fixed object frontally at a right angle (e.g. hitting a crossing passenger car from the side). Both solutions have been proved to be very effective under certain circumstances, mainly in crash tests or simulation, but there were no studies found using road accidents.

4.1.5 Seat belt (effectiveness) SBR and Load limiter included

Colour Code: Green

The 3-point seat belt measure can be qualified as effective, referring to the unanimous and high positive effects regarding prevention of injuries and fatalities during a crash for which this type of occupant safety system is designed.

Abstract

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.

4.1.6 Anti-submarining (airbags, seat bossage, knee airbag, seatbelt pretensionner…)

Colour Code: Grey

The effects of anti-submarining devices on preventing or mitigating injuries is largely unknown.

Abstract

Submarining is the phenomenon of sliding of the pelvis under the lap belt in the event of a collision. Several systems have the aim of preventing or limiting the submarining process. Knee airbags are designed to reduce leg injuries and to stop the road user submarining. They can be mounted on both the driver and the passenger side. 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. Pretentioners aim at clamping the driver and passengers to their seats in case of an accident. Knee bolster position and physical characteristics can also reduce occupants' likelihood of sliding under the seat belt.

None of the articles studied assessed 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. However, 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 by 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. 20061):

- The first category is composed of the studies that investigate the means to prevent or limit the submarining process.
- 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 studies that focus on the description and the characterisation of submarining as a physical phenomenon.

4.2 CRASHWORTHINESS – SIDE IMPACT

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

Colour Code: Light Green

The bibliographic review on the effectiveness of Directive 96/27/CEE or ECE.R95 does not highlight it as a real benefit to road safety by itself. The road safety improvement seems to be a combination of several different factors and actions rather than simply in respect of a regulation. Nevertheless, all studies establish that Directive 96/27/CEE or ECE.R95 had a positive effect on road safety even if not clearly identified. Therefore, the classification is probably effective.

Abstract

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 synopsis presents 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 synopsis 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.

4.2.2 Regulation UN R135 (Pole side-impact protection)

Colour Code: **Light Green**

There is only one study that specifically considers the benefit of the R135 approval test. It can be stated that very few studies are dedicated to the effectiveness or the benefit of the side pole impact test in general. In the end, only two studies have shown some figures in terms of lives saved, so this synopsis is based on few data. Luckily, the two studies have samples coming from representative national databases in Europe, which give them a particular interest. One deals with the exact configuration as proposed in the ECE R135. The other one has been coded because although the safety benefits have not been considered as fully dependent on a precise direction of forces, they are based on the fact that the vehicles sustained a side impact against a fixed object, a pole or a narrow tree. Both studies lead to different figures in terms of number of lives saved, but the effect in both cases is indicated as positive. In addition to the previous comments, it is important to note that it is not possible to measure the benefits due only to the adoption of ECE R135, as the safety measures taken are also dimensioned and balanced to respond to other safety requirements such as other regulations and consumer tests. Estimations coded for this measure do not consider the requirements of active safety devices nor of a possible migration of the type of impacts due to their generalisation on future vehicles. Therefore, the classification of this measure is probably effective, but the number of studies is too low to rate the benefit of this regulation at a higher level than this one.

Abstract

The side impact problem in Europe remains substantial. UK data shows that between 22% and 26% of car occupant casualties are involved in a side impact, but this rises to between 29% and 38% for those fatally injured. The higher percentage of fatally injured compared to all involved indicates the more injurious nature of side impacts compared with other impacts (mainly frontal impacts). The proportion of fatalities occuring during side impacts with fixed objects (such as poles and narrow trees) is a little bit over one third of all fatalities observed in side impact. As stated before, 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 (different types of impacts, different severity or crash configurations,…).

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. The introduction of a pole side impact test in the regulation is one of the options of the study, and safety benefits are proposed on this item. The second study was performed in France. It is based on the technical work necessary to achieve both the perpendicular pole side impact test and the oblique test as currently done in the ECE R135. Costs and safety benefits are evaluated separately both for M1 and N1 vehicles. Safety benefits are expressed in different ways in the two studies and do not allow a real comparison of the results.

The UK study uses two data sources to enable the safety benefit estimation: the national STATS19 database and the detailed Co-operative Crash Injury Study (CCIS) database. Results show a benefit of 5% of all car occupant fatalities and of 2% of all severely injured car passengers. The French study is based on the BAAC (Bulletin d'Analyse d'Accident Corporel) data base which is the French National database coming from the police. The year 2009 was taken into account and it sampled the distribution of fatalities and serious injuries for passenger cars (M1 vehicles) and light commercial vehicles (N1 vehicles) involved in side impact (see Table 4: Fatalities and serious injuries distribution regarding side impact types in 2009). 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.

M1 vehicles	Fatalities: pole side impacts	Fatalities: barrier side impacts	Fatalities: all side impacts
ONISR year 2009	167	307	474

N1 vehicles	Fatalities: pole side impacts	Fatalities: barrier side impacts	Fatalities: all side impacts
ONISR année 2009	11	14	25

M1 vehicles	Serious injuries: pole side impacts	Serious injuries: barrier side impacts	Serious injuries: all side impacts
ONISR year 2009	312	1301	1613

N1 vehicles	Serious injuries: pole side impacts	Serious injuries: barrier side impacts	Serious injuries: all side impacts
ONISR année 2009	6	95	101

Table 4: Fatalities and serious injuries distribution regarding side impact types in 2009

Source BAAC 2009 (F)

4.2.3 Side impact measure – EuroNCAP (MDB & Pole)

Colour Code: Light Green

EuroNCAP publishes safety performance data continuously. Vehicle crash performance has steadily improved after the introduction of EuroNCAP tests. The scientific literature contains limited evaluation of the effectiveness of EuroNCAP for improving side impact protection but there are positive evaluations of EuroNCAP's contribution to improved frontal impact protection.

Abstract

EuroNCAP tests vehicles in a number of test configurations for side impact. These tests are complementatary 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. The literature contains limited effectiveness studies of EuroNCAP for side impact although several studies were published using the EuroNCAP test procedure as a tool to demonstrate improved structural performance.

4.2.4 Side airbag (Head, Thorax, Pelvis)

Colour Code: Green

The studies reviewed indicated strong benefits of side airbags, especially in comparison to vehicles in side impact crashes which did not have these airbag systems. There is evidence dual airbags provide more protection than single airbags, though exact numbers vary a lot.

Abstract

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.

This synopsis aims at pointing out the benefits and possible disadvantages of side airbags as well as providing further information on side impact crashes referring to five studies and a literature review available on the topic.

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.

4.3 CRASHWORTHINESS – REAR IMPACT

4.3.1 Anti Whiplash (Seat, active headrest …)

Colour Code: Green

The use of anti-whiplash systems and EuroNCAP testing has a positive effect on safety. This was a common conclusion of all reports.

Abstract

The present synopsis addresses the effectiveness of whiplash injury protection systems or Anti Whiplash systems. Anti-whiplash systems are designed to reduce the relative motion of the head and torso. Of a particular interest is the effectiveness of Anti Whiplash systems that are rated good in EuroNCAP. EuroNCAP tests car seats and their head restraints in three test configurations for rear impact. The tests are published on the EuroNCAP webpage and are used by manufacturers to improve the marketing of their products through good performance rating.

Anti Whiplash systems were evaluated in American and European studies (Sweden). Both studies reported lower risks for systems designed to reduce whiplash injuries. The USA study reported 43% injury reduction while the Swedish study reported 51% reductions.

Vehicle seats evaluated good in EuroNCAP or a similar test programme were shown to provide better results (lower injury risk) than seats without good ratings. Only one study could provide statistical data. This study found a 15% reduction in whiplash injuries for seats with good ratings.

4.4 CRASHWORTHINESS – ROLLOVER

4.4.1 Rollover protection system

Colour Code: Grey

Some studies from the USA show that there is a relationship between roof crush and injury severity in rollover crashes. However, no literature was found on the effectiveness of certain measures to reduce roof crush.

Abstract

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 having contact with the roof during the rollover event. By a reduction of roof intrusion at rollover accidents a substantial reduction in injuries can be achieved.

Burns et at. (2010) found a direct reduction in spinal cord injuries from vehicle crashes if the maximum roof intrusion could be reduced. 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, resulting from a prevention of 134 cases of spinal cord injuries annually. If the maximum roof intrusion in rollover crashes were limited to 15-30 cm, fewer cases with spinal cord injuries could be avoided thus cost savings would be considerably smaller. Dobbertin et al. (2013) also found a direct association between roof crush and head, neck and spine injuries. Using the NASS CDS accident 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. Mandell et al. (2010) found a similar result also using the NASS CDS database: The odds ratio for mortality, severe injuries to the spine and head injuries increased significantly with higher roof crush also when accounting for other crash parameters such as passenger age, vehicle type or seat location.

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. In this synopsis the focus lies on the passive safety measures. 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. For example, Cho et al. (2012) show that adding reinforcement to the roof front header panel of a car can noticeably improve the strength of the roof against crush in a rollover.

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).

4.5 CRASHWORTHINESS – PEDESTRIAN

4.5.1 Pedestrian protection – Active Technology

Colour Code: Light Green

International literature indicates that active technology for pedestrian protection such as pop up bonnets or pedestrian airbags, can lead to better injury outcomes for pedestrians and a lower risk of fatality.

Abstract

Vehicle collisions with pedestrians can vary significantly in severity. An important protective measure for this injury outcome relates to active protection systems fitted to vehicles. It can be shown that vehicles with pop up bonnets which provide more space between hood and rigid components can reduce pedestrian head impact criterion (HIC) scores, thereby providing the potential to lower the severity of a head injury. In addition, it can be seen that the inclusion of a hood, A-pillar and windscreen airbag that deploys from the scuttle area (normally in parallel with a pop-up bonnet) can also reduce severe pedestrian head injury outcomes over a range of speed bands. Most research has

been conducted in Sweden and South Korea where the vehicle fleet is broadly representative of the EU situation and is not skewed by the inclusion of more 'aggressive' light trucks as with US data.

4.5.2 Pedestrian protection – Vehicle Shape

Colour Code: Light Green

International literature indicates that detail changes in passenger vehicle shape, particularly when considering geometric differences or heights of structural components, can lead to better injury outcomes and a lower risk of fatality for pedestrians.

Abstract

Passenger vehicle collisions with pedestrians of all ages can vary significantly in severity. An important protective measure for this injury outcome relates to the geometric shape of a vehicle front end and differences in heights and stiffness of vehicle structures. It can be shown that passenger vehicles with more forgiving front end structures or more protective front end designs can reduce pedestrian head impact speeds with bonnets and windscreens, thereby providing the potential to lower the severity of a head injury. In addition, it can be seen that detail changes to the heights of front end structures (bumper height, bumper leading length, hood edge height and hood stiffness) can impact both head impact velocity and angular rotations for different pedestrian heights. Most research has been conducted in Sweden and Australia where the passenger vehicle fleet is broadly representative of the EU situation and is not skewed by the inclusion of more 'aggressive' light trucks as with US data.

4.5.3 Pedestrian regulation

Colour Code: Light Green

No studies were found that directly addressed the effectiveness of regulations for pedestrian protection after their implementation. On the other hand, there were some simulation studies demonstrating the effectiveness of improving vehicle front-end design. Therefore, the classification is probably effective.

Abstract

Motor vehicles may be aggressive to pedestrians due to their mass, speed and design. During a crash between a motor vehicle and a pedestrian, the amount of energy transferred to the pedestrian could be relatively high, possibly leading to severe and fatal injuries. Pedestrian regulations aim at providing better protection for pedestrians (and probably cyclists) during these kinds of crashes by regulating vehicle designs in order to reduce the amount of energy transfer.

The Japanese government has established a regulation on pedestrian protection. The regulation addresses the issue of providing protection for children's and adults' heads. It applies to passenger cars with up to 9 seats and to small trucks of up to 2,500 kg Gross Vehicle Mass (GVM) with application from 2005 for new vehicle types and from 2010 for existing vehicle types (certain other vehicles have a timetable which is postponed by two years). The regulation requires compliance with test requirements using representative head impactors.

The European Parliament and Council adopted the Directive 2003/102/EC which provides for the introduction of requirements for leg injuries, and adult and child head injuries. The Directive and its requirements are incorporated into community legislation under the European Union (EU) whole vehicle type approval system. It applies to passenger cars of category M1 and to light commercial vehicles derived from passenger cars of M1 category, both up to 2,500 kg GVM, with application dates in two phases starting in 2005 and 2010. The second phase consisted of more stringent test criteria for type approval. This Directive has been replaced by European regulation No. 78/2009

which implies the repeal of phase 2 of the directive and the introduction of the active safety system "brake assist" as a mandatory system.

Other countries like the US and Australia have adopted the Global Technical Regulation No. 9 (GTR9) which applies to passenger cars, vans and light trucks under 4,500 kg GVM. It consists of child and adult headform impact tests to the bonnet and a legform impact test to the bumper. Active safety such as "brake assist" and "anti-lock brakes" were recommended but not made mandatory.

A systematic literature search was conducted in order to determine the effectiveness of such regulations. Only one study was found to possibly be relevant. This study (Anderson, Ponte, and Searson 2008) was conducted before the adoption of GTR9 by the Australian government and determines the potential benefit of such an implementation in addition to making the brake assist system mandatory. It estimates that this would reduce fatalities in Australia by approximately 28, serious injuries by 947 and slight injuries by 1248 each year. Other studies (Carlos Arregui-Dalmases et al. 2017; C Arregui-Dalmases, Lopez-Valdes, and Segui-Gomez 2010) have investigated pedestrian injury mechanisms and which part of the vehicle was responsible for pedestrian injuries. They concluded that current regulations are not severe enough because they don't address the vehicle's windshield which is responsible for approximately 42% of pedestrian head injuries. Kalra et al. (2016) set an overview of physical and numerical models for pedestrian tests. Lv et al. (2015) address vehicle front-end design optimisation by the use of two different legform surrogates (TRLPLI & FLEX-PLI). Teibinger et al. (2015) make a new virtual test proposal for small electric vehicles. B. Mueller et al. (2013) denote a good correlation between EuroNCAP and GTR9 headform tests and fatal and incapacitating injury rates. They also show that softer vehicle components correspond to lower risks of fatality. Krishnamoorthy et al. (2013) investigate the design of vehicle bonnet in order to optimise for the application of GTR9 in Australia. Ptak and Karlinski (2012) give suggestions for SUV pedestrian tests. They suggest the use of a full scale dummy and the application of a supplemental criterion for SUVs in order to make sure that the pedestrian will not be dragged underneath the chassis. Mizuno et al. 2012) make a comparison of the responses of the two legform test surrogates currently available. B. C. Mueller et al. (2012) compare the types and sources of realworld pedestrian injuries with the parts of the vehicles addressed by GTR9. They show that a significant pedestrian injury problem may persist even if GTR9 completely eliminates the injuries it addresses. Page, Hermitte, and Cuny (2011) estimate 1083 pedestrians saved in France from 2000 to 2010 due to vehicle safety improvement. Xu et al. (2010) estimate by simulation the pop-up hood to be efficient in improving head protection.

4.6 CRASHWORTHINESS – CHILD

4.6.1 Child Restraint System – 'CRS'

Colour Code: Green

From the literature which considers the safety effects of child restraint systems, it was found that overall the use of child restraint systems affects safety in a positive way. The results of a meta-analysis show clear consistency in the positive benefits of child restraint systems despite individual studies reporting similarly positive but less robust/non-significant results. Overall it is possible to say that child injury risk is lowest for appropriate child restraint use, higher for inappropriate child restrain use and highest when not using child restraints.

Abstract

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 show that the use of an appropriate and correctly used child restraint reduces the risk of death and injuries compared to a child either using a CRS incorrectly, using a standard seat belt or being 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.

4.6.2 Child Restraint System – 'booster seats'

Colour Code: Green

International literature indicates that belt positioning booster seats are particularly effective in reducing child injury levels in motor vehicle collisions compared to standard seatbelt alone.

Abstract

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 is a belt positioning booster seat. These 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, three point adult belt fitted to passenger vehicles. Typically, for this age group a standard three point belt will not sit across a child's 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 USA where the child seat laws are broadly representative of the EU situation[3].

4.7 CRASHWORTHINESS – PTW SPECIFICITIES

4.7.1 Protective clothing

Colour Code: Green

International literature indicates that the use of Powered Two Wheeler protective equipment in the form of motorcycle specific jackets, trousers, gloves and boots provides a protective effect, reducing the level of injury sustained in the event of a collision.

Abstract

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. PTW 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. By comparing injury outcomes and other factors related to PTW injury severity (for example, time off work or rehabilitation time due to a crash) it can be estimated that PTW users who wear protective clothing are less likely to suffer from a range of injuries compared to unprotected riders.

4.7.2 PTW Helmets

Colour Code: Green

From all the literature that is available which considers the safety effects of Powered Two Wheeler (PTW) helmets, the results show consistent reductions in certain severities and types of head and facial injuries when a helmet is used compared to no helmet. In all of the studies, these results were significant with strong consistency between the studies forming the meta-analyses. Despite the overall positive effect there is evidence in some instances that injuries to the neck may not be reduced by using a PTW helmet, however it can be concluded that use of a PTW helmet does reduce road safety risk.

Abstract

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. PTW helmets vary in design, construction and intended purpose and this synopsis should be treated as considering 'helmets' as one homogeneous group rather than individual designs or construction standards . Helmets are generally split between open face and full face designs although small subgroups such as off road helmets and system/modular helmets do exist (see figure 1). 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. Data on PTW helmet performance and effectiveness can be drawn from a wide range of sources, for example; computer simulations, laboratory crash testing or collision data, however for this synopsis the large samples and robust results derived from case-controlled analysis of real world collision data, hospital information and public health data is used over and above other sources as it provides a real world measure of how helmet use impacts PTW users injuries. The results found that the use of a PTW helmet can reduce the risk of death and serious injuries to the head or face compared to not wearing a PTW helmet. Despite the overall positive effect there is evidence in some instances that injuries to the neck may not be reduced by using a PTW helmet.

4.8 CRASHWORTHINESS – CYCLIST PROTECTIVE CLOTHING

4.8.1 Cycle protective clothing

Colour Code: Green

International literature indicates that the use of cyclist protective equipment in the form of high visibility clothing provides a protective effect and can reduce the risk of collisions with motorised vehicles and the subsequent level of injury.

Abstract

Collisions between cyclists and motorised vehicles can vary significantly in severity due to a wide range of different and diverse factors. One of the factors that can impact both the likelihood of a collision occurring and the subsequent severity of the collision is cyclist clothing colour and/or the presence of high visibility clothing. By comparing injury outcomes and other factors related to cyclist injury severity (for example, time off work due to a crash) and the presence or habitual use of high visibility clothing it has been estimated that cyclists who wear bright/high visibility clothing are less likely to be involved in a collision with a motor vehicle and if they are involved, have lower injury

severities. In addition it can also be shown from trials that cyclists who wear high visibility or bright clothing are easier and earlier seen by motorists and are potentially less likely to be involved in a collision.

4.8.2 Cycle protective clothing - Helmet

Colour Code: Green

From the literature available on the safety effects of cycle helmets, the results show reductions in certain severities of head and facial injuries when a helmet is used compared to no helmet. In all studies, these results were significant with strong consistency between the studies forming the meta-analyses. Despite the overall positive effect there is evidence in some instances that severe brain injuries or injuries to the neck may not be reduced by using a cycle helmet, however it can be concluded that cycle helmet use does reduce road safety risk.

Abstract

Cycle helmets aim to reduce injuries to the wearer in the event of a bicycle crash by providing additional impact protection to the head. Cycle helmets vary in design, construction and intended purpose and this synopsis should be treated as considering 'helmets' as one homogeneous group rather than individual designs or construction standards[1]. 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. Data on cycle helmet performance and effectiveness can be drawn from a wide range of sources, for example; computer simulations, laboratory crash testing or collision data. However, for this synopsis the large samples and robust results derived from case-controlled analysis of real world collision data, hospital information and public health data is used over and above other sources as it provides a real-world measure of how helmet use impacts cyclist injuries. The results found 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. Despite the overall positive effect there is evidence in some instances that injuries to the neck or severe brain injuries may not be reduced by using a cycle helmet.

4.9 CRASHWORTHINESS – HGV SPECIFICITIES

4.9.1 Underrun protection (Lateral Side Guards / Rear)

Colour Code: Light Green

Only a few studies were found on underrun protection on heavy goods vehicles as a measure to reduce the accident severity when other road users have an accident with an HGV. A positive effect of an appropriate underrun protection is postulated in the studies; however the effectiveness of the measure in terms of injury reduction is not always clear – especially for the lateral side guards.

Abstract

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 as well as 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).

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).

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 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 (see Figure 1, ADAC 2006). 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).

Figure 1: Results of ADAC crash test with underrun protection conforming to 2006/20/EC [from Smith et al. 2008, ADAC 2006]

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 cites 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.

4.10 ACTIVE SAFETY – LONGITUDINAL CONTROL

4.10.1 Emergency Braking Assistance system

Colour Code: Green

The bibliographic review on the effectiveness of Emergency Braking System suggests that Emergency Brake Assists have a positive effect on road safety.

Abstract

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 manoeuvre is initiated by the driver.

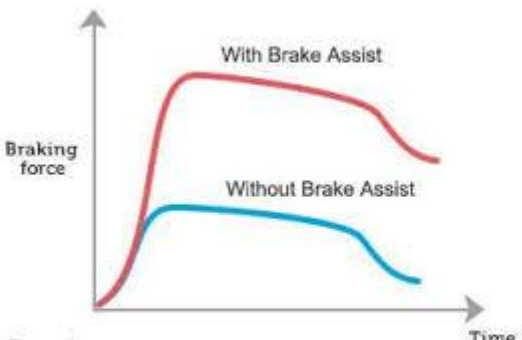

Figure1

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.

4.10.2 Autonomous Emergency Braking AEB (City, interurban)

Colour Code: Green

The bibliographic review on the effectiveness of AEB city & interurban suggests that this is an effective measure. While no studies were found dealing with AEB interurban, five studies were found dealing with AEB city and all suggest that it has a positive effect on road safety.

Abstract

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. This document presents a literature review of the effects of AEB city and interurban systems in terms of 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. Essentially Volvo cars were used in the analyses. This is certainly due to the fact that Volvo was the first to make AEB standard on different vehicle models.

4.10.3 Autonomous Emergency Braking AEB (Pedestrians & cyclists)

Colour Code: Green

The bibliographic review on the effectiveness of AEB pedestrian and cyclist systems suggests that these are effective. All studies establish that AEB has (or would have) a positive effect on road safety of pedestrians and cyclists.

Abstract

Autonomous Emergency Braking (AEB) for pedestrians and cyclists 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.

This document presents 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 analysed. 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.

4.10.4 Emergency Stop Signal (ESS)

Colour Code: Grey

Not much literature was found on emergency stop signals. The available literature describes how emergency stop signals affect the response times of road users by reducing reaction times on the appearance of brake lights. However, no study was found on the effect of emergency stop signals as a measure to reduce road traffic accidents.

Abstract

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 manoeuvre. By means of

flashing indicator lights or flashing brake lights the attention of the driver of the following vehicle is drawn to the lead vehicle when it is indicating that it is performing a high deceleration braking manoeuvre. This prolongs the time for the following vehicle to respond to this situation.

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

Colour Code: Green

Powered Two Wheelers (PTW) enhanced braking systems is a proven countermeasure to avoid PTW road accidents. Some of the systems have been proven to be very effective in reducing the accident risk, e.g. ABS, but some others are too new or not yet developed enough to provide the same results, e.g. Stability Control Systems.

Abstract

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 braking systems. The PTW braking systems have the potential to considerably reduce motorcycle accidents and to reduce the consequences of them.

There are some systems that have been proven 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.

4.10.6 Collision Warning system

Colour Code: Grey

The effect of collision warning systems in cars on road safety is unclear. Although the coded studies use several outcome indicators with good levels of quality and consistency, a number of findings are difficult to interpret due to a lack of statistical analyses.

Abstract

In-vehicle collision warning systems assist drivers to react in time in order to avoid a collision. Simulator and field experiments showed that this measure has mixed and unclear effects on 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. On the basis of both the studies and effect numbers, it can be argued that collision warning systems have a mixed impact on road safety. There were also studies that did not apply statistical tests, and therefore conclusions cannot be strongly supported. The results seem generally transferable, but this should be done with caution.

4.10.7 Intelligent Speed adaptation, Speed Limiter & Speed regulator

Colour Code: Light Green

The effects of Intelligent Speed Adaptation (ISA) devices in cars are mostly positive in reducing crash frequency, vehicles' mean speed and drivers exceeding the speed limit. Furthermore, the coded studies encompass several topics and have good levels of quality and consistency. However, there are a number of findings which cannot be strongly supported due to lack of statistical tests. For the reasons mentioned above, the overall impact of speed adaptation is characterised as probably effective.

Abstract

In-vehicle systems assist drivers to maintain a safe speed or prevent them from driving above the speed limit. Overall, the impact of Intelligent Speed Adaptation devices on road safety is beneficial. 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.

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

Colour Code: Grey

International literature indicates that adaptive cruise control impacts road safety through monitoring and maintaining a safe following distance to a vehicle ahead. The outcomes of this measure are normally recorded in terms of driver comfort or stress, or as an impact on the traffic flow and performance. Although the topic remit lies within vehicle engineering, the outcomes of the measure are not commonly reported as such.

Abstract

Time headway and following distance are major factors for both the overall traffic flow performance and safety outcomes of a particular road segment. Short following distances and small time gaps to vehicles ahead affect safety performance as there may not be sufficient time to stop or avoid another vehicle in the case of an emergency. Adaptive Cruise Control (ACC) systems can help to prevent short following distances by monitoring and maintaining a safe following distance to a vehicle ahead by automatically adjusting vehicle speed. This is particularly helpful in stable driving conditions, such as motorways and other high-speed **roads where a vehicle can follow another** vehicle for sometimes extended periods.

4.11 ACTIVE SAFETY – LATERAL CONTROL

4.11.1 Electronic Stability Control (ESC)

Colour Code: Green

Results consistently show that the Electronic Stability Control (ESC) system reduces road safety risk. ESC is mandatory in many countries and researchers were able to produce good indicators proving **ESC benefit.**

Abstract

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. 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.

4.11.2 Lane Keeping Systems

Colour Code: Grey

Some literature was found on Lane Departure Warning (LDW) systems, but no relevant literature evaluating the effect of Lane Keeping Assist (LKA) systems was found. The available literature mostly describes the benefit of LDW systems by identifying the target population (share of crashes that could have been addressed by a LDW system). Little is known however about the number of cases where LDW would have been effective.

Abstract

Available literature was mostly found on Lane Departure Warning (LDW) systems while no relevant study was identified on the effect of Lane Keeping Assistants (LKA).

The available literature mostly describes the benefit of LDW systems by identifying the target population (share of crashes that could have been addressed by a LDW system). Little is known however about the number of cases where LDW would have been effective. It is questionable if LDW can restore the attention of a driver that has fallen asleep in time to avoid an unintentional lane departure.

Jermakian (2010) describes the crash avoidance potential of LDW by analysing crash data from two American databases maintained by NHTSA (NASS GES and FARS).Here the crashes where a LDW could have been effective were identified accounting for circumstances where LDW cannot work such as lane markings not available/not visible, loss of control before leaving the lane, low speeds under 40 mph (≈ 65 km/h) or intentional manoeuvres (avoidance manoeuvre). The analysis found that 4-6% of the single vehicle crashes had a potential to be avoided by LDW, 23-27% of head on crashes, and 22-29% of sideswipe crashes.

Kuasno et al. (2014) analysed the potential injury reduction in the U.S. vehicle fleet by LDW. The study simulated single vehicle crashes from the NASS-CDS 2012, taking into account driver reaction times to LDW signals which were found in literature. Crashes with prior loss of control or a medical condition (e.g. heart attack) were excluded when mentioned in the database. The study finds that LDW could prevent 28.9% of all road departure crashes, resulting in a 24.3% reduction in the number of seriously injured drivers (MAIS 3+; computed using injury risk curves).

Sternlund (2017) studied fatal lane departure crashes in Sweden in 2010 using the in-depth studies from the Swedish Transport Administration. The potential crash prevention of LDW was quantified by identifying the target population while also accounting for circumstances where LDW could not have been effective (loss of control prior to lane departure, intentional lane departure (evasive manoeuvre), already available rumble strips or excessive speeding). The target population where

LDW systems may have been of benefit was identified to be 33 crashes from 100 analysed fatal head on and single vehicle crashes.
When looking at truck crashes, Hickman et al. (2014) conducted a retrospective cohort study comparing the reported crashes of trucks (>11.8 t), with and without LDW systems, from large carriers in the U.S. for the years 2007-2009. With the known mileage of all trucks in the cohort a crash rate was calculated for trucks with and without LDW for relevant crash types (run off road, head on crash, sideswipe), accounting for exclusion criteria such as the result of an avoidance manoeuvre, turn signal was used, covered/missing lane markings or incapacitated drivers. Hickman found that for trucks, the non-LDW cohort had an LDW-related crash rate that was 1.9 times higher than the LDW cohort ($p = 0.001$).

4.12 ACTIVE SAFETY – DRIVER ASSISTANCE

4.12.1 Alcohol Interlock (ALC)

Colour Code: Light Green

An in-vehicle alcohol interlock prevents a vehicle from starting if a driver exceeds a certain alcohol threshold. As such, alcohol interlocks have positive effects on road safety. Two coded studies both showed a small proportion of ignition attempts blocked due to blood alcohol levels above the threshold. However, more research is needed as the number of relevant studies is limited.

Abstract

Field experiments showed that alcohol interlocks can have a clear effect on road safety in terms of ignition attempts blocked due to too high levels of alcohol. Two high quality field studies were coded. Both concern drivers of commercial vehicles in Sweden. Results showed that only in few cases the alcohol interlock resulted in a blocked ignition attempt. The studies do not permit a conclusion about the amount of false positives or false negatives, nor about the percentage of drivers who would have been drinking if the vehicles had not been equipped with an alcohol interlock. Nevertheless, the alcohol interlock systems are likely to prevent drink-driving, and as such have a positive impact on road safety.

4.13 ACTIVE SAFETY – VISIBILITY ENHANCED

4.13.1 Adaptive headlights

Colour Code: Grey

Adaptive headlights rotate in the direction of steering and are intended to improve visibility on curved roads. Studies quantifying the safety benefits of adaptive headlights are scarce. Jermakian (2011) estimated that adaptive headlights could prevent 2% (142 000) of the annual passenger vehicle crashes in the US.

Abstract

Adaptive headlights rotate in the direction of steering and are intended to improve visibility on curved roads. Studies quantifying the safety benefits of adaptive headlights are scarce. Jermakian (2011) estimated that adaptive headlights could prevent 2% (142 000) of the annual passenger vehicle crashes in the US.

Adaptive headlights rely on different technologies in order to adapt the lighting to road and traffic conditions. Earlier systems (introduced in the United States in 2004) used an electromechanical

control of headlights by which the light source is rotated in order to ensure optimum illumination of the lane on curved roads. Equipped drivers could spot low reflectance objects located inside curves significantly earlier than if they had been equipped with standard headlights.

Those early systems usually relied on xenon High Intensity Discharge (HID) lamps as light source. In order to control the system, input data such as vehicle yaw rate and steering wheel angle were necessary. Combined to the complexity of design and installation of the mechanical actuator, this technical obstacle made the system relatively expensive and difficult to adapt to situations like preceding or oncoming traffic, thus generating glare to other drivers. Glare to others was the main issue associated to this technology, especially in dense traffic.

More recent systems - bound to conquer the market, at least in the US - often use LED lighting technologies. These technologies are more adaptable and do not 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. Thus, drivers get the best possible visibility without putting other drivers at risk through glaring. Yet, as the glare issues disappear, and adaptive headlights technologies spread (they were standard on 14% of 2014 US car models and optional on 22%), road safety issues might rise from drivers' increased confidence through increased visibility conditions.

4.13.2 Daytime running lights

Colour Code: Green

Evaluation studies have found that cars using daytime running lights are involved in fewer multiparty accidents in daylight compared to cars not using daytime running lights. However, studies evaluating the effects of a law mandating the use of daytime running lights have shown smaller effects.

Abstract

Daytime running lights (DRL) refer 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 there are too few studies to make any conclusions.

4.13.3 Night Vision

Colour Code: Grey

Night vision enhancement systems are believed to have a high visibility and safety potential, yet there is currently no quantitative evidence for this. The total safety effect will depend on the design of the system so that drivers do not compensate for the increased visibility and safety by for example driving faster.

Abstract

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. Typically, 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 an adaptive design of HMI interfaces (Rudin-Brown 2010). Regarding NVES, experiments have indicated that if the full display is lit up (or if a 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).

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

Colour Code: Grey

Not much literature was found on the effectiveness of vehicle reversing cameras and other reversing assistant systems especially in Europe. The available literature describes that vehicle reversing cameras, especially when being supported by vulnerable road user (VRU) detection and alarming system, have a positive effect on casualty reduction. Although cost benefit analysis did not show a monetary benefit exceeding the costs, vehicle reversing cameras are made mandatory in the USA by May 2018 in order to save VRU and believing that the costs will drop down in the future.

Abstract

Collisions with a reversing vehicle are particular dangerous for pedestrians and other vulnerable road users (VRUs). 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. Analysis of police reported accident data shows that young children and the elderly are at greater risk of being injured or killed by a reversing vehicle than others. Furthermore, comparison between police reported accident data and insurance reported accident data show a large number of unreported accidents, especially because reversing accidents often happen outside public accessible roads (e.g., on private pathways).

Back-up camera systems are considered to be 3 to 4 times more effective than ultrasonic based (or similar) assistant systems. However, cost benefit analysis did not suggest that the monetary benefit exceeds the costs. Despite that, reversing camera systems are mandated in the US by May 2018.

4.13.5 Blind Spot Detection

Colour Code: Light Green

Only one paper deals specifically with the benefit and effectiveness of assistance systems for blind spot detection. In this paper it is estimated that such systems would probably be effective in most of the blind spot scenarios.There are many papers about the improvement of the direct vision of HGV drivers, regardless of the system, but none of them can provide statistically worked out data showing a safety benefit. They claim the effectiveness of systems by showing the improved vision from the driver's cabin or the implementation of an additional system without influencing the existing structures and visibility. So these systems are probably effective, but there are no studies that provide data from real life.

Abstract

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 manoeuvre or reversing.

The blind spots of passenger cars and heavy goods vehicles 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 (almost) 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 larger and areas around the driver's cabin are completely obstructed. These limitations can be overcome with the aid of mirrors, camera-monitor systems (could prevent 27,1 % [1]), 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 (7,9 % of all truck accidents [1]) on motorways or during overtaking.

4.14 ACTIVE SAFETY – TECHNICAL DEFECTS

4.14.1 Tyre Pressure Monitoring and Warning

Colour Code: Grey

Little literature was found on the effect of Tyre pressure monitoring on road safety. No quantitative effect was found.

Abstract

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.

According to UN regulation R64 Tyre Pressure Monitoring Systems are mandatory for all M1 vehicles since 2014. The main reason seems to be ecological, as vehicles with underinflated tyres have higher fuel consumption. There is also an effect of tyre inflation pressure on road safety, but these effects 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).

4.14.2 Vehicle inspection

Colour Code: Light Green

The bibliographic review on vehicle inspection suggests that this type of countermeasure can be given the colour code **light green** (probably effective). This choice comes from the fact that the results of the chosen studies are not clear. Also, it is complicated to determine the real effect of the periodical technical inspection, because in most European countries they have been compulsory for a long time and in other countries where they are newly introduced, the effect will only become apparent after a few years.

Abstract

This synopsis presents the periodical technical inspection (PTI) and the road side inspection (RSI) as countermeasures for technical defects. RSI, an inspection of vehicles selected directly from the traffic, shows a clear positive effect on road safety, by reducing the accident rate of HGVs by 7.2% with an increase of 100% of the frequency of RSI. PTI, a vehicle inspection done at regular intervals as defined by national law, reduces the relative accident frequeny of the main causing party of an accident by around 2%. But this effect often starts before the PTI, because many people got their vehicles repaired before the PTI. The results of the PTI from Norway are inconsistent. On the one hand, there is a reduction of the technical defects and thereby an increase of the roadworthiness of the passenger cars. On the other hand, a regression analysis shows a slight increase of the accident rate after the PTI.

4.14.3 Autonomous Emergency Brake (AEB) in HGVs

Colour Code: Light Green

The bibliographic review on autonomous emergency brakes in HGVs suggests that this type of countermeasure can be given the colour code **light green** (probably effective).. This conclusion is based on the fact that the studies only provided an estimate of the benefits of this active safety system. The real-world benefit is hard to determine, because the systems are relatively new, and it is hard to separate their benefit from other safety systems. Besides, there is a possibility to deactivate the system by a shutdown of the driver.

Abstract

The autonomous emergency brake (AEB) 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 large differences in speed, 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 AEB systems, and the fitting of "Level 1" systems is mandatory for all new vehicles since 01.11.2015. The AEB system first warns the driver of a risk of collision, and if the driver does not react appropriately, the system itself initiates an emergency brake. The minimum system effect requested by the law is a speed reduction of 10km/h.

The high end AEB systems in trucks can not only detect moving or stationary vehicles in front of them, but they can also detect pedestrians and cyclists during turning manoeuvres.

Since these systems are relatively new, there is not much data available about the benefits of the AEB. Also because of the fast developments of new ADAS it is difficult to determine the effectiveness of current systems and their abilities.

However, there have been some in-depth analyses of accidents of HGVs and their avoidability had the HGV would have been equipped with an AEB. These analyses show a great potential of these systems: around 52% of all rear-end collisions could be avoided, and up to 50% of all fatalities in an accident with a HGV on motorways could be adressed.

4.15 ACTIVE SAFETY – CONNECTED

4.15.1 Vehicle to Vehicle communication

Colour Code: Light Green

Vehicle to Vehicle communication is an emerging technology that has the potential to reduce crashes by alerting vehicles that are approaching surrounding vehicles on collision paths. The technology is not yet operational in traffic and quantitative analyses are not yet available. The **potential impact is positive.**

Abstract

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.

4.16 TERTIARY SAFETY – POSTCRASH

4.16.1 ECall

Colour Code: Light Green

Available studies report small positive safety effects of E-Call or Automatic Crash Notification. However, the system is new and not fully implemented as proposed, so the number of objective studies is limited. Almost all studies reviewed are subjective, providing a wide range in effectiveness.

Abstract

The eCall system is intended to automatically contact emergency rescue services in the event of a motor vehicle crash. The system is still not implemented and only a few 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 used an expert panel to reassess the crash outcome if an eCall system had been present and are thus only indicative of the actual benefit. The international distribution of papers and analyses confirms the transferability of the results.

4.16.2 Rescue Data Sheet & Rescue code

Colour Code: Light Green

Rescue data sheets and rescue codes provide information about a specific vehicle in order to help emergency services on the scene of the accident to gain precious time in extricating victims safely from their crushed vehicle. Even though there is a lack of relevant scientific studies that assessed its effect, the information collected from the internet show that this type of information can be effective.

Abstract

Rescue data sheets provide the emergency services at the scene of an accident with detailed information to help them rescue the victim from a crashed 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 standardised information. Most of these sheets are available on each manufacturer's website (Audi[1], Mercedes[2], Renault[3], ...) but some associations (ADAC, FIA foundation[4], VDIK[5], VDA[6], ACL[7], ...) or official government agencies (French ministery[8]) or rescue departments themselves make these sheets public in the appropriate language.

To avoid difficulties related to the language, a rescue 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. These definitions concern passenger cars and light commercial vehicles (Part1). An extension for buses, coaches and heavy commercial vehicles is in progress (Part2).

4.16.3 ECE R100 (Battery electric vehicle safety)

Colour Code: Light Green

Although the use of electric batteries in motor vehicles can be a particularly delicate subject, and despite a quite old regulatory text that refers to it (date of application: 23 August 1996), there are very few studies that refer to the safety of their use. In fact, these studies do not mention their level of safety but only the legal framework for their use. Nevertheless, car manufacturers with a hybrid or pure electric vehicle in their catalogue are particularly keen to assure their customer of the highest level of safety in this field. Therefore, while there is nothing in public studies that shows any effectiveness of this regulatory measure, it is clear that it provides a basis for work on which car manufacturers rely to define their safety policy.

Abstract

The objective of the UN ECE Regulation No. 100 is to provide a regulatory framework for electric propulsion vehicles meeting the application criteria of this regulation. It imposes a minimum level of safety in order to safeguard as much as possible both the passengers of these electric vehicles and the persons who would have to intervene on this type of vehicle.

The R100 regulation text applies to safety requirements with respect to all battery electric road vehicles of categories "Passenger cars" and "Light Good Vehicles", with a maximum design speed exceeding 25kph. Such vehicles are intended to be exclusively powered by an electric motor whose traction energy is supplied exclusively by a traction battery installed in the vehicle. More information can be found at the following website: https://www.unece.org/?id=39145 and select n ° 100 regulation text.

The second revision of R100 also requires that electric vehicles complying with R94 (frontal crash regulation test1) 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.

4.16.4 Event Data Recorder

Colour Code: Light Green

Not much literature was found on the effectiveness of Event Data Recorders (EDR). The available literature based on the experimental studies establishes that EDR - driver behaviour tracking device has a positive effect on road safety, especially reducing accidents or safety incidents by impacting driver behaviour.

Abstract

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 type only records 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 "Journey Data Recorder (JDR)" is used to monitor the behaviour of the driver throughout the whole driving activity. Currently this type of system is used to monitor the behaviour of drivers in order to reduce road accidents. A systematic literature search was conducted on EDR and JDR effectiveness and two relevant studies were selected and analysed. The present abbreviated synopsis describes these two studies. In both of them, an experimental study was carried out and the effect of the data recorders on accidents and incidents occurrence was studied. The results show that the systems improve driver safety through reducing accidents or safety incidents by impacting the driving behaviour.

5 Conclusion

5.1 RESULTS AND DISCUSSION

For each specific safety measure of the vehicle taxonomy, a systematic search of the literature was undertaken. The identified relevant studies were coded using a uniformed 'coding template'. This captured quantifiable objective findings about countermeasures. Where sufficient studies could be identified, a synopsis was written summarising the interaction with the road user targeted and the global efficiency of the countermeasure on road safety. Each synopsis has a common format which starts with a colour code indicating the level of efficiency of the safety measure. This is followed by an abstract providing a summary of the findings for this countermeasure.The following table presents the safety measures and their their colour code.

Table 5: safety measures by colour code

Green	Light Green	Grey (Unclear)
! **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	

Scientific literature shows that most measures from the category of crashworthiness have proven effective in mitigating injuries in road crashes and thus protecting road users. Systems such as seatbelt and airbags offer good protection in case of a frontal or side impact, if used in combination. When it comes to protecting vulnerable road users, protective clothing and helmets are capable of effectively mitigating injuries. The protection of children in cars is proven to be enhanced when child restrains systems and booster seats are appropriately used.

Concerning active safety systems most systems are available for cars and have proven effective in terms of reducing crashes by intervention or driver warning. For longitudinal control braking systems like EBA (Emergency Braking Assistance) or AEB (Autonomous Emergency Braking) for cars or trucks have proven most effective and for lateral control ESC (Electronic Stability Control) is effective in terms of crash reduction or mitigation. In terms of visibility enhancements studies have found that vehicles using daytime running lights are involved in fewer multi-party accidents.

Many of the most advertised ADAS features were classified in the "unclear"section. This requires some explanations:

- Mosts studies related to these systems only state the associated *stakes*, in terms of accident avoiding potential.
- These systems are still scarce on the markets and scarcer yet is the literature addressing real-life effectiveness. Additionnally, many of these systems can be switched off by drivers if they e.g. do not feel confident enough to use them or get annoyed by warning messages. An even touchier topic is whether the use of these systems would generate new kinds of accidents by over-confident or insufficiently informed drivers, e.g. on self-switch off operating conditions.
- In short, the actual effectiveness of these measures depends of their availability on the market but even more of their social acceptance and actual use by drivers. This is hard to assess and has not made its way in the scientific literature to an extent that it could have been recorded in the DSS.

One more fact about ADAS and V2X systems is worth mentioning: it is increasingly clear that they will have to work together in order to reach full effectiveness. Adaptive Cruise Control (ACC) is an efficient longitudinal control on vehicles travelling on (e.g.) highways in flowing traffic conditions. Only when ACC is augmented with other capabilities, such as Frontal Collision warning (FCW) or Advanced Emergency Braking (AEB) does it reach its full potential as a part of a road safety package. ABS+ESP, Traffic Sign Recognition + ISA are other examples of efficient cooperation.
This kind of effects is hardly captured within the current Safety Cube approach, in which measures are assessed individually. The scientific literature in a broader sense also has to come to terms with this kind of "safety ecosystems".

For these reasons, some of the "hot topics" questions mentioned by stakeholders interested in vehicle-related issues will not find a full answer in the DSS. Especially, the following questions come to mind in that line:

• How effective are vehicle safety countermeasures (and under which circumstances)?
• What is the effect of the new vehicle technology on road safety (autonomous vehicles, connected vehicles, ADAS …)?
• A priori evaluations of effectiveness of new ADAS: how to harmonise methodologies?
• Acceptability of ADAS: balance between false and missing detection

Although some knowledge regarding these questions exists in the road safety field, it is quite common that it is not made public for reasons related to industrial strategies or by general agreement between stakeholders.

Another surprising result is the classification of regulations, which mostly appears in the "probably effective" section. This certainly doesn't mean that regulations are a weak link in the array of vehicle-related countermeasures. It only means that the progresses in vehicle design are regulated by so many factors, consumer and competitor pressure not the least, that assessing the effects of an individual regulation becomes a difficult task. Not to mention the fact that this kind of assessment hardly makes its way to the scientific literature and mostly remains confined within the individual stakeholder's design departments.

Due to limited human resources, prioritising of study coding was necessary in order to deal with safety measures on which abundant literature existed. The criteria for prioritising are detailed in the "supporting document" section of each synopsis. The approach focused on studies with the highest methodological quality; yet the selection criteria might have left some countermeasures out. Finally, the literature studied did not always provide us sufficient information to allow an accurate evaluation.

Unfortunately it was not possible to produce a synopsis for all specific countermeasures listed in the taxonomy. The missing countermeasures are the following:

- Regulation UN R32 (Behaviour of the structure in rear-end collision)
- EuroNCap (whiplash) Merged wih Anti Whiplash
- AirBag protection (Roof, curtains, ...) Merged with side airbag
- RollOver protection systems incl. ECE R66
- Drowsiness and Distraction Recognition
- Vehicle reversing camera - Reversing Detection or Camera systems (REV)
- Blind Spot mirror - Direct vision and VRU detection (VIS) for HGV Merged with Blind Spot
- ISO 26262 (road vehicles - functional safety)

The limitations of this work should be noted. The process of allocating colour codes was related to both the efficiency of the countermeasure and the quality of the evidence available to prove it - ranging from comprehensive statistic analyses over decades to expert opinion only.Findings were limited by both the implemented literature search strategy and the quality (and sometimes by the number) of studies available.

5.2 ACCESSING THE RESULTS

The coded studies and synopses for the vehicle countermeasures are accessible to the users of the DSS. The colour code for each specific safety measure are clearly presented within the DSS itself. Future users will have the option to undertake a search of the DSS in several ways. Regardless of the type of search results will always be presented in a consistent manner. For details on the way the results in the present report will be integrated / presented in the DSS, please see Deliverable 8.1 of SafetyCube.

References

Martensen, H. et al. (2017). Methodological framework for the evaluation of road safety measures. Deliverable Number 3.3 of the H2020 project SafetyCube.