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Inventory of vehicle-related risk factors and measures

Deliverable 6.4

SafetyCube

Inventory of vehicle related risk factors and measures

Work package 6, Deliverable 6.4

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Executive summary

Safety CaUsation, Benefits and Efficiency (SafetyCube) is a European Commission supported Horizon 2020 project aiming at developing an innovative Road Safety Decision Support System (DSS). The DSS is aimed at enabling policy-makers and stakeholders to select and implement the most appropriate strategies and cost-effective approaches to reduce casualties for all road user types and all injury severities.

Within the SafetyCube project, 'risk factor' (often abbreviated as 'risk') refers to any factor that contributes to an increase in either frequency or severity of any type of road accident. In the same context, 'countermeasure' (often abbreviated as 'measure') refers to any system, strategy or regulation that contributes to mitigating the consequences of road accidents or reducing their frequency.

Risks and measures can have an influence on accident frequency or injury severity either directly or through influence on a Safety Performance Indicator (SPI). Accident risks and countermeasures pertain to three domains that have been tackled in parallel within the SafetyCube project: "Road Users", "Infrastructure" and "Vehicles". Work Package 6 (WP6) deals with vehicle-related risks and measures, although pedestrian safety issues have also been included in this work package, as they are often vehicle-related as well.

This deliverable summarizes the results of the research work performed in WP6 to identify vehicle-related risks and measures as well as to quantify their effect on road safety. These results were used to feed the Decision Support System (DSS) tool (https://www.roadsafety-dss.eu/) in order to allow future users to gain access to a summary of the available literature on as many vehicle and road safety related topics as possible.

In order to ensure the relevance of the DSS, stakeholders and policy-makers were involved in the project at an early stage and asked to elaborate on their needs and the hot topics they felt should be dealt with. Identification and assessment of vehicle-related risks and measures was then completed in accordance with the methodology developed in Work Package 3 (WP3)

Our starting point consisted in creating taxonomies – one for risks and one for measures. We then proceeded to systematically search the scientific literature and select studies relevant to each of the identified topics and providing quantified estimates of effects in road safety. We addressed the main types of vehicles (e.g. cars, trucks, cycles, PTW) and identified risks associated to each category. Regarding measures, we tried to include all major measures found in the literature even if the effectiveness was still unclear – for lack on actual data on too recently introduced technologies, for instance. Technologies, such as MAEB, that hadn't reached the market when countermeasures were selected, were left out of the scope.

Taking these considerations into account, studies were selected and the reported effects as well as general information such as research design were fitted into a "coding template". This predefined coding template was a valuable tool in view of collecting information in a standardized way so that results could be compared.

Results related to each individual study were fed into a database (which underlies the Road Safety DSS) together with the study information. Once all studies pertaining to a risk or measure were coded, a synopsis was created, outlining the main findings as a meta-analysis (when possible) or as another type of comprehensive synthesis (e.g. vote-count analysis).

Each DSS-stored synopsis consists of three sections: a short (generally 2-pages long) **summary** (including abstract, overview of effects and analysis methods); a **scientific overview** (literature synthesis, overview of studies, analysis methods and analysis of the effects) and a "**supporting documents**" section containing e.g. details of literature search and comparison of available studies in detail, if relevant. As an addition to this, a four-staged "**colour code**" was assigned per topic (thus, per synopsis) to provide a quick insight into the riskiness of a risk factor or the effectiveness of a countermeasure. Finally, synopses underwent a self-imposed Quality Assurance procedure, including cross-reviews.

Overall, the inventory includes 32 synopses written for vehicle-related risk factors, 46 synopses on vehicle-related countermeasures. The following tables give an overview of the assessed risk factors and countermeasures along with their colour codes.

Vehicle-related risk factors:

Red (Risky)	Yellow (Probably risky)	Grey (Unclear)
! Pedestrian characteristics	! Ped. / Vehicle design	? Pedestrian / Impact characteristics
! Bicycle / Accident characteristics	! Ped. / Low NCAP rating	? Pedestrian / Visibility / Conspicuity
! Bicycle / Injury severity in accidents	! Bicycle / Visibility - Conspicuity	? PTW / Crash characteristics
! Pedestrian / injury level	! PTW / Poor helmet performance	? PTW / Vehicle characteristics
! PTW / impact characteristics	! PC / Prevalence of vehicle factors in crash data	? PTW / Technical defect
! PTW / injury level	! PC / injury mechanism / Rear impact	? HGV / Crash data
! PC / Injury mechanism / frontal impact	! PC / Low star rating	? HGV / Vehicle data
! PC / injury mechanism / Side impact	! PC / Technical defects / Maintenance	? HGV / Injury level
! PC / injury mechanism / Rollover	! LGV / Accident characteristics	
! PC / Abdominal injuries & submarining	! LGV / Impact characteristics	
! LGV / self & partner protection	! HGV / Impact characteristics	
! LGV / Visibility		
! HGV / Blind spot issue		

Vehicle-related countermeasures :

Green (Effective)	Light Green (Probably effective)	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	

All content listed is accessible through the DSS database. Risks and measures were linked to each other within a system-based approach. The present document details vehicle-related risks and measures only, but links have also been established cross-thematically to risks and measures related to infrastructure and road users.

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 restraint 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 is essentially because 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. This also explains why most studies related to these systems only state the associated *stakes*, in terms of accident avoiding potential.

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. This kind of effect 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**

Another surprising result is the classification of regulations, which mostly appears in the "probably effective" section. This 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. Additionally, this kind of assessment hardly ever makes it to the scientific literature and mostly remains confined within the individual stakeholders' design departments.

Whenever sufficient data was available, cost-benefit analyses (CBA) and corresponding sensitivity analyses were performed for vehicle-related countermeasures. Within the SafetyCube project, European crash costs were updated (to 2015) and factors to correct for inflation as well as purchasing power parity were provided and applied to measure costs. A synthesis was drawn and added into the DSS as a supporting example for the E^3 (Economic Efficiency Evaluation) cost-benefit calculator.

CBA were included as examples. As time horizons or methods used to evaluate benefits or costs are country-dependant, existing CBA are not-transferable from one country to another and should not, therefore, be compared with one another. By giving users the opportunity to alter existing time horizons or benefit-cost calculations, the DSS-included E^3 calculator is the only tool that should be used for that purpose**. This should allow policy makers to identify road safety effective measures that are currently too expensive and on which efforts could be made, be it by imposing lower prices or, more effectively, by making given systems mandatory and let the market self-regulate itself into reaching lower prices.**

The DSS currently contains 9 vehicle-related CBA examples. The associated countermeasures are:

Name of measure	Effectiveness	Example BCR > 1?
Child Restraint System – 'CRS'	Effective	Yes
Seat belt (effectiveness) SBR and Load limiter included	Effective	Yes
Helmet + reflective equipment + lighting (usage + performance)	Effective	Yes
Emergency Braking Assistance system	Effective	Yes
Autonomous Emergency Braking AEB (City, interurban)	Effective	No
Autonomous Emergency Braking AEB (Pedestrians & cyclists)	Effective	Depending on country
Braking system PTW (ABS, Combined braking system …)	Effective	Yes
Electronic Stability Control (ESC)	Effective	Yes
PTW airbag	Probably Effective	No

An accident scenario-based analysis was also performed for each type of vehicle and implemented alongside risk factors and safety measures. This approach helped us underline major accident configurations for each type of vehicle, including pedestrians. **This part is most useful to industry designers, road safety researchers and policy makers alike**, because the full complexity of accidents situations, aggregating human, infrastructure and vehicle issues appears clearly. Additionally, scenarios are easily ranked by frequency, thus helping policy makers to address the most critical situations first. These situations or scenarios are however not easily transferable from one country to another, the most country-dependant item being each scenario's proportion in the global road accidents picture. The DSS and the present document feature an example built on French data.

1 Introduction

This chapter describes the Safety Cube project and the purpose of the present deliverable. A short description of WP6 is also provided.

1.1 SAFETYCUBE

Safety CaUsation, Benefits and Efficiency (SafetyCube) is a European Commission supported Horizon 2020 project aiming at **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. Developing new analysis methods for (a) Priority setting, (b) Evaluating the effectiveness of measures (c) Monitoring serious injuries and assessing their socio-economic costs (d) Performing cost-benefit analysis taking human and material costs into account
2. Applying these methods to road safety data in order to identify key accident causation mechanisms, risk factors and cost-effective measures addressing fatalities and injuries (regardless of level)
3. Developing an operational framework to ensure that the project facilities can be accessed and updated beyond the completion of the SafetyCube project.
4. Enhancing the European Road Safety Observatory and working with road safety stakeholders to ensure that the results of the project are widely disseminated.

The core of the project consists of a **comprehensive study of road safety risks along with an effectiveness and cost-benefit analysis of countermeasures. A systems-based approach taking into account interactions between road users, infrastructure and vehicles was used,** with road safety stakeholders at national and international (EU and beyond) levels involved at all stages.

1.2 WORK PACKAGE 6

The objective of the Work Package 6 (WP6) is to analyse data, implement developed methodologies concerning accident risk factors and road safety measures related to all types of vehicles. This WP makes use of a large amount of existing accident data (both macroscopic and in-depth) and knowledge (e.g. existing studies) in order:

i. to identify vehicle-related risks and sort them by vehicle categories,
ii. to identify vehicle-related measures and sort them by domain (active, passive, tertiary safety),
iii. to assess the cost-effectiveness of vehicle-related measures.

WP6 thus contributes to SafetyCube by providing an insight on vehicle-related risks and measures. As compared to other Safety Cube work packages, WP6 includes **five specific and complementary tasks**, detailed hereafter:

Task 6.1. Identification of vehicle-related risk factors
Task 6.2. Identification of safety effects of vehicle-related measures
Task 6.3. Evaluation of key vehicle related road safety measures
Task 6.4. Inventory of risk factors and measures related to the vehicle
Task 6.5. Towards a better road safety level from vehicle point of view

More specifically, the WP started with the creation of a comprehensive list of vehicle-related risk factors and road safety measures (**taxonomy**). This list was used to build the structure of the DSS related to the vehicle. This exhaustive list was examined in order to make a selection of risk factors and measures that were analysed and assessed. This list was also used to build the structure of the DSS related to the vehicle.

To enrich the background information in the risk factor section, several accident databases were used:

- BAAC (ONISR)
- Overview data from the CARE CADaS database
- Internal LAB database

1.3 PURPOSE OF THIS DELIVERABLE

The purpose of this deliverable is to summarize the results of the research work undertaken in Work Package 6, which is dedicated to vehicle-related risk factors and countermeasures. Although many road safety issues are related to road user behaviour or road infrastructure, numerous preventive or mitigating measures are vehicle-related. This document describes the methodology used to address vehicle-related risk factors and safety measures tackled in this inventory, as well as the type of information available in the DSS. It consists of six sections and five appendices.

Section 1 provides background information about the SafetyCube project and work package 6.
Section 2 details "hot topics" that were selected by the SafetyCube stakeholders and gives an insight on the methodology that was used to assess vehicle-related risk factors and measures.
Section 3 considers vehicle-related risk factors, presenting a taxonomy of risks and typical information available in the DSS. This section also includes an insight on accident scenario analysis, based on French data as an example.
Section 4 considers vehicle-related safety measures, presenting a taxonomy of measures and typical information available in the DSS.
Section 5 reports the work carried out to assess the economic efficiency of some of the road safety measures that were identified as effective in task 6.2.
Section 6 concludes the report, summarizing the main findings and challenges, as well as possible next steps for further updating of the inventory.

Appendix A presents an abstract for each analysed vehicle-related risk factor summarising the findings of the related synopsis.
Appendix B presents an abstract for each analysed vehicle-related measure summarising the findings of the related synopsis.
Appendix C includes the documentations of all the cost-benefit analyses available. These will also be available through the final version of the DSS.
Appendix D lists the taxonomy used for accidents scenarios.
Appendix E gives an insight on risk and measure implementation into the DSS.

2 The SafetyCube Methodology for the Assessment of Risks and Measures

2.1 IDENTIFICATION OF VEHICLE "HOT TOPICS"

To obtain the widest-ranging impact for most of the vehicle types, the DSS is aimed at providing evidence for a broad set of road safety risk factors and countermeasures. Therefore, in a very first step a comprehensive list of vehicle related risks and measures was created by collecting topics known and reported in literature. As the DSS is (not exclusively but primarily) targeted at decision makers in the realm of road safety, it is crucially important to consider their day to day challenges as well as their perception of problematic, emerging and relevant risk factors and countermeasures. Given the limited time and resources of the project, priorities had to be set and emphasis was put on ensuring that a selection of "hot topics" relevant to road safety were covered.

Stakeholder consultations

In order to identify user needs and to further prioritize risk factors and measures "hot topics", workshops were organized.

- Risk factor identification and prioritization: Brussels, June 17th, 2015
- Measure identification and prioritization: Brussels, September 27th, 2016

Workshops were held to consult with international stakeholders. Their contribution helped in prioritizing and completing the lists of risks and measures. The information collected was evaluated according to the interest of the stakeholders.
Pedestrian road safety issues were also included in the scope of this WP as there are mostly vehicle-related.

For each type of vehicle, the most important topics were considered while considering the availability of related studies.

Thus, the following main topics were selected for WP6:

- Technologies in the "driverless car" field
- Vehicle Technology in active safety
- Vehicle Technology in passive safety
- Advanced driver support system
- Vehicle Automation
- Heavy goods vehicle priority
- Regulation influence on road safety

All these "hot topics" are included in the DSS, though not all could be dealt with using the same level of detail.

Another "hot topic" was also considered but, due to lack of available studies satisfying the selection criteria in Safety Cube, it was not included in the final list for the DSS: "Influence of semi-automated and automated driving on driving skills and road safety in general".

2.2 OVERVIEW OF SAFETYCUBE METHODOLOGY

The first activity in the work package consisted in the creation of a comprehensive list of vehicle-related risk factors and road safety measures (**taxonomy**). This list was used to build the structure of the DSS related to the vehicle. This exhaustive list was examined in order to make a selection of risk factors and measures that were analysed and assessed. This list was also used to build the structure of the DSS related to the vehicle.

A standard methodology was developed within work package 3 (WP3). This included developing:

- *A Literature search strategy* to support systematic literature search and selection of relevant studies,
- *A 'Coding template'* used to record key data and metadata from individual studies,
- *Guidelines* supporting the analysis of key risk factors and measures based on coded studies as well as a method for summarising the findings in 'Synopses',
- *An Economic Efficiency Evaluation* (E^3) calculator, aimed at helping stakeholders to prioritize road safety measures.

These documents and the associated instructions and guidelines can be found in Martensen et al (2017).

Literature Search

For each of the identified risk factor / measure, a standardised literature following the guidelines from WP3 was conducted in order to identify relevant studies for inclusion in the DSS and to form a basis for a concluding summary (synopsis) and further analyses. 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 **literature databases used** in WP6 are as follows:

- Scopus
- Web of Science
- Google Scholar
- Science Direct
- CARE
- LAB internal database

Selection of studies

Regarding **risk factors**, the aim was to find studies that provided an estimate of the risk of being in a crash due to the presence of the risk factor. Therefore, studies considering crash data were designated the most important. However, while the actual occurrence of crashes can be seen as the ultimate outcome measure for road safety, Safety Performance Indicators (SPI) have in recent years been taken into consideration to quantify the road safety level (Gitelman et al., 2014). SPIs include driving behaviour, like speed choice and lane positioning. These metrics give an indication of safe (or unsafe) driving behaviour. The SPI variables included for analysis are those for which there is some scientific evidence of an association with increased crash risk. For some risk factors, studies considering SPIs are included in addition to those focusing directly on crashes. However, where possible the coding of studies including crash data was prioritised.

Since the study design and the outcome variables are just basic criteria, for some risk factors the literature search had the potential to yield an excessive number of related studies and therefore additional selection criteria were adopted. Furthermore, on major and well-studied vehicle related risk factors, meta-analyses were available and the results of these were identified and incorporated.

While the aim was to include as many studies as possible for as many risk factors as possible, it was clearly not possible, given the scope and resources of the project, to cover all the topics. The general **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 origin: Europe prioritized over North America/Australasia prioritized over other countries
- Importance: number of citations
- Language: English
- Peer reviewed journals

At this stage, we had an issue with some risks which, although clearly identified, were not dealt with in open scientific publications. For example, the risk of submarining in passenger cars is clearly identified in the car manufacturer's world and even taken into account in car design but very few, if any, high quality publications were found on this topic. The associated countermeasure was nevertheless taken into account and coded for introduction into the DSS. It is therefore important to remember that the DSS doesn't necessarily contain literature pertaining to the risk (or risks) associated to a given measure (or the other way round).

Regarding **measures**, the aim was to find studies that provided an estimate of effectiveness of the countermeasure under study. 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 prioritized over USA/Australia/Canada prioritized over 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.

2.2.1 Study Coding

With the aim of creating a vehicle-related risk and measure database, **the template created in the context of WP3** was used to capture relevant information from each study so that information could be uniformly reported and shared within the overall SafetyCube project. Guidelines were also made available with detailed instructions on how to use the coding 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. A workshop was organised in 2017 to train coders on how to use the template.

For each study the following information was coded in the template, for inclusion into 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 of publication, source, origin, abstract)
- Road user group object of study
- Study design
- Measures of exposure to the risk factor
- Measures of outcome (e.g. number of injury crashes)
- Type of effects (within SafetyCube this refers to the numerical and statistical details of a given study in a manner to quantify a particular association between exposure (either to a risk factor or a countermeasure) and a road safety outcome)
- Effects (including corresponding measures e.g. confidence intervals)
- Limitations or biases
- Summary of the information relevant to SafetyCube (this may be different from the original study abstract).

For the full list of information provided per study see Martensen et al (2016). **Completed coding files (one per study) were uploaded to the DSS relational database**. This database, with the included synopses and CBAs represents the inventory of road safety risks and measures.

2.2.2 Synopses Creation

The DSS provides information for all coded studies (see previous section) for various risk factors and measures. The synthesis of these studies is made available in the form of a 'synopsis' indicating the main findings for a particular risk or measure, as derived from **meta-analyses or another type of comprehensive synthesis of the results** (e.g. vote-count analysis), according to the guidelines and templates available in Martensen et al. (2016).

In Task 6.1, synopses were created for several risk factors (see deliverable 6.1), on various levels of the related taxonomies, thus, for various levels of detail, mainly depending on the availability of studies. Moreover, the synopses contain context information for risk factors that could not be coded. On the other hand, not all the coded studies present in the DSS are included in the synopsis.

In a similar way, synopses were created in the context of Task 6.2 for several measures on various levels of the related taxonomies thus, for various levels of detail, mainly depending on the availability of studies. Moreover, the synopses contain context information for risk factors that could not be coded. In some cases, taxonomy topics at the specific measure level were merged in order to reach critical mass in terms of sound evidence for a synopsis (e.g. blind spot mirror & blind spot issues for trucks and buses, roof airbag protection & side airbag).

For some measures, it was impossible to write a synopsis because of too few evidence. Yet the related studies were coded for inclusion in the DSS, with no associated full-synopsis. It was therefore decided to write an abbreviated synopsis summarizing the knowledge available, and sometimes an expert point of view based on 1 or 2 studies. This is a specificity of vehicle-related measures.

The synopses aim at helping different end users: decision-makers looking for global estimates but also scientists and experts belonging to the road safety community and interested in results and methodology details. Therefore, synopses contain sections (that can be read independently) aimed at different end user groups. The **structure of each risk factor or measure synopsis** is as follows (small variations may occur, depending on the available literature):

1. **Summary**
    i. Colour Code
    ii. Keywords
    iii. Abstract
    iv. Background
    v. Overview of results
    vi. Analysis methods
2. **Scientific overview**
    vii. Literature Review
    viii. Description of the available studies
3. **Supporting documents**
    ix. Methodology
    x. Details of literature search
    xi. Comparison of available studies in detail (optional)

Final Synopses

After completion of the search and coding process, it became apparent that *for some specific risks /measures, there were insufficient relevant studies to justify the preparation of a synopsis*.

Ultimately the inventory includes 32 synopses on vehicle-related risk factors and 46 synopses on vehicle-related countermeasures. These were included in the DSS, sometimes with slightly content-adapted titles. More details are available in sections 3 and 4.

2.2.3 The Economic Efficiency Evaluation tool

One of the most unique feature of the SafetyCube-project is an Economic Efficiency Evaluation (E^3) calculator that was developed as a Microsoft Excel application in the context of the project.

This tool allows cost-effectiveness calculations for a variety of road safety measures, based on the available literature and SafetyCube specific methodology. It is important to mention that one of the basic assumptions underlying the tool assumes is that road safety measures are evaluated in specific units of intervention, such as a vehicle equipped with a safety system or a specific infrastructure location. Important E^3 tool concepts include:

- **Crash Modification Factor** (**CMF**): CMF consist of multipliers applied to the number of crashes that occurred before the implementation of the measure. A CMF is used to estimate the number of crashes that will occur when the measure is implemented and is a measure of the expected effect.
- **Effectiveness** (**E**) or **percentage reduction** (**PR**) is defined by the formula E=PR=100*(1-CMF) and represents the reduction of crash frequency after the measure is implemented.

The following Figure 1 gives an overview of the E^3 tool, explained in more detail in SafetyCube Milestone 12 (Wijnen & Martensen, 2016).

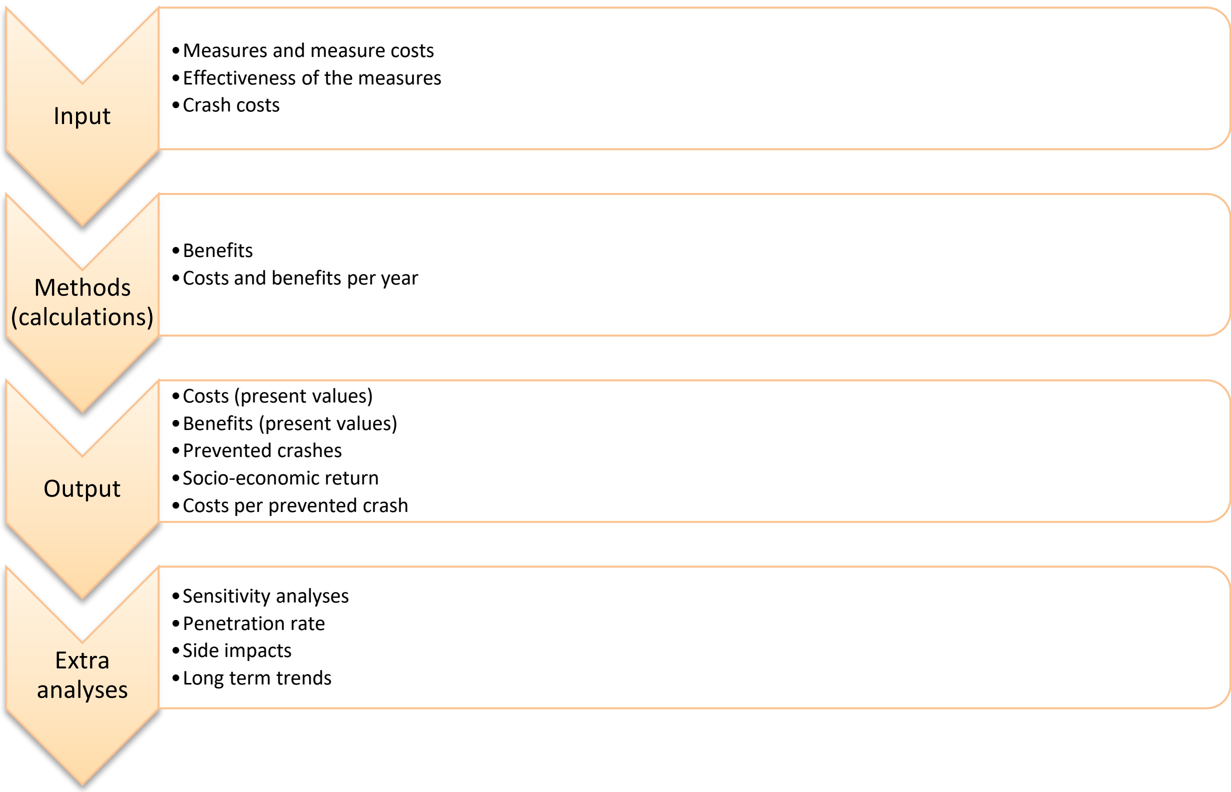


Figure 1 Overview of the SafetyCube E³ Tool

Inputs

First it is important to consider whether a specific road safety measure or intervention helps preventing or mitigating the consequences of crashes. In the E³ tool, all the measures that can prevent crashes are assessed as having a crash-frequency reduction effect and it is recommended to take different levels of injury severity into account when assessing the effectiveness of measures. This is related to the fact that the implementation of a given measure can lead to different costs and benefits (and have different effects) depending on the addressed injury level.
Second, when including the costs of a road safety measure as an input of the E³ tool, maintenance costs and implementation costs should be considered and introduced in the tool on a yearly basis. These costs depend on country and have to be updated to 2015 since this is the year in which the costs of crashes (benefits) that are provided in the E³ tool are expressed.

Another important input for the tool is the target group, the population of crashes for which safety measures are expected to have an impact. In the tool, the target group should be specified for all the levels of severity that have CMF data available. Moreover, the effectiveness (or percentage reduction) should be added for each injury severity level.

In the E³ tool, a database containing all the crashes and costs is available per country and for all European countries together, according to the level of severity. The user can select the relevant data for the country s/he wants to analyse from the database as an input for the analysis.

Method

Benefits derived from the introduction of a measure are calculated as follows.

$$Benefits = \sum_{s} TargetCrashes_s * Effectiveness_s * CrashCosts_s$$

where s refers to injury severity level.

The tool calculates the costs and benefits at a default time horizon of 30 years (that the user can alter for his/her own purposes). First, the actual values of the implementation and maintenance costs are calculated. Then, a discount rate that can be chosen for present value cost calculation.

$$present\ value = \frac{actual\ value}{(1 + discount\ rate)^{year}}$$

Benefits represent the number of crashes avoided per year due to the implementation of the measure. The actual value of these benefits is calculated by multiplying the costs related to each target group by its effectiveness.

Output
The output consists of the present values of the costs and benefits of implementing the measure over the selected time horizon.
Net present value and benefit-cost ratio are also shown, calculated with the following formulas to estimate the socio-economic return of introducing the measures:

Net present value = Present value benefits – Present value costs
Benefit-cost ratio = Present value benefits / present value costs

Other analyses
Extra analyses might be included in the tool. For example, sensitivity analyses, penetration rate of the measures, side effects derived from the implementation of the measure and long-term trends.

Analysis methods
In order to implement the SafetyCube methodologies described above, the following steps were taken.

First, a literature review was performed for the candidate topics of the SafetyCube infrastructure measures taxonomy, in order to identify existing published CBAs that could be used as a basis for SafetyCube CBAs. The studies found were analysed to identify usable data elements. The items of interest were:

- **Target group, unit of implementation and time horizon**: a specific case study was sought, clearly defining these elements, in combination with other relevant information; however, in most cases this was not possible, so the researcher had to define his/her own case study.

- **Measures costs**: costs associated with a specific case study (unit of implementation, target group etc.) were preferred, otherwise a value transfer from another source case study was performed.

- **Measures safety effects**: these could be available either through the previous WP5 work which summarised the safety effects of measures (by means of meta-analysis, or other comprehensive synopsis), or through a specific CBA in the literature.

In general, there were two options for conducting a CBA on the selected measures:

Generic CBA: this would be the preferred option when a meta-analysis with confidence intervals of the estimate of the measure was available, as such an estimate is considered highly reliable and transferable. However, in this case no "perfectly matching" measure cost and target group was available. Consequently, a generic unit of implementation and related target group was defined, and measure's cost information was sought from the available sources and value-transferred to the generic context, as required.

Adjustment of an existing CBA: if no meta-analysis was available giving a generic estimate of the measures safety effect, specific case-studies were sought from the literature, with particular emphasis on existing CBAs. The advantage of this case is the "matching" measures cost, implementation conditions and safety effect; which is however at the detriment of transferability of the estimates. The existing case-study was adjusted in two ways: first, with the improved SafetyCube crash costs estimates, and second, with the update of all figures and estimates to the reference year 2015.

More details on the adopted methodologies and analysis procedure are available in Daniels & Papadimitriou (2017).

3 Vehicle-related risk factors

This chapter summarizes what is a risk factor, which vehicle-related risk factors are addressed in the context of WP6 and which kind of results can DSS users find in synopses or coded studies.

3.1 WHAT IS A RISK FACTOR?

Within the SafetyCube project 'risk factor' refers to any factor that contributes to increasing road accidents frequency or injury severity. Risk factors impact can be direct or assessed through the mediation of a Safety Performance Indicator (SPI). All elements of the road system (Vehicle, Human, Environment …) can contribute to an accident risk factor. WP6 focuses on vehicle-related risk factors only.

3.2 TAXONOMY OF VEHICLE-RELATED RISK FACTORS

The identification of a comprehensive taxonomy of vehicle-related risks was a real challenge by itself. Most of the risk factors present in the scientific literature are related to human behaviour and it is often difficult to dissociate driver and his/her vehicle in the literature. In in-depth data, contributing factors related to vehicle or infrastructure are underrepresented compared to human behaviour issues. This is mainly because the driver is the regulator of the system. In many situations, the vehicle has only a potential to help him/her in mitigating the consequences of driving errors. One more difficulty is worth mentioning: it is often difficult to analyse what remains of vehicles in order to look for mechanical failures, especially when dealing with violent single-vehicle crashes resulting in fatalities.

Nevertheless, a specific taxonomy based on expertise and some well-known issues was finally identified. As recommended by the project, the vehicle-related risk factor taxonomy has a **three levels** structure.
Because every vehicle type has its own characteristics (size, weight, agility …) and is used in a variety of contexts, including infrastructure (roadway, sidewalk, path …), the **first level** of this taxonomy consists in a vehicle category listing (including pedestrians):

- Pedestrian
- Bicycle
- Powered Two-Wheeler / All-Terrain Vehicle
- Passenger car
- Light Commercial Vehicle or Light Goods Vehicle
- Truck / Bus

This second level was developed from the literature review, results on previous European projects (such as SafetyNet, TRACE, DaCoTA, etc.) and our expertise. We tried to harmonize this 2nd level through the different vehicle categories when it was possible. The 3rd level proposes more specific risk factors for each road user types.

The Pedestrian category was added to the initial list composed by vehicle types. The main reason was to gather all the pedestrian risk factors, that would otherwise have been distributed throughout every category of vehicle, in the same category.

WP4 and WP6 taxonomies overlap e.g. for pedestrians or riders' protective equipment. The main difference comes from the perspective used to tackle these risk factors, WP4 taking into account the human behaviour and the use of the equipment aspects while WP6 dealing with interaction between road users and with the protection (in term of injury risk) brought by this equipment.

Table 1: Taxonomy of vehicle risks related to pedestrian.

Vehicle element	Risk factor	Specific risk factor
Pedestrian	**Prevalence of pedestrian factors in crash data**	Pedestrian accidents characteristics (pedestrian, impact, type of vehicle striking, time of crash, ...)
		Injury level
	Vehicle design	Vehicle shape
	Crashworthiness	Pedestrian low star rating (NCAP)
	Visibility / Conspicuity	Prevalence with the presence of sight obstructions (parked vehicles, traffic, street furniture, uneven lighting condition, etc.)

Table 2: Taxonomy of vehicle risks related to Cyclist.

Vehicle element	Risk factor	Specific risk factor
Cyclist	**Prevalence of cyclist factors in crash data**	Accident characteristics (cyclist, vehicle striking, infrastructure, type of impact, time of crash...)
		Injury level
	Visibility / Conspicuity	Prevalence with the presence of sight obstructions (parked vehicles, traffic, street furniture, uneven lighting condition, etc.)

Table 3: Taxonomy of vehicle risks related to Powered Two-Wheeler (PTW) and All –Terrain Vehicle (ATV)

Vehicle element	Risk factor	Specific risk factor
PTW / ATV	**Prevalence of PTW factors in crash data**	Accident characteristics (driver, vehicle, infrastructure, impact, time of crash ...)
		Injury level
	Protective equipment design	Poor helmet performance
		other equipment

	Technical defects / Maintenance	Faulty headlights & taillights
		Problem related to tire
		Faulty steering system and suspension
		Faulty brakes
		Engine modification
	Visibility / Conspicuity	Visibility / Conspicuity / sight obstruction / small size

Table 4: Taxonomy of vehicle risks related to Passenger car

Vehicle element	Risk factor	Specific risk factor
Passenger Car	**Prevalence of vehicle factors in crash data**	Accident characteristics (driver, vehicle, infrastructure, impact, time of crash, ...)
		Injury level
	Injury mechanism	Risk to be injured in frontal impact (driver, front passenger, rear passenger)
		Risk to be injured in rear impact
		Side impact : risk to be injured following nearside/farside impact
		Risk of injury in Rollover
		Risk of injury in single v/s multiple impacts
		Risk of injury in case of fire
		Risk for child
		Submarining & abdominal injury risk
		Risk of injury with airbag deployment (burn, blast, out of position, airbag generation, etc.)
		Load limiter with occupant characteristics (age, pregnant, gender, etc.)
		risk of occupant projection (against rigid part or interaction with occupants and/or restraint)
		risk of ejection (body or part of the body outside the vehicle)

	Crashworthiness	Compatibility (self-protection / partner protection)
		Age of the vehicle
		Crash with animals
		Low star rating (EuroNCAP)
	Technical defects / Maintenance	Faulty headlights & taillights
		Tire blow out
		Faulty steering system and suspension
		Faulty brakes
		Airbag deployment at untimely moment
	Visibility / conspicuity	Blind spot issue
		Visibility limitation du to design (A-pillar, rear view, etc.)
	Specificities	Risk associated to SUV

Table 5: Taxonomy of vehicle risks related to Light Commercial Vehicle (LCV) or Light Goods Vehicle (LGV)

Vehicle element	Risk factor	Specific risk factor
LCV / LGV	**Prevalence of vehicle factors in crash data**	Accident characteristics (driver, vehicle, infrastructure, impact, time of crash, ...)
		Injury level
	Crashworthiness	Compatibility (self-protection / partner protection)
	Technical defects / Maintenance	Faulty headlights & taillights / retroreflective stripes
		Problems related to tire (blow out, defects, etc.)
		Faulty steering system and suspension
		Faulty brakes
		Load / Distribution of the load / cargo securing
	Visibility / conspicuity	Blind spot issue
		Visibility limitation du to design

Table 6: Taxonomy of vehicle risks related to Trucks or Bus & Coaches

Vehicle element	Risk factor	Specific risk factor
Trucks **Bus & Coach**	**Prevalence of vehicle factors in crash data**	Accident characteristics (driver, vehicle, infrastructure, impact, time of crash, ...)
		Injury level
	Injury mechanism	Bus: Risk for unbelted occupants
		Risk with intrusion
		Risk of injury in case of fire
	Crashworthiness	Compatibility (self-protection / partner protection)
		Risk for VRU
	Technical defects / Maintenance	Faulty headlights & taillights / retroreflective stripes
		Tire blow out
		Faulty steering system and suspension
		Faulty brakes
		Truck: Load / Distribution of the load / cargo securing
		Truck: Risk associated with transport of dangerous goods
	Visibility / conspicuity	Blind spot issue
		Visibility limitation du to design

3.3 RISK FACTOR CODING TEMPLATES

A risk factor coding template developed inWP3 (Martensen et al., 2017) was used to record key data and metadata from individual studies.

For each study the following information was coded in the template and is 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 - URL, abstract)
- Road user group examined
- Study design
- Estimates of exposure to the risk factor
- Measures of outcome (e.g. number of injury crashes)

- Type of effects; within SafetyCube this refers to statistical details allowing to quantify an association between exposure – either to a risk or a measure – and outcome in terms of road safety
- Effects (e.g. confidence intervals)
- Limitations and possible biases
- Summary of the information relevant to SafetyCube (this may be different from the original study abstract or be only a part of it).

For the full list of information provided per study see Martensen et al. (2017). Completed coding templates (one file per study) were uploaded to the DSS relational database.

3.4 VEHICLE-RELATED CRASH SCENARIOS USING ACCIDENT DATA

To enrich the background information in the risk factor, accident data from the LAB (VOIESUR), BAAC (ONISR) and generic data from the CARE CADaS database was used.

3.4.1 Injury accidents database VOIESUR (LAB)

VOIESUR is the name of a French project funded by ANR (Agence Nationale pour la Recherche – the French National Research Agency) and Fondation MAIF. Four scientifically well-known and complementary organizations and research centres, in Europe were involved in this project: CEESAR, CETE NC[1], IFSTTAR[2] and LAB.

The main objective of this project was "*To reduce road accidents and injuries by identifying road safety issues or giving stakeholders knowledge to make decisions".*

The VOIESUR project is based on the in-depth analysis of road accident reports in France in 2011. In the context of this project, all fatalities police reports were coded. Regarding PV injury accidents, only 1 / 20th of the reports were randomly chosen and coded. The database totals 8500 accident entries. The VOIESUR database is composed of:

- 8 500 accidents (among which 3 500 resulting in at least one fatalities)
- 11 400 infrastructure settings
- 14 000 vehicles, out of which 7 000 with initial speed estimates
- 21 300 road users involved : 8 300 persons without any injury, 6 500 slightly injured, 2 600 seriously injured and 3900 killed
- 8 000 medical reports
- 16 000 collisions[3]

Because not all injury accidents that occurred in France in 2011 were analysed, weighting factors were calculated in order to transpose results at national level. These weighting factors are based on the following criteria:

- Type of road users
- Presence of a third party in the accident
- Type of Police (Gendarmerie, Police) reporting
- Injury severity
- Type of Road (Expressway, Country road, Highway ...)

[1] Centre d'Etudes Techniques de l'Equipement Normandie Centre (today called CEREMA)

[2] Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux

[3] Collision refers to direct impact between vehicles or vehicle and object. Several collisions can occur in one single accident.

3.4.2 BAAC Database

The database called BAAC[4] is the national injury road accident census provided by the French ministry (ONISR[5]). Every year, all road injury accidents (any accident occurred on a road open to the public traffic, involving at least one vehicle and with at least a victim requiring medical care) collected by the police are coded and gathered in this database. This database allows to complete the CARE database with the French figures. In this report the data for the year 2014 will be used.

3.4.3 CARE Accident database CADaS

Crash scenario analysis conducted using cases from the CARE Database, considers all fatal accidents[6] recorded in year 2013. In total, records from 23 577 accidents which occurred in 28 European countries were analysed. The CARE Database comprises detailed data on individual accidents as collected by the Member States. Data are recorded according to a Common Accident Data Set (CADaS) consisting of a minimum set of standardised data elements, which allows for comparable road accident data to be available in Europe. Accident reports are comprehensive of crash circumstances, which doesn't necessary mean that a coded circumstance has had influence on the crash. Note that risk factor is identified in relation to the involved party who was considered most at fault.

3.4.4 Safetycube scenarios for all types of road users

Within SafetyCube, a hierarchical **taxonomy of accident scenarios** was developed (see Appendix D), using the same structure as in risk factors and measures taxonomies. This allowed the identification of eight primary accident categories:

- Pedestrian Accident
- Bicyclist Accident
- Single Vehicle Accident
- Head-On Collision / On-Coming Traffic
- Rear-End Collision / Same Direction Traffic
- Junction Accident (No Turning)
- Junction Accident (Turning)
- Railway Crossing

Several sub-categories were also considered within each scenario, corresponding to the different pre-crash configurations. For example, the Pedestrian Accident scenario has been divided into 9 sub-scenarios:

- pedestrian crossing road out of crossing path
- pedestrian crossing road on crossing path at straight stretch
- pedestrian crossing road in front of junction
- pedestrian crossing road behind junction
- pedestrian moving along the road
- vehicle reversing
- pedestrian sitting or lying on the ground
- pedestrian – changing mode (e.g. driver getting off the car)
- other pedestrian configuration

[4] Bulletin d'Analyse des Accidents corporels de la Circulation
[5] Observatoire National Interministériel de la Sécurité Routière
[6] Data refer to accidents where at least a person was fatally injured (death within 30 days of the road accident, confirmed suicide and natural death are not included).

It is noteworthy that this hierarchy doesn't take the initial situation or factors having caused this kind of accident into account, but rely on the configuration prevailing prior to crash.

If we look at the main scenarios (Figure 1) we can see that "Single vehicle accidents" are the most frequent configuration (21%) followed by pedestrian accidents (18,8%) and "Rear-End collisions or same traffic direction collisions" (18,7%).

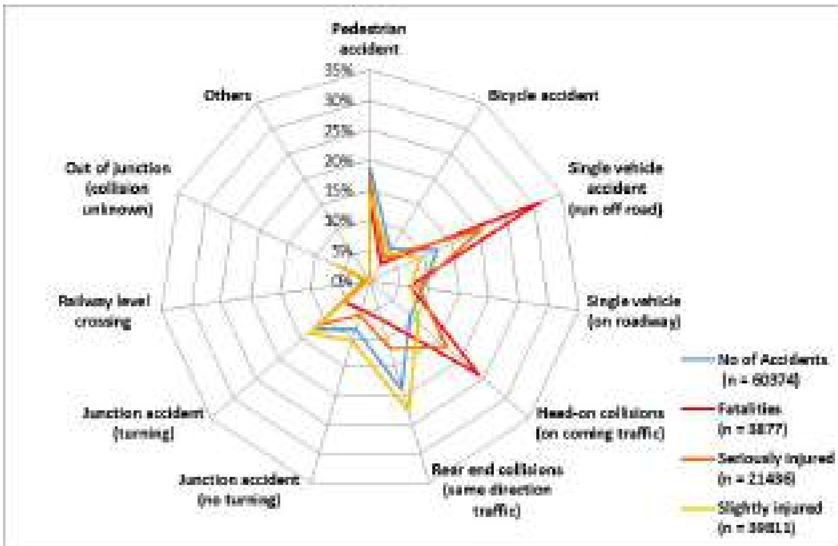


Figure 2 : Distribution of the SafetyCube scenarios according to the number of accidents and the severity (source: VOIESUR, France 2011)

In Figure 2, a zoom on single vehicle accident is made ("single vehicle accidents" gathers scenarios "run-off road" and "on roadway" categories) giving the distribution of the accidents and the associated severities among the Single vehicle accidents sub-scenarios. The three most deadly sub-scenarios are "Leaving the road nearside collision with object)" (27%), "Leaving the road farside (collision with object)" (20%) and "Leaving the road nearside (without roll-over)" (12%).

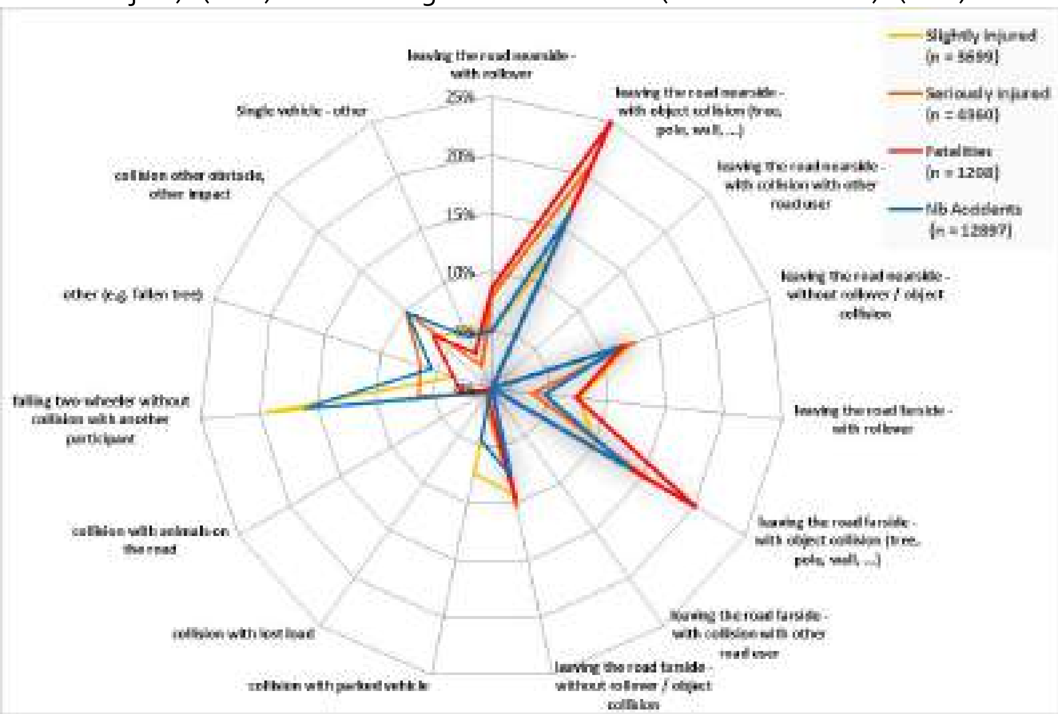


Figure 3 : Distribution of the severity according to the sub-level scenarios of single vehicle accident scenario (source: VOIESUR, France 2011)

Now, we focus our results on sub-scenarios, i.e. all scenarios considered at the second level of taxonomy. The total number of these is 69.

The first 10 most frequent sub-scenarios (Table 7) represent 43% of injury accidents. The three most frequent scenarios are "Pedestrian crossing road in front of junction" (5.3%), "Rear-End collision or same traffic direction: lane changing vehicle" (5.22%) and "Pedestrian crossing the road behind the junction" (5.19%).

Rank (top 10)	Scenarios		Nb Accidents	% Accidents
1	Pedestrain : pedestrian crossing road in front of junction	1.3	3222	5%
2	RE collisions / same direction traffic : lane changing vehicle	6.4	3150	5%
3	Pedestrain : pedestrian crossing road behind junction	1.4	3136	5%
4	RE collisions / same direction traffic : - type of collision unknown, out of junction	6.9	2709	4%
5	Junction accident – turning : farside turn - other participant in opposite direction	8.2	2686	4%
6	RE collisions / same direction traffic : standing vehicle	6.1	2647	4%
7	RE collisions / same direction traffic : other	6.6	2341	4%
8	RE collisions / same direction traffic : breaking vehicle	6.2	2161	4%
9	Single Aehicle Accident (Run off road) : leaving the road nearside - with object collision (tree, pole, wall, ...)	3.2	2102	3%
10	Single Vehicle Accident (on roadway) : falling two-wheeler without collision with another participant	4.5	2084	3%

Table 7 : Top 10 of the most frequent accident scenarios (Source VOIESUR, France 2011)

If we consider now the most deadly sub-scenarios (Table 8), the first 10 scenarios represents 52% of the fatalities. The three most frequent scenarios are "Single vehicle accidents: leaving the road nearside (collision with object)" (9.4%), "Head-on collision or on-coming traffic (unintended lane change)" (8.0%) and "Single vehicle accidents: leaving the road farside (collision with object)" (7.6%).

Rank (top 10)	Scénarios		Fatalities	% Fatalities
1	Single Aehicle Accident (Run off road) : leaving the road nearside - with object collision (tree, pole, wall, ...)	3.2	366	9%
2	HO collisions / on coming traffic : front to front (unintended lane change stable)	5.2	310	8%
3	Single Aehicle Accident (Run off road) : leaving the road farside - with object collision (tree, pole, wall, ...)	3.6	294	8%
4	Single Aehicle Accident (Run off road) : leaving the road nearside - without rollover / object collision	3.4	174	4%
5	HO collisions / on coming traffic : side collision with other participant oncoming (loss of control)	5.4	169	4%
6	HO collisions / on coming traffic : front to front (unintended lane change instable)	5.3	166	4%
7	RE collisions / same direction traffic : - type of collision unknown, out of junction	6.9	157	4%
8	Single Aehicle Accident (Run off road) : leaving the road farside - without rollover / object collision	3.8	141	4%
9	Single Aehicle Accident (Run off road) : leaving the road nearside - with rollover	3.1	127	3%
10	HO collisions / on coming traffic : other collision (unintended lane change instable)	5.6	113	3%

Table 8 : Top 10 of the most deadly accident scenarios (Source VOIESUR, France 2011)

The top10 of the most severe accidents (number of KSI[7] for 100 accidents) (Table 9) represents 12% of the overall accidents and 26% of the KSI. The top3 of this category are included in the "Head-On or on-coming traffic accidents scenario. The first is "front to front with overtaking maneuver" (151 KSI for 100 accidents) followed by "Side collision with other participant oncoming (loss of control)" (126 KSI for 100 accidents) and "front to front with unintended lane change instable" (109 KSI for 100 accidents).

Rank (top 10)	Scenarios		Nb Accidents	KSI	KSI for 100 accidents
1	HO collisions / on coming traffic : front to front (overtaking)	5.1	335	506	151
2	HO collisions / on coming traffic : side collision with other participant oncoming (loss of control)	5.4	540	681	126
3	HO collisions / on coming traffic : front to front (unintended lane change instable)	5.3	845	924	109
4	Single Vehicle Accident (on roadway) : collision with lost load	4.2	44	44	100
5	Pedestrain : pedestrian sitting or lying on the ground	1.7	18	18	100
6	Single Aehicle Accident (Run off road) : leaving the road nearside - with rollover	3.1	648	612	95
7	HO collisions / on coming traffic : front to front (unintended lane change stable)	5.2	1537	1402	91
8	Single Aehicle Accident (Run off road) : leaving the road farside - without rollover / object collision	3.8	964	762	79
9	Single Aehicle Accident (Run off road) : leaving the road nearside - with object collision (tree, pole, wall, ...)	3.2	2102	1650	79
10	Single Vehicle Accident (on roadway) : collision with animals on the road	4.3	95	73	76

Table 9 : Top 10 of the most severe accident scenarios
(Source VOIESUR, France 2011)

This approach is a quick mean for underlining major accident configurations for each type of vehicle, including pedestrians. **This part is most useful to industry designers, road safety researchers and policy makers alike**, because the full complexity of accidents situations, aggregating human, infrastructure and vehicle issues appears clearly. One additional advantage is that the approach provides a **ranking**, which is however not easily transferable from one country to another, the most country-dependant item being each scenario's proportion in the global road accidents picture.

3.5 VEHICLE RELATED RISK FACTOR SYNOPSES

For each specific risk factor of the vehicle taxonomy, a systematic search of the literature was realized. The identified relevant studies were coded using a uniformed 'coding template'. This captured quantifiable objective findings about crash risk, frequency and severity influenced by the risk factor implementation. Where sufficient studies could be identified, a synopsis was written summarising the impact of the risk factor on road safety. Each synopsis has a common format which starts with a colour code indicating the level of evidence available as to the risk affected. This is followed by an abstract providing a summary of the findings for the examined risk factor.

In applying the method outlined in this chapter it was initially intended that each of the 59 specific risk factor would have a synopsis. However, following completion of the search and coding procedure it

[7] KSI : Killed and Severely Injured

became apparent that for some specific risk factors there were insufficient code-able studies to justify the preparation of a synopsis. Finally, 32 synopses were developed for inclusion in the DSS.

Furthermore, it should be underlined that the synopses included in this Deliverable are the **final versions available at the time of the submission**, which have been thoroughly reviewed within the WP, and also within the project (Deliverables internal review procedures). Nevertheless, **the synopses are living documents**, which may be further improved also after the Deliverable submission. Moreover, a thorough Quality Assurance procedure is being implemented for all the contents of the DSS before the end of the project. Therefore, any further improvements in the synopses included in this Deliverable will be reflected in the **final versions available in the DSS at the end of the project**. (*Annexe A*)

Pedestrian risk factors
A1 Pedestrian characteristics
A2 Impact characteristics
A3 Type of vehicle striking
A4 Injury level
A5 Time of crash
A6 Pedestrian - Visibility / Conspicuity
A7 Low NCAP rating

Cyclist risk factors
A8 Accident characteristics
A9 Injury severity
A10 Visibility / Conspicuity

Powered Two Wheelers risk factors
A11 Accident characteristics
A12 Injury severity
A13 Technical_Defects_Maintenance
A14 Visibility / Conspicuity

Passenger car risk factors
A15 Frontal Impact
A16 Side impact
A17 Rear Impact
A18 Rollover
A19 Submarining & abdominal injury risk
A20 Compatibility
A21 Low Star Rating
A22 Technical_Defects_Maintenance

Light Goods Vehicle (LGV) or Light Commercial Vehicle (LCV) Risk Factors
A23 Accident characteristics
A24 Injury severity
A25 Compatibility
A26 Visibility / Conspicuity

Truck or Heavy Goods Vehicles (HGV)
A27 Accident characteristics
A28 Compatibility
A29 Visibility / Conspicuity

A30 Unbelted Occupants

Bus & Coaches

A31 Rollover

A32 Fire risk

3.6 MAIN RESULTS OF RISK FACTOR EVALUATION

Table 10 presents the risk factors in association with their colour code. The code can be **Red** (Risky), Yellow (Probably risky), **Grey** (Unclear results).

In total 13 risk factors were given the colour **Red, indicating that there is consistent evidence** that they represent a high-risk factor on road safety. 11 risk factors were marked as yellow (potential risk factor) with a likely high level of risk on road safety. Grey (unclear) was assigned to 8 risk factors, where no clear conclusion could be drawn.

The following table presents the risk factors sorted by colour code.

Table 10: vehicle-related risk factor synopses by colour code

Red	Yellow	Grey
! Pedestrian characteristics	! Ped. / Vehicle design	? Pedestrian / Impact characteristics
! Bicycle / Accident characteristics	! Ped. / Low NCAP rating	? Pedestrian / Visibility / Conspicuity
! Bicycle / Injury severity in accidents	! Bicycle / Visibility - Conspicuity	? PTW / Crash characteristics
! Pedestrian / injury level	! PTW / Poor helmet performance	? PTW / Vehicle characteristics
! PTW / impact characteristics	! PC / Prevalence of vehicle factors in crash data	? PTW / Technical defect
! PTW / injury level	! PC / injury mechanism / Rear impact	? HGV / Crash data
! PC / Injury mechanism / frontal impact	! PC / Low star rating	? HGV / Vehicle data
! PC / injury mechanism / Side impact	! PC / Technical defects / Maintenance	? HGV / Injury level
! PC / injury mechanism / Rollover	! LGV / Accident characteristics	
! PC / Abdominal injuries & submarining	! LGV / Impact characteristics	
! LGV / self & partner protection	! HGV / Impact characteristics	
! LGV / Visibility		
! HGV / Blind spot issue		

The limitations of this work should be noted. The process of allocating colour codes was related to both the magnitude of risk observed, the level of evidence for this and on expertise when not enough evidence was found. Findings are limited both by the implemented literature search strategy the quality and sometimes by the number of the studies identified.

Prioritising of study coding was necessary for risk factors with many identified studies. The criteria for prioritising within each synopsis is detailed in the supporting document. This approach focused on studies with the highest methodological quality, however, it is possible that some detail of level of risk may have been missed by failure to consider a broad range of methodological approaches. Finally, within the considered literature, crash risk and crash frequency are much more commonly studied than crash severity. For some risk factors this makes it difficult (or impossible) to consider the implications for injury causation.

4 Vehicle-Related Measures and their effects

This chapter summarizes what is a measure, which vehicle-related measures are addressed in the context of WP6 and which kind of results can DSS users find in synopses or coded studies.

4.1 WHAT IS A MEASURE?

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.

4.2 TAXONOMY OF VEHICLE-RELATED MEASURES

The aim of creating a taxonomy was to identify the relevant topics covering all aspects of vehicle-related countermeasure, and structure them in a meaningful way to serve as the **back-bone of the analyses**. This was initiated with the creation of a comprehensive list of road safety measures (as it was done for the risk factors) specific to vehicles.

The initial intention was 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 was 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 by the contribution of the vehicle perspective. 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 otherwise have been scattered throughout every vehicle category.

The full taxonomy is presented in Tables 11 to Table 13. It should be noted that the taxonomy is not comprehensive

Table 11: Taxonomy of vehicle countermeasure related to crashworthiness.

Topic	Subtopic	Countermeasure / Safety System
crashworthiness	**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 12: 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 13: 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

4.3 ROAD SAFETY MEASURE CODED TEMPLATES

4.3.1 Overview of coded studies

A measure coding template developed inWP3 (Martensen et al., 2017) was used to record key data and metadata from individual studies.

For each study the following information was coded in the template and is 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 - URL, abstract)
- Road user group examined
- Study design
- Estimates of exposure to the measure
- Measures of outcome (e.g. number of injury crashes)
- Type of effects; within SafetyCube this refers to statistical details allowing to quantify an association between exposure – either to a risk or a measure – and outcome in terms of road safety
- Effects (including corresponding measures e.g. confidence intervals)
- Limitations and possible biases
- Summary of the information relevant to SafetyCube (this may be different from the original study abstract or only be a part of it).

For the full list of information provided per study see Martensen et al. (2017). **Completed coding templates were uploaded to the DSS relational database**.

In total, more than 100 studies on vehicle related measures were coded within WP6. This is slightly lower than for WP4 and WP5. This can be explained by the fact that for several safety systems too few studies were found, leading to *abbreviated synopses* without any coding template.

4.3.2 DSS output

As an example of the output displayed by the DSS after a specific query, two examples of individual study pages are presented below. All the features of the coding template are presented to the user of the DSS:

SafetyCube DSS — European Road Safety Decision Support System

Search | Knowledge | Calculator | Methodology | Support

Effectiveness of belt positioning booster seats: An updated assessment

Arbogast, KB; Jermakian, JS; Kallan, MJ; Durbin, DR

Abstract

The objective of this study was to provide an updated estimate of the effectiveness of belt-positioning booster (BPB) seats compared with seat belts alone in reducing the risk for injury for children aged 4 to 8 years. Data were collected from a longitudinal study of children who were involved in crashes in 16 states and the District of Columbia from December 1, 1998, to November 30, 2007, with data collected via insurance claims records and a validated telephone survey. The study sample included children who were aged 4 to 8 years, seated in the rear rows of the vehicle, and restrained by either a seat belt or a BPB seat. Multivariable logistic regression was used to determine the odds of injury for those in BPB seats versus those in seat belts. Effects of crash direction and booster seat type were also explored. Complete interview data were obtained on 7151 children in 6591 crashes representing an estimated 120646 children in 116503 crashes in the study population. The adjusted relative risk for injury to children in BPB seats compared with those in seat belts was 0.55. This study reconfirms previous reports that BPB seats reduce the risk for injury in children aged 4 through 8 years. On the basis of these analyses, parents, pediatricians, and health educators should continue to recommend as best practice the use of BPB seats once a child outgrows a harness-based child restraint until he or she is at least 8 years of age.

http://doi.org/10.1542/peds.2009-0908

Basic Study Information

Topic: COUNTERMEASURE
Year: 2009
Source: PEDIATRICS JOURNAL

Design: CROSS-SECTIONAL

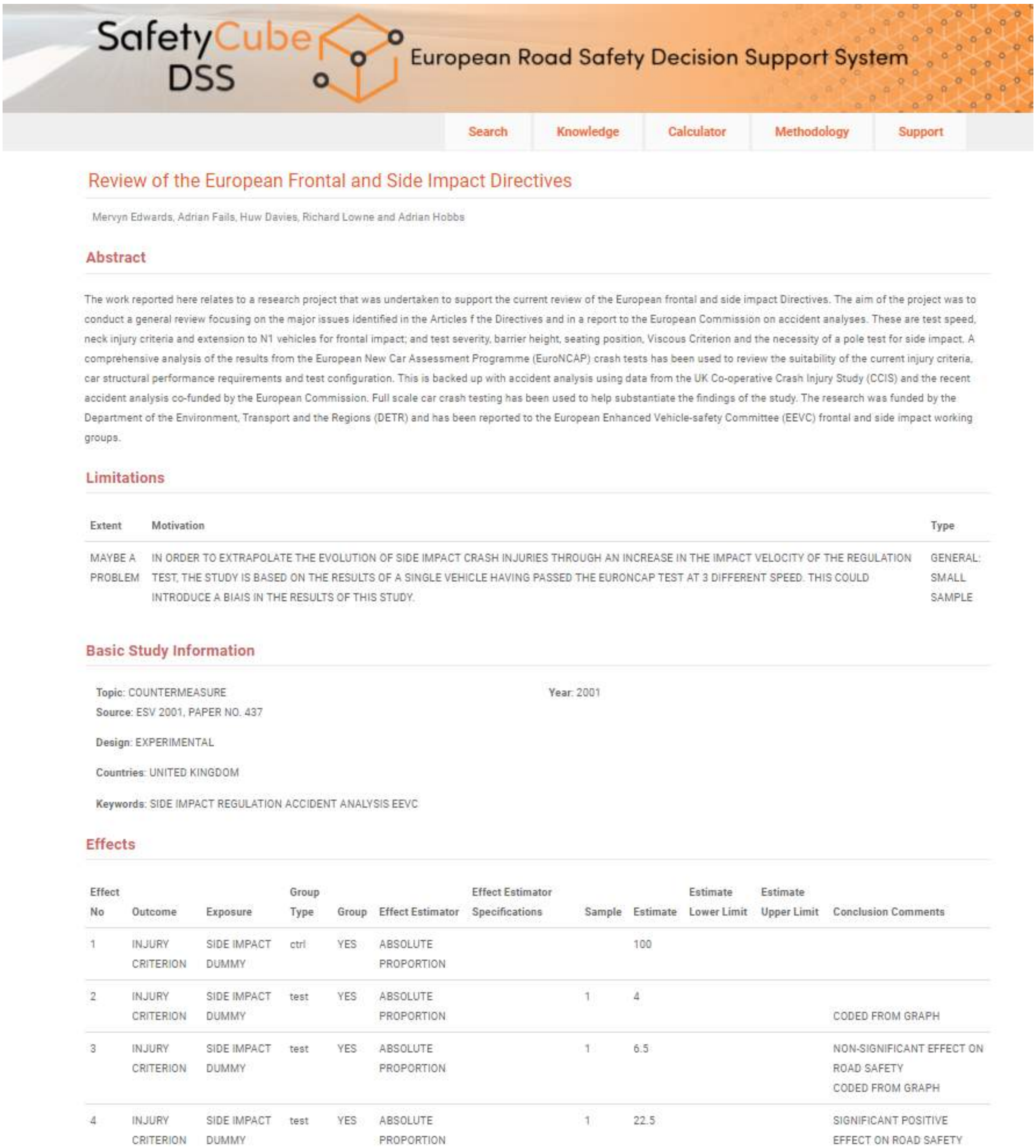
Countries: UNITED STATES

Keywords: CHILD PASSENGER SAFETY SEAT BELTS BOOSTER SEATS

Effects

Effect No	Outcome	Exposure	Group Type	Group	Effect Estimator	Effect Estimator Specifications	Sample	Estimate	Estimate Lower Limit	Estimate Upper Limit	Conclusion Comments
1	AIS 2+ INJURY	BELT-POSITIONING BOOSTER SEAT USE	ctrl	NON-EXPOSED	ODDS RATIO	BELT POSITIONED BOOSTER SEAT AND SEAT BELT VS NO BELT POSITIONED BOOSTER SEAT AND SEAT BELT	cases = 1604; controls = 5547	0.55	0.32	0.96	SIGNIFICANT POSITIVE EFFECT ON ROAD SAFETY COMPARED WITH CHILDREN IN NORMAL THREE POINT SEATBELTS, THOSE IN BELT POSITIONING BOOSTER SEATS AND THREE POINT SEATBELTS WERE 45% LESS LIKELY TO HAVE AN AIS 2+ INJURY
1	AIS 2+ INJURY	BELT-POSITIONING BOOSTER SEAT USE	test	EXPOSED	ODDS RATIO	BELT POSITIONED BOOSTER SEAT AND SEAT BELT VS NO BELT POSITIONED BOOSTER SEAT AND SEAT BELT	cases = 1604; controls = 5547	0.55	0.32	0.96	SIGNIFICANT POSITIVE EFFECT ON ROAD SAFETY COMPARED WITH CHILDREN IN NORMAL THREE POINT SEATBELTS, THOSE IN BELT POSITIONING BOOSTER SEATS AND THREE POINT SEATBELTS WERE 45% LESS LIKELY TO HAVE AN AIS 2+ INJURY

Figure 4: First study example – Effectiveness of belt positioning booster seats: An updated assessment



SafetyCube DSS European Road Safety Decision Support System

Search | Knowledge | Calculator | Methodology | Support

Review of the European Frontal and Side Impact Directives

Mervyn Edwards, Adrian Fails, Huw Davies, Richard Lowne and Adrian Hobbs

Abstract

The work reported here relates to a research project that was undertaken to support the current review of the European frontal and side impact Directives. The aim of the project was to conduct a general review focusing on the major issues identified in the Articles f the Directives and in a report to the European Commission on accident analyses. These are test speed, neck injury criteria and extension to N1 vehicles for frontal impact; and test severity, barrier height, seating position, Viscous Criterion and the necessity of a pole test for side impact. A comprehensive analysis of the results from the European New Car Assessment Programme (EuroNCAP) crash tests has been used to review the suitability of the current injury criteria, car structural performance requirements and test configuration. This is backed up with accident analysis using data from the UK Co-operative Crash Injury Study (CCIS) and the recent accident analysis co-funded by the European Commission. Full scale car crash testing has been used to help substantiate the findings of the study. The research was funded by the Department of the Environment, Transport and the Regions (DETR) and has been reported to the European Enhanced Vehicle-safety Committee (EEVC) frontal and side impact working groups.

Limitations

Extent	Motivation	Type
MAYBE A PROBLEM	IN ORDER TO EXTRAPOLATE THE EVOLUTION OF SIDE IMPACT CRASH INJURIES THROUGH AN INCREASE IN THE IMPACT VELOCITY OF THE REGULATION TEST, THE STUDY IS BASED ON THE RESULTS OF A SINGLE VEHICLE HAVING PASSED THE EURONCAP TEST AT 3 DIFFERENT SPEED. THIS COULD INTRODUCE A BIAIS IN THE RESULTS OF THIS STUDY.	GENERAL: SMALL SAMPLE

Basic Study Information

Topic: COUNTERMEASURE **Year**: 2001
Source: ESV 2001, PAPER NO. 437

Design: EXPERIMENTAL

Countries: UNITED KINGDOM

Keywords: SIDE IMPACT REGULATION ACCIDENT ANALYSIS EEVC

Effects

Effect No	Outcome	Exposure	Group Type	Group	Effect Estimator	Effect Estimator Specifications	Sample	Estimate	Estimate Lower Limit	Estimate Upper Limit	Conclusion Comments
1	INJURY CRITERION	SIDE IMPACT DUMMY	ctrl	YES	ABSOLUTE PROPORTION			100			
2	INJURY CRITERION	SIDE IMPACT DUMMY	test	YES	ABSOLUTE PROPORTION		1	4			CODED FROM GRAPH
3	INJURY CRITERION	SIDE IMPACT DUMMY	test	YES	ABSOLUTE PROPORTION		1	6.5			NON-SIGNIFICANT EFFECT ON ROAD SAFETY CODED FROM GRAPH
4	INJURY CRITERION	SIDE IMPACT DUMMY	test	YES	ABSOLUTE PROPORTION		1	22.5			SIGNIFICANT POSITIVE EFFECT ON ROAD SAFETY

Figure 5: Second study example – Review of the European Frontal and Side Impact Directives

4.4 ROAD SAFETY MEASURE SYNOPSES

Similar to the risk factors, the main findings of the examined road safety measures are provided as 'synopses', which are available through the DSS. Within the synopses, each countermeasure (or group of measures) was analysed systematically based on scientific studies and was further assigned to one of three levels of effectiveness (marked with a colour code).

Each synopsis has a common format which starts with a colour code indicating the level of evidence available. This is followed by an abstract providing a summary of the findings for the examined measure.

Finally, 46 synopses on vehicle related measures have been developed for inclusion in the DSS. This has been accomplished by 8 different SafetyCube partner organisations. In a further step, the quality of the synopses was checked by reviewers. Now, 46 synopses have passed the quality assurance process and the abstracts and colour codes of these are presented in Appendix B.

Crashworthiness – Frontal impact
B1 Directive 96/79/CEE, ECE.R94 & EuroNCAP
B2 EuroNCAP (Full Width & ODB)
B3 Frontal airbag
B4 PTW airbag
B5 Seat belt effectiveness (SBR and Load limiter included)
B6 Anti-submarining (airbags, seat bossage, knee airbag, seatbelt pretensioner...)

Crashworthiness – Side impact
B7 Directive 96/27/CEE, ECE.R95 & EuroNCAP
B8 Regulation UN R135 (Pole side-impact protection)
B9 Side impact measure – EuroNCAP (MDB & Pole)
B10 Side airbag (Head, Thorax, Pelvis)

Crashworthiness – rear impact
B11 Anti Whiplash (Seat, active headrest ...)

Crashworthiness – rollover
B12 Rollover protection system

Crashworthiness – pedestrian
B13 Pedestrian protection – Active Technology
B14 Pedestrian protection – Vehicle Shape
B15 Pedestrian regulation

Crashworthiness – child
B16 Child Restraint System – 'CRS'
B17 Child Restraint System – 'booster seats'

Crashworthiness – PTW specificities
B18 Protective clothing
B19 PTW protective clothing (Helmet)

Crashworthiness – Cyclist protective clothing
B20 Cyclist protective clothing
B21 Cyclist protective clothing (Helmet)

Crashworthiness – HGV specificities
B22 Underrun protection (Lateral Side Guards / Rear)

Active safety – longitudinal control

B23 Emergency Braking Assistance system
B24 Autonomous Emergency Braking AEB (City, interurban)
B25 Autonomous Emergency Braking AEB (Pedestrians & cyclists)
B26 Emergency Stop Signal (ESS)
B27 Braking system PTW (ABS, Combined braking system ...)
B28 Collision Warning system
B29 Intelligent Speed adaptation, Speed Limiter & Speed regulator
B30 Adaptive Cruise Control (ACC & ACC Stop & start)

Active safety – lateral control

B31 Electronic Stability Control (ESC)
B32 Lane keeping Systems

Active safety – driver assistance

B33 Alcohol Interlock (ALC)

Active safety – visibility enhanced

B34 Adaptive headlights
B35 Daytime running lights
B36 Night Vision
B37 Vehicle backup camera - Reversing Detection or Camera systems (REV)
B38 Blind Spot Detection

Active safety – technical defects

B39 Tyre Pressure Monitoring and Warning
B40 Vehicle inspection
B41 Automatic Emergency Braking (AEB) for trucks

Active safety – connected

B42 Vehicle to Vehicle communication

Tertiary safety – post crash

B43 ECall
B44 Rescue Data Sheet & Rescue code
B45 ECE R100 (Battery electric vehicle safety)
B46 Event Data Recorder

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).

The following Table 14 presents the safety measures relating to their colour code. 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.

Table 14: safety measures by colour code

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

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 with Anti Whiplash
- Airbag protection (Roof, curtains, ...) Merged with side airbag
- Rollover protection systems incl. ECE R66
- Drowsiness and Distraction Recognition
- 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, the level of evidence for this and on expertise when not enough evidence was found.
Findings are limited both by the implemented literature search strategy, the quality and sometimes by the number of studies identified.

5 Economic evaluation of vehicle-related measures

This section provides an overview of the results of the Cost-Benefit Analyses (CBA). The first chapter lists all the selected measures. In total a CBA was conducted or updated for 9 measures. The second chapter provides and discusses briefly the benefit-to-cost ratios (BCR) and net present values (NPV) for all the selected measures while the third chapter discusses break-even costs. In the last chapter the results are presented and discussed.

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5.1 SELECTED MEASURES

5.1.1 Selection criteria

Following a common method, systematic information on the safety effects of 46 vehicle-related measures was gathered in Task 6.2. The 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). 46 synoptic documents *(synopses)* were created, synthesising the coded studies and outlining the main findings in the form of a meta-analysis (if possible), a review type analysis or a vote-count analysis. In these synopses, each measure was assigned a colour code, which indicates how effective this measure is in terms of the amount of evidence demonstrating its impact on crash reduction. The code can be one of the following:

- Green: **clearly reducing risk (Effective).** 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 (probably effective)**. 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.

In total, 17 measures were assigned a **green** code (e.g. Seat belt (effectiveness) SBR and Load limiter included, Frontal airbag,...), 19 were given a light green code (e.g. PTW airbag, Regulations,...) and 10 were given a grey code (e.g. Rollover protection system, Emergency stop signal,...).

For the purpose of the cost-benefit analyses, measures that turned out to have a green or light green code in D6.2 were selected in a first step. Measures with a grey colour code were not considered to be meaningful candidates for CBA as cost-benefit analyses only make sense if some beneficial effect of the measure can be assumed.

All these measures were reviewed and for each of them it was checked whether they could be the subject of a meaningful CBA. For some measures, insufficient information could be retrieved.

Table 1 gives an overview of this initial selection of measures and indicates for each of these measures whether a CBA could be elaborated or not. The most important reasons for not being able to complete a CBA were:

- Lacking information on measure costs
- Lacking information on measure effectiveness
- Lacking information on the number or the nature of affected accidents

Table 15: Overview of measures

Measure	Colour code	CBA executed
Seat belt (effectiveness) SBR and Load limiter included	Green	**Yes**
Frontal Airbag	Green	No
Side Airbag	Green	No
Anti-Whiplash	Green	No
Child Restraint System – 'CRS'	Green	**Yes**
Child Restraint System – 'Booster seats'	Green	No
PTW protective clothing	Green	No
PTW protective clothing - Helmet	Green	**Yes**
Cyclist protective clothing	Green	No
Cyclist protective clothing - Helmet	Green	No
Emergency Braking Assistance system	Green	**Yes**
Autonomous Emergency Braking AEB (City, interurban)	Green	**Yes**
Autonomous Emergency Braking AEB (Pedestrians & cyclists)	Green	**Yes**
EuroNCAP (Full Width & ODB)	Green	No
Electronic Stability Control (ESC)	Green	**Yes**
Daytime running lights	Green	No
Braking system PTW (ABS, Combined braking system, ...) ABS (PTW)	Green	**Yes**
Directive 96/79/CEE et ECE.R94	Light green	No
Directive 96/27/CEE et ECE.R95	Light green	No
Regulation UN R135 (Pole side-impact protection)	Light green	No
EuroNCAP (MBD & Pole)	Light green	No
Vehicle inspection	Light green	No
ECE R100 (Battery electric vehicle safety)	Light green	No
PTW Airbag	Light green	**Yes**
Underrun protection	Light green	No
Pedestrian protection - 'active technology'	Light green	No
Pedestrian protection - 'vehicle shape'	Light green	No
Pedestrian regulation	Light green	No
Blind Spot Detection	Light green	No
AEB for trucks	Light green	No
Vehicle to Vehicle communication	Light green	No
Event Data Recorder	Light green	No
Alcohol Interlock (ALC)	Light green	No
Intelligent Speed adaptation + Speed Limiter + Speed regulator	Light green	No
eCall	Light green	No
Rescue Data Sheet & Rescue code	Light green	No

5.1.2 Selected measures per category

Crashworthiness

Cost-benefit analyses of this type of measures have been carried out for Child Restraint Systems (CRS), Seat belt (effectiveness) SBR and load limiter included, Helmet usage and performance and PTW airbag.

Active safety/ADAS

Within the measure category "Active safety/ADAS" effectiveness was examined for Emergency Braking Assistance system, Autonomous Emergency Braking AEB (City, interurban), Autonomous Emergency Braking AEB (Pedestrians & cyclists), braking systems PTW (ABS, Combined braking system ...) and Electronic Stability Control (ESC)

Tertiary safety

There was not enough information to perform CBA for any of the Tertiary safety measures identified in D6.2

5.2 BENEFIT-TO-COST RATIOS AND NET PRESENT VALUES

Using the E^3-calculator, developed within SafetyCube, benefit- cost ratios were calculated for most of the selected measures. The results are provided in table 16 below. The table also contains a monetary estimate of the net present value per unit and the break-even point. All the values are expressed at the price level 2015 and accounted for PPP[8] EU-28.

Ratios above 1 indicate a favourable **benefit-to-cost ratio** (BCR). They are indicated in green. For example, a BCR of 2 indicates that the calculated benefits of the measure are twice higher than the costs. BCR values below 1 are indicated in red. They reflect a situation in which the measure benefits (in terms of the monetary value of the reduced number of accidents) are not likely to exceed the measure costs. The smaller the value, the larger the unbalance between costs and benefits. A BCR of 0.2 for instance indicates that the calculated measure costs are five times higher than the calculated benefits.

Negative values for the BCR are only possible in case a measure is likely to cause an increase in the number of crashes. As the selected measures reflect measures that had a green ('effective' or a light green ('probably effective') colour code in the measure synopsis, negative values don't occur.

Table 5 also includes net present values (NPV) of the measures. All NPV are calculated per unit of analysis in order to enable a proper comparison. In case of a BCR below 1 the NPV becomes negative by definition as the estimated costs exceed the benefits. All negative NPV are indicated in red.

5.3 BREAK-EVEN COST FOR MEASURES

Break-even costs reflect the measure cost value at which benefits and costs are equally high. They indicate the maximal costs for one unit of a measure to be still economically efficient. Using break-even costs is especially relevant when no estimates or no reliable estimates of measure costs are available. Although the cost estimates for most measures were found, it is still worthwhile to look at

[8] Purchasing Power Parities

break-even costs as they indicate for every measure at what point – given an assumed effect on traffic safety – it starts to become cost-effective.

Table 16 provides the break-even costs for each of the included measure, independent of the availability of measure costs. Also, the used best estimate for the measure cost is provided. This easily allows to assess the magnitude of the difference between the currently known best estimate of the measure cost and the break-even cost.

Table 16: BCR and Net Present Values per unit for all the selected measures

Measure	**Unit of analysis**	**Total costs per unit of analysis** (in EUR EU-2015 PPP)	**BCR Best estimate**	**NPV** (in EUR EU-2015 PPP)	**Break-even measure cost**
Seat belt (effectiveness) SBR and Load limiter included	One car equipped with a seat belt remainder	€60	1.40		€80
Child Restraint System – 'CRS'	Norway, 90% 90% of all children who belong to families owning a car are correctly restricted	214 EUR /child restraint	3.4	389,612,640	€717
Helmet + reflective equipment + lighting (usage + performance)	One motorcyclist using a helmet	€46	2.2		€353
Emergency Braking Assistance system	One vehicle equipped with EBA system	€529	3		€1500
Autonomous Emergency Braking AEB (City, interurban)	One vehicle equipped with AEB city system	€216.5	0.6		€130
Autonomous Emergency Braking AEB (Pedestrians & cyclists) – High effectiveness	One vehicle equipped with AEB pedestrian system	€216.5	1.5		€325
Braking system PTW (ABS, Combined braking system …)	One motorcycle equipped with ABS	€400	7.8	90,270,625,483	€3135
	One motorcycle equipped with TCS	€325	1.7		€511
Electronic Stability Control (ESC)	One vehicle equipped with ESC system	€146.9	5.7	148,736,168,292	€853

Measure	Unit of analysis	Total costs per unit of analysis (in EUR EU-2015 PPP)	BCR Best estimate	NPV (in EUR EU-2015 PPP)	Break-even measure cost
PTW airbag	One PTW with airbag	*2196.92*	0.03		61

5.4 RESULTS AND LIMITATION

5.4.1 Results obtained

The results of the performed CBA provide the reader with relevant information about the balance between costs and benefits of the selected measures. The CBA documentations themselves are added in the Appendix and provide more details about the underlying assumptions and data. In the present report, the information on the individual analyses was listed in synoptic tables that allow to compare the results for different measures. It was tried as much as possible to express the outcomes (BCR, break-even costs) per unit in order to enable comparisons between the different measures.

First of all, it can be noticed that most of the effective measures have a BCR (benefit-to-cost ratio) above 1 which means that the benefits outweigh the costs. Only for AEB city and PTW airbag, is the BCR below 1. In the case of the PTW airbag, the cost of the system is too high and the accidents which can contribute to mitigate are very few which leads to a very poor BCR of 0.03. The BCR of the cost-efficient measures shows some variability with a range between 0.03 and 7.8.

Second, it was shown that the BCR are sensitive to changes in the underlying assumptions. For four measures, it was possible to evaluate the consequences of a variation in the effectiveness estimate. However, three out of four measures remained cost efficient. Next to that, the effect of a variation of the measure costs was inquired. This could be done for four measures, all of them were consistent even with the change of their costs.

Finally, a worst-case scenario and a best-case scenario analysis were performed. In the worst-case scenario, decreased effectiveness and increased costs were assumed. With these assumptions BCR only remained above 1 for three measures:

- PTW braking systems ABS
- Electronic Stability Control ESC
- Child Restraint Systems CRS

For some measures such as AEB pedestrian and Seatbelt (effectiveness) SBR and Load limiter included, the BCR is close to 1, which means that costs and benefits are balanced. Any detrimental change in measure costs or effectiveness would lead to costs exceeding the benefits.
The highest BCR, 7.8, resulted for PTW ABS. For this measure the costs are low and the effectiveness is quite high, in spite of the estimate has being conservative (some studies gave more potential to this measure).

5.4.2 Description of the approach

The economic evaluation has principally been done by executing cost-benefit analyses. In cost-benefit analyses, the crash costs enter as benefits (because they are prevented) and the costs for measures are compared to them. For countermeasures, the costs are mostly direct costs (i.e. resources used to implement the measure).

One of the major advantages of CBA is that all elements are monetarised and therefore can be compared in various ways. In the SafetyCube project, a common method was established to estimate average crash costs for different injury levels for all European countries. The resulting numbers easily allow to monetarise effects on crashes or injuries as long as quantitative estimates are available on the size of the effects.

The principal tool for all the above-mentioned analyses was the Economic Efficiency Evaluation (E^3) calculator that has been developed in the SafetyCube project. A major advantage of this tool is that it enables to standardise the input and output information. The use of the tool in its test phase also allowed to provide feedback that has been used to gradually improve it. Thanks to the availability of the tool, CBAs could be executed for 9 different measures.

By far the most important limitation of using cost-benefit analysis is its dependence on underlying assumptions that are not always straightforward to assess. The examples show that the assumptions on three elements have a great impact:

- Assumptions about the effectiveness of the measures
- Assumptions about the costs of the measures
- Assumptions about the size of the target group

Most importantly, the scarce and fragmentary information available in the literature resulted in several cases for **a combination of information sources to be used for a single CBA**. In particular, a safety effect from a meta-analysis, being the most reliable effectiveness estimate, needed to be combined with measure cost information from another source, and applied for a customised case (unit of implementation and target group or number of crashes / casualties affected). Although every effort was made by SafetyCube experts to use as consistent sources as possible, and limit the number of different sources to be combined in a CBA, in several cases this could simply not be avoided in order to produce a CBA estimate. Even in these cases, particular caution was put on the transparent and substantiated combination of information.

In other words, the **flexibility provided by the E^3 tool**, which allows to transfer any cost value from any country to another (EU countries, USA, Canada, Australia) was exploited as much as possible, but with particular care to properly combine related information.

Multiple examples can be given of CBA that – according to the assumptions made – easily change from highly beneficial to vastly inefficient or vice versa. These uncertainties were the main arguments to execute a series of sensitivity analyses. These clearly showed what can be the consequences of changing some basic assumptions on measure costs or effectiveness.

The reader should realise that the dependency on all these assumptions is not as such a weakness of the method but rather a weakness of the data that are usually available. In this regard, one can observe that in a number of the executed CBA the most uncertain elements appeared to be the ones that could have been expected to be the easiest to collect: the measure costs and the target numbers of crashes. One could expect that much knowledge on these elements should be available as they represent phenomena that are relatively straightforward to observe in the real world and therefore to collect data about. However, this was not eventually the case, as the documented information was often poor, fragmentary and unreliable.

Clearly, no CBA should just be copied to any situation. Given the above-mentioned limitations, any reader should use CBA values critically and make sure to check thoroughly any of the assumptions made before inferring results about the CBA values for other applications.

In general, it is recommended in any particular case to complement the available information with specific information on the measure's target group, likely effects, the measure costs and the circumstances in which they are applied.

The number of CBA on vehicle safety measures in the scientific literature so far is very limited and much further work is needed to systematically assess costs and benefits of road safety measures. It not just deserves recommendation to carry out this work but also to publish it more systematically in the scholarly literature. Moreover, very little information can be found on (quantified) side effects of measures, which were not considered in the 9 conducted economic evaluations.

In general, we strongly recommend avoiding relying on existing CBA results and transfer them to a different context, but in any particular case to complement the available information with the case-specific information on the measures target group, the likely safety effects, the measure costs and the circumstances in which they are applied.

The E^3 Calculator from the SafetyCube DSS is explicitly designed to meet this need, by allowing users to **customise any input value of the existing examples on the basis of more case-specific information**, or to perform one's own CBA with new data.

9 Cost Benefit Analysis will be available in the DSS for WP6 (Vehicle related countermeasures). Cost-benefit analyses are provided for the following topics (See appendix C for details):

C1 Autonomous Emergency Braking (city, inter-urban)
C2 Autonomous Emergency Braking (AEB) for pedestrians
C3 Child restraints
C4 Emergency Braking Assistance system (EBA)
C5 Electronic Stability Control (ESC)
C6 PTW Helmet
C7 Seatbelt and Seatbelt Reminders
C8 PTW Airbag
C9 PTW braking systems (ABS, TCS)

6 Conclusions

This section addresses the main challenges encountered within this work, the methodological and data limitations that need to be taken into account when interpreting the results. We also give a general conclusion to this deliverable and hints for the next steps.

6.1 GENERAL CONCLUSION

Within the project SafetyCube an inventory of road user related risk factors and countermeasures was created. Risk factors and countermeasures have been systematically analysed and assessed with regard to their effect on road safety. This inventory brings together European and international evidence on both road safety risks and the related interventions that effectively mitigate these threats. Further, the available knowledge is easily accessible for decision makers and other stakeholders of all kinds by the web-based Road Safety Decision Support System (https://www.roadsafety-dss.eu/).

One prominent feature of the DSS is that interlinked information is available on both risk factors and countermeasures across the fields human, infrastructure, vehicles and on the topic of serious injuries. This should help decision makers to easily find effective and efficient measures for an existing problem or gaining information which problems can be tackled by a specific measure. The linkage of risks and measures across the fields human, infrastructure and vehicle should make users aware that solutions can be found in various areas.

The scenario approach provides an evidence-based ranking of situations to be addressed. The DSS offers a rare opportunity to overcome the usual shortcoming of this particular approach, that consists in not giving a clear view of which factor has an influence on the situation, and to which of the road safety domain it pertains. However, the authors of this deliverable encourage research bodies worldwide to build similar scenarios and scenario rankings. The work on French data that is presented in the DSS is hardly transferable to other countries and is only presented as an example.

Coming back to **vehicle-related risks and measures**, 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 restraint 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.

Some Cost-Benefit Analyses were included as examples. As time horizons or methods used to evaluate benefits or costs are country-dependant, existing CBA are not-transferable from one country to another and should not, therefore, be compared with one another. By giving users the opportunity to alter existing time horizons or benefit-cost calculations, the DSS-included E^3 calculator is the only tool that should be used for that purpose**. This should allow policy makers to identify road safety effective measures that are currently too expensive and on which efforts could be made,** be it by imposing lower prices or, more effectively, by making given systems mandatory and let the market self-regulate itself into reaching lower prices.

Our last word concerns regulations, which mostly appears in the "probably effective" measure 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. Yet, progressively introduced regulations aimed at making safety systems mandatory have a known effect: they bring the targeted safety system out of market and price competition. To the benefit of all.

6.2 CHALLENGES

There were several challenges and limitations involved to reach the content incorporated in the DSS. Some of these challenges are associated with the overall approach of SafetyCube and therefore are common to all the thematic areas (infrastructure, road users and vehicle). And some are specifically related to the aim of quantifying the effect of vehicle related risk factors and measures.
For a more in-depth discussion of the methodological approach of SafetyCube, please refer to deliverable 3.3.

6.2.1 SafetyCube challenges

Exhaustiveness
Every effort has been made to cover as wide a range of risks and measures as possible. However, some risks or measures may not be included in the DSS. This can be explained in different ways. Here are the reasons encountered in WP6:

- Insufficient number of high-quality studies to develop a topic
- Too recent topic to allow the writing of a synopsis
- Time constraint and limited resources

Some topics have also been merged in order to get enough material for writing a synopsis. This is, for example, the case for the blind spot detection measure regrouping all types of vehicle concerned by this aspect.

Linking risks and measures
The interlinking of problems (risks) and solutions (measures) across the topics "road user", "infrastructure" and "vehicle", is very comprehensive. Links have been established in the DSS when there is evidence that supports this link. However, for some topics this results in high number of suggested measures. Furthermore, the suggested solutions cannot be applied blindly to very specific real-world situations. It is rather a support to point out various potential solutions.

Meta-analyses
When evaluating the impact of a risk or measure within a synopsis the intention was to undertake a meta-analysis. However, where the assumptions for meta-analysis could not be met (e.g. insufficiently similar studies) a literature review was completed. For vehicle related topics, only few meta-analyses could be carried out.

Cost-benefit-analysis

By far the most important limitation of using cost-benefit analysis is its dependence on underlying assumptions that are not always straightforward to assess. The executed examples show that mainly the assumptions on three elements can play a decisive role regarding the resulting benefit-to-cost-ratio:

- Assumptions about the effectiveness of the measures
- Assumptions about the costs of the measures
- Assumptions about the size of the target group

Sensitivity analyses showed the variability of some basic assumptions about costs, efficiency or target group. The hypotheses formulated must imperatively be verified before applying the figures presented to other contexts.

Very little information is available on the quantified side effects of the measures. They have therefore not been taken into account in the 9 analyses conducted in WP6.

6.2.2 Vehicle related challenges

The discussion of the following challenges is to a certain extent also applicable to the topic areas "infrastructure" and "road user", however, these aspects are particularly severe for the means of transport. Taking all the following factors into account, it is safe to say that quantifying risk factors and assessing measures quantitatively is a challenging endeavour when only one aspect is taken into account. Therefore, complementary qualitative information is provided in the individual synopses. It is highly recommended to consider these aspects when using the DSS.

Safety measure efficiency in a given scenario

Safety measures relatives to vehicle are developed to respond to a particular type of scenario. In this context their effectiveness is real and in fact should not be calculated in a global context but related to this type of specific scenario. In parallel to this, a countermeasure can also be effective for several types of scenario. For example, the seatbelt is effective in a frontal collision but also in a rollover accident. When calculating efficiency these aspects were well taken into account in WP6.

Safety measures as a system

In Safety Cube, the effectiveness of each safety measure was considered separately. This is an issue for some of them – even some of the best known of them. For example, in passive safety, the efficiency of a frontal airbag could not be calculated without taking into account the wearing of the seatbelt. In short: "airbag on and seat belt off" compares with "nothing on" in terms of injury severity – in some cases unfavourably. It is also increasingly clear active systems (ADAS) 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.

The scientific literature in a broader sense also has to come to terms with this kind of "safety ecosystems" Therefore the efficiency calculated can be taken as a minimum and then a greater efficiency could be expected if the whole of the safety is considered.

Cost-benefit analysis

The limiting aspects mentioned previously also have implications for the possibility of carrying out cost-benefit analyses (CBA) for countermeasures in the area of the means of transport. A CBA can only be achieved if the savings potential in terms of accident reduction (or reduction of injury severity) is known. Frequently, it is the reliable measure of effectiveness that is missing. But determining the

costs of measures is not always easy. The cost of each safety measure is very often an assumption. Car manufacturer or safety system suppliers are not very likely to provide the real price of their equipment. Therefore, the calculation of efficiency remains approximate and only an approach of the real effectiveness of the measure considered.
SafetyCube's deliverable 6.3 provides detailed information on CBA of road user related countermeasures (Martin et al., 2017).

6.3 METHODOLOGY AND DATA LIMITATIONS

The purpose of this section is to state the limits of the present study. First, the results are limited by several criteria:

1. The literature search criteria used
2. The quantity and the quality of the identified studies
3. Resource constraints

For several safety measures, it was the number of studies dealing with the subject that was really a drag to our work. This explains why some topics were grouped together to be able to make available the maximum information available.

Secondly, the process of assigning colour codes was related to both the magnitude of the safety impact observed for a risk or a measure but also to the presence of results in the literature. It is possible that a safety measure with a light green colour code has a greater impact on road safety than a green coded one but that the literature does not have enough evidence to support its colour code.

Finally, within the considered literature, crash risk and crash frequency are much more commonly studied than crash severity. For some topics this makes it difficult (or impossible) to consider the implications for injury mitigation.

The search strategy specific to each subject is explained in the support document of each synopsis.

6.4 NEXT STEPS

In order to keep the included evidences up to date, a constant updating process is needed. The Road Safety DSS is expected to remain open for updates and for additional synopses after the SafetyCube project. In order to maintain an adequate level of scientific quality, a similar quality assurance procedure should be followed.

The above includes:

- Dealing with measures for which actual effectiveness depends of their availability on the market (scarce at the time we set the DSS up) but even more of their social acceptance and actual use by drivers. Autonomous driving pertains to this category. Effectiveness for these 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.
- Dealing with measures that will reach full effectiveness when cooperating with other vehicle or infrastructure related measures
- Dealing with new road users, such as one-wheel equipped pedestrians, running full speed on the sidewalks
- Incorporating more international scientific literature, especially from low income or emerging industrial countries, where the road safety picture would certainly be very different

References

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Martin, O. et al. (2017), Economic evaluation of vehicle related measures, Deliverable Number 6.3 of the H2020 project SafetyCube

Appendix A Risk factor Abstracts

Pedestrian risk factors

A1 Pedestrian characteristics
A2 Impact characteristics
A3 Type of vehicle striking
A4 Injury level
A5 Time of crash
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Passenger car risk factors

A15 Frontal Impact
A16 Side impact
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Light Goods Vehicle (LGV) or Light Commercial Vehicle (LCV) Risk Factors

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Truck or Heavy Goods Vehicles (HGV)

A27 Accident characteristics
A28 Compatibility
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A30 Unbelted Occupants

Bus & Coaches

A31 Rollover
A32 Fire risk

Pedestrian risk factors

A1 Pedestrian characteristics

Abstract

Many studies reflect the pedestrian age as a contributing factor for a pedestrian to be involved in a traffic accident. It has been observed a higher involvement of younger pedestrians (under 15 years old), males between 15–24 years old and elderly pedestrians (Over 65 years old around 45% of the fatalities). However, the fatality rate for children is below the average rate whereas the pedestrian fatality rate of the elderly is well above the average.

Older pedestrians are over-represented in crashes at intersections, particularly those without traffic signals, and being struck by a turning vehicle. Older pedestrians are also overrepresented in crashes when they are crossing mid-block sections of roads, particularly on wide multi-lane roads, in busy bi-directional traffic.

Gender is also a risk factor because 2 out of 3 pedestrians involved in a traffic accident are males.

Other characteristics which have been found as contributing factors of this type of accidents are alcohol or drug use which is a clear risk factor and there is a higher risk in pedestrians with vision or hearing impairments or a sudden illness

Concerning the driver of the vehicle that struck the pedestrian, it has been found that younger (Under 25 years old) and older age drivers (>65 years old), and especially driving under the influence of alcohol, were related with a greater likelihood of colliding with a pedestrian. Other study also found that drivers without valid license and driver who were driving alone had a greater risk of being involved in this type of accident.

A2 Impact characteristics

Abstract

The pedestrian traffic accidents occurred mostly urban areas (around 60%-80%) however, when the accident is located in a non-built up area, the pedestrian have higher risk of sustain serious injuries. When the road layout is considered, approximately 70% of the accidents happened outside an intersection, 20% at intersections and 10% in other locations. Regarding the road type, some studies found the roads with two ways undivided as more risky than the other types of roads

The light condition is a contributing factor but it has great variability between countries. For example, in Ireland 94% of these accidents happened in darkness whereas in France only 35% were in darkness.

A clear risk factor is the speed limit. It has been pointed in many studies that when the speed limits increase the risk for a run over accident increases as well.

Time and seasonality depends on the geographic zone, the working days, etc....So even that they seem to be risk factors, they have big variability.

A3 Type of vehicle striking

Abstract

The vast majority of pedestrian's accidents involved passenger cars.(70% Spain, 81% UK, 76% USA) . In 90% of the accidents involving a passenger car, a SUV or a pick up the pedestrians were struck by the front of the vehicle.
The literature pinpoint that increasing vehicle curb weight was strongly associated with increased pedestrian mortality and increasing injury severity. The vehicle mass and the type of vehicle are linked risk factors and, in many cases, they also linked to speed.
More than 90% of these accidents involved a single vehicle.

A4 Injury level

Abstract

For both children and adults, more fatal injuries associated with male gender, darkness, mid-block location, and lack of traffic control device. In children, wet road conditions also associated with fatalities and in adults, hit-and-run crashes associated with fatalities.
An important cause of the high fatality rate of older cyclists and pedestrians is the physical vulnerability of elderly people. Since their bones are more brittle and their soft tissue less elastic, they are at higher risk of severe injury, even if the crash forces are the same
The type of vehicle is a risk factor for sustain more severe injuries. The differences in mortality compared to conventional passenger cars are SUVs ($P = 0.001$) and Pick-ups ($P = 0.016$), but not for vans ($P = 0.654$). Similarly, being hit by a SUV or Pick up appeared to result in an overall higher pedestrian ISS score.
When the speed increases, the pedestrian mortality and injury level also increased. Pedestrians hit in speed limit areas of ≤50 kph died 25% of the time, whereas, those hit in areas of 70 kph or greater died more than 40% of the time. Thus, the crash severity is higher in rural areas, because generally these accidents registered higher speeds.

A5 Time of crash

Abstract

Pedestrian accidents patterns vary by time of year due to the seasonal changes in sunset time. For example, in the US, in December, collisions are concentrated around twilight and the first hour of darkness throughout the week while, in June, collisions are most heavily concentrated around twilight and the first hours of darkness on Friday and Saturday. Friday and Saturday nights in June may be the most dangerous times for pedestrians.
Generally, other known risk factors as alcohol or drugs use, young adults' involvement are linked to the time of the crash. Although the exact risk of fatal collisions by time of day is unclear (due to lack of exposure data), the relative fatal collision frequencies by time of day indicate when crashes are occurring.

A5 Vehicle design / Vehicle shape

Abstract

Vehicle collisions with pedestrians can vary significantly in severity and an important contributory factor in this outcome relates to the shape of the vehicle. It has been estimated that the effect of being hit by a more 'aggressive' vehicle relates to a 3-fold increase in fatality risk, in other words being hit by a light truck/pickup can result in a significantly higher fatality risk than being hit by a standard passenger car. In addition, although to a lesser degree than fatalities, there is evidence of increased injury risk for light trucks, motorcycles and SUV vehicle shapes. Most research has been conducted in the USA where the vehicle fleet features proportionally more 'aggressive' vehicles, however recent fleet changes in the EU make the result for more relevant.

A6 Pedestrian - Visibility / Conspicuity

Abstract

A few studies had investigated the pedestrian conspicuity as a contributing factor to run over accidents. There is no clear evidence that conspicuity could be a risk factor on its own. However, it appears linked to the lighting conditions, especially at dusk, dawn and in darkness.

A7 Low NCAP rating

Abstract

Vehicle collisions with pedestrians can vary significantly in severity and an important contributory factor in this outcome relates to the passive crash performance of the vehicle in a collision. This passive performance can be measured and compared by using the European new car assessment program (EuroNCAP) score. By comparing injury outcomes from real world collision data and the EuroNCAP score of the striking vehicle it has been estimated that the effect of being hit by a vehicle which scores just one point more than a comparative vehicle through the EuroNCAP pedestrian testing regime relates to a 1% decrease in risk of serious injury. This rises to 2.5% decrease in risk of fatality per additional EuroNCAP point.

2003-2014

The most important point to emphasise with this topic is that there is currently a significant limitation to the analysis as the very best performing vehicles as tested by EuroNCAP feature less commonly in the general vehicle fleet. This effect is only seen with the very latest vehicles with potentially the highest pedestrian test scores as there will be latency in the system between a particular vehicles NCAP assessment and being seen in sufficient numbers on the roads to feature in collision data. Potential issues may occur when drawing conclusions on this type of vehicle as the collision statistics do not support robust conclusions. In addition, the effect of high impact speeds (>50kph) are less well understood as this is above the limits of current testing (currently 40kph for head and upper and lower leg impact tests). As such pedestrian kinematics, Impact locations and crush pattern are likely to be different to that seen in testing and possibly beyond the performance limits of vehicles designed to meet testing limits.

In addition, it is important to understand how EuroNCAP scores are derived. Scores awarded to vehicles are not directly comparable between different vehicles or over time. For example, a vehicle that scored 5 EuroNCAP stars will only be broadly comparable between its direct competitors and will not be comparable to vehicles manufactured earlier or later that also score 5 stars. The main reason for this is that the NCAP tests evolve to include more stringent requirements; vehicles tested five years ago, despite scoring 5 stars in period, are not comparable with 5-star vehicles tested today as the threshold for scoring has changed. The studies included cover data collections periods between 4 and 14 years (all between 2003 and 2014) so the effect of evolving testing protocols may be evident.

Although not affecting the pedestrians testing to the same degree, the test protocol in full scale crash testing results in vehicles that are only measured against themselves, in effect this result in a crash test vehicle hitting itself in frontal and side impacts. This test design means that a vehicle's 5-star

score is only comparable with other vehicles in its group. (Supermini vs supermini as opposed to supermini vs large family car).

Cyclist risk factors

A8 Accident characteristics

Abstract

Being vulnerable road users, cyclists are often injured when involved an accident. According to in-depth accident data about 15% of the participants in injury accidents are cyclists which are among the injured participants in over 90% of these accidents. Most accidents with cyclists occur inside city limits thus accidents with cyclists have a prevalence at crossings and junctions. According to in-depth accident data (GIDAS) more than half of the collision opponents of cyclists are cars. However, when cyclists have an accident with another road user cyclists are mostly found not to be the main causers of the accident.

A9 Injury severity

Abstract

Being vulnerable road users cyclist are often injured when involved an accident. According to in-depth accident data about 15% of the participants in injury accidents are cyclists. These cyclists remain uninjured in only about 8% of cases. Even though about ¾ of cyclists involved in injury accidents only suffer slight injuries from the accident, about 14% of cyclists have more serious injuries. When in an accident a cyclist often suffers two collisions: a primary collision when colliding with the accident opponent or with an object and a secondary collision when subsequently falling on the ground. Thereby nearly 60% of Cyclists have injuries on the legs, nearly half of the cyclists have injuries on the arms and over 30% suffer from head injuries. It is proven than a reduction of head injuries and especially of serious head injuries can be achieved by using a bicycle helmet.

A10 Visibility / Conspicuity

Abstract

Being vulnerable road users cyclist are often injured when involved an accident. Visibility and Conspicuity are important factors for cyclists. Accidents with cyclists occurred during night time in about 10% of the cases and during twilight in about 7% of the cases according to the German in-depth accident study GIDAS. Because cyclists are prone to having an accident even when there are slight road surface deficiencies visibility plays an important role. On the other hand, cyclists are easily overlooked by other road users due to their slim silhouette. For example, in Germany during twilight about two thirds of the cyclists involved in an accident did not have light or did not use their light. And during night time about half of the cyclists did not have light or did not use their light. In about 75% of cases street lighting was available during night time.

Powered Two Wheelers risk factors

A11 Accident characteristics

Abstract

The accident characteristics for powered two wheelers (PTWs) encapsulate a range of different aspects which have been documented through real world crash data for accidents involving PTWs. Compared to studies on passenger vehicles there are few studies which investigate the features of PTW crashes, and fewer still that have examined common factors. This poses problems with identifying a few specific characteristics that exist in PTW collisions, and has made it necessary to contemplate a diverse range of PTW crash studies under this one topic. The benefit of this multifactorial approach is that it reveals where PTW users are exposed to a greater risk of injury or mortality. For example, within this wide range of topics, we have found that young PTW users and those with limited experience of a particular PTW are at increased risk of injury or death. Additionally, greater engine size and travel speeds over the posted speed limit also increase the risks to PTW users. The effect that PTW use has on vulnerable groups such as pedestrians was also examined and showed that PTWs are at a higher risk of hitting pedestrians than four wheeled vehicles. The approach of combining various studies and multi factors into one synopsis presents difficulties for statistical analysis (due to low statistical power), as there are too many variables each with a limited amount of data about each individual characteristic. For the same reasons generalizability and transferability of the findings is also low.

A12 Injury Severity

Abstract

Real-world crash data and the literature point at a wide range of PTW accident characteristics. The factors affecting the PTW accidents and their consequences have been split into different categories: Age, gender, experience, road type, road environment, type of accident, speed, alcohol and drugs, engine displacement, and injuries.

The results of the literature reviewed show that most crashes are the result of a combination of these factors. Some of these factors are clearly a risk factor (e.g. alcohol use, speeding, etc.). Preventing them appears to be an obvious way to reduce road trauma. Driver and rider related behaviour factors are often considered more prevalent in PTW crashes, compared to vehicle and road environment factors.

A13 Technical Defects or Maintenance

Abstract

Some motorcycle defects contribute to Powered Two Wheelers (PTWs) road accidents. However, when a PTW crash occurs many other contributing factors are present, and the technical failures are not considered one of the main problems. Even though a significant portion of the PTWs have some technical defects, only in certain circumstances do these defects contribute to a road accident. In addition, a large percentage of motorcycle accidents involved inexperienced riders with newer motorbikes with no faulty mechanisms.

A14 Visibility / Conspicuity

Abstract

The most common scenarios resulting in motorcycle road accidents are:

- Single vehicle accident – a motorcyclist riding along a road and losing control (e.g. at a curve).
- PTW approaches a junction and hits, or is hit by a car whose driver fails to see the two-wheeler in time.
- When turning across a carriageway, a car driver fails to stop and give way to a motorcyclist/moped rider coming in the opposite direction.

In the last two categories the car driver fails to give right-of-way to motorcyclists. According to the literature reviewed, the main cause of this, is the failure of other road users to detect the motorcyclist's presence.

The MAIDS project (ACEM, 2009) clearly demonstrated the number of PTW crashes related to conspicuity problems. This study concluded that in over 36% of cases, the driver of the other vehicle did not see the two-wheeler; while in 12% of the cases, the rider of the two-wheeler failed to see the other vehicle.

Commonly, increasing motorcycle conspicuity through well-lit headlights, reflective clothing and helmets in some way helps to solve this problem.

The literature reviewed focuses on two aspects: the conspicuity/visibility issue and the solutions proposed to solve this problem.

Passenger car

A15 Frontal Impact

Abstract

Frontal impacts are those occurring to the front-end of a vehicle and are generally defined by the principal direction of forces (PDOF) being between 11 and 1 o'clock, or, by the principal area of damage being to the front of the vehicle. Many vehicle factors can influence the outcome of a frontal impact, for example, the position of the occupant in the vehicle (driver, front passenger, rear left passenger), vehicle safety equipment (seatbelts, airbags), and aggressiveness or protection capacity of different vehicle interior components.

This document is a review of frontal impact risk factors. A systematic literature search has been conducted and relevant studies have been analysed. The studies identified were very diverse in their nature (different samples, different exposures and outcomes) and a bibliographic review has been completed in order to summarise any important conclusions. Results show that frontal impacts impose a greater risk than rear impacts, but are less hazardous than side impacts. In frontal impacts, front passengers and rear passengers have almost the same chance of being fatally injured. Unbelted rear passengers increase the risks of driver fatality, especially in severe crashes. Airbag deployment reduces the risk of injury, especially when combined with seatbelt use. Seatbelts were found to reduce the risk of severe brain injury for full frontal and offset frontal impacts. Second generation, depowered airbags increase injury risk for the thoracic region and decrease injury risk for the upper extremity region when compared with first generation airbags.

A16 Side impact: risk to be injured following nearside/farside impact

Abstract

Side impacts are those occurring to the side of a vehicle and generally defined by the principal direction of force (PDOF) between 2 and 4, and between 8 and 10 o'clock or by the principal area of damage as being the side of the vehicle. Many factors may influence the outcome of a side impact such as the position of the occupant in the vehicle (driver, front passenger, rear passenger), the impact location relative to the occupant position (near-side or far-side), the impact location on the vehicle side (front side, centre side, or side distributed), or the aggressiveness and protection capacity of different vehicle interior components…

A review on side impact risk factors has been conducted based on a systematic literature search. Results show that side impacts are more risky than frontal impacts and rear impacts. Most studies distinguish between two types of side impacts: near-side and far-side. In general, near-side impacts are associated with higher risks of severe or fatal injuries. The body regions that are more at risk were found to be the thorax, the lower extremities and the head. Impact location on the vehicle side has a strong effect on the injury outcome for occupants. For example, in near-side impacts, vehicles with side distributed and side centre damage are respectively 17 and 10 times more associated with driver severe chest injury than vehicles with side front damage. Some driver contact points inside the vehicle have been found to be more risky than others like the door, the armrest, and the driver's seat.

A17 Risk to be injured in rear impact

Abstract

Rear impacts are those occurring to the rear end of a vehicle and generally defined by the principal direction of forces (PDOF) between 5 and 7 o'clock or by the principal area of damage being defined as "rear" of the vehicle. Many factors may influence the outcome of a rear impact such as the position of the occupant in the vehicle (driver, front passenger, rear passenger), the deformation of the front seat, or contact between the occupants and vehicle interior components…

A review on rear impacts has been achieved based on a systematic literature search. Many studies show that the number of fatalities and the risk of severe or fatal injuries in rear impacts are low when compared to frontal and side impacts. A study showed that the odds of severe injury occurring in frontal impacts or side impacts are between 3 and 17 times higher than in rear impacts. However, risks of some types of injury may be relatively high after a rear impact, especially whiplash induced injuries. In severe rear-end impacts, it has been shown that the risk of a driver sustaining a whiplash induced injury is twice that of front seat passengers. In addition, the risk of whiplash injuries for females is 3 times higher than the risk for males. Another problematic issue in rear impacts is the risk for rear seat occupants. Indeed, risk of severe injury to a rear occupant is two to four times higher than the risk for a front occupant. Some factors may worsen the situation for rear seat occupants such as the deformation of the front seat during the crash. For example, it has been shown that when front seat deformation occurs directly in front of a restrained child seated in an outboard position, the odds of injury were 2.4 times higher; this indicates that some vehicle interior components may need to be given some more attention. This is borne out in a study that shows that when a driver contacts the armrest in a rear impact, they have a 6-fold increase in getting a severe chest injury than when no contact with the armrest happens. Other vehicle interior components have been reported as aggressive in a rear impact such as the door and the steering wheel.

A18 Risk to be injured in Rollover

Abstract

The synopsis summarises 9 articles. The aim of this synopsis is to summarise how the risk of injury for passenger car occupants involved in rollover crashes has been studied and what are the main results. Most papers analysed use North American databases. Rollover motor vehicle crashes account for a disproportionate number of serious injuries compared to other crashes Several factors have been studied in order to better understand the injury mechanisms and to prioritise safety measure development.

The body type of the vehicle is one risk factor. Higher profile vehicles (SUVs, trucks, and vans) seem more protective during rollover than cars.

There is no difference found in the risk of death in a rollover between rear and front passengers. Nevertheless, the risk of death among rear-seated occupants was higher in rollovers than in frontal impacts.

Roof structure intrusion is a common factor that has an influence on the risk of injuries especially for head, neck and spine body regions. In general, most the intrusion is high, higher is the risk of serious injury.

Other passenger (age, BMI…) or accident (road condition, speed limit…) parameters have been taken into consideration in some articles (but not in most) and show consistent results.

A19 Submarining & abdominal injury risk

Abstract

The abdominal injuries are caused either by a direct contact with vehicle component (car door, steering wheel, armrest, console …) or by direct contact with passive safety components (seatbelt, seatbelt anchor, airbags …) or inferred by a mechanism called submarining (sliding of the pelvis under the lap belt). Most of the epidemiological studies shows that abdominal injuries are mainly observed in frontal impact. The progress made on vehicle structural performance and the development of better seatbelt systems and airbag restraint allowed to decrease intrusion and direct contact with vehicle component (in frontal impact) but increased the level of deceleration and favoured the submarining mechanism. The abdominal injury risk is different following the seat location. The more risky position are for the rear seats due to more relax position and less effective seatbelt systems (no pretensioner and few load limiter). Front passengers have a higher risk compared to the driver, essentially caused by more relax position and a more distant dashboard.

A20 Compatibility (self and partner protections) & age

Abstract

Vehicle compatibility and vehicle age are two important factors when dealing with risks to passenger car occupants during a crash.

Compatibility refers to how well two vehicles match up in a two-vehicle crash. Compatibility related risks are generated by a vehicle on its occupants and on the occupants of the impacted vehicle during a two-vehicle crash. Two notions can be distinguished: “self-protection” or the vehicle’s ability to reduce risks to its occupants and “partner protection” or the vehicle’s ability to reduce risks to occupants of the impacted vehicle. Compatibility is an issue since passenger car designs are very varied and include cars of differing heights and mass. In addition, passenger cars crash into other types of vehicles, such as light trucks, minivans, etc. which may not be optimised in terms of compatibility. Risks related to vehicle age can be studied from two complementary points of view; they can be seen as a difference in risks to occupants between older and newer vehicles or they could be viewed as a compatibility issue between older and newer vehicles.

A review on compatibility and vehicle age risk factors has been conducted, based on a systematic literature search. Risk of injury in collisions between different car types (small saloons, luxury cars, sports cars, etc.) has been reviewed. Collisions between passenger cars and other types of vehicles (light trucks, minivans, etc.) have also been reviewed. Results show that heavier cars tend to be more risky for occupants of the opposing vehicle and more protective for their own occupants. For example, when a car impacts another car with a bigger mass ratio, the odds of severe or fatal injury for the driver in the lighter car is 28% higher than for the driver of the heavier car. Newer vehicles have the same effect on older vehicles' occupants as the risk for drivers colliding against a newer car is higher than when colliding against an older car. For example, the mean risk of death for a car driver in collision with a car registered in 2004–2007 is about 23% greater than in collision with a car registered in 1988–1991. On the other hand, newer cars are associated with lower risk of injury than older cars in all other respects, namely protection of occupants in fatal and serious accidents. However, an elevated risk of death for rear seat occupants, as compared with front seat occupants, has been found in the newest model year vehicles. This provides evidence that rear seat safety is not keeping pace with advances in the front seat.

A21 Low star rating (Euro NCAP)

Abstract

Vehicle collisions with pedestrians can vary significantly in severity and an important contributory factor relates to the passive crash performance of the vehicle involved. This passive performance can be measured and compared using the European new car assessment program (EuroNCAP) score. Comparing injury outcomes from real-world collision data and the EuroNCAP score of the striking vehicle, it has been estimated that there is a 1% decrease in risk of serious injury when the striking vehicle scores one point more than a comparative vehicle. This rises to 2.5% decrease in risk of fatality per additional EuroNCAP point.

2003-2014
It is of fundamental importance that current analysis is significantly limited: the very best performing vehicles (as tested by EuroNCAP) feature less commonly in the general vehicle fleet. This effect is only seen with the very latest vehicles having potentially the highest pedestrian test scores. There will be latency in the system between a particular vehicle's NCAP assessment, and it being seen in sufficient numbers on the roads for it to feature in collision data. This makes it difficult to draw concrete conclusions for this type of vehicle. Additionally, the effect of high impact speeds (>50kph) are less well understood as this is above the limits of current testing (currently 40kph for head and upper and lower leg impact tests). Consequently, pedestrian kinematics, impact locations and crush pattern are likely to be different to those seen in testing, and possibly beyond the performance limits of vehicles designed to meet testing limits.

It is also important to understand how EuroNCAP scores are derived. Scores awarded to vehicles are not directly comparable between different vehicles or over time. For example, a vehicle that scores 5 EuroNCAP stars will only be broadly comparable between its direct competitors, and will not be comparable to vehicles manufactured earlier or later that also score 5 stars. The main reason for this is that the NCAP tests evolve to include more stringent requirements. Despite scoring 5 stars at the time of testing, vehicles tested five years ago are not comparable to those scoring 5 stars in today's tests, as the threshold for scoring has changed. The studies included here cover data collection periods between 4 and 14 years (all between 2003 and 2014) so the effect of evolving testing protocols may be evident.

A22 Technical defects & Maintenance

Abstract

The synopsis stayed at the subtopic level (technical defect / maintenance) and not as a specific risk factor (Faulty headlights & taillights, Tyre blow out, Faulty steering system and suspension, Faulty brakes, Airbag deployment at untimely moment…) because of the lack of available articles.

A roadworthy vehicle is one in which no safety related defects exist at a particular time. Papers collected for this topic aim at identifying the prevalence of vehicles with roadworthiness defects in vehicle populations, the effect of vehicle defects on the incidence and severity of crashes and the effect of vehicle inspection on accident rates.

The number of vehicles (among the vehicle population) with a technical defect varies to a large extent according to the papers: from 2% to almost 100%. Results are different depending on the country (Russia, UK, Germany, South Africa, US…), the way the vehicle is inspected (full (destructive) inspection or not…) and the organisation in charge of the inspection (police services, vehicle experts…). In the UK, approximately 40 % of vehicles fail their initial periodic technical inspection, although this varies depending on vehicle class, vehicle age and mileage at the time of the test. The rate of defects increases for older vehicles.

Vehicle defects are likely to be a contributory factor in 0.5% to 24% of accidents. Even if the interval is not as great as the one for technical defects among the vehicle population, it is still important (probably, for the same reasons as explained above).

The effect of vehicle defects on the prevalence of accidents is not clearly proven.

Light Goods Vehicle Risk Factors

A23 Accident characteristics

Abstract

The accident characteristics synopsis aims at describing which LGVs are involved in accidents, what the trip purpose was, who was involved, where inside the vehicle they were, how the accidents happened and what the crash conditions are. Most of the studies inside the Decision Support System (DSS) are descriptive studies.

LGVs and especially LTVs are becoming increasingly common. That means that the proportion of such vehicles in the vehicle fleet has been increasing for the last decade. This vehicle fleet change has an influence on road safety. Indeed, some studies assess that a 1% increase in light truck share would increase significantly the yearly number of road traffic fatalities. In Europe, LGVs are mainly goods cars (car derived vans) or a van (up to 12 m3 useful volume). They are mainly used on behalf of crafts businesses, companies and other trades persons.

Impact areas and age of killed LGV road user are similar to the figures found for passenger cars. The most frequent impact configuration is the frontal one and fatality rates increase as drivers' age increases. Nevertheless, LGVs are more often involved in intersection accidents. This synopsis includes several results such as:

The consequence of a 1% LGV increase in the vehicle fleet, the body type description, the age and gender of LGV road users, the type of road on which the accidents happened and the kind of trip, and the accident and impact configurations. There is also a focus on emergency vehicles (ambulance, fire truck, police car etc.).

A24 Injury severity

Abstract

The synopsis summarises 5 articles. The aim of this synopsis is to have an overview of LGV-LTV injury risk according to the body region, the vehicle type and the impact location. Even if the risk of injury of light goods vehicle occupants is lower than that of passenger cars (even for occupants wearing a seat-belt); issues still remain. The articles estimate the risk of injury according to the body region and the vehicle type. Opposite results are presented in these articles. Bambach et al. (2013) found that the LTV occupant risk of sustaining serious thoracic injuries is 3.35 times more likely than car occupants. Desapriya et al. (2005) estimated that passenger car occupants have more risk of sustaining a torso, head and neck injury than LTV occupants.

There is more risk of sustaining lower limb injuries in a passenger car than in a LTV. And in far side impact, serious injuries to LTV occupants are almost uniformly distributed among head, chest, upper extremity, and lower extremity injuries. In passenger cars with far side impact, chest and head injuries are the most frequent injuries.

It is difficult to draw conclusions about injury level risk with only these results.

A25 Compatibility

Abstract

Vehicle compatibility is defined and assessed according to the combination of its self-protective capacity and aggressivity when involved in collisions with another vehicle. Self-protection focuses on a vehicle's chance of shielding its occupants in a collision, whereas aggressivity is measured by the impact (in terms of casualties) affecting the occupants of the other vehicle in a crash. As the number of LGVs/LTVs is increasing, (at least in North America and Europe) the composition of fleet vehicles on the roads will be altered and negative effects on road safety may be expected to occur (Fredette et al., 2008). Most studies focus on the compatibility between LGV and passenger cars, as it is the most common accident configuration. The main conclusion is that in the event of a collision between an LGV and a car, the risk of injury at all levels of severity is greater in cars.

A26 Visibility / Conspicuity

Abstract

The synopsis summarises 4 articles and deals with the risk of having an accident according to the visibility limitation of LGVs (because of its design). All the papers analysed focus on the risk of being involved in a rear-end collision involving a passenger car and a LGV. The LGV is the followed vehicle. Methodologies differ according to the article: accident data analysis and modelling, driving simulator experiment or FOT (Field Operational Test) analysis. Conclusions are the same. There is a higher chance of rear-end crashes when a regular passenger car follows an LTV than when it follows another passenger car. Gap distances for following LTVs are significantly smaller than those for following a passenger car.

Truck or Heavy Goods Vehicles (HGV)

A27 Accident characteristics

Abstract

Heavy Goods Vehicles - HGVs can be configured in different combinations of size and articulations. There are different regulations restricting the length, number of articulations, and the types of truck and trailer units that can be combined in a single vehicle. There is an unclear trend in the literature whether these different combinations have different safety risks. Similarly, buses have different heights that may influence their safety in extreme side wind conditions.

A28 Compatibility

Abstract

Compatibility is a road safety topic that addresses the safety issues in a collision between two vehicles. The topic is further divided into "self-protection" describing how a vehicle protects its own occupants, and "partner protection" which describes how a vehicle influences the crash outcome of the occupants of the partner vehicle. HGVs are larger, higher, and heavier than most other road users. The main vehicle structures are much stronger than those in their collision partners and do not typically absorb energy during a crash. In general, a crash with a HGV (and with other large and heavy vehicles like buses) has a greater negative effect for the collision partner than a smaller vehicle. Although it is not easy to quantify the specific design aspects of the HGV that can lead to incompatibility issues, safety outcomes for this field of work are typically reported as odds ratios.

A29 Visibility / Conspicuity / Blind Spot issue by tight turning trucks

Abstract

Accidents with right turning trucks mostly happen with pedestrians or cyclists. Due to the big difference in mass, and high risk of being run over (80% in 2014 [2]), around 87% of these accidents end in a severe or fatal injury of the VRU. The main reason for this type of accident is the blind spot of the HGV.

This document is a review of the risk for VRU by the blind spot of a HGV. A systematic literature search has been achieved and relevant studies have been analysed. These studies were very homogeneous in their nature. Results show that most accidents with right turning trucks and VRU happen between 6 a.m. and 6 p.m. and during the working days. Cyclists older than 65 years are at high risk (41% of all accidents between HGV and bicycle **[2]**) to get fatally injured during an accident with a right turning truck. Most impacts are on the right sight of the driver's cabin.

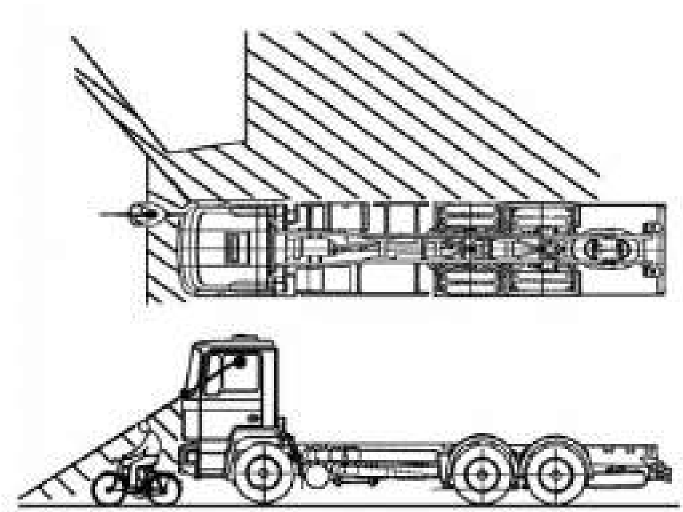

Figure 6: **Examples of blind spots impairing the direct view, in a top-down view and as side view (object size up to 1.6 m).**

A30 Unbelted Occupants

Abstract

Buses and HGVs have a greater range of passenger travel positions than cars. Passengers may travel while in a sleeper berths; seated in forward, sideways, or rearward facing seats to travel, or between seats. These different travel positions create different risks for injury in the event of a collision as the occupant may not be protected by an engineered restraint system (belt, airbag, or energy absorbing structure) or they may "out of position" which means the designed restraint system cannot provide the intended protective effect. HGVs and Buses do not have as many passenger safety systems as passenger car occupants addition, there are opportunities for bus occupants to be injured when entering or exiting the bus or in non-crash events such as sudden lateral or lateral accelerations during operation. All studies showed that unbelted or unrestrained passengers had a higher risk for injury.

Bus & Coaches

A31 Rollover

Abstract

Most rollover accidents involving buses or coaches (18% [2]) result in fatal or severe injuries for bus passengers. Even though the rate of killed or injured passengers per person kilometre is very low, a few serious accidents account for these cases. Passive safety systems like 2- or 3-point seat belts, deformable seat backrests and an enforced superstructure can prevent some of these cases.
Between 2001 and 2009 the fatality rate for bus passengers was reduced in 15 countries of the European Union (EU-15), because of new regulations regarding these areas. However, a low seat belt wearing rate (around 25%) means the total number of fatalities could be further reduced.
In addition, there are other countries without mandatory wearing of seat belts and with other less strict regulations.

This document is a review of the risk of a bus rollover and the seat belt as a countermeasure. A systematic literature search has been achieved and relevant studies have been analysed. These studies were very homogeneous in their nature.

A32 Fire risk

Abstract

About 1% of all registered buses are involved in fire incidents every year. This is probably a conservative estimate as accident statistics often do not list fires. Thus, insurance data and data provided by fire departments were also considered. However, it is important to bear in mind that small incidents where fires were put out with a fire extinguisher or were self-extinguishing are not included in fire department's statistics. In addition, fires on buses without comprehensive coverage are also not listed in the statistics from insurance companies.

From the data examined, the majority of fires were shown to start in the engine compartment. Around 2/3 of all fires started here. The main risk factor was found to be inadequate maintenance.
Most fires were noticed by bus passengers, other road users, or by technical abnormalities and not by the driver. Non-collision fires did not usually result in direct injuries. Those cases resulting in injuries/fatalities involved elderly and/or handicapped passengers.
New European noise and exhaust regulations appear to have led to an increase of bus fires by 15% annually.
The mandatory fire extinguishers found on buses are often insufficient.
In Germany, fewer fires were found to originate in the wheels/tyres/axles than in other countries. Regular, technical inspection is seen as the main reason for that.
The studies used for this synopsis and coding are relatively homogenous in their results. The explanation for decreasing numbers of fires being reported on U.S. coaches is that the U.S. has different noise and exhaust standards.

Appendix B Road Safety Measure Abstracts

Crashworthiness – Frontal impact

B1 Directive 96/79/CEE, ECE.R94 & EuroNCAP
B2 EuroNCAP (Full Width & ODB)
B3 Frontal airbag
B4 PTW airbag
B5 Seat belt effectiveness (SBR and Load limiter included)
B6 Anti-submarining (airbags, seat bossage, knee airbag, seatbelt pretensioner…)

Crashworthiness – Side impact

B7 Directive 96/27/CEE, ECE.R95 & EuroNCAP
B8 Regulation UN R135 (Pole side-impact protection)
B9 Side impact measure – EuroNCAP (MDB & Pole)
B10 Side airbag (Head, Thorax, Pelvis)

Crashworthiness – rear impact

B11 Anti Whiplash (Seat, active headrest …)

Crashworthiness – rollover

B12 Rollover protection system

Crashworthiness – pedestrian

B13 Pedestrian protection – Active Technology
B14 Pedestrian protection – Vehicle Shape
B15 Pedestrian regulation

Crashworthiness – child

B16 Child Restraint System – 'CRS'
B17 Child Restraint System – 'booster seats'

Crashworthiness – PTW specificities

B18 Protective clothing
B19 PTW protective clothing (Helmet)

Crashworthiness – Cyclist protective clothing

B20 Cyclist protective clothing
B21 Cyclist protective clothing (Helmet)

Crashworthiness – HGV specificities

B22 Underrun protection (Lateral Side Guards / Rear)

Active safety – longitudinal control

B23 Emergency Braking Assistance system
B24 Autonomous Emergency Braking AEB (City, interurban)
B25 Autonomous Emergency Braking AEB (Pedestrians & cyclists)
B26 Emergency Stop Signal (ESS)
B27 Braking system PTW (ABS, Combined braking system …)
B28 Collision Warning system
B29 Intelligent Speed adaptation, Speed Limiter & Speed regulator
B30 Adaptive Cruise Control (ACC & ACC Stop & start)

Active safety – lateral control

B32 Electronic Stability Control (ESC)
B32 Lane keeping Systems

Active safety – driver assistance

B33 Alcohol Interlock (ALC)

Active safety – visibility enhanced

B34 Adaptive headlights
B35 Daytime running lights
B36 Night Vision
B37 Vehicle backup camera - Reversing Detection or Camera systems (REV)
B38 Blind Spot Detection

Active safety – technical defects

B39 Tyre Pressure Monitoring and Warning
B40 Vehicle inspection
B41 Automatic Emergency Braking (AEB) for trucks

Active safety – connected

B42 Vehicle to Vehicle communication

Tertiary safety – post crash

B43 ECall
B44 Rescue Data Sheet & Rescue code
B45 ECE R100 (Battery electric vehicle safety)
B46 Event Data Recorder Crashworthiness – PTW specificities

Crashworthiness – Frontal impact

B1 Directive 96/79/CEE, ECE.R94 & EuroNCAP

Abstract

Although the number of road accident casualties in Europe (EU27) is falling, the problem still remains substantial. In 2011 there were still over 30,000 road accident fatalities. Approximately half of these were car occupants and about 60 percent of these occurred in frontal impacts. Lots of studies have focussed on this issue, but the safety solutions proposed are not only responding to a specific requirement in a regulation but also at the same time to other points such as the ones taken into account in frontal dynamic tests of consumer test rating programmes. In the end, only one study corresponding to the safety benefit due to cars becoming compliant to the ECE R94 frontal test procedure was found in the peer reviewed literature, and only part of it deals with the subject of this synopsis. The main objective of this study deals with the improvement in compatibility of cars involved in a frontal crash (FIMCAR project). For the analyses national data were used from Great Britain (STATS 19) and from Germany (German Federal Statistical Office). In addition, in-depth real word crash data were used 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.

Results for UK data, based on the renewal of the UK car fleet, and considering only passenger cars involved in a frontal impact show a potential reduction of 2% of fatalities and 1.7% of severe injuries. It also indicates that a disbenefit is expected for car to car frontal collisions.

Looking at the results coming from the German data. It is interesting to note that a benefit is estimated for two-car frontal accidents for killed casualties in contrast to the GB analysis which predicts a disbenefit. However, the German analysis did consider some additional factors for the evolution of the car fleet (higher masses of new cars and some better self-protection as a result of the general technical improvement). This could be a reason for such differing results. A global benefit of 1.8% for fatality rates and a disbenefit of 0.1% for severe injuries is estimated.

The benefits for Europe were estimated to be about 2.0% of car occupants killed and seriously injured. As stated before, it is important to note that it is not possible to isolate the benefits due only to the adoption of a dynamic test similar to ECE R94, because the safety measures developed also depend on other safety regulatory requirements (different types of impacts, different severity or crash configurations,...) and the EuroNCAP rating program .It should also be remembered that the study does not consider active safety devices in general, and therefore a possible migration of the proportion of types of impacts.

Another study has been kept in the synopsis but not coded. It is a prediction of what would be the effect for emerging markets of adopting basic secondary safety measures such as seatbelt standards, UN regulation 94 and 95 and NCAP ratings. The country chosen in the study is Malaysia. It aims to quantify how many car users' fatalities are likely to be prevented. The study is also based on the renewal of the car fleet with different timing scenarios. The study has not been coded because expected benefits are not only caused by the improvement of the frontal impact situation, but also a more general change in the car generation with changes in frontal impacts (ECE R94), side impacts (ECE R95 and R135) and in parallel, an increase in the equipment of cars with active safety systems (due to regulations and consumer testing). Nevertheless, the study was sufficiently close to our objective: frontal impacts are globally still the major car crash configuration observed on the road so a large part of the benefit could be achieved by the adoption of ECE R94 by emerging markets. As for global results, it is estimated that about 1200 to 4300 car users' fatalities could have been prevented between 2014 and 2030 by the adoption of new rules in Malaysia, depending on the motorisation rate considered.

B2 EuroNCAP (Full Width & ODB)

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 aims of providing objective information for the consumer and to encourage manufacturers to improve their vehicles beyond the demands of legislation.

After 21 years of the programme, 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 rating programme, only the obligation of manufacturers to comply with similar regulation tests.

EuroNCAP tests are complementary to regulatory crash tests and are more severe. The tests are published on the EuroNCAP webpage and are used by manufacturers to improve the marketing of their products through good performance rating. 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 the Swedish data analysed, Lie and Tingvall (2000) indeed found that EuroNCAP tested vehicles rated four stars had a lower average serious injury risk in real crashes than those rated three stars. The three-star vehicles had a correspondingly lower average risk than vehicles rated two stars. Newstead et al., 2005 found a general trend of improvement in the new crashworthiness measure based on real world accidents with increasing EuroNCAP star rating, in line with the findings of Lie and Tingvall (2002 and 2010).

However, Seguí-Gomez et al. did not find any statistically significant relationships between the EuroNCAP safety scores and real-world death or severe injury outcomes for frontal impacts.
Fildes et al., studied the estimated benefit of introducing the ODB test in Australia and they found a potential benefit above regulation between 24% to 36% in reduced Harm in frontal crashes.

B3 Frontal airbag

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 shown a clear effectiveness to reduce injuries and mortality with the availability of an airbag in a frontal collision. E.g. Lackner et al. (2007) found that the airbag reduced the early mortality rate (first 24 h) decidedly, from 29.3% to 8.0% and Williams et al. (2008) found that airbags are associated with reduced in-hospital mortality and with decreased injury severity and also the probabilities of sustaining evident and disabling injuries are reduced when vehicles with airbags are involved in crashes (Obeng 2008).
For airbags especially in frontal impact situations the protection level depends also on the seat belt usage. Donaldson et al (2008) found that the drivers using the airbag-only had a significantly higher

rate of cervical fractures than those using both airbag and a seatbelt and that other severity indexes were significantly worse in patients who used an airbag-only.
Furthermore, there are different generations of airbag systems. Especially with the introduction of the second airbag generation the associated risk for car occupants in non-optimal positions was reduced by depowering the airbag and improving the inflation process. And MacLennan et al. (2008) found that there was no significant difference in the protection of front-seated occupants in vehicles equipped with first-and second-generation airbags, while Jernigan et al. (2005) found that occupants exposed to a depowered airbag deployment were significantly more likely to sustain a severe upper extremity injury (3.9%) than those occupants exposed to a full-powered airbag deployment.

B4 PTW airbag

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).But only recently have these systems started to appear and been implemented in real production vehicles and garments.
Firstly, research has predominantly followed the successful path already traced for cars, mainly focused on collisions between the vehicle and an obstruction with a vehicle mounted airbag. 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.

B5 Seat belt effectiveness (SBR and Load limiter included)

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.

B6 Anti-submarining (airbags, seat bossage, knee airbag, seatbelt pretensioner…)

Abstract

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 passenger sides. A seat ramp is part of the occupant seat. An anti-submarining ramp is a ramp located in the seat base which is inclined so that the front edge points upwards. This ramp is designed to prevent the seat occupants from sliding underneath the lap belt when they are pushed deep into the seat cushion in a collision. Pretensioners aim at clamping the driver and passengers to

their seats in case of accidents. Knee bolster position and physical characteristics can also reduce occupants' likelihood of sliding under the seat belt.

None of the articles studied assess the effectiveness of these systems in preventing or mitigating injuries due to submarining. Indeed, occupants submarining during a crash could cause abdomen and lower extremities injuries. But abdominal and lower extremities injuries can be caused either by direct contact with a vehicle component (car door, steering wheel, armrest, console ...) or by direct contact with passive safety components (seatbelt, seatbelt anchor, airbags ...) or generated by a mechanism called submarining (sliding of the pelvis under the lap belt). That is probably why there is no study assessing the effectiveness of anti-submarining systems.

Many articles are derived from biomechanics research and aim at understanding the accident characteristics which cause the occupant to slide under the seat belt. Articles can be sorted into three categories (Uriot et al. 2006[9]).
The first category is composed of the studies where the means to prevent or limit the submarining process are investigated. The second category of studies consists of research works dealing with the technology available to measure submarining or its consequences on dummies. The third category contains the papers where the authors focused on the description and the characterisation of submarining as a physical phenomenon.

Crashworthiness – Side impact

B7 Directive 96/27/CEE, ECE.R95 & EuroNCAP

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 paper 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 document mainly presents the coverage of this regulation through the study of accidents and its limits. Indeed, although these studies agree that this law brought an improvement in accident outcome, the latter remains limited because of its low representativeness of automobile accidentology. The studies quoted indicate coverage of 45 to 63% of side impact crashes, all levels of force and all configurations against a particular vehicle. On the other hand, when we look at lateral impact mortality, the configuration against a particular vehicle represents only 25 to 37% depending on the country studied. The pole/tree side impact represents 24 to 30% of fatal lateral accidents,

[9] Uriot, J, P Baudrit, P Potier, X Trosseille, P Petit, H Guillemot, L Guérin, and G Vallancien. 2006. "Investigations on the Belt-to-Pelvis Interaction in Case of Submarining." *Stapp Car Crash Journal* 50: 53–73. https://www.scopus.com/inward/record.uri?eid=2-s2.0-33947500534&partnerID=40&md5=2155c31b147514c973cf3c92a73d441d.

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.

B8 Regulation UN R135 (Pole side-impact protection)

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 occurring 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). 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 17: Fatalities and serious injuries distribution regarding side impact types in 2009

Source BAAC 2009 (F)

B9 Side impact measure – EuroNCAP (MDB & Pole)

Abstract

EuroNCAP tests vehicles in a number of test configurations for side impact. These 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. 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.

B10 Side airbag (Head, Thorax, Pelvis)

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.

Crashworthiness – rear impact

B11 Anti Whiplash (Seat, active headrest …)

Abstract

The present synopsis addresses the effectiveness of whiplash injury protection systems or Anti Whiplash systems. Of a particular 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) where both reported lower risks for systems designed to reduce whiplash injuries. The US 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 where a 15% reduction in whiplash injuries was found for seats with good ratings.

Crashworthiness – rollover

B12 Rollover protection system

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 has 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 SCI 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 accidents data, he found a 44% increase in the odds of sustaining any injury to the head, neck or spine with every 10 cm increase in roof crush. 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).

Crashworthiness – pedestrian

B13 Pedestrian protection – Active Technology

Abstract

Vehicle collisions with pedestrians can vary significantly in severity and an important protective measure for this injury outcome relates to active and passive protection systems fitted to vehicles. It can be shown that vehicles with more forgiving front end structures, particularly more space between hood and rigid components or the use of pop up bonnets can reduce pedestrian head impact criterion (HIC) scores thereby providing a potential to lowering 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.

B14 Pedestrian protection – Vehicle Shape

Abstract

Vehicle collisions with pedestrians of all ages can vary significantly in severity and 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 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 a potential to lowering 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 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.

B15 Pedestrian regulation

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)

sets 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 (TRL-PLI & FLEX-PLI). (Teibinger et al. 2015) makes a new virtual test proposal for small electric vehicles. (B. Mueller et al. 2013) denotes 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) gave 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) gave a comparison of the responses of the two legform test surrogates currently available. (B. C. Mueller et al. 2012) compared the types and sources of real-world pedestrian injuries with the parts of the vehicles addressed by GTR9. They showed that a significant pedestrian injury problem may persist even if GTR9 completely eliminates the injuries it addresses. (Page, Hermitte, and Cuny 2011) estimated to 1083 the number of pedestrians saved in France from 2000 to 2010 due to vehicle safety improvement. (Xu et al. 2010) estimated by simulation the pop-up hood to be efficient in improving head protection.

Crashworthiness – child

B16 Child Restraint System – 'CRS'

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 found that the use of an appropriate and correctly used child restraint can reduce the risk of death and injuries compared to a child either using a CRS incorrectly, using a standard seat belt or completely unrestrained. Despite the overall positive effect on road safety there is evidence in some instances, such as comparing a correctly used child restraint to a standard seatbelt, that fatalities and very serious injuries are not significantly reduced for infants involved in higher speed motor vehicle crashes or where intrusion into the interior space is present.

B17 Child Restraint System – 'booster seats'

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, belt positioning booster seats, are designed to provide optimal belt geometry for forward facing child occupants between 15 and 36kg (broadly 4 to 10 years of age) who use the standard, 3-point adult belt fitted to passenger vehicles. Typically for this age group a standard three-point belt will not sit across a child'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 US where the child seat laws are broadly representative of the EU situation[10].

Crashworthiness – PTW specificities

B18 Protective clothing

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. Powered two-wheeler protective clothing is designed to mitigate the risk of injury from these interactions by providing protection in a number of ways, either through impact resistance, abrasion resistance or by containing and controlling damage to body parts, for example, the stiffness of the ankle protection provided by a motorcycle boot. 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 suffer from a range of injuries compared to unprotected riders.

B19 PTW Helmet

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.

[10] Data and regulation similar to EU position when taking data from the US as a whole. Variations in regulation do exist on a state level but analysis is typically not disaggregated to this level.

Crashworthiness – Cyclist protective clothing

B20 Cyclist protective clothing

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.

B21 Cyclist Helmet

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 . 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.

Crashworthiness – HGV specificities

B22 Underrun protection (Lateral Side Guards / Rear)

Abstract

Underrun protection of heavy goods vehicles (HGV) includes the lateral side guards to provide protection to vehicle and vulnerable road users in the collisions with the side of the HGV and includes 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 often runs under the stiff structures of the HGV, to the effect that its safety systems are bypassed which results in extensive passenger compartment intrusion and serious or fatal injury. RUP systems are intended to act as a located underneath the stiff structures of the HGV to prevent this underrun and to provide a stable surface for the front of the smaller car to interact with, so as to allow the frontal crush zone and restraint systems of the car to work as they were supposed to. By achieving this, the protection offered to passenger car occupants can greatly be increased (Smith et al. 2008).
The fitment of RUP to HGVs was made mandatory by the directive 70/221/EC.
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).
In 2006, the Directive was amended (2006/20/EC) to increase the test loads which the RUP must withstand 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.

Figure 7: 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 casualty 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 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 mostly 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 are identified by a document produced by TRL in the scope of a GSR-2 report (TRL, 2016) to be a reduction of the vehicle functionality or its off-road capability due to the added structures under the HGV's body. Due to the increased mass of the underrun protection structures payload of the HGV may be decreased and fuel consumption and emissions are likely to increase.

Active safety – longitudinal control

B23 Emergency Braking Assistance system

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.

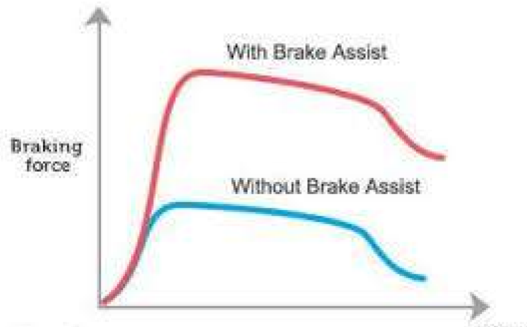

Figure1

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.

B24 Autonomous Emergency Braking AEB (City, interurban)

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 benefits of AEB city and interurban systems in terms of reduction in accident numbers and injury severity. A systematic literature search has been conducted and relevant studies have been analysed. No relevant study was found dealing with AEB interurban while five relevant studies were found for AEB city. Four of them undertook retrospective analyses and only one prospective analysis was found. The latter consists of a study of the potential benefit of AEB systems in reducing injuries in frontal crashes between heavy goods vehicles and passenger cars, if the system was designed to work in this configuration. The other studies

demonstrated that AEB city is efficient in reducing rear-end crashes and injuries in different environments and on different car models. 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.

B25 Autonomous Emergency Braking AEB (Pedestrians & cyclists)

Abstract

Autonomous Emergency Braking (AEB) for pedestrian and cyclist is an in-vehicle system that can avoid a crash with a pedestrian or a cyclist or mitigate its consequences by automatically applying the brakes. Depending on the system supplier or manufacturer, the system may give a warning to the driver and apply the brakes only in case of no driver reaction. Other parameters may vary from one system to another, depending on the sensing and braking technologies that were used by the manufacturer, thus influencing the outcome in terms of accident avoidance and mitigation.

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.

B26 Emergency Stop Signal (ESS)

Abstract

Rear-end crashes account for a substantial share of all road crashes. Many times, those 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 indicating that the vehicle in front is performing a high deceleration braking manoeuvre. This prolongs the time of the following vehicle to respond to this situation.

According to literature (Li et al. 2014) emergency stop signals have a potential of reducing the reaction time by 0.14 to 0.95 seconds.

B27 Braking system PTW (ABS, Combined braking system …)

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 safety 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 proved to be very effective in certain configurations i.e. PTW Active Braking Systems, and others that are not fully developed but have a great potential to contribute to PTW safety e.g. Electronic stability control.

The literature reviewed provides insights of the effectiveness of the multiple systems and indicates that the newer technologies and systems need more development and/or conclusive studies to determinate their efficiency.

B28 Collision Warning system

Abstract

In-vehicle systems related to collision warning 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 the level of road safety, and more specifically on road safety outcome indicators like travel speeds, reaction time, force on brake etc. Five high quality studies consisting mainly of simulator experiments were coded. 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 cases where results did not include any statistical tests, and therefore conclusions cannot be strongly supported. The results seem generally transferable but this should be done with caution.

B29 Intelligent Speed adaptation, Speed Limiter & Speed regulator

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.

B30 Adaptive Cruise Control (ACC & ACC Stop & start)

Abstract

Time headway and following distance in stable driving conditions, such as motorways and other high-speed roads where there is a potential to be following other vehicles for extended periods is seen as a major measure 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 can 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 provide one facet of an overall Advanced Driver Assistance System (ADAS) by monitoring and maintaining a safe following distance to a vehicle ahead by automatically adjusting vehicle speed.

Active safety – lateral control

B31 Electronic Stability Control (ESC)

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 and it became mandatory for all new cars after 2010. From 2000, many studies focused on ESC and its effectiveness. As a significant number of vehicles were equipped with ESC, researchers conducted retrospective studies based on accident data. The evaluation methodology relied on a comparison between two groups of crashes: the case group and the control group. The case group concerns accidents sensitive to ESC and in the control group, it is expected that ESC would have no effect on the accidents. In both groups, it is necessary to identify vehicles equipped or not with ESC.
The first challenge was the identification of vehicles equipped or not with ESC as ESC was not a standard safety system. So they used different vehicle criteria to identify them.
The second challenge was to choose the control group. Several accident situations were identified as ESC non-sensitive situations.
Then, several accident parameters were studied that make it difficult to compare the results.
Nevertheless, we can easily conclude that all these results confirm the great effectiveness of ESC.

B32 Lane keeping Systems

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 2 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 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, 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 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 ($p = 0.001$).

Active safety – driver assistance

B33 Alcohol Interlock (ALC)

Abstract

Field experiments showed that this measure has clear effects on the level of road safety in terms of ignition attempts blocked when the blood alcohol concentration is high. Two high quality experimental studies were coded. On the basis of both studies and effect numbers, it can be argued that alcolock systems have a mixed impact on road safety. There were also cases where results did not include any statistical tests, and therefore conclusions cannot be strongly supported. The results seem generally transferable but this should be done with caution.

Active safety – visibility enhanced

B34 Adaptive headlights

Abstract

Adaptive headlights rotate in the direction of steering and are intended to improve visibility on curved roads. There is a lack of studies that can quantify the safety benefits of adaptive headlights. Jermakian (2011) estimated that adaptive headlights could prevent 2% (142 000) of the annual passenger vehicle crashes in the US.

B35 Daytime running lights

Abstract

Daytime running lights (DRL) refers to headlights that are switched on while driving in daylight. The main purpose of daytime running lights is to make vehicles more conspicuous and easier to detect in any light condition, thereby reducing daytime multi-party accidents. Results provide consistent support that the cars using daytime running lights are involved in fewer multiple-party accidents than cars not using DRL. Studies evaluating the effect of mandatory use of DRL show smaller safety effects. Three out of three meta analyses and another individual study showed a reduced accident rate. There are several potential influencing factors, but in most cases, there are too few studies to make any conclusions.

B36 Night Vision

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. Typical such crashes are crashes between motor vehicles and VRUs as well as animals, single-vehicle crashes and rear-end crashes. Quantitative estimates of traffic safety effects of NVES have a large range and vary from 1% to -25%, partly because of potential risk factors (Rumar 2003).

While the safety benefit of NVES in theory could be large, there are concerns that drivers would compensate the increased visibility by for example increasing the driving speed so that the potential safety benefit is diminished (Rumar 2003). Another term for this compensatory driver behaviour is "behavioural adaptation" (BA), and is defined as "unintended behaviour that arises following a change in the road traffic system that has negative consequences on safety". Some empirical evidence indicates that NVES lead to BAs such as increased driving speed, reduced attention to the peripheral field and increased exposure at night and in bad weather conditions. Negative BA may be moderated

with adaptive design of HMI interfaces (Rudin-Brown 2010). Regarding NVES, experiments have indicated that if the full display is lit up (or if safety critical object is lit up within the display) when safety critical events are detected, then BA and variance in reaction times can be reduced (Kovordanyui et al., 2006; Tsimhoni et al. 2007).

B37 Vehicle backup camera - Reversing Detection or Camera systems (REV)

Abstract

Collisions with a reversing vehicle are particular dangerous for pedestrians and other VRU. Mainly in order to protect the car owner from property damage ultra-sonic based reversing assistant systems were introduced and further developed to reversing camera systems. The reversing camera systems were believed to especially contribute additional benefit to protection against property damage by VRU detection and thus protection against injuries. 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.

B38 Blind Spot Detection

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 a passenger car and a heavy goods vehicle are different. The blind spot of a passenger car can be mainly eliminated with the aid of mirrors or a glance over the shoulder. The limitation of visibility due to vehicle structure is small and (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 bigger 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.

Active safety – technical defects

B39 Tyre Pressure Monitoring and Warning

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. However, the main reason seems to be ecological, as vehicles with underinflated tyres have higher fuel consumption.
Tyre inflation pressure seems to be mainly related to fuel efficiency. There is also an effect of tyre inflation pressure on road safety but the effects on road safety are not clear (Jansen et. al. 2014). It is known that severely underinflated tyres can lead to bad vehicle handling and increased stopping distances due to a reduced friction coefficient (Choi 2012).

B40 Vehicle inspection

Abstract

In this synopsis the periodical technical inspection and the road side inspection are presented as countermeasures for technical defects.
The road side inspection shows a clear positive effect on road safety, with an increase of 100 % in the frequency of RSIs reducing the accident rate of HGVs by 7.2 %.
The periodical technical inspection reduces the relative accident frequency of the main causing party of an accident by around 2 %. But this effect often starts before the PTI, because many people get their vehicles repaired before the PTI.
The results of the PTI from Norway are inconsistent, because it clearly shows a reduction of technical defects due to PTI and thereby an increase of the roadworthiness of the passenger cars. On the other hand, the analysis with negative binomial regression models shows a slight increase of the accident rate after the PTI.

B41 Automatic Emergency Braking (AEB) for trucks

Abstract

The autonomous emergency brake system was first introduced by Daimler for HGVs in 2006.
This system was mainly developed to reduce crashes between HGVs and the rear end of traffic jams. Due to the big mass of the HGV and the high-speed differential, this accident scenario has serious consequences for the vehicles in the traffic jam.
EU Regulation No. 347/2012 specifies the technical requirements and test procedures for advanced emergency braking systems and the fitting of "Level 1" systems is mandatory for all new vehicles since 01.11.2015.
The AEBS should warn the driver of risk of collision and if the driver does not react appropriately, the system itself should initiate an emergency brake.

Modern AEBs in trucks can not only detect moving or stationary vehicles in front of them, even pedestrians and cyclists during turning manoeuvres can be detected.
Since these systems are relatively new, there is not much data available about the benefits of the AEB. But there are some in-depth analyses of HGV accidents with regard to avoidability had the HGV been equipped with an AEBS.
These analyses show the great potential of these systems, because around 52 % of all rear-end collisions could be avoided and fatalities in accidents with HGVs on motorways could be reduced by up to 50 %.

Active safety – connected

B42 Vehicle to Vehicle communication

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.

Tertiary safety – post crash

B43 ECall

Abstract

The E-Call 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 use an expert panel to reassess the crash outcome if an eCall system was present and are thus only indicative of the actual benefit. The international distribution of papers and analyses confirms the transferability of the results.

B44 Rescue Data Sheet & Rescue code

Abstract

The rescue data sheet provides the emergency services at the scene of an accident with detailed information to help them rescue the patient from the vehicle in an appropriate manner. This includes a diagram of the vehicle with various components marked on it (tank, battery, airbag, belt tensioners,

structural reinforcements, high voltage components and cables, etc.) and possibly additional information.
At present, almost all car manufacturers offer a rescue data sheet for each of their new models. Some, however, have to draft it again for older models or develop it with standardised information. Most of these sheets are available on each manufacturer's website (Audi[11], Mercedes[12], Renault[13], ...) but some associations (ADAC, FIA foundation[14], VDIK[15], VDA[16], ACL[17], ...) or official government agencies (French ministry[18]) or rescue departments themselves make these sheets public in the appropriate language.
To avoid difficulties relating to the language, a sheet provides pictures of the vehicles and schemes with different views of the vehicle (lateral and top view) giving the location of some relevant elements such as structure of reinforcements , pyrotechnic safety systems, battery or cable with strong voltage. The ISO 17840-1:2015 document defines the content and the layout of the rescue sheet providing necessary and useful information about a vehicle for supporting rescue teams. These definitions concerned at that time passenger cars and light commercial vehicles (Part1). An extension for buses, coaches and heavy commercial vehicles is in progress (Part2).

B45 ECE R100 (Battery electric vehicle safety)

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 test[19]) and R95 (side impact regulation test[1]) 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.

B46 Event Data Recorder

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[11] https://www.audi.de/de/brand/de/kundenbereich/geschaeftskunden/sonderfahrzeuge/einsatzfahrzeuge/leitfaden-fuer-rettungsdienste.html
[12] http://rk.mb-qr.com/en/
[13] https://www.renault.de/services/tipps-und-anleitungen/rettungskarten.html
[14] http://rescuesheet.info/
[15] http://www.vdik.de/department/technology/rescue-data-sheets.html
[16] https://www.vda.de/en/topics/safety-and-standards/rescue/rescue-data-sheets.html
[17] https://www.acl.lu/Mobilite/Rescue-Sheet/La-Rescue-Sheet-mode-d-emploihttps://www.acl.lu/Mobilite/Rescue-Sheet/Rescue-Sheet-des-constructeurs
[18]https://www.interieur.gouv.fr/fr/Le-ministere/Securite-civile/Documentation-technique/Les-sapeurs-pompiers/Doctrines-et-techniques-professionnelles/La-desincarceration-des-vehicules
[19] More information of these regulations can be found in the corresponding synopsis

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 that works under an accidentology context, only saves the data in case of an accident. This type of EDR captures vehicle dynamic and occupant information for a brief period of time before, during and after a crash. The second, called "driver behaviour tracking device" 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 has been conducted on EDR effectiveness and two relevant studies have been selected and analysed. The present abbreviated synopsis describes these two studies. An experimental study was conducted and the effect of the data recorders on driver behaviour was studied. The results show that the systems improve driver safety through reducing accidents or safety incidents by impacting driving behaviour.

Appendix C Documentation of cost-to-benefit analyses

This appendix includes the documentations of all the cost-benefit analyses that are available as of October 2017. These will also be available through the final version of the DSS. Cost-benefit analyses are provided for the following topics:

C1 Autonomous Emergency Braking (city, inter-urban)
C2 Autonomous Emergency Braking (AEB) for pedestrians
C3 Child restraints
C4 Emergency Braking Assistance system (EBA)
C5 Electronic Stability Control (ESC)
C6 PTW Helmet
C7 Seatbelt and Seatbelt Reminders
C8 PTW Airbag
C9 PTW braking systems (ABS, TCS)

CBA Autonomous Emergency Braking (city, inter-urban)

Reakka Krishnakumar, CEESAR, September 2017

ABSTRACT

(Grover et al. 2008) conducted a Cost – Benefit – Analysis (CBA) of the Autonomous Emergency Braking System. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used to perform our own CBA. The resulting best estimate of the benefit-cost ratio (BCR) is 0.6 which means that the costs outweigh the benefits. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: (Grover et al. 2008) reported reductions of fatalities and serious injuries from front to rear shunt accidents (M1 vehicle front collides with any vehicle rear) between 25% and 75% and reduction of slight injury accidents between 0% and 10%.

Crash costs: The updated SafetyCube estimates for 2015 for Europe were used (see SafetyCube Deliverable 3.2)

Measure Costs: The costs of the AEB system reported in the study (NHTSA 2012) were used in the present paper. The estimated prices vary between 269 and 304 US dollars (2011 prices). These costs were converted in euros by using 2015 exchange rate (0.92), then updated to 2015 by applying the inflation conversion value (1.08) and finally the values were converted to EU averages by multiplying them by the PPP conversion value (0.76).[20].

*Min 269 *0.92*1.08*0.76 = 203 euros*

*Max 304 *0.92*1.08*0.76 = 230 euros*

Time horizon: The applied time horizon for the measure is 8 years.

Area/Unit of implementation: All costs and effects are expressed per vehicle equipped with AEB system. The vehicle stock considered in EU-25 is about 220 million vehicles (M1).

Number of cases affected: The affected number of casualties was retrieved from (Grover et al. 2008). The study contains an estimate number of the effect of the system separately for each severity class: serious injury, slight injury and fatal injury. The number of PDO crashes is derived from the SafetyCube calculator. It assumed that the AEB effectiveness for PDO crashes is equivalent to AEB effectiveness for slight injury accidents.

Side effects: (Grover et al. 2008) considered the congestion benefit by avoiding accidents and/or reducing the severity. In the study congestion benefit cost was provided for Germany (2005). This cost was updated to 2015 value by applying the inflation conversion value of 1.15 and then the value was converted to EU averages by multiplying by the PPP conversion value of 1.03.

*Side effects cost in 2015 = 34,678,670.10*1.15*1.03= 41,076,884.70 euros*

[20] This inflation rate is taken from SafetyCube estimates (see SafetyCube Deliverable 3.2)

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for AEB system. It shows a B/C ratio of 0.6. This means that the costs outweigh the benefits.

Table 1 Input values and B/C ratio for the 'best estimate' scenario

Scenario	Input values	B/C ratio
Best estimate	Horizon: 8 years	0.6
	Number of units implemented: 220,000,000	
	Fatal injury crashes reduction: 50[21]%	
	Serious injury crashes reduction: 50%	
	Slight injury crashes reduction: 5%	
	PDO only crashes reduction:5%	
	Implementation cost: 216.5[22] €/vehicle	
	Annual cost: no recurrent cost	
	Affected nr. of crashes per year: Fatalities: 709 Ser. Inj. 12453 Slight inj.: 506805 PDO: 4275899.8	
	Side effects costs (congestion benefit): 41,076,884.70€	

SENSITIVITY ANALYSIS

We used the upper and lower values for each parameter according to the information available from the two studies (Grover et al. 2008) and (NHTSA 2012) to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Then the effect is calculated with lowest and highest measure costs. Table 2 presents the results.

Table 2 Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Horizon: 8 years	0.2
	Number of units implemented: 220,000,000	
	Fatal injury crashes reduction: **25**%	
	Serious injury crashes reduction: **25**%	
	Slight injury crashes reduction: **0**%	
	PDO only crashes reduction: **0**%	
	Implementation cost: 216.5 €/vehicle	
	Affected nr. of crashes per year: Fatalities: 709 Ser. Inj. 12453 Slight inj.: 506805 PDO: 4275899.8	
	Side effects costs (congestion benefit): 20,538,442.40€	
High measure effect	Horizon: 8 years	1.1
	Number of units implemented: 220,000,000	
	Fatal injury crashes reduction:**75**%	
	Serious injury crashes reduction: **75**%	
	Slight injury crashes reduction: **10**%	
	PDO only crashes reduction: **10**%	
	Implementation cost: 216.5 €/vehicle	
	Affected nr. of crashes per year: Fatalities: 709 Ser. Inj. 12453	

[21] Average reduction of crashes derived from the study (Grover et al. 2008).
[22] Average cost of the AEB system derived from the study (NHTSA 2012): (203+230)/2 = 216.5 euros

	Slight inj.: 506805 PDO: 4275899.8	
	Side effects costs (congestion benefit): 61,615,327.10€	
Low measure cost	Horizon: 8 years	1.3
	Number of units implemented: 220,000,000	
	Fatal injury crashes reduction:50%	
	Serious injury crashes reduction:50%	
	Slight injury crashes reduction: 5%	
	PDO only crashes reduction: 5%	
	Implementation cost: **108.25 €/vehicle**	
	Affected nr. of crashes per year: Fatalities: 709 Ser. Inj. 12453 Slight inj.: 506805 PDO: 4275899.8	
	Side effects costs (congestion benefit): 41,076884.70€	
High measure cost	Horizon: 8 years	0.3
	Number of units implemented: 220,000,000	
	Fatal injury crashes reduction:50%	
	Serious injury crashes reduction: 50%	
	Slight injury crashes reduction: 5%	
	PDO only crashes reduction: 5%	
	Implementation cost:**430 €/vehicle**	
	Affected nr. of crashes per year: Fatalities: 709 Ser. Inj. 12453 Slight inj.: 506805 PDO: 4275899.8	
	Side effects costs (congestion benefit): 41,076884.70€	

We defined a 'worst case' scenario as a combination of a worst expected effect and a highest expected measure cost. Also, an 'ideal case' scenario is defined which is a combination of a better expected effect and a lower expected measure cost. The results of the CBA for these scenarios are presented in Table 3.

Table 3 CBA for worst case and best-case scenarios

Combined Scenario	**Input values**	**B/C ratio**
	Horizon: 8 years	0.2
	Number of units implemented: 220,000,000	
	Fatal injuries reduction: 25%	
	Serious injury crashes reduction: 25%	
	Slight injury crashes reduction: 0%	
	PDO only crashes reduction: 0%	
	Implementation cost: 230 €/vehicle	
	Affected nr. of crashes per year: Fatalities: 709 Ser. Inj. 12453 Slight inj.: 506805 PDO[23]: 4275899.8	
	Side effects costs (congestion benefit): 20,538,442.40€	
Best case	Horizon: 8 years	1.1
	Number of units implemented: 220,000,000	

	Fatal injuries reduction:75%	
	Serious reduction: 75%	
	Slight injury crashes reduction :10%	
	PDO only crashes reduction: 10%	
	Implementation cost: 203 €/vehicle	
	Affected nr. of injuries per year: Fatalities: 709 Ser. Inj. 12453 Slight inj.: 506805 PDO [24]: 4275899.8	
	Side effects costs(congestion benefit) : 61,615,327.10€	

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CBA Autonomous Emergency Braking (AEB) for pedestrians

Jacques Saadé, CEESAR, September 2017

ABSTRACT

The SafetyCube Economic Efficiency Evaluation (E^3) calculator was used to estimate the benefit-cost ratio (BCR) of the Autonomous Emergency Braking for pedestrians (AEB pedestrian). Benefit data and target population were taken from Edwards et al. (2014) while AEB cost was taken from a report by NHTSA (2012). BCR analysis suggest that the pricing might be too high, depending on country, but also that break-even costs are in the range used for sensitivity analysis.

INPUT INFORMATION

Case studied: Edwards et al. (2014) studied the potential benefit of AEB pedestrian in reducing fatal, serious, and slight injuries among all pedestrian casualties in the UK and Germany and then estimated the benefit for the European Union 27 member states except Bulgaria and Lithuania. Since it was impossible to assess with certainty why UK and German data were so different, we performed two CBA, one for each country. Table and **Table 2** sum up the effectiveness values we took from Edwards et al. to calculate the benefit-cost ratio and to undertake the sensitivity analysis.

Table 18 Reduction of pedestrian casualty estimates that were used in the cost-benefit analysis (Germany).

	Mean (%)	Minimum (%)	Maximum (%)
Fatal injuries	6.7	2.75	10.3
Serious injuries	9.7	3.8	15.6
Slight injuries	8.6	2.9	13.7

Table 2 Reduction of pedestrian casualty estimates that were used in the cost-benefit analysis (UK).

	Mean (%)	Minimum (IC 5%)	Maximum (IC 95%)
Fatal injuries	14.1	6.3	20.8
Serious injuries	8.8	4.0	13.6
Slight injuries	9.36	4.0	19.4

Crash costs: The updated SafetyCube estimates for 2015 for Europe were used (see SafetyCube Deliverable 3.2).

Measure Costs: The costs of the AEB system reported in a study made for NHTSA (2012) were used in the present analysis. It was supposed that the detection system includes a camera and a radar. The estimated prices vary between 269 and 304 US dollars (2011 prices) depending on the supplier. The prices include sensors, image processors and ECUs, structural components, visual displays, and wiring and electrical architecture. The costs were converted to euros by taking into account the 2015 exchange rate (0.92) and then converted to EU-28 values by multiplying with the corresponding PPP conversion value (0.76). Inflation was accounted for by applying the inflation conversion value from 2011 to 2015 (1.08). For 2015, this results in a price range from 203 to 230 € that would be used for the sensitivity analysis. The mean value of 216.5 € will be used to estimate the benefit-cost ratio.

Time horizon: Based on the literature reviewed, the applied time horizon for the measure is 1 year.

Area/Unit of implementation: The number of new passenger cars registered in Europe per year is 12.5 million (Edwards et al. 2014).

Number of cases affected: In Edwards et al. (2014), the percentage of reduction in casualties were expressed as a percentage of the number of pedestrian casualties (fatal, serious, and slight injuries). The number of cases affected would be the number of pedestrian casualties in Europe. Edwards et al. (2014) took the average values from 2008 to 2010 which means 6,770 killed, 39,663 seriously injured, and 116,873 slightly injured pedestrians. This figure is very optimistic because not all the pedestrian casualties occur when passenger cars hit pedestrians.

Penetration rate: The system is considered to be applied on all new units (100% of 12.5 million).

Side effects: No side effect could be found or evaluated. We considered that side effects are negligible.

RESULTS

Germany

	Best estimate scenario	Worst scenario	Best scenario
Efficiency on fatal injury (%)	6.7	2.75	10.3
Efficiency on serious injury (%)	9.7	3.8	15.6
Efficiency on slight injury (%)	8.6	2.9	13.7
Cost per unit (€) SafetyCube WP4 values	216.5	433	108.25
Benefit-cost ratio	0.77	0.059	3.9

UK

	Best estimate scenario	Worst scenario	Best scenario
Efficiency on fatal injury (%)	14.1	6.3	20.8
Efficiency on serious injury (%)	8.8	4.0	13.6
Efficiency on slight injury (%)	9.36	4.0	19.4
Cost per unit (€) SafetyCube WP4 values	216.5	433	108.25
Benefit-cost ratio	1.5	0.15	7.3

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CBA Child restraints

Christos Katrakazas, LOUGH November 2017

ABSTRACT

Latest effectiveness data available (Hoye, A., 2013) regarding the effects of child restraints were used. The SafetyCube Economic Efficiency Evaluation (E3) Calculator was used. The resulting best estimate of the benefit-cost ratio (BCR) is 3.4 which means that the costs tend to exceed the benefits. The sensitivity analysis proved this measure to be very robust with a BCR exceeding 1 even in the worse scenario.

INPUT INFORMATION

Cases studied: Hoye, A (2013) reports a reduction of 81% (95% CI [-92%; -57%] of fatalities, 69% (95% CI [-73%; -64%] of KSI and 33% (95% CI [-32%; -16%] of slight injuries, as an effect of the use of child restraints.

Crash costs: The updated SafetyCube estimates for 2015 for Europe were used (see SafetyCube Deliverable 3.2)

Measure Costs: The reported costs were obtained from the Handbook of Road Safety (Elvik, Hoye, Vaa, & Sorensen, 2009), where it is reported that the unit cost of a child restrain is about 2,000 NOK. This cost applies to Norway in 2005 and was updated to 2015 values by applying the inflation conversion value of 1.38. Subsequently the values are converted to EU averages (in EUR) by multiplying with the PPP conversion value of 0.08.

Time horizon: 4 years was assumed to be the time horizon for child restraints in order to take into account the expected duration of usage for child restraints.

Area/Unit of implementation: All costs were expressed according to the assumption that 90% of all children who belong to families owning a car are correctly restricted. The total number of such children in Norway is 860,000. Hence, 774000 units were taken into account.

Number of cases affected: The number of prevented casualties was retrieved from the available study. No side effects were taken into account.

RESULTS

Table 1 provides the input values used for benefit-to-cost ratio and sensitivity analyses

Table 19 Reduction in casualties estimates that were used in the cost-benefit analysis.

	Mean (%)	Minimum (%)	Maximum (%)
Fatal injuries	81	57	92
Serious injuries	64.5	63	65.8
Slight injuries	25	16	32

SENSITIVITY ANALYSIS

The available meta-analysis does provide confidence intervals regarding the number of prevented casualties. Therefore, a sensitivity analysis was conducted.

	Best estimate scenario	Worst scenario	Best scenario
Efficiency on fatal injury (%)	81	57	92
Efficiency on serious injury (%)	64.5	63	65.8
Efficiency on slight injury (%)	25	16	32
Cost per unit (€) SafetyCube WP4 values	214	428	107
Benefit-cost ratio	3.4	1.3	7.5

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CBA Emergency Braking Assistance system (EBA)

Vuthy PHAN, CEESAR, October 2017

ABSTRACT

DG TREN (2006) conducted a Cost-Benefit-Analysis of Emergency Brake Assistance system (EBA). We performed our own CBA using the SafetyCube Economic Efficiency Evaluation (E3) and the information available in DG TREN (2006). The resulting best estimate of the benefit-cost ratio (BCR) is 3 which means that the benefits tend to exceed the costs. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: DG TREN (2006) reported reductions of 8% of fatalities, seriously and slightly injured persons in EU-25.

Crash costs: The updated SafetyCube estimates for 2015 for Europe were used (see SafetyCube Deliverable 3.2).

Measure Costs: DG TREN (2006) did not find any cost of EBA and tested a range of values from 200 € per vehicle to 1000 €. The break-even cost is 460 € per vehicle in 2005 (EU-25 price).
Considering inflation, this cost, from 2005, has to be up-dated to the 2015 price-level. This inflation rate is taken from SafetyCube estimates (see SafetyCube Deliverable 3.2).

*EBA total cost in 2015 = 460 * 1.15 = 529 €*

1.15 is the EU-28 inflation rate considered to update EBA cost from 2005 to 2015.

There is no correction for price-level (to level price from one country to EU-28) as the cost given by DG TREN (2006) is already a EU-25 cost.

Time horizon: The applied time horizon for the measure is 20 years.

Area/Unit of implementation: All costs and effects are expressed per vehicle equipped with EBA. The car stock considered in EU-25 is 213.1 million cars (2003 reference).

Number of cases affected: The affected number of casualties was retrieved from DG TREN (2006) The study contains separate estimates of the effect on the total number of slightly or seriously or fatally injured road user. The number of affected PDO crashes is derived from SafetyCube calculator that predicts PDO target population according to injury target population. We made the hypothesis that EBA effectiveness for PDO crashes would be equivalent to EBA effectiveness for slight injured road users.

Penetration rate: DG TREN (2006) considered two EBA market penetration scenarios. In the first one, the penetration increases from 5% to 20% and in the second one, the penetration increases from 5% to 100%

Side effects: No side effect has been considered by DG TREN (2006).

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for EBA. It shows a B/C ratio of 3. This means that the benefits tend to largely exceed the costs.

Table 1 Input values and B/C ratio for the scenario using DG TREN parameters

Scenario	Input values	B/C ratio
Best estimate	Horizon: 20 years Number of units implemented: 213,100,000 cars (European fleet) Fatal injuries reduction: 8% Serious injuries reduction: 8% Slight injuries reduction: 8% PDO reduction: 8% Implementation cost: 529 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 24,843 Serious injuries: 240,021.5 Slight injuries: 2,365,225.5 PDO: 19,955,342 Side effects : no side effect	3

SENSITIVITY ANALYSIS

We used upper and lower values for each parameter according to the information availability in the literature. When it was possible, we changed one parameter value (the other parameter values were the ones presented in table 1). In the table below, a green arrow upwards (↑) indicates that a value lower/higher than the estimate makes is more likely that the measure is evaluated as being economically efficient. A red arrow downwards (↓), indicates that a lower/higher value makes it less likely that the measure is evaluated as being economically efficient.

Table 2: Sensitivity analyses

	DG TREN (2006) values	Lower value			Higher value		
		Value	Source	B/C	Value	Source	B/C
Costs							
Implementation costs per unit	529	102.573	VSS (2013)	15.6 ↑	1150	DG TREN (2006)	1.4 ↓
Annually recurrent costs per unit							
Total costs (initial + annual costs for all years) per unit							
Affected number of cases per year (target group)							
Fatal	24843						
Serious	240021.5						
Slightly injured	2365225.5						
PDO	19955342						
Injuries (slight/serious)							
Casualties (slight/serious/fatal)							
Effectiveness (percentage reduction in target group)							
Fatalities / fatal crashes	8.0%	4.0%	DG TREN (2006)	2.7 ↓	16%	DG TREN (2006)	3.6 ↑
Serious injuries / serious injury crashes	8.0%	4.0%	DG TREN (2006)	2.6 ↓	16	DG TREN (2006)	3.8 ↑
Slight injuries / slight injury crashes	8.0%	4.0%	DG TREN (2006)	2.7 ↓	16	DG TREN (2006)	3.7 ↑
PDO	8.0%	4.0%	DG TREN (2006)	2.6 ↓	16.0%	DG TREN (2006)	3.9 ↑
Injuries (slight/serious)							
Casualties (slight/serious/fatal)							
Penetration rate							
Pentration rate before implementation		5%	DG TREN (2006)	2.9 ↓	5%	DG TREN (2006)	3 ~
Penetration rate after implementation		20%	DG TREN (2006)		100%	DG TREN (2006)	
Side effects							
Description of side effects							
Annual cost side effects							
Total cost of side effects							

The cost sensitivity of the measure was also analysed using the SafetyCube methodology. We assessed the effects of a price variation of +100% (worst case) and -50% (best case).

Scenario	Input values	B/C ratio
Best case Reduction of price 50%	Horizon: 20 years Number of units implemented: 213,100,000 cars (European fleet) Fatal injuries reduction: 8% Serious injuries reduction: 8% Slight injuries reduction: 8% PDO reduction: 8% Implementation cost: 264.9 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 24,843 Serious injuries: 240,021.5 Slight injuries: 2,365,225.5 PDO: 19,955,342 Side effects : no side effect	6
Scenario	**Input values**	**B/C ratio**
Worst case Increasing the price 100%	Horizon: 20 years Number of units implemented: 213,100,000 cars (European fleet) Fatal injuries reduction: 8% Serious injuries reduction: 8% Slight injuries reduction: 8% PDO reduction: 8% Implementation cost: 1058 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 24,843 Serious injuries: 240,021.5 Slight injuries: 2,365,225.5 PDO: 19,955,342 Side effects : no side effect	1.5

We defined a 'worst case' scenario as a combination of a much worse than expected effect and a higher than expected measure cost. The results of the CBA for these scenarios are reflected in Table 3.

Table 3 CBA for worst case and best-case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Horizon: 20 years Number of units implemented: 213,100,000 cars (European fleet) Fatal injuries reduction: 4% Serious injuries reduction: 4% Slight injuries reduction: 4% PDO reduction: 4% Implementation cost: 1150 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 24,843 Serious injuries: 240,021.5 Slight injuries: 2,365,225.5 PDO: 19,955,342 Side effects : no side effect	0.7
Best case	Horizon: 20 years Number of units implemented: 213,100,000 cars (European fleet)	31.2

	Fatal injuries reduction: 16% Serious injuries reduction: 16% Slight injuries reduction: 16% PDO reduction: 16% Implementation cost: 103 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 24,843 Serious injuries: 240,021.5 Slight injuries: 2,365,225.5 PDO: 19,955,342 Side effects : no side effect	

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VSS (2013) - Regulation Impact Statement for Brake Assist Systems - Vehicle Safety Standards Branch, Department of Infrastructure and Regional Development, Canberra, Australia – Report DoIT VSS 02/2012

CBA Electronic Stability Control (ESC)

Vuthy PHAN, CEESAR, September 2017

ABSTRACT

Baum et al. (2007) conducted a Cost-Benefit-Analysis (CBA) of Electronic Stability Control. We performed our own CBA using the SafetyCube Economic Efficiency Evaluation (E3) and the information available in Baum et al. (2007). The resulting best estimate of the benefit-cost ratio (BCR) is 13.9 which means that the benefits tend to exceed the costs. The BCR is sensitive to changes in the underlying assumptions as is shown by the sensitivity analysis but the ratios still remain over 1 (that means that ESC benefits are higher than ESC costs).

INPUT INFORMATION

Case studied: Baum et al. (2007) reported a reduction 25.5% of fatalities and injured persons in EU-25 single vehicle crashes.

Crash costs: The updated SafetyCube estimates for 2015 for Europe were used (see SafetyCube Deliverable 3.2).

Measure Costs: Baum et al. (2007) stated that the cost of equipping a car with ESC is 130 € (it is a mean cost in EU-25). This cost was verified by experts from eIMPACt project in 2006. Baum et al. (2007) added too that there is normally no recurrent cost per ESC.
Considering inflation, this cost, from 2006, has to be up-dated to the 2015 price-level. This inflation rate is taken from SafetyCube estimates (see SafetyCube Deliverable 3.2).

*ESC total cost in 2015 = 130 * 1.13 = 146.9 €*

1.13 is the EU-28 inflation rate considered to update ESC cost from 2006 to 2015.

There is no correction for price-level (to level price from one country to EU-28) as the cost given by Baum et al. (2007) is already a EU-25 cost.

Time horizon: The applied time horizon for the measure is 12 years.

Area/Unit of implementation: All costs and effects are expressed per vehicle equipped with ESC. The car stock considered in EU-25 is 212 million cars, in 2002 (Baum et al. (2007)).

Number of cases affected: The affected number of casualties was retrieved from Baum et al. (2007). The study contains an estimate of the effect on the total number of injured people and a separate estimate on the effect on the number of fatalities. The number of affected PDO crashes is derived from SafetyCube calculator that predicts PDO target population according to injury target population. We made the hypothesis that ESC effectiveness for PDO crashes would be equivalent to ESC effectiveness for slight or serious injured road users.

Penetration rate: no information available

Side effects: Baum et al. (2007) considered that there are savings in accident costs, property damage and congestion in injury accidents; that is to say in total 11,000€ per injury accident.

*Side effects cost in 2015 = 11,000 * 1.13 = 12,430€*

1.13 is the EU-28 inflation rate considered to update side effects cost from 2006 to 2015.

There is no correction for price-level (to level price from one country to EU-28) as the cost given by Baum et al. (2007) is already a EU-25 cost.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for ESC. It shows a B/C ratio from 5.7 (including side-effects) to 5.8 (excluding side-effects). This means that the benefits tend to largely exceed the costs.

Table 1 Input values and B/C ratio for the scenario using Baum et al. parameters

Scenario	Input values	B/C ratio
Best estimate	Horizon: 12 years Number of units implemented: 212,000,000 cars (European fleet) Fatal injuries reduction: 25.5% Serious or slight injuries reduction: 25.5% PDO reduction: 25.5% Implementation cost: 146.9 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 15,642 Serious or slight injuries: 372,815 PDO: 2,746,274 Side effects - savings in accident costs, property damage and congestion in injury accidents: 951,330,050€	Excluding side-effects: 5.8 Including side-effects: 5.7

SENSITIVITY ANALYSIS

We used upper and lower values for each parameter according to the information availability in the literature. When it was possible, we changed one parameter value (the other parameter values were the ones presented in table 1). In the table below, a green arrow upwards (↑) indicates that a value lower/higher than the estimate makes is more likely that the measure is evaluated as being economically efficient. A red arrow downwards (↓), indicates that a lower/higher value makes it less likely that the measure is evaluated as being economically efficient.

Table 2: Sensitivity analyses

	Baum et al. (2007) values	Lower value				Higher value			
		Value	Source	B/C w/ side-effects	B/C w/o side-effects	Value	Source	B/C w/ side-effects	B/C w/o side-effects
Costs									
Implementation costs per unit	146.9					328.93	Elvik R., Vaa T., Hoye A, Sorensen M.; (2009), Pthe handbook of road safety measures. Second edition.	2.6 ↓	2.6 ↓
Annually recurrent costs per unit									
Total costs (initial + annual costs for all years) per unit									
Affected number of cases per year (target group)									
Fatal	15642								
Serious									
Slightly injured									
PDO	2746274								
Injuries (slight/serious)	*372815*								
Casualties (slight/serious/fatal)									
Effectiveness (percentage reduction in target group)									
Fatalities / fatal crashes	25.5%	16.6%	eIMPACT Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe. Report type Deliverable D4	4.7 ↓	4.8 ↓	70%	Høye, Alena. 2011. "The Effects of Electronic Stability Control (ESC) on crashes—An Update."	10.7 ↑	11.1 ↑
Serious injuries / serious injury crashes									
Slight injuries / slight injury crashes									
PDO	25.5%					41.1%	Chouinard, Aline, and Jean-François Lécuyer. 2011. "A Study of the Effectiveness of Electronic Stability Control in Canada." Accident Analysis & Prevention 43 (1): 451–60.	6.2 ↑	6.4 ↑
Injuries (slight/serious)	*25.5%*	6.6%	eIMPACT Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe. Report type Deliverable D4	4.3 ↓	4.4 ↓	54.8%	Chouinard, Aline, and Jean-François Lécuyer. 2011. "A Study of the Effectiveness of Electronic Stability Control in Canada." Accident Analysis & Prevention 43 (1): 451–60.	7.9 ↑	8.1 ↑
Casualties (slight/serious/fatal)									
Side effects									
Description of side effects									
Annual cost side effects									
Total cost of side effects	*951330050*	1.5E+08	eIMPACT Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe. Report type Deliverable D4	5.8 ↑	5.8 ~				

The cost sensitivity of the measure was also analysed using the SafetyCube methodology. We assessed the effects of a price variation of +100% (worst case) and -50% (best case).

Scenario	**Input values**	**B/C ratio**
Best case Reduction of price 50%	Horizon: 12 years Number of units implemented: 212,000,000 cars (European fleet) Fatal injuries reduction: 25.5% Serious or slight injuries reduction: 25.5% PDO reduction: 25.5% Implementation cost: 73.45 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 15,642 Serious or slight injuries: 372,815 PDO: 2,746,274 Side effects - savings in accident costs, property damage and congestion in injury accidents: 951,330,050€	11.2
Scenario	**Input values**	**B/C ratio**
Worst case Increasing the price 100%	Horizon: 12 years Number of units implemented: 212,000,000 cars (European fleet) Fatal injuries reduction: 25.5% Serious or slight injuries reduction: 25.5% PDO reduction: 25.5%	2.9

	Implementation cost: 293.8 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 15,642 Serious or slight injuries: 372,815 PDO: 2,746,274 Side effects - savings in accident costs, property damage and congestion in injury accidents: 951,330,050€	

We defined a 'worst case' scenario as a combination of a much worse than expected effect and a higher than expected measure cost. The CBA results of these scenarios are reflected in Table 3.

Table 3 CBA for worst case and best-case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Horizon: 12 years Number of units implemented: 212,000,000 cars (European fleet) Fatal injuries reduction: 16.6% Serious or slight injuries reduction: 6.6% PDO reduction: 25.5% Implementation cost: 328.93 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 15,642 Serious or slight injuries: 372,815 PDO: 2,746,274 Side effects - savings in accident costs, property damage and congestion in injury accidents: 145,000,000€	Excluding side-effects: 1.5 Including side-effects: 1.5
Best case	Horizon: 12 years Number of units implemented: 212,000,000 cars (European fleet) Fatal injuries reduction: 70% Serious or slight injuries reduction: 54.8% PDO reduction: 41.1% Implementation cost: 146.9 €/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 15,642 Serious or slight injuries: 372,815 PDO: 2,746,274 Side effects - savings in accident costs, property damage and congestion in injury accidents: 951,330,050€	Excluding side-effects: 13.9 Including side-effects: 13.4

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Høye, A. (2011). "The Effects of Electronic Stability Control (ESC) on crashes—An Update."

CBA PTW Helmet

Cecil Mettel, DEKRA Automobil GmbH, December 2017

ABSTRACT

A benefit-analysis regarding the effects of motorcycle helmets in the USA (NHTSA, 2015) and a meta-analysis of the worldwide cost-benefit of motorcycle helmets (UNECE, 2016) was revisited. For the NHTSA paper the SafetyCube Economic Efficiency Evaluation (E3) calculator was used. The resulting best estimate of the benefit-cost ratio (BCR) is between 1.2 and 4.3 depending on the country, which means that the benefits tend to exceed the costs.

INPUT INFORMATION

Case studied: UNECE (2016) reported that helmets are effective in reducing serious (head) injuries in motorcyclists who crash by 69% and death by 42%.

Crash costs: The United Nations Motorcycle Helmet study applies the iRAP (International Road Assessment Programme) economic appraisal model parameters.

The NHTSA study (2015) uses another table, which estimates the economic cost with 1,381,645 $ per fatality.

Measure Costs: UNECE (2016) stated that the cost for a motorcycle helmet (conformal with UN regulation 22) can vary between 50 and 600+ $ in many European countries. In China, the Philippines, Thailand, Vietnam, and Venezuela, motorcycle helmets are considered luxury goods that are primarily sold to foreigners and a small group of wealthy local consumers. Helmets manufactured in China but sold in the United States are sold at 8 $; yet, because of ineffective helmet-wearing enforcement, cultural and other factors, even bicycle helmets are not readily available in China at this relatively low price.
Considering that helmets sold as low as 50 $ fulfil UN ECE R 22 and high-end helmets are designed primarily to provide additional comfort, the estimated measure cost is 50 $ per helmet.

Motorcycle helmet cost in 2017 = 46€

Time horizon: UNECE (2016) study analyses the data over a period of 12 years.

The NHTSA (2015) study analyses the data from one year (2013).

Area/Unit of implementation: All costs and effects are expressed per vehicle. The motorcycle stock considered in USA is 8.4 million motorcycles, in 2013 (NHTSA 2013 (2015)).

Number of cases affected: The affected number of casualties was retrieved from NHTSA (2015) and UNECE (2016). The NHTSA study contains an estimate of the current effect on the total number of fatalities and a separate estimate with a 100 % helmet wearing rate. The UNECE study uses different publications to make an estimation for the current situation and a future situation in 2020.

Penetration rate: Varies considerably depending on the respective country. It depends on mandatory laws and general culture.

Side effects: There might be a disadvantage if low-cost helmets are used, which don't fit safety standards. They could give a feeling of false safety.

RESULTS

Table 1 provides the result estimated benefit-to-cost ratio for motorcycle helmets given in the UNECE paper. It shows a B/C ratio from 1.2 to 4.3, depending on country. This means that the benefits tend to exceed the costs.

Table 1 B/C ratio for the scenario using UNECE parameters

Scenario	Input values	B/C ratio
Worst Case	Horizon: 12 years Number of units implemented: unknown (worldwide fleet) Fatal injuries reduction: 42% Serious or slight injuries reduction: 69% Implementation cost: varies Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 122,000 to 250,000 Serious injuries: 1,600,000 to 5,000,000 Side effects – no known side effects	Low income countries: 1 Middle income countries: 4 High income countries: 1.2
Best Case	Horizon: 12 years Number of units implemented: unknown (worldwide fleet) Fatal injuries reduction: 42% Serious or slight injuries reduction: 69% Implementation cost: varies Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 250,000 Serious injuries: 5,000,000 Side effects – no known side effects	Low income countries: 2.2 Middle income countries: 4,3 High income countries: 1.2

In the worst-case scenario, it's estimated, that the benefit will just break-even with the costs in low income countries, because there might be a disadvantage if low-cost helmets are used, which don't fit safety standards. They could give a feeling of false safety.
The B/C ratio for high income countries is relative low, because it is estimated with a maximum purchase of highest-end, most expensive, helmets.

Table 2 provides the input value and the result estimated break-even cost for motorcycle helmets in the USA. It shows that even if only the benefit of fatality reduction is considered the break-even cost is 384 $. Compared to the price for helmets in the EU-25, the benefit is significantly exceeding the cost.

Table 2 Break-even cost using NHTSA parameters

Scenario	Input values	Break-even
Worst Case	Horizon: 1 year Number of units implemented: 8404687 (USA fleet) Fatal injuries reduction: 50% Implementation cost: 50 $/vehicle Annual cost: no recurrent cost Affected nr. of injuries per year: Fatalities: 4,668 Side effects – no known side effects	Break-even cost: 384 Dollar

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CBA Seatbelt and Seatbelt Reminders

Robert Thomson, SAFER, January 2018

ABSTRACT

Seatbelts are a proven road safety countermeasure. The fitment of seatbelts in passenger cars and heavy vehicles like trucks and buses are mandatory in countries participating in the United Nations – Economic Commission of Europe Vehicle Regulation (UN-ECE) activities. Seatbelt Reminders, devices that detect the presence of a passenger in a designated seating position and issues an audible and visual warning if the belt is not fastened, have previously been optional equipment and have been encouraged in consumer testing programs. Rulemaking activities will soon require that seatbelt reminders are mandatory for all passenger car seats and at least the driver and front seat passenger of commercial vehicles. Cost benefit analyses to assess future implementations of these systems are not necessary as there are essentially all vehicles have seatbelts and vehicles without seatbelt reminders will be phased out of the fleet. This legislation has been implemented as both systems have positive benefits on road safety. Estimates of benefit/cost ratios of seat belt reminders using assumed wearing rates, seatbelt effectiveness, and costs for 1005-2003 produced a result of 1.6 for the European Union. A similar study in Australia in indicated a cost benefit ratio ranging from 0.8-1.40 depending on the type of system and number of passengers addressed.

There are no SafetyCube E3 tool calculations for these 2 cases as future CBAs would not be applicable for legislated measures. Summaries of the previous CBAs are provided below.

Seatbelt reminders are a parallel measure to seatbelt enforcement and the reader is referred to the Seatbelt Enforcement CBA.

CASE INFORMATION

Case studied 1: The ETSC report from 2003 (ETSC 2003) provided an estimate of the number of lives saved in Europe using audible seatbelt reminders. The study assumed a unit cost of 60€ to fit the vehicles. The study assumed that 483 lives per/year could be saved using seatbelt usage rates and effectiveness estimates from other studies. The estimate includes a benefit to society beyond the fatalities avoided using estimates for injury severity reductions for non-fatality crashes. The study assumed 20 Million new vehicles were sold per year and used a 5% discount factor. The estimates were based on 1990-2000 data for costs, road trauma estimates, and safety technologies

Case studied 2: Researchers in Australia performed a CBA for seatbelt reminders using 3 different implementation strategies. Each system was more aggressive in warning when passengers were unbelted. The CBA used the Harm reduction model developed by Monash University which quantifies road trauma costs using the type and number of injuries. Similar to the ETSC study (ETSC 2003), the study used other empirical data to estimate new seatbelt usage rates and seatbelt effectiveness in crashes. The effectiveness of the systems ranged from 10%-40%. The cost to implement the systems ranged from $10 (Aus) for the simplest system for the driver only to $165 (AUS) for the complex system equipped for all passengers. The costs and benefits were based on Australian data from 2002.

RESULTS

Table 1 summarizes the two studies reviewed

Table 1

Scenario		B/C ratio
Europe (2003)	Best estimate – Society Benefit	1.4
Australia (2003)	Worst case:	0.8
	Best Case	1.4

Table 3 CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Fatalities reduction by using seat belt: 53% Serious injury reduction by using seat belt: 53% Impl. cost: Annual cost: 133,102,800 NOK	0.5
Ideal case	Fatalities reduction by using seat belt: 66% Serious injury reduction by using seat belt: 66% Impl. cost: Annual cost: 133,102,800 NOK	3.5

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CBA PTW Airbag

Oscar Martin, Cidaut Foundation, December 2017

ABSTRACT

Anderson et al. (2011), conducted a study to estimate the potential benefits of some of the safety technologies emerging for passenger vehicles, trucks and motorcycles. Within this study they performed a Cost – Benefit – Analysis (CBA) of the PTW in vehicle Airbag. The resulting best estimate of the benefit-cost ratio (BCR) is 0.03 which means that the costs outweigh the benefits. The study reviewed also gives break-even analysis estimation, being the unit cost of 61 Euro.

INPUT INFORMATION

Case studied: (Anderson et al. 2011) reported reductions of fatalities and serious injuries from frontal collisions between motorcycles and passenger vehicles. Ten percent of fatal motorcycle crashes and about 2% of motorcycle injury crashes fall into this category of crash. The study assumed that about ten percent of these crashes might be avoided with an airbag.

Crash costs: The updated SafetyCube estimates for 2015 for Europe were used (see SafetyCube Deliverable 3.2)

Measure Costs: The costs of the PTW Airbag estimated in Anderson et al. (2011) study were used in the present paper. The estimated price was 6000 Australian dollars (2011 prices). These costs were converted in euros by multiplying 2015 exchange rate (0.69), after were updated to 2015 by applying the inflation conversion value (1.08) and then the values were converted to EU averages by multiplying with the PPP conversion value (0.76).[25].

*6000 *0.69*1.08*0.49 = 2196.92 euro*

Time horizon: The applied time horizon for the measure is 11 years.

Area/Unit of implementation: All costs and effects are expressed per vehicle equipped with PTW in-vehicle Airbag. The vehicle stock considered in EU-28 is about 33 million of PTW (mopeds + motorcycles). However, there was not enough information to replicate the study with European data, so the results are based on historical crash data and vehicle fleet from New South Wales (Australia).

Number of cases affected: The affected number of casualties was retrieved from (Anderson et al. 2011). The study contains an estimate number of the effect of the system for fatal crashes and injury accidents.

Side effects: There are no side effects described in (Anderson et al. 2011). However, side effects are named in the literature reviewed, especially from the second impact (rider on ground).

[25] This inflation rate is taken from SafetyCube estimates (see SafetyCube Deliverable 3.2)

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for PTW in vehicle Airbag system reported in the Anderson et al., study. It shows a B/C ratio of 0.03. This means that the costs outweigh the benefits.

Table 1 Input values and B/C ratio for the 'best estimate' scenario

Scenario	Input values	B/C ratio
Best estimate	Injury reduction (fatal, serious, slight): 1% Motorcycle accidents NSW Prevented casualties: • Fatal: 7 x 11 years= 77 • injured: 49 x 11 years=539 Implementation cost: *2196.92* EUR /PTW Airbag	0.03

SENSITIVITY ANALYSIS

The available meta-analysis does not provide confidence intervals regarding the number of prevented casualties. Therefore, a sensitivity analysis could not be conducted.

REFERENCES

Anderson et al. 2011. "Analysis of crash data to estimate the benefits of emerging vehicle technology.", Report: CASR 094, Centre for Automotive Safety Research, University of Adelaide, http://casr.adelaide.edu.au/publications/researchreports

CBA PTW braking systems (ABS, TCS)

Oscar Martin, CEESAR, December 2017

ABSTRACT

To perform the Cost-Benefit Analysis (CBA) of the Powered Two Wheelers (PTW) it has been used 4 studies. Alena Høye (2016) conducted a meta-analysis of the effectiveness of PTW Advanced Braking Systems (ABS) and Combined Braking systems (CBS). Also three CBA studies were use. The SafetyCube Economic Efficiency Evaluation (E3) Calculator was used to perform our own CBA. The resulting best estimate of the benefit-cost ratio (BCR) is 7.8 which means that the benefits outweigh the costs. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

The values of CBA found in the literature reviewed vary between 4.0 and 27 for PTW ABS.

For Traction Control Systems (TCS) only one study was found and this study gives an estimate BCR of 1.7.

INPUT INFORMATION

Case studied: The meta-analysis from Alena Høye reported reductions of motorcycles accidents between 24% and 35%, and a best estimate of 29%. Other studies (Rizzi et al., Teoh) gave a greater around 40% of all accidents. This reduction is higher for more severe accidents. The estimation is a reduction of a 32% for kill or seriously injured accidents.

Anderson et al., estimated an effectiveness of 25% for the TCS, and that it will affect to 20% of all motorcycle crashes.

Crash costs: The updated SafetyCube estimates for 2015 for Europe were used (see SafetyCube Deliverable 3.2)

Measure Costs: The costs of the PTW ABS system reported in the different studies vary between 185 and 525 euro. The costs from the Australian study were converted in euros by multiplying 2015 exchange rate (0.69), after were updated to 2015 by applying the inflation conversion value (1.08) and then the values were converted to EU averages by multiplying with the PPP conversion value (0.46)[26].

For TCS price there was only one estimation of 365 euro.

Time horizon: The applied time horizon for the measure varies between the studies from 11 years to 13.2 years.

Area/Unit of implementation: All costs and effects are expressed per vehicle equipped with PTW ABS or TCS system. The vehicle stock considered in EU-25 is about 33 million vehicles.

Number of cases affected: The affected number of casualties was retrieved from the literature reviewed. The studies contain an estimate number of the effect of the system separately for each severity class: serious injury, slight injury and fatal injury. The number of PDO crashes is derived from the SafetyCube calculator. It assumed that the PTW ABS effectiveness for PDO crashes is equivalent to PTW ABS effectiveness for slight injury accidents.

No side effects were described.

[26] This inflation rate is taken from SafetyCube estimates (see SafetyCube Deliverable 3.2)

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for AEB system. It shows a B/C ratio of 7.8. This means that the costs outweigh the benefits.

Table 1 Input values and B/C ratio for the 'best estimate' scenario

Scenario	**Input values**	**B/C ratio**
Best estimate	Horizon: 13 years	7.8
	Number of units implemented: 33,000,000	
	Fatal injury crashes reduction: 32[27]%	
	Serious injury crashes reduction: 29%	
	Slight injury crashes reduction: 18%	
	PDO only crashes reduction:18%	
	Implementation cost: 400[28] €/vehicle	
	Annual cost: no recurrent cost	
	Affected nr. of crashes per year: Fatalities: 1351 Ser. Inj. 15313 Slight inj.: 15088	

For PTW TCS there was only one study which gave a best estimate of BCR 1.7

SENSITIVITY ANALYSIS

We used the upper and lower values for each parameter according to the information available from the two studies to run a sensitivity analysis. The values represent a lower than expected and a higher than expected effect respectively. Then the effect is calculated with lower and higher measure costs. Table 2 presents the results.

Table 2 Sensitivity analyses

Scenario	**Input values**	**B/C ratio**
Low measure effect	Horizon: 13 years	6.3
	Number of units implemented: 33,000,000	
	Fatal injury crashes reduction: **25**%	
	Serious injury crashes reduction: **24**%	
	Slight injury crashes reduction: **14**%	
	PDO only crashes reduction: **14**%	
	Implementation cost: 400 €/vehicle	
	Affected nr. of crashes per year: Fatalities: 1351 Ser. Inj. 15313 Slight inj.: 15088	
High measure effect	Horizon: 13 years	9.5
	Number of units implemented: 33,000,000	
	Fatal injury crashes reduction: 39%	
	Serious injury crashes reduction: **35**%	
	Slight injury crashes reduction: **22**%	
	PDO only crashes reduction: 22%	
	Implementation cost: 400 €/vehicle	
	Affected nr. of crashes per year: Fatalities: 1351 Ser. Inj. 15313 Slight inj.: 15088	
	Horizon: 13 years	

[27] Average reduction of crashes derived from the study (Grover et al. 2008).
[28] Average cost of the AEB system derived from the study (NHTSA 2012): (203+230)/2 = 216.5 euros

Low measure cost	Number of units implemented: 33,000,000	15.7
	Fatal injury crashes reduction: 32%	
	Serious injury crashes reduction: **29**%	
	Slight injury crashes reduction: **18**%	
	PDO only crashes reduction: **18**%	
	Implementation cost: 200 €/vehicle	
	Affected nr. of crashes per year: Fatalities: 1351 Ser. Inj. 15313 Slight inj.: 15088	
High measure cost	Horizon: 13 years	3.9
	Number of units implemented: 33,000,000	
	Fatal injury crashes reduction: 32%	
	Serious injury crashes reduction: **29**%	
	Slight injury crashes reduction: **18**%	
	PDO only crashes reduction: **18**%	
	Implementation cost: 800€/vehicle	
	Affected nr. of crashes per year: Fatalities: 1351 Ser. Inj. 15313 Slight inj.: 15088	

We defined a 'worst case' scenario as a combination of a worst expected effect and a highest expected measure cost. Also, an 'ideal case' scenario is defined which is a combination of a better expected effect and a lower expected measure cost. The results of the CBA for these scenarios are presented in Table 3.

Table 3 CBA for worst case and best-case scenarios

Combined Scenario	**Input values**	**B/C ratio**
	Horizon: 13 years	4.8
	Number of units implemented: 33,000,000	
	Fatal injury crashes reduction: 25%	
	Serious injury crashes reduction: **24**%	
	Slight injury crashes reduction: **14**%	
	PDO only crashes reduction: **14**%	
	Implementation cost: 525€/vehicle	
	Affected nr. of crashes per year: Fatalities: 1351 Ser. Inj. 15313 Slight inj.: 15088	
Best case	Horizon: 13 years	20.5
	Number of units implemented: 33,000,000	
	Fatal injury crashes reduction: 39%	
	Serious injury crashes reduction: **35**%	
	Slight injury crashes reduction: **22**%	
	PDO only crashes reduction: **22**%	
	Implementation cost: 185€/vehicle	
	Affected nr. of crashes per year: Fatalities: 1351 Ser. Inj. 15313 Slight inj.: 15088	

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Approval and market surveillance of two- or three-wheeled vehicles and quadricycles, DIRECTORATE GENERAL FOR INTERNAL POLICIES, POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICY, European Parliament, 2012

Cost -Benefit Analysis for ABS of motorcycles, Baum et al., 2008, **BASt-Bericht F 68**

Appendix D Accident scenarios taxonomy

Accident scenario	sub-scenario / pre-crash configuration
Pedestrian Accident	pedestrian crossing road out of crossing path
	pedestrian crossing road on crossing path at straight stretch
	pedestrian crossing road in front of junction
	pedestrian crossing road behind junction
	pedestrian moving along the road
	vehicle reversing
	pedestrian sitting or lying on the ground
	pedestrian – changing mode (e.g. driver getting off the car)
	other pedestrian configuration
Bicyclist Accident	Bicycle alone
	Crossing configuration, Cyclist coming from farside (C1)
	Crossing configurations, Cyclist coming from nearside (C2)
	Same direction, Vehicle turning farside (T1)
	Opposite direction, Vehicle turning farside -T2)
	Opposite direction, Vehicle turning nearside (T3)
	Cyclist coming (nearside) farside,
	Vehicle turning (nearside) farside (T4)"
	Same direction, Vehicle turning nearside (T5)
	Same direction, cyclist ahead (L1)
	Same direction, cyclist ahead and changing lane (L2)
	Opposite direction, Cyclist turning nearside (FAR SIDE) (On)
	Dooring accident
	Other (Re)
Single vehicle accident	The vehicle leaving the road nearside - with rollover
	The vehicle leaving the road nearside - with object collision (tree, pole, wall, ...)
	The vehicle leaving the road nearside - without rollover / object collision
	The vehicle leaving the road farside - with rollover
	The vehicle leaving the road farside - with object collision (tree, pole, wall, ...)
	The vehicle leaving the road farside - without rollover / object collision
	The vehicle leaving the road - other configurations
	Collision with parked vehicle
	Collision with lost load

Accident scenario	sub-scenario / pre-crash configuration
	Collision with animals on the road
	Falling bus occupant without collision
	Falling PTW without collision with another participant
	Other configurations (e.g. fallen tree)
	Collision other obstacle, other impact
Head-on collision / Oncoming traffic	Head-on collision - overtaking
	Head-on collision - unintended lane change stable
	Head-on collision - unintended lane change instable
	Side collision with other participant oncoming - loss of control
	Other type of collision - unintended lane change instable
	Other oncoming traffic accident configuration
Rear-end collision / Same direction traffic	Standing vehicle (Rear-end collision while the vehicle ahead is standing)
	Breaking vehicle (Rear-end collision while the vehicle ahead is braking)
	Driving vehicle (Rear-end collision while the vehicle ahead is driving)
	Lane changing vehicle (Rear-end collision while at least 1 vehicle is changing lane)
	Side-swipe collision with other participant in same direction
	Other configurations (all configurations not included in the previous ones, e.g. overtaking, moving between lanes ...)
Junction accident (no turning)	No turning : participant required to yield crossing from nearside road
	No turning : participant required to yield crossing from farside road
	No turning : other
Junction accident (turning)	Turning : farside turn - other participant in direction (following or overtaking)
	Turning : farside turn - other participant in opposite direction
	Turning : farside turn - other participant from other road
	Turning : farside turn - both participant farside turning
	Turning : farside turn - other
	Turning : nearside turn - other road user in direction
	Turning : nearside turn - other road in opposite direction
	Turning : nearside turn - other road user from other road
	Turning : nearside turn - other
	Turning : other
Railway crossing	with barriers
	without barriers
	barriers unknown

Appendix E Building the Inventory of vehicle risk factors and measures

Entering the information in the DSS database

This chapter describes the procedures adopted to ensure a high-level quality of information included in the inventory of risks and measures.

E.1 QUALITY ASSURANCE OF THE PROCESS

E.1.1 Quality of coded templates

A common template and related set of coding instructions was developed to capture relevant information from each study in a manner that this information could be uniformly reported and shared across topics within the overall SafetyCube project.

Coding and interpreting the study results correctly require a good understanding of how exactly the studies were conducted. The guidelines present a taxonomy of study designs and discuss the main features of the different designs, including potential biases and flaws.

Even though the instructions for coding were detailed, they still allowed room for interpretation e.g. which design describes the study the best (if not mentioned by author), which estimates to include or exclude, what are essentially the weak points of the study etc. Therefore, dedicated workshops and webinars were held during the project to train coders and to define common approaches to emerging issues not specifically addressed by the guidelines.

A further quality check of coding is undertaken by six coding experts based on the analysis of result tables provided by the DSS. The analysis is aimed at finding empty fields, inappropriate values and inconsistencies. In case of mistakes that cannot easily be solved, specific requests can be submitted to the related coders to discuss issues.

E.1.2 Quality of synopses

The guidelines cover all aspects related to selecting, coding, analysing and describing the relevant information about the identified risk factors and countermeasures. The main results and conclusions are summarised in a synopsis. The guidelines describe the required structure of a synopsis, its lay-out and approximate length of the various sections.

In order to ensure a systematic and transparent procedure for including studies in the DSS, the guidelines provide concrete instructions for identifying potentially relevant studies and prioritising them for coding. The process was documented in a standard format to make the gradual reduction of relevant studies transparent. This documentation of each search is included in the corresponding supporting documents of the synopses.

Analysing and integrating the findings from different studies can be done in different ways, ranging from a merely descriptive approach to advanced statistical analyses. The guidelines describe several options and specify the related criteria and conditions.

A Quality Assurance Committee, consisting of eight senior experts from the SafetyCube partner institutes, guided and coordinated a subsequent independent expert review of all synopses. The main aim of this stage is to detect obvious errors or omissions in the messages and conclusions of the synopses. Synopses were assigned to a limited number of Senior Researchers with proven expertise in the relevant area. These reviewers focused on:

- The selection and prioritising of studies for coding, including the search terms that were used, the database(s) that were checked and the transparency of the study selection.
- The contents of the two-page synopsis summary, for example whether the abstract covered the most relevant findings, whether the reported results were valid and logical and whether the summary sufficiently reflected the current state of knowledge.

If needed, as so decided by the QA Committee, a more thorough review was carried out and/or the original authors were asked to improve the synopsis.

Finally, for all synopses the abstract and the overall conclusion–as expressed in the assigned colour code–were checked by one and the same expert in order to ensure readability as well as consistency of information within and between synopses.

E.1.3 Quality of efficiency analysis

Efficiency analysis was supported by using a common tool: the Economic Efficiency Evaluation (E3) calculator. The SafetyCube E3 tool was used to perform cost-benefit analyses based on a set of input data collected and required by the tool: the effectiveness of the measure, unit of implementation and time horizon, the target group, and the measure costs. About crash costs, the improved SafetyCube estimates for EU countries were used in all CBAs.
Furthermore, sensitivity analyses of the CBA results were performed to address uncertainty in the safety effects and costs as found in the literature.

All results and assumptions were summarized in a two-page synopsis document. All these synopses were reviewed by a Senior Expert to check assumptions made and accuracy of the results, as well as to ensure readability and consistency of information within and between synopses.

E.2 DEVELOPING THE DSS DATABASE

All the information constituting the inventory of road user risks and measures is recorded in a standard way in the DSS database and is available to the DSS users.
The main types of DSS contents are:

- SafetyCube coded studies
- SafetyCube synopses on the effects of risk factors or measures and synopses on the economic efficiency of measures

Before DSS content is published and becomes available to the DSS user a number of steps should be accomplished.

E.2.1 SafetyCube coded studies

Results from a relevant study were coded according to a dedicated template as described in the guidelines (Martensen et al., 2016a). The template is an Excel-file with seven sheets:

- Core info, containing core variables that should be considered for every study
- Results, providing the numerical and statistical details of effects that are reported in a given study
- Flexible info, containing flexible variables that should only be used when they are relevant for coding the study at hand
- Custom info, aiming at addressing variables or values/levels not included in the template that are needed for a correct representation of the study
- $exposure, including the details of exposure variable(s)
- $outcome, including the details of the outcome(s)
- Summary, intended to provide a synthesis of the design and the conclusions

An example of a results sheet in the excel template, completed for a study on the effect of the Autonomous emergency braking system for vulnerable road users, is provided below:

Figure 8: Example of coded template (results sheet) effect of Autonomous emergency braking for vulnerable road users

When a coding template is completed for a study, it is located in a shared repository. Periodically, the coding templates are processed by an automatic routine checking for missing (important) data and inconsistencies. If no errors are detected, the information in the template is recorded in the DSS database. Otherwise, coders might be contacted for clarifications/corrections.

E.2.2 SafetyCube synopses

Besides the standardised information for all coded studies for various risk factors and measures, the synthesis of these studies will be made available in the form of a "synopsis" indicating the main findings for a particular risk factor or measure.
Each synopsis is coupled for searching purpose with a record in the DSS database storing the synopsis title, synopsis abstract, references to the studies coded in the preparation of the synopsis, the coder name and the main searching information: taxonomy and keywords.
This information is recorded by the synopsis author(s) in an Excel coding sheet for synopses. When a synopsis is completed, a zip-file containing the pdf of the synopsis and the synopsis excel coding sheet is located in a shared repository.

E.3 LINKING RISKS AND MEASURES WITHIN A SYSTEMS APPROACH

Following the system approach all risk factors were linked to measures from all three areas human, infrastructure and vehicle. This was done on a theoretical basis and further validated through studies and synopses results.
Within the DSS, users are guided from specific risk factors or specific measures to related risk factors/measures from all areas. This takes into account the interrelationship of both, risks and the appropriate measures for infrastructure, road users and vehicles.
To illustrate this approach an example for the related measures for the risk factor speed choice, originated from the road user related taxonomy, is provided.

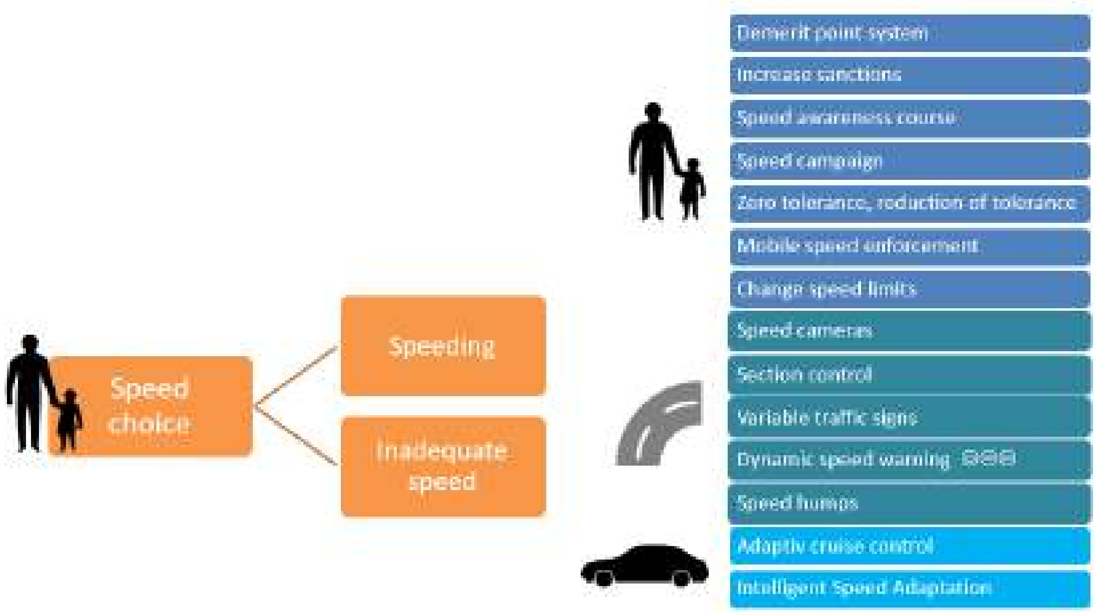

Figure 9: Example of linking between the risk factor speed choice and the related measures from different areas (road user related, infrastructure and vehicle).

E.3.1 The Calculator

The calculator for Economic Efficiency Evaluation (E3) of road safety measures will also be available through the DSS (currently under development). It will allow the user to retrieve existing SafetyCube CBAs and possibly adapt them with their own data / for their own country etc. It will also allow users to conduct their own CBA for any measure they wish.