Inventory of road user related accident risk factors and road safety measures

Deliverable 4.4

SafetyCube

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Inventory of road user related risk factors and safety measures

Work package 4, Deliverable 4.4

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Executive summary

Safety CaUsation, Benefits and Efficiency (SafetyCube) is a European Commission supported Horizon 2020 project with the objective of developing an innovative Road Safety Decision Support System (DSS). The DSS 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. The three thematic pillars of SafetyCube, which have been tackled in parallel, are "Road Users", "Infrastructure" and "Vehicles".

This document represents the synthesized work conducted in order to identify road user related risk factors and countermeasures as well as to quantify their effect on road safety. Furthermore, it demonstrates the incorporation of developed contents into the Road Safety DSS (https://www.roadsafety-dss.eu/) and points out the specific challenges which make the research on road user related risks and measures distinct from the thematic areas "infrastructure" and "vehicles".

Stakeholders and policy-makers have been involved in the project work early on. Their needs and perceived hot topics were considered to ensure the relevance of the DSS. The identification and assessment of road user related risk factors and countermeasures was conducted in a standardized manner following the methodology developed to be applied to all three thematic pillars (road user, infrastructure, vehicle).

Starting point was the creation of a taxonomy of topics (separate for risks and measures), followed by a systematic literature search and selection of studies for each of the identified topics (e.g. drink-driving, distraction, fatigue, diseases, speeding etc.). Only studies were selected which provide a quantitative estimate of effect on road safety – either in terms of accident occurrence or other safety performance indicators such as performance in a driving simulator or self-reported behaviour. The preferable assessment of accident outcomes is oftentimes, however, especially for risks and measures associated with humans, a challenging endeavour. Human risk factors are mainly not dichotomous variables which are either present or not but are rather on a spectrum and present to a certain extent which can vary over time (e.g. level of fatigue). Furthermore, they are often latent variables which are not observable and have to be inferred (e.g. by means of self-reports or psychometric tests). Eventually, they tend to *not* occur isolated from further risk factors and the level of entanglement can pose methodological challenges and the availability of e.g. crash modification factors is scarce. Also for road user countermeasures, the effect is not always extracted from a single measure but from combined intervention (e.g. campaigns).

Taking these considerations into account, studies were selected and the reported effects as well as further information like the research design were filled into a "coding template". The predefined coding template was a valuable tool to collect information in a standardized way so that results are comparable. Effects per study are on the one hand fed into the database (which underlies the Road Safety DSS) together with the further study information. On the other hand, they are the basis for the risk factor/countermeasure analysis which then is summarized in a document, referred to as "synopsis". These risk factor/countermeasure synopses are also available through the DSS. The overall effect assessment was conducted by either meta-analysis, vote-count-analysis or review type analysis. To provide a rough impression for the user at first glimpse, a four-staged "colour code" was assigned per topic (thus, per synopsis) to indicate the riskiness of a risk factor (note only

three out of four colours could be assigned to the risk factors, no risk factor was qualified as green - no increased risk) or the effectiveness of a countermeasure. Furthermore, the synopses contain theoretical background on the risk factor/countermeasure and are prepared in different sections with distinct levels of detail for an academic as well as a non-academic audience. These sections are readable independently.
All the created synopses, underwent a self-imposed quality assurance procedure. At this point, due to this task, some of the synopses are still under review or being revised. As soon as the quality procedure is complete, further synopses will be introduced into the Road Safety DSS.

For 12 road user related countermeasures, an economic evaluation in terms of cost-benefit analysis and corresponding sensitivity analysis or an update of an existing cost-benefit analysis could be conducted. 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 the measures costs. As outlined, effects in terms of accident reduction are not widespread for road user measures. Thus, the number of cost-benefit analysis is limited for this kind of road safety measures.

The following tables give an overview of the assessed risk factors and measures and the colour code assigned to each of the topics:

Road user related risk factors

Risky	Probably risky	Unclear
• Driving under the influence – legal and illegal drugs • Traffic rule violations – red light running • Distraction – cell phone use – Handheld • Distraction – cell phone use –Texting • Fatigue – sleep disorders – sleep apnea	• Risk taking – overtaking • Risk taking – close following • Functional impairment – vision loss • Diseases and disorders –diabetes • Personal factors – sensation seeking • Emotions – aggression, anger • Fatigue – not enough sleep, driving while tired • Distraction – conversation with passengers • Distraction – cognitive overload, inattention	• Functional impairment – hearing loss (few studies) • Distraction – music – entertainment systems • Distraction – operating devices

Road user related countermeasures

Topic	Effective	Probably effective	Unclear results	Ineffective or counterproductive
Law and Enforcement	• Laws and enforcement for seatbelt wearing • License suspension	• Lowering BAC limits (general and novice drivers) • Increasing traffic fines • Hours of service regulations for commercial drivers • Demerit point systems • Red light cameras	• Mobile phone use	
Education and voluntary trainings/programs	• Hazard perception training	• Pedestrian skills training	• None statutory training for novice drivers	
Driver training and licensing		• Formal pre-license training, graduated		

		driver licensing and probation		
Fitness to drive assessment and rehabilitation	• Alcohol interlock	• Fitness to drive assessment tools for medical referrals • Rehabilitation courses as measure for drink-driving offenders		• Age-based screening of elderly drivers
Awareness raising and campaigns		• Road safety campaigns in general • Seatbelt campaigns • Child restraint campaigns • Driving under the influence campaigns • Speeding campaigns • Aggressive and inconsiderate behaviour campaigns		

All created content was introduced into the DSS-database and risk factors and countermeasures were linked to each other. While this report documents only the road user related risks/measures, the links have also been established cross-thematical to risks and measures related to infrastructure and vehicles.

While the applied methodology and procedure were considered carefully, there are limitations to be considered. The already mentioned difficulty to quantify road user related risks and measures in terms of accident outcomes is one aspect. Exhaustiveness is another one. The aim was to cover as many human risk factors and measures as possible. However, it is not claimed to provide a comprehensive list of risks and measures. This is simply beyond the time resources at hand. However, in some cases, also the evidence base was not good enough. So, there are various reasons why one or the other risk factor/measure is missing in this document and the DSS, respectively. The goal is to not only maintain the DSS but to expand it to add what is not yet covered.

1 Introduction

1.1 SAFETYCUBE

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

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

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

1.2 WORK PACKAGE 4

The objective of work package 4 is to analyse data, implement developed methodologies concerning accident risk factors and road safety measures related to the road users. It examines accident risks and safety measures concerning all types of road users including Vulnerable Road Users (VRU). Personal as well as commercial transportation aspects are considered.
Therefore, various data sources (macroscopic and in-depth accident data) and knowledge bases (e.g. existing studies) will be exploited to:

- identify and rank risk factors related to the road users which compromise road safety
- identify road user related measures which address the most important risk factors
- assess the effect of measures

The work on road user related risks and measures in road traffic is done according to the methodology and guidelines developed within SafetyCube (Martensen et al., 2017) and uniform and in parallel with the work packages dealing with infrastructure- (WP5) and vehicle- (WP6) related risks and measures.
All main results of WP4 will be integrated into the DSS and linked with each other (risk factors and measures) and with outcomes of other work packages (WPs 5, 6 and 7[1]).

[1] WP7 is dealing with serious injuries.

1.3 PURPOSE OF THIS DELIVERABLE

The main purpose of this deliverable is to represent the synthesis of the procedure and results of the tasks carried out within Work Package (WP) 4, which is dedicated to the assessment of effect of road user related risk factors and countermeasures. While, road users are the determined focus of SafetyCube's WP4, the deliverable presented hereby, furthermore aims at reflecting the results in broader context and linked to the other thematic SafetyCube pillars: road infrastructure, vehicles and serious injuries (WP7).

The vast majority of contributing factors to road accidents are inherent to the road users and their behaviour. Numerous preventive or mitigating measures are, however, vehicle or infrastructural solutions or results of effective post-impact care. In turn, risks which come e.g. with a vehicle can be countered with e.g. increased awareness of road users. This is just one example of the fostered systems approach, which is also adopted within the SafetyCube project by linking risk factors and countermeasures of the different thematic pillars.

Since the created inventory of assessed risks and measures is targeted at practitioners (amongst others) dealing with manifest road safety problems, it is crucial to provide actual evidence rather than "perceived best practises". Therefore, this deliverable presents the applied methodology and the process of assessing the risk and measure topics in a condensed version to make decisions transparent.

1.4 EXEMPLARY OUTPUT OF THE ROAD SAFETY DECISION SUPPORT SYSTEM

The DSS presents quantitative and qualitative information about a wide range of crash risks and the effectiveness and cost-benefit (where possible) of road safety measures.

As an example of the contents displayed in the DSS after a specific query, an example of each, a page of topic search results and one of single study information, is presented below.

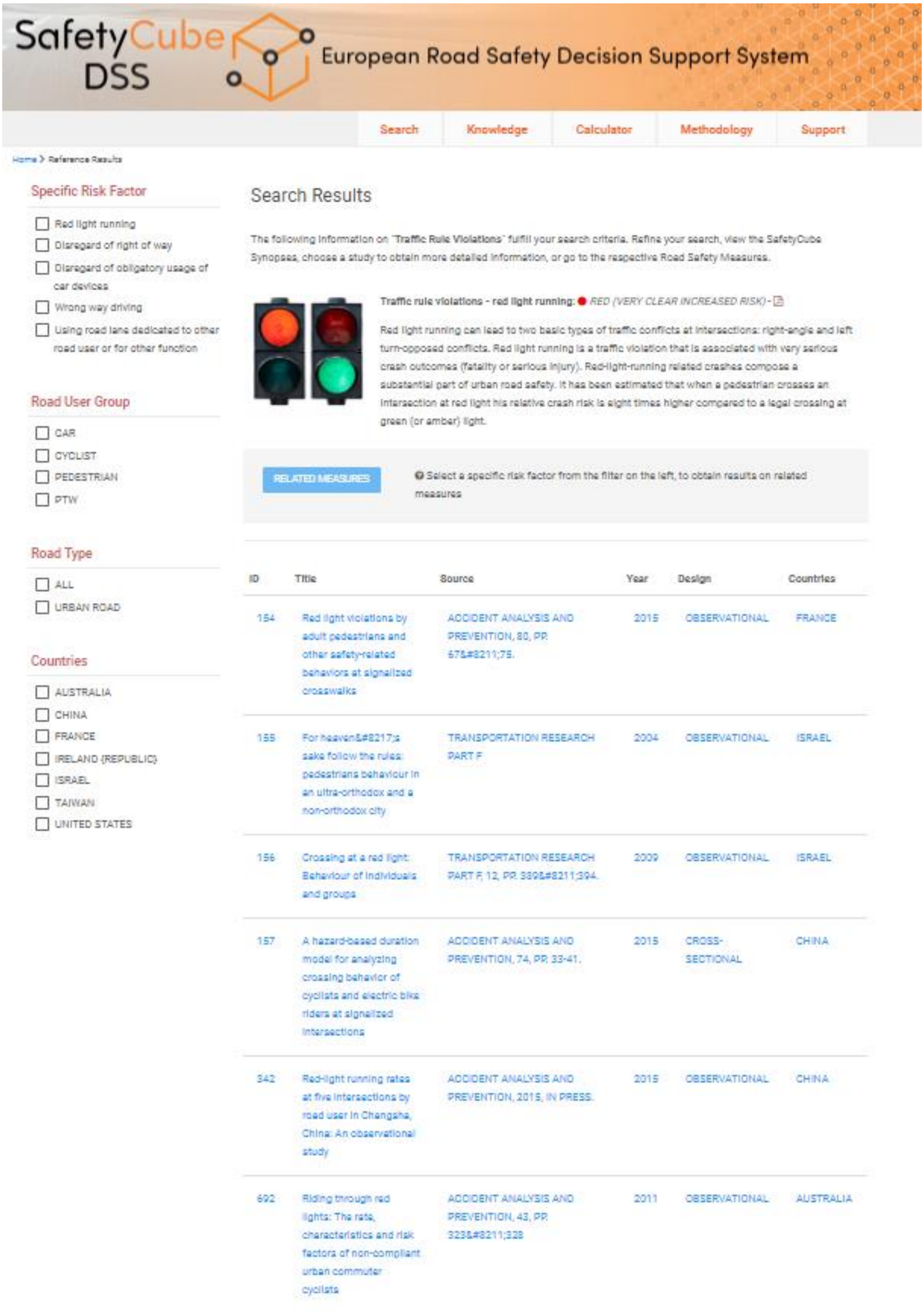

Figure 1: Search results for the risk factor "Traffic Rule Violations"

Figure 2: Search results for the measure "Education and voluntary training/programmes"

Search | Knowledge | Calculator | Methodology | Support

A meta-analysis of the effects of cell phones on driver performance.

Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C.

Abstract

The empirical basis for legislation to limit cell phones while driving is addressed. A comprehensive meta-analysis of the effects of cell phones on driving performance was performed. A total of 33 studies collected through 2007 that met inclusion criteria yielded 94 effect size estimates, with a total sample size of approximately 2000 participants. The dependent variables of reaction time, lateral vehicle control, headway and speed and the moderating variables of research setting (i.e., laboratory, simulator, on-road), conversation target (passenger, cell phone) and conversation type (cognitive task, naturalistic) were coded. Reaction time (RT) to events and stimuli while talking produced the largest performance decrements. Handheld and hands-free phones produced similar RT decrements. Overall, a mean increase in RT of .25 s was found to all types of phone-related tasks. Observed performance decrements probably underestimate the true behavior of drivers with mobile phones in their own vehicles. In addition, drivers using either phone type do not appreciably compensate by giving greater headway or reducing speed. Tests for moderator effects on RT and speed found no statistically significant effect size differences across laboratory, driving simulation and on-road research settings. The implications of the results for legislation and future research are considered.

DOI:10.1016/J.AAP.2008.01.009

Summary

A comprehensive meta-analysis of the effects of cell phones on driving performance was performed. A total of 33 studies collected through 2007 that met inclusion criteria yielded 94 effect size estimates, with a total sample size of approximately 2000 participants. The direction of the effect size difference indicated that slower reaction times (RT) resulted from conversing on either type of phone than in baseline conditions. Handheld and hands-free phones produced similar mean Reaction Time effect sizes, such that the meta-analytic estimates for each type of phone were essentially the same. The meta-analysis and the in-depth RT analysis of older and younger driver performance provide convergent evidence for older drivers having slower RT performance while using cell phones.

Limitations

Extent	Motivation	Type
MAYBE A PROBLEM	AS PER CODING OF META-ANALYSES IN SAFETYCUBE GUIDELINES	META-ANALYSIS: EXCLUDED STUDIES NOT LISTED
MAYBE A PROBLEM	AS PER CODING OF META-ANALYSES IN SAFETYCUBE GUIDELINES	OTHER: META-ANALYSIS: COUNTRIES OF THE STUDIES VAGUE

Basic Study Information

Topic: RISK FACTOR **Year:** 2008

Source: ACCIDENT ANALYSIS & PREVENTION, 40(4), 1282-1293.

Design: META-ANALYSIS EXPERIMENTAL CASE-CONTROL

Countries:

Keywords: EXPERIMENTAL METHODS CELLULAR OR MOBILE PHONES META-ANALYSIS DRIVER PERFORMANCE

Effects

Effect No	Outcome	Exposure	Group Type	Group	Effect Estimator	Effect Estimator Specifications	Sample	Estimate	Estimate Lower Limit	Estimate Upper Limit	Conclusion Comments
1	REACTION TIME	CELLPHONE USE - HANDS-FREE	test	EXPOSED	CORRELATION COEFFICIENT	RC, WEIGHTED MEAN CORRELATIONS CORRECTED FOR RELIABILITY;	1263	0.46	0.1	0.82	SIGNIFICANT NEGATIVE EFFECT ON ROAD SAFETY SIGNIFICANCE DETERMINED FROM CIS
1	REACTION TIME	CELLPHONE USE - HANDS-FREE	ctrl	NON-EXPOSED	CORRELATION COEFFICIENT	RC, WEIGHTED MEAN CORRELATIONS CORRECTED FOR RELIABILITY;	1263	0.46	0.1	0.82	SIGNIFICANT NEGATIVE EFFECT ON ROAD SAFETY SIGNIFICANCE DETERMINED FROM CIS

Figure 3: Second study example - A meta-analysis of the effect of cell phones on driving performance (Caird et al., 2008).

1.5 READING GUIDE AND RELATED DOCUMENTS

This document presents both, the procedure and summarised methodology underlying the created content, as well as the content – evaluated road safety risks and measures related to road users – itself. The following table gives an overview of the upcoming chapters and the type of information which is provided in the chapters in question. Further and more in-depth information on each of the chapters is indicated in the last column. All results of the SafetyCube project can be found in the Road Safety DSS: https://www.roadsafety-dss.eu

	Method and procedural information on the DSS development	**Project results on road user related accident risks and countermeasures**	**Further SafetyCube references**
Chapter 2	Overview of the developed and applied methodology for the assessment of risk factors and measures		· Martensen et al. (2017) · Martensen et al. (2016a) · Martensen et al. (2016b) · Wijnen et al. (2017)
Chapter 3		Evaluated risk accident factors related to road users	· Talbot et al. (2016) · www.roadsafety-dss.eu
Chapter 4		Evaluated road safety measures related to road users	· Theofilatos et al. (2017) · Daniels et al. (2017) · www.roadsafety-dss.eu
Chapter 5	Challenges and limitations of quantifying risks and measures in SafetyCube and concerning road users in particular		· Talbot et al. (2016) · Theofilatos et al. (2017)
Chapter 6	Quality Assurance process for produced results and process of data base development		· Martensen et al. (2017)
Chapter 7	Conclusions on the process of developing the DSS and evaluating road user related accident risk factors and countermeasures		

2 The SafetyCube methodology for the assessment of risks and measures

2.1 IDENTIFICATION OF ROAD USER RELATED "HOT TOPICS"

To create a wide-ranging impact for different user groups, 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 road user related risks and measures was created by collecting topics known and reported in literature, group them thematically and differentiate further (see 2.2 for further details). 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, "hot topics". Given the limited time and resources of the project, priorities had to be set and emphasis was put on ensuring that the hot topics in road safety are covered.

The following sources have been used to identify hot topics regarding the risks and measures tied to road users:

- **Stakeholder workshops**[2]
  - Risk factor identification and prioritization: Brussels, June 17th, 2015
  - Risk factor identification and prioritization: Ljubljana, October 14th, 2015
  - Measure identification and prioritization: Brussels, September 27th, 2016
- **Project results**
  - PROS (Urban, 2014)
  - Rosee (Štaba & Možina, 2014)
- **Policy papers**
  - Towards a European road safety area: policy orientations on road safety 2011-2020 (EC, 2010)
  - Towards Zero Deaths: A National Strategy on Highway Safety (Zegeer et al., 2010)
  - Towards safer roads in Europe (FERSI, 2014)
- **Individual expert consultation**
  - FERSI representative
  - Project consortium

Workshops were held to consult with international stakeholders. Their contribution helped in prioritizing and completing the lists of risks and measures. The collected information was assessed in terms of count analyses. To identify further topics, outcomes of previous projects and policy papers were screened. Risk factors have been dealt with prior to countermeasures (rather than in parallel). This procedure allowed to furthermore prioritize measures that tackle risk factors which were assessed as 'risky' or 'probably risky'.

In general, the consulted experts and stakeholders were much more specific regarding road user related risk factors than regarding countermeasures. Some nominations are very explicit like

[2] Lists of participants can be found in SafetyCube's deliverables 4.1 as well as 4.2

"distraction due to texting while driving" and some are on a very global level such as "driving under the influence". While this was already observed at the workshops on risk factors, responses were even more global for countermeasures. A further analysis of the responses for measures was therefore not meaningful. The called for measures are at the same time the five broad categories for road user related measures:

- Law and enforcement
- Education and voluntary training
- Driver training and licensing
- Fitness to drive assessment, screening and rehabilitation
- Awareness raising and campaigns

As regards road user related risk factors, the following were considered hot topics (minimum of three nominations, also highlighted in the taxonomy tables in chapter 3):

- Speed choice
- Drunk driving/riding
- Drugged driving/riding (legal, medicine)
- Fatigue
- Cell phone use and operation other devices (e.g. in-vehicle information systems)
- Cognitive impairment
- Aggression and anger
- Elderly road users
- Young adult road users
- Children

All identified hot topics – regarding risk factors as well as measures – are included in the DSS.

2.2 OVERVIEW OF THE SAFETYCUBE METHODOLOGIES

A standard methodology was developed in SafetyCube, which was applied for each identified risk factor and measure in order to assess their quantitative effect on road safety. This included developing a:

- *Literature search strategy* to support systematic review of literature and selection of relevant studies risks and measures,
- '*Coding template*' to record key data and metadata from individual studies,
- *Guidelines* supporting the analysis of key risk factors and measures based on coded studies and summarising the findings in 'Synopses',
- *SafetyCube Economic Efficiency Evaluation* (E^3) Calculator, for priority setting between different road safety measures.

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

2.2.1 Literature search and study selection

Literature search

For each of the identified risk factor and measure topics a standardised literature search was conducted in order to identify relevant studies to include in the Decision Support System (DSS). It should be noted that the literature search process was started for each risk factor and measure in the taxonomy, however, in some cases insufficient literature was identified and some risks/measures could not be evaluated. The literature search, study coding and synopses creation for a particular risk factor was completed within the same SafetyCube partner organisation. 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.

The databases used in WP4 are the following:

1. Scopus
2. TRID
3. Web of Science
4. Science Direct
5. Dok Dat[3]
6. PubMed
7. Google Scholar

Study selection

The initial aim was to find studies that provided an estimate of the risk of being in an accident due to the presence of the risk factor. However, while the actual occurrence of accidents is the ultimate measure for road safety, in recent years more and more often, Safety Performance Indicators (SPI) have been taken into consideration to quantify the road safety level (Gitelman et al., 2014) like driving behaviour, such as speed choice, drink driving or seat belt use. In addition, attitudes and intentions can be utilised as SPI given that a link between attitudes and behaviour can be established by psychological theory (Martensen et al., 2017). Especially for road user related risks and measures it was important to also have a look at studies that report on SPIs such as self-reported behaviour or psychometric tests, since it is not always straightforward to quantify them.

That is because the presence of a road user related risk factor in an accident is far less easy to determine than the presence or absence of a safety feature in a vehicle or the presence or absence of an infrastructural element. However, it is important to note that the effect of a given risk factor on accidents via a SPI is indirect and often the relationship between an SPI and accident involvement is a missing link in road safety knowledge (see also 5.2).

Studies have been considered which either assess the effect of a risk factor or a safety measure on accident occurrence (fatal, injured, material damage) or on one or several SPIs. The following outcome variables have been considered:

- Accident and injury data, statistics
- Self-reported accident history
- Near miss or critical event data (self-reported, observed)
- Directly observed or measured behaviour (e.g. red light running, speeding)
- Self-reported behaviour (e.g. speeding, risk taking etc.)
- Real world driving (naturalistic, driving test on road)
- Driving test in simulator (e.g. reaction time, lane deviation etc.)
- Attitudes towards unsafe behaviours
- Results of psychological diagnostic assessment and psychometric tests

Studies that compare variations of the same risk factors/measures (e.g. effects of different levels of blood alcohol concentration) are not suitable and were excluded since the aim was to capture the effect compared to a neutral control condition. Studies with no control or comparison group (e.g. group not exposed to risk factor, before-after design) were also excluded.

Since the study design and the outcome variables are just basic criteria, for some risk factors or measures the literature search had the potential to yield an excessive number of related studies and

[3] Internal database of Austrian Road Safety Board

therefore additional selection criteria were adopted. While the aim was to include as many studies as possible for as many risk factors and measures as possible, it was simply not feasible, given the scope and resources of the project, to examine all available studies for all risk factors and measures. The general criteria for prioritising studies for further analysis and eventual inclusion in the DSS were based on the following guideline:

1. Key meta-analyses (studies already included in the key meta-analysis were not coded again)
2. Most recent studies
3. High quality of studies
4. Country origin: Europe before North America/Australasia before other countries
5. Importance: number of citations
6. Language: English
7. Peer reviewed journals

2.2.2 Study coding

Within the aim of creating a database of crash risk estimates and effective countermeasures, a template was developed to capture relevant information from each study in a manner that this information could be uniformly reported and shared across topics and WPs within the overall SafetyCube project. Guidelines were also made available for the task of coding with detailed instructions on how to use the template. The coding template was designed to accommodate the variety and complexity of different study designs.

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

1. Road system element (road user related risks and measures, Infrastructure, Vehicle), which is at the same time one of the search fields within the DSS
2. Level of taxonomy so that users of the DSS will be able to find information on topics they are interested in.
3. Basic information of the study (title, author, year, source, origin, abstract)
4. Road user group examined
5. Study design
6. Measures of exposure to the risk factor/measure
7. Measures of outcome (e.g. number of injury crashes)
8. 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)
9. Effects (including corresponding measures e.g. confidence intervals)
10. Limitations
11. 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. (2017). 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.

2.2.3 Summarizing studies and creation of synopses

The DSS will provide information for all coded studies (see above) 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/measure 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. (2016a).

Synopses were created for several risk factors (see deliverable 4.1) and measures (see deliverable 4.2), on various levels of the related taxonomies, thus, for various levels of detail, mainly dependent on the availability of studies for a certain topic. Moreover, the synopses contain context information for each risk factor from literature that could not be coded (e.g. literature reviews or qualitative studies). On the other hand, not all the coded studies that will populate the DSS are included in the analysis in the synopsis.

The synopses aim to facilitate different end users: decision-makers looking for global estimates vs. scientific users interested in result and methodological details. Therefore, they contain sections for different end user groups that can be read independently. The structure of each risk factor or measure synopsis, including the corresponding sub items (uniform for human, vehicle, and infrastructure related risk factors), is as follows (*note*. Slight differences occur between synopses due to the variability in information from the literature):

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

Final synopses

By following completion of the search and coding procedure it became apparent that *for some specific risk factors/measures there were insufficient codable studies to justify the preparation of a synopsis*.

Ultimately the inventory includes 25 synopses on road user related risk factors and 26 synopses on road user related measures that have been considered for inclusion in the DSS. It must be noted that due to available studies and some contents of the synopses their titles were slightly adapted by the authors in certain cases. More details on road user related risk factors and measures synopses available in the inventory are provided in chapter 3 and chapter 4.

Colour code

To indicate the overall conclusion about the road safety risks or the effectiveness of a measure a colour code was assigned to each of the studied risk factors and measures (Table 1). The colour code is based on the results of the studies and previous described analyses. A short statement gives further information about the reasons for choosing this colour code. In the DSS the colour code and the link to the synopses is shown on the search results page (Figure 4).

Table 1: Description of colour codes for risk factors and countermeasures (Martensen, 2017).

	Risk factor		Countermeasure
Red	Results consistently show an increased risk when exposed to the risk factor concerned.	Green	Results consistently show that the countermeasure reduces road safety risk.
Yellow	There is some indication that exposure to the risk factor increases risk, but results are not consistent.	Light green	There is some indication that the countermeasure reduces road safety risk, but results are not consistent.
Grey	No conclusion possible because of few studies with inconsistent results, or few studies with weak indicators, or an equal amount of studies with no (or opposite) effect.		
Green	Results consistently show that exposure to the presumed risk factor does not increase risk.	Red	Results consistently show that the countermeasure does NOT reduce road safety risk and may even an increase it.

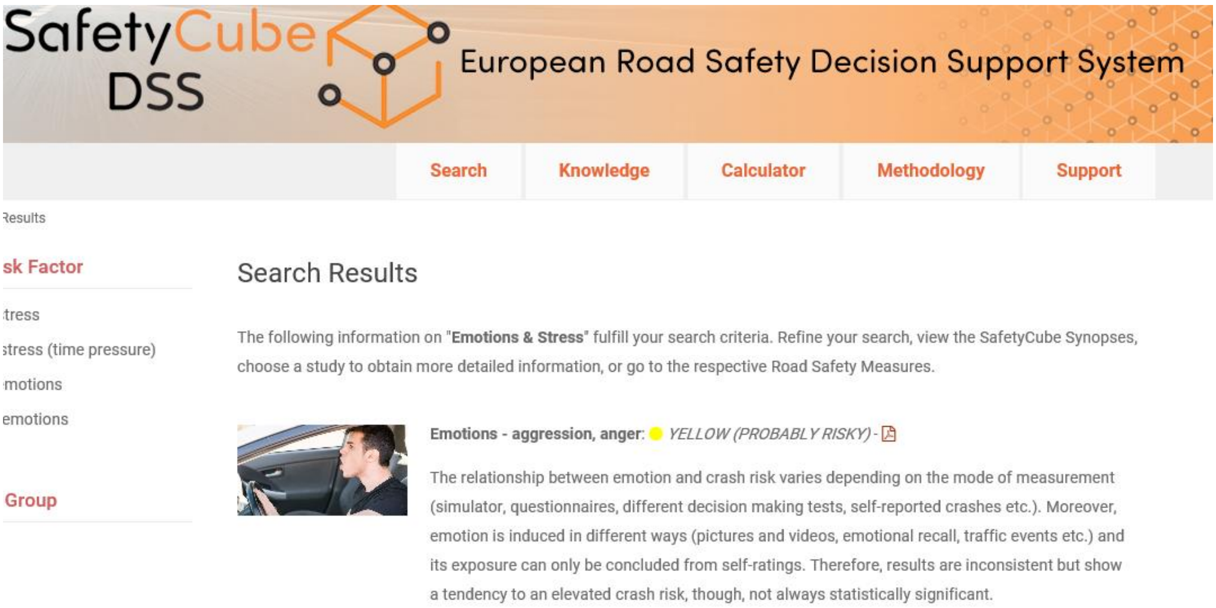

Figure 4: Example of search results page in the DSS showing the colour code of a risk factor

2.2.4 The Economic Efficiency Evaluation tool

For further priority setting of the effective road safety measures an economic efficiency evaluation was conducted. For this purpose
an Economic Efficiency Evaluation (E^3) calculator has been developed within the SafetyCube project. This tool is one in which information regarding the effectiveness of a certain road safety measure and its implementation costs are present. In addition, such a tool can determine the costs and benefits in monetary terms and allows for further analyses. An E^3 tool is currently incorporated in SafetyCube as a Microsoft Excel application. This section is a brief description of the tool. Further information can be found in SafetyCube Milestone 14 (Martensen et al. 2016b).

In order to use the tool, certain inputs and considerations should be taken into account. First of all, it is important to mention that the tool assumes that the road safety measures are evaluated in specific units of intervention, such as one campaign/one training or a vehicle equipped with a safety system or a specific infrastructure location. Furthermore, for the purposes of the E^3 tool it is important to define certain concepts including:

- **Crash Modification Factor** (**CMF**): A CMF consists of a multiplier applied to the 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 it represents the reduction of crashes after the measure is implemented.

The following Figure 1 gives an overview of the E^3 tool, explained in more detail in SafetyCube Milestone 14 (Martensen et al., 2016b).

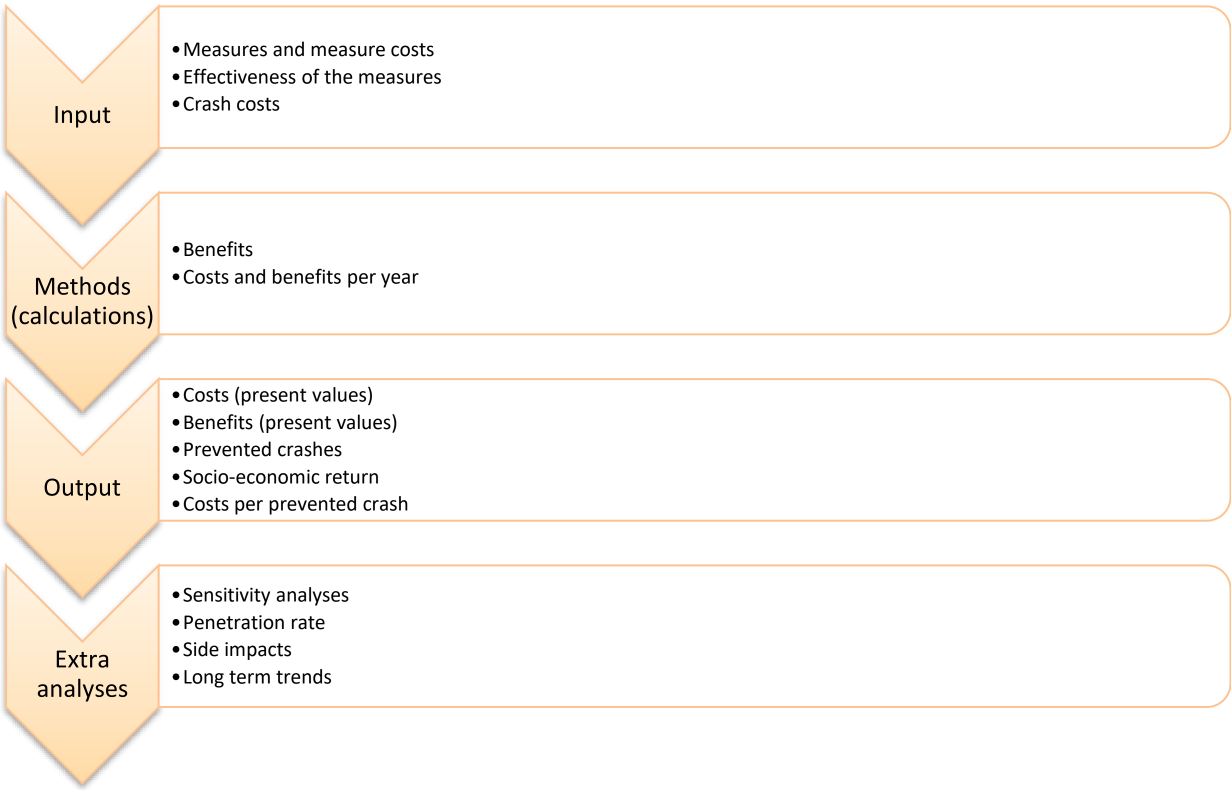

Figure 5 Overview of the SafetyCube E^3 Tool

Analysis procedures

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

A selection procedure was followed for topics which seemed meaningful candidates for a CBA. 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 WP4 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 et al. (2017).

2.2.5 Vulnerable road users

Even though the number of fatalities on EU's roads decreased in the decade to 2010 (45% reduction in fatalities, 30% reduction of all injured, EuroStat, 2012), in 2010 more than 50% of all fatally injured were vulnerable road users (VRU, European Commission, 2010). These figures highlight the need to address this specific group in road safety.
The term "vulnerable road users" either refers to the modes of transport that provide the least protection for the road user or a certain age group. The latter is considered vulnerable due to their physiology or potentially limited task capability. Resilience is also a factor that distinguishes between vulnerable road users and others (SWOV, 2012). VRU are defined in the SafetyCube project to be pedal cyclists, pedestrians, powered two-wheelers, children and elderly.

To incorporate VRU into SafetyCube's methodological and assessment process, various road user groups were aimed at being considered within the work on each of the risk factors or countermeasures. There are not separate synopses on any of the defined VRU groups (e.g. age as a risk factor). It was refrained from declaring a whole group as a risk. Whenever a coded study deals with a risk factor for a specific road user group (e.g. cognitive impairment of elderly, insufficient skills and children or young males and speeding), it was assigned to both, the risk factor and the age group or mode of transport. Consequently, DSS users will find the study information by either searching for the risk factor or the VRU group, respectively.

While road user groups are per definiton subject to the work on human related risks and measures (in contrast to infrastructure and vehicles), it should be noted that VRU are also represented in the DSS in the other thematic areas *infrastructure* and *vehicles*. In some cases users can find two different colour codes for one topic if the effect on road safety is not the same for different groups (e.g. car drivers and cyclists in roundabouts). Mainly, this refers to transport mode rather than age groups. Furthermore, the Road Safety DSS provides the opportunity to choose from a list of seven road user groups as a starting point for exploring the contents (cyclists, LGV, bus, pedestrian, HGV, PTW, passenger car).
However, it should be noted that, even though VRU have received more attention, road safety research is still rather car-centric.

3 Road user related risk factors

This chapter demonstrates which road user related risk factors are addressed in the inventory and how they have been assessed, as well as the type of information the DSS user will find in the system regarding accident risk factors related to road users.

3.1 RISK FACTORS ADDRESSED

In order to identify and rank road user related risk factors[4] in terms of their impact on accident causation a taxonomy of road user related risk factors was developed.

As a first step, pre-existing classifications of road safety risk factors in the literature were screened. Risk factors, for example, are often categorised alongside the order of events leading up to the accident, corresponding personal and situational circumstances or cognitive information processing (e.g. Wallen et al., 2008; Naing et al., 2007). However, these classifications were constructed for specific purposes and are therefore not suitable for the particular needs of the SafetyCube project. Consequently, new taxonomies of road user related risk factors were created.

This taxonomy is based on risk factors known and reported in literature and follows the three-level structure – topic, subtopic and specific topic – developed within the SafetyCube project. This approach creates a uniform structure over all work packages. The developed taxonomies form the main structural part of the DSS system, and are one of the search option in the DSS. Further and it is used as a basis for linking risk factors with their corresponding measures.

Within the road user related risk factors a special focus was on integrating all individual modes of transport (pedestrians, cyclists, powered two-wheelers, car drivers) and all kinds of road users (children, elderly etc.). This was done by addressing road user groups such as pedestrians or cyclists within the relevant specific topics. Further, in the DSS itself there is an entry point 'road users' provided, which is linked to the specific risk factors for a road user group.

Another issue which had to be addressed while creating the taxonomy, was how to treat the factor 'age'. 'Age' is not a risk factor per se, only certain age groups are more at risk than others (e.g. young males, children, elderly). Therefore, similar to road user groups, age groups are treated within the relevant topics. Elderly for example, are more affected by functional impairment and therefore studies for this topic focus mainly on this age group. For reasons of practicality, (enable the search for an age group) age was included in the main topics of the taxonomy.

In order to control for completeness of risk factors and to make sure all the topics of high relevance for practitioners were identified for analyses, workshops were held to consult with international stakeholders. Their contribution helped in prioritizing and completing the lists of risks.
Several adaptations of the taxonomy had to be made in an iterative process. As the DSS is designed to be a living rather than a static system, the taxonomies of road safety risks do not claim to be exhaustive.

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[4] Within the SafetyCube project 'risk factor' refers to any factor that contributes to the occurrence or the consequence of road accidents. Risk factors can have a direct influence on the risk of an accident occurring, on the consequences of the accident (severity), or more indirectly by influencing a Safety Performance Indicator (SPI). All elements of the road system are potential crash risk factors.

The taxonomy for road user related risk factors includes 15 main topics:

- Speed choice
- Driving under the influence of alcohol
- Driving under the influence of drugs
- Risk taking
- Fatigue
- Distraction and inattention
- Functional impairment
- Insufficient skills
- Insufficient knowledge
- Emotion and stress
- Misjudgement and observation errors
- Traffic rule violations
- Personal factors
- Diseases and disorders
- Age

The tables below (Table 2 to Table 14) represents the entire road user related taxonomy of risk factors with the three levels topic, subtopic and specific risk factor and includes furthermore the indication of 'hot topics'. Risk factors named by stakeholders or are mentioned in policy papers and research reports three times and more are highlighted in dark orange. Bright orange flagged risk factors were named twice and are considered a second level priority.

Table 2: Taxonomy of road user related risks related to speed choice

Topic	Subtopic	Specific risk factor
Speed choice	Speeding	Built-up areas
		Rural roads
		Motorways
	Inappropriate speed	Too fast weather-related
		Too fast traffic related
		Too slow

Table 3: Taxonomy of road user related risks related to driving under the influence of alcohol and driving under the influence of drugs

Topic	Subtopic	Specific risk factor
Driving under the influence of alcohol	Drink-driving or riding (cyclists, PTW)	0–0.5‰ BAC
		0.51–0.8‰ BAC
		0.81–1.6‰ BAC
		> 1.6‰ BAC
		Benzodiazepine

Topic	Subtopic	Specific risk factor
Driving under the influence of drugs	Drugged driving or riding, legal (medicine)	Z-drugs
		Medicinal opiate
		Other legal drugs (e.g. antidepressants)
	Drugged driving or riding, illegal	THC
		Cocaine
		Amphetamine
		Opiates, non-medical
		Synthetic drugs
	Combined usage of substances	Combined usage of substances

Table 4: Taxonomy of road user related risks related to risk taking

Topic	Subtopic	Specific risk factor
Risk taking	Risky overtaking	Wrong side (undertake)
		Without adequate visibility
		Without warning others
		Into oncoming traffic
	Headway distance	Misjudgement of headway distance
		Tailgating

Table 5: Taxonomy of road user related risks related to fatigue

Topic	Subtopic	Specific risk factor
Fatigue	Insufficient sleep	Insufficient sleep
		Sleeping disorders
	Driven a long time	Driven a long time

Table 6: Taxonomy of road user related risks related to distraction and inattention

Topic	Subtopic	Specific risk factor
Distraction and inattention	Distraction inside vehicle or while riding or walking	Conversation with others
		Music, entertainment systems
		Cell phone use, talking, handheld mode
		Cell phone use, talking, hands-free mode
		Cell phone use, texting
		Operating devices (e.g. IVIS, navigation systems)
		Pets, insects, others
		Consummation of goods (eating, drinking, smoking)
	Distraction by outside factors	Watching others, situation
		Static objects (e.g. advertisement, traffic management information)
		Glare due to sun or other vehicles' lights
	Internal distraction (e.g. state of mind, cognitive overload)	Internal distraction (e.g. state of mind, cognitive overload)
	Inattention	Inattention

Table 7: Taxonomy of road user related risks related to functional impairment

Topic	Subtopic	Specific risk factor
Functional impairment	Visual impairment	Night-time driving
		Safety margins
		Pedestrian detection
		Road sign recognition
		Driving out of a tunnel
		Manoeuvring
		Permanent visual impairment
		Missing visual information from other road users
	Hearing impairment	Decreased driving performance due to distractors
		Missing out auditory information of other road users

Topic	Subtopic	Specific risk factor
		Permanent impairment (physical condition)
	Cognitive impairment	Dementia
		Alzheimer's disease
		Mild cognitive impairment
		Parkinson's disease
		Depression
		Other psychiatric disorders

Table 8: Taxonomy of road user related risks related to insufficient skills and insufficient knowledge

Topic	Subtopic	Specific risk factor
Insufficient skills	Insufficient skills and operating errors	Vehicle manoeuvring (e.g. control of speed and position)
		Traffic situation (e.g. communication, speed adjustment, observation)
		Trip (e.g. trip planning)
		life goals and personal factors
Insufficient knowledge	Insufficient knowledge	Vehicle features and properties
		Rules and regulations
		Trip (e.g. knowledge of location)
		Life goals and personal factors

Table 9: Taxonomy of road user related risks related to emotion and stress

Topic	Subtopic	Specific risk factor
Emotions and stress	Internal stress (e.g. overburden)	Overburden
	External stress (e.g. time pressure)	Time pressure
	Positive emotions	Euphoria
	Negative emotions	Aggression, anger
		Fear, anxiety

Table 10: Taxonomy of road user related risks related to misjudgement and observation errors

Topic	Subtopic	Specific risk factor
Misjudgement and observation errors	Misjudgement of oneself	Misjudgement of own speed
		Misjudgement of braking distance, acceleration
		Misjudgement of vehicle capability
		Misjudgement of driver assistance information
	Misjudgement of others or situation	Misjudgement of others' speed
		Misjudgement of others' distance
		Misjudgement of development of situation
		Misunderstanding between road users
	Observation errors	Missed observation
		Late observation
		False observation

Table 11: Taxonomy of road user related risks related to traffic rule violations

Topic	Subtopic	Specific risk factor
Traffic rule violations	Red light running	Red light running
	Disregarding right of way	Not yielding for pedestrians
		Disregarding stop or yield sign
	Disregarding obligatory use of light or turn signal	Not using vehicle lights
		Not using indicators
	Driving against the traffic flow	One-way roads
		Opposing lane
	Misusing restricted lanes	Bus lanes
		Truck lanes
		Emergency lanes
		Cycle lanes

Table 12: Taxonomy of road user related risks related to personal factors

Topic	Subtopic	Specific risk factor
Personal factors	Sensation seeking	Sensation seeking
	Type A personality (impatience, time urgency and hostility)	Type A personality (impatience, time urgency and hostility)
	ADHD	ADHD
	Locus of control	Locus of control
	Introversion, extraversion	Introversion, extraversion

Table 13: Taxonomy of road user related risks related to diseases and disorders

Topic	Subtopic	Specific risk factor
Diseases and disorders	Diabetes	Type 1 diabetes
		Type 2 diabetes
	Epilepsy	Epilepsy
	Influenza	Influenza
	Psychiatric disorders	Anxiety disorder
		Mood disorder
		Psychotic disorder
		Personality disorder
		Impulse control disorder
	Sudden illness	Heart attack, stroke
		Fainting

Table 14: Taxonomy of road user related risks related to age

Topic	Subtopic	Specific risk factor
Age	Children (4-12 years)	Children (4-12 years)
	Adolescents (12-18 years)	Adolescents (12-18 years)
	Young people (18-24 years)	Young people (18-24 years)
	Elderly (65+)	Elderly (65+)

3.2 CODED STUDIES

In order to create an inventory of estimates for risk factors and safety effects key data from individual studies have to be included in the DSS. For this purpose, standardised coding template was developed within SafetyCube (Martensen et al., 2017) (for more details see 2.2.2).

Concerning the effects, it should be noted that ideally, the outcomes are measured in terms of the number or share of accidents caused. However, road user related risks are sometimes mediated and not directly connected to accident probability. Driving under the influence, for instance, can increase the willingness to drive above speed limit, which might eventually be the cause of the accident (for further discussion of limitations see chapter 5). Therefore, studies which document alternative outcome measures have also been taken into consideration.
Following outcome measures were taken into account:

- Accident and injury data/statistics
- Self-reported accident history
- Critical event data (self-reported, observed)
- Observed behaviour (e.g. red light running, speeding)
- Self-reported (intended) risk behaviour such as speeding or risk taking
- Naturalistic driving, driving test on road
- Driving performance in simulator (e.g. reaction time, lane deviation etc.)
- Attitudes towards (un)safe behaviours
- Outcomes of psychological diagnostic assessment

The following figures and table provide some characteristics (years of publication, orgin, study design) of the coded studies.

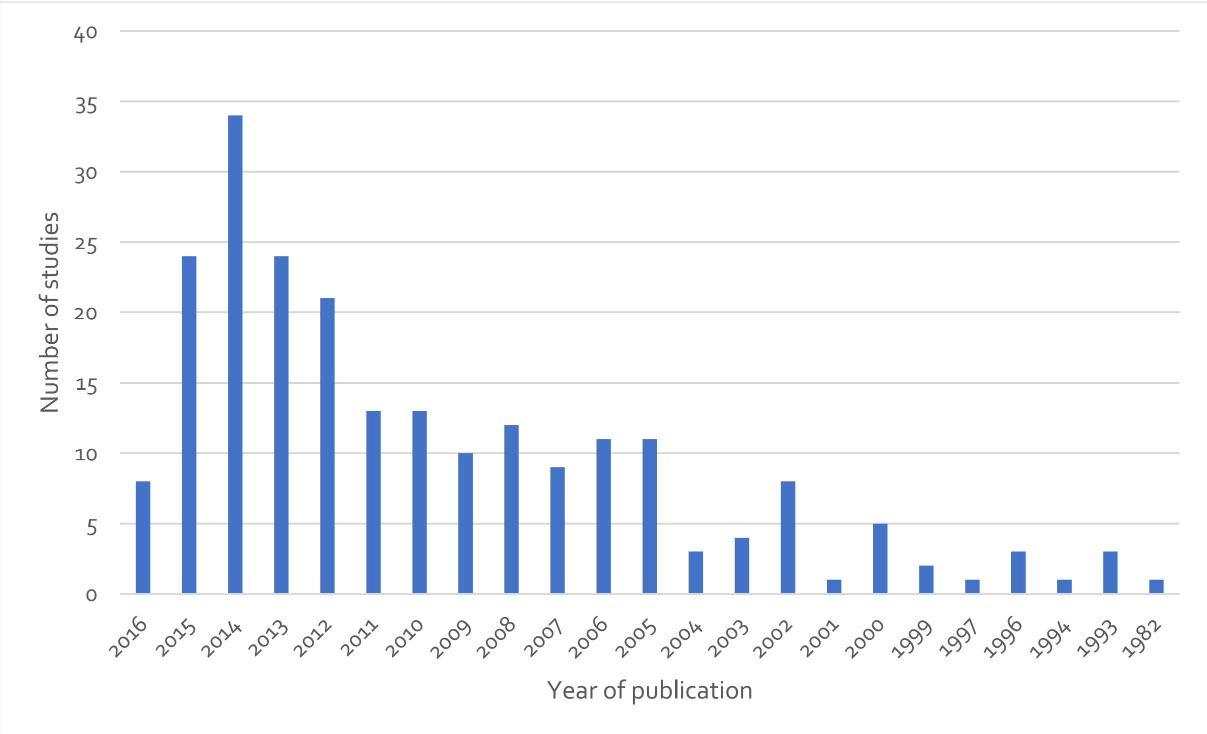

Figure 6: Years of publication of the included studies.

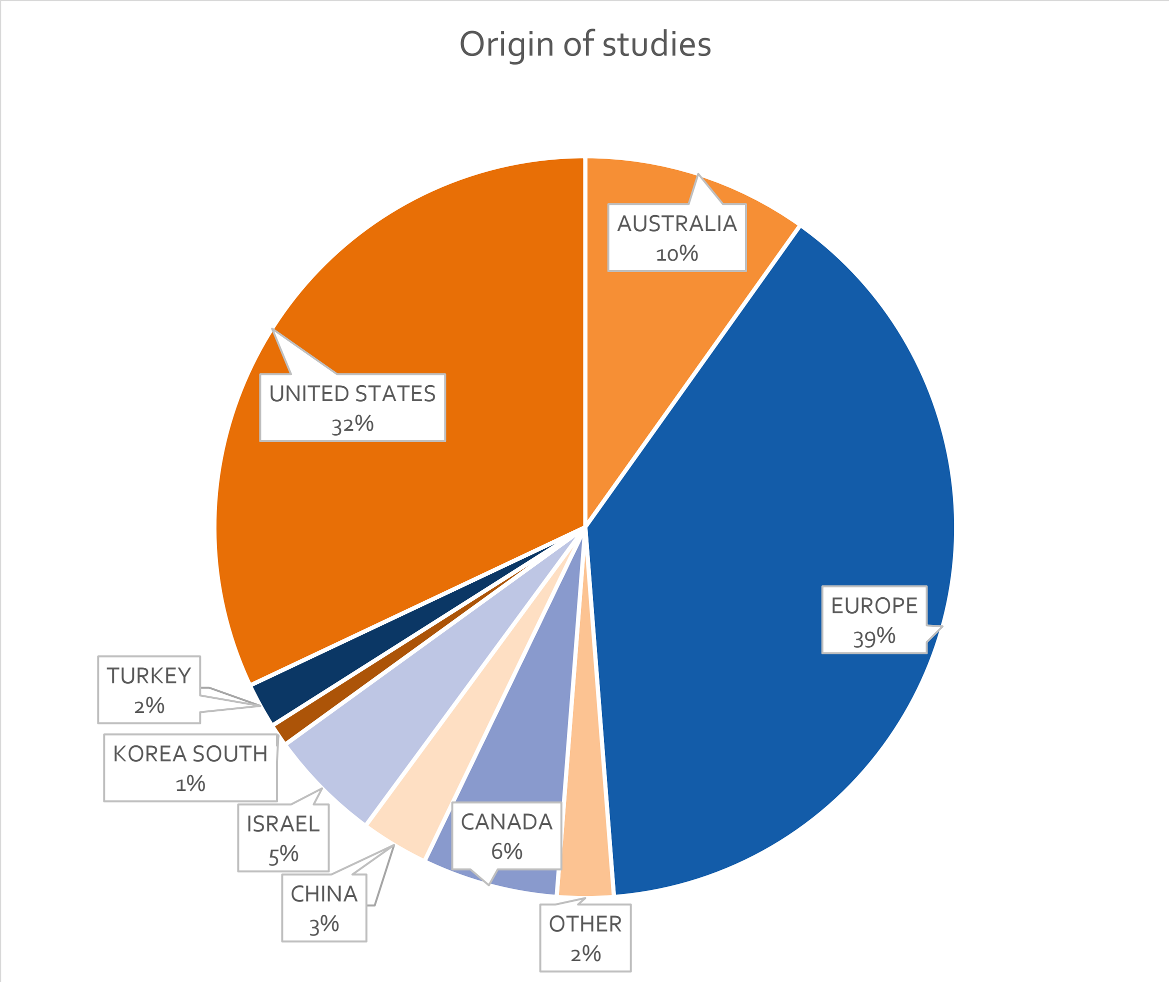

Figure 7: Origin of the included studies.

Table 15: Study design of the included studies

Type of study	Number of studies
Observational	82
Experimental	39
Cross-sectional	29
Meta-analysis	19
Case-Control	18
Quasi-experimental	8
Simulation	5
Longitudinal	5
Emperical bayes	4
Cohort	4
Time-series	2

3.3 RISK FACTOR SYNOPSES

The effects of risk factors are summarised and provided as 'synopses' which include two separate sections, one targeted at policy stakeholders, the other at a scientific audience. Within the synopses, each risk factor was analysed systematically on basis of scientific studies either through a meta-analysis or, if a meta-analysis is not possible, through another type of comprehensive synthesis of existing results (e.g. vote-count). Furthermore, the synopses contain theoretical background on the risk factor.

25 synopses based on 186 individual risk assessment studies were produced. In a further step, the quality of the synopses was checked by reviewers (see chapter 6.1). Now, 17 synopses have passed the quality assurance process and the abstracts and colour codes of these are presented in Appendix A.

List of available synopses:[5]

- A1 Driving under the influence: legal and illegal drugs
- A2 Red light running
- A3 Risk taking – Overtaking
- A4 Risk taking – Close following
- A5 Distraction – Cell phone use – Handheld
- A6 Distraction – Cell phones – Texting
- A7 Distraction – Music and entertainment systems
- A8 Distraction – Operating devices
- A9 Distraction – Cognitive overload, inattention
- A10 Distraction – Conversation with passengers
- A11 Fatigue – Not enough sleep, driving while tired
- A12 Fatigue – Sleep disorders – Sleep apnea
- A13 Functional impairment – Hearing loss
- A14 Functional impairment – Vision loss
- A15 Diseases and disorders – Diabetes
- A16 Personal factors – Sensation seeking
- A17 Emotions – Aggression, anger

3.4 MAIN RESULTS OF RISK FACTOR EVALUATION

The results of individual risk factor evaluation are presented in the respective synopsis. In this chapter, the effects of the risk factors are summarized and illustrated with some examples.

To provide an initial indication of the level of evidence about the effect of a risk factor on road safety, each risk synopsis was assigned a colour code (see chapter 2.2.3). Red ("risky") was used when the study results were relatively consistent in showing an increased risk upon exposure to the risk factor in question. Yellow ("probably risky") indicates that exposure to the risk factor increases the risk of accident or injury, but that the results reported in the literature are not consistent. In thematic areas where there were few studies with inconsistent results, few studies with weak indicators or an equal number of studies with no (or opposite) results, the evidence for the effect of the risk factor on road safety was concluded to be 'unclear' and assigned the category 'grey' [Adapted from Martensen et al., 2017].

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

Five risk factors show clearly negative effects on road safety (Table 16). One example is the risk factor fatigue due to sleep disorders and sleep apnea (Talbot and Filtness, 2016), where studies consistently show that untreated Obstructive Sleep Apnea is associated with increased risk for road traffic accidents: driver with untreated OSA have a two to three times higher risk to be involved in an accident, for truck drivers, this risk is potentially higher. Another example of a risk factor where studies, including a meta-analysis (Craid et al., 2014) consistently show an increased risk is cell phones for texting while driving (Ziakopoulos et al., 2016c). Texting while driving, which induces a level of distraction to the person driving, creates negative impacts on road safety: an increase of accidents and near misses, injury severities, reaction times to events, percentage of time with eyes off the road, speeding, and to inconsistencies in driving behaviour.

A further nine risk factors were categorised as probably risky, colour code yellow (Table 14). For example, this colour code was assigned to functional impairment - vision loss. According to the examined studies visual acuity (generally tested during application for a driving license) is very weakly associated with crash risk, while contrast sensitivity, visual field, and in particular cognitive aspects of vision have better evidence for their relevance to road safety (Sandin & Strand, 2016).

Another risk factor labelled as probably risky is sensation seeking. Sensation seeking is a personality trait that that leads individuals to seek novel and exciting feelings and experiences and is associated with risk taking. Sensation seeking can have an immediate, direct effect on driving behaviour and crashes because sensation seekers are more inclined to look for new, exciting and intense sensations of, for example, driving fast and recklessly. Studies generally show an association between sensation seeking and self-reported risky driving and self-reported crashes. However, the independent effect of sensation seeking is generally small, and the causal relationship is not always clear (Goldenberg & van Schagen, 2016b)

It should be noted that 'risks' in the red category can be directly observed and/or measured, while for some risks with the colour code yellow the effects on road safety in terms of crash risk are more difficult to measure and therefore links between the experience of the risk factor and accident risk are more difficult to make. For example, the relationship between emotion and accident risk varies depending on the mode of measurement (simulator, questionnaires, different decision-making tests, self-reported accidents etc.). Emotions can be measured by self-ratings or induced in different ways (pictures and videos, emotional recall, traffic events etc.) (Eichhorn & Pilgerstorfer, 2016).

Three of the analysed risk factors were labelled as unclear, colour code grey. For the risk factor, functional impairment hearing loss, only few studies could be identified, which quantify the effect of hearing loss on road safety and these studies do not show a clear association between reduced hearing and increased crash risk.

The two other risk factors in this category (distraction due to entertainment systems and distraction due to operating devices) are well researched and many relevant scientific studies could be found, but results showed mixed effects (positive, negative and non-significant) and no common conclusion for the effects of this risk factor could be drawn (Ziakopoulos et al., 2016a and 2016b). None of the considered risk factor was coded as green, indicating results consistently show that exposure to the presumed risk factor does not increase risk.

Table 16: road user related risk factor synopses by colour code. Risk factors highlighted bold were identified as hot topics in a previous step

Risky	Probably risky	Unclear
• Driving under the influence – legal and illegal drugs • Traffic rule violations – red light running • Distraction – cell phone use – Handheld • Distraction – cell phone use –Texting • Fatigue – sleep disorders – sleep apnea	• Risk taking – overtaking • Risk taking – close following • Functional impairment – vision loss • Diseases and disorders –diabetes • Personal factors – sensation seeking • Emotions – aggression, anger • Fatigue – not enough sleep, driving while tired • Distraction – conversation with passengers • Distraction – cognitive overload, inattention	• Functional impairment – hearing loss (few studies) • Distraction – music – entertainment systems • Distraction – operating devices

Note: None of the risk factors was assigned the colour code green (no increased risk).

As described in chapter 3.1 special road user groups and traffic modes are addressed within the respective risk factors. Whenever studies differentiated between road user groups or traffic modes and showed an increased risk for a specific group or traffic mode, this is highlighted in the synopses and can be searched for in the DSS. For example, as far as the traffic violation 'red light running' is concerned, the relative risk of accident for pedestrians is eight times higher when they cross an intersection on a red light instead of a green (or amber) light (Goldenbeld & van Schagen, 2016a).

3.5 FURTHER ANALYSES OF SELECTED VULNERABLE ROAD USER GROUPS

Additionally, key risk factors that are related to serious road injuries (MAIS3)[6] and their health impact were gathered within SafetyCube[7] (Reed et al., 2017). For this purpose, in-depth data for groups of casualties that are relevant from a serious road injury perspective were analysed and contributing factors for road traffic causalities identified and discussed. These analyses give further insight towards risk factors for vulnerable road user groups and therefore will be included here.

The analyses conducted in SafetyCube, Deliverable 7.4 (Reed et al., 2017) include two steps. As a first step, relevant groups of road users were selected using national crash statistics data from England, The Netherlands, the Rhone region in France, Spain and Austria. Selection was based on the following criteria:

- Relatively high number of MAIS3+ casualties in relation to fatalities, i.e. a high MAIS3+ to fatality ratio
- A relatively high burden of injury, expressed in Years lived with Disability (YLD) of MAIS3+ casualties (in relation to the burden of injury of fatalities, expressed in Years of life lost - YLL)

The second step concerns the identification of the main contributing factors for the selected groups of MAIS3+ casualties by analysing in-depth data from a number of countries (Germany, England, The Netherlands and Spain).

Road user groups that had been selected on basis of the described categories are:

- **Cyclists:** This group shows a relatively large share of MAIS3+ causalities and further the MAIS3+ fatality ratio and Years Lived with Disability per Years of Life Lost is the highest for

[6] MAIS 3 is defined as the Maximum AIS represents the most severe injury obtained by a casualty according to the Abbreviated Injury Scale (AIS) (Perez et al., 2016).
[7] SafetyCube gathered and analysed information on serious road injuries (MAIS3+ causalities) including their health impacts and costs in parallel to the work on road users, infrastructure and vehicles

cyclists in all included countries. Cyclists are often injured in crashes without motorized vehicles. Most relevant injuries are skull-brain injuries other than concussions, open head wounds and facial injuries and hip fractures

- **0-17 year olds;** In all analysed countries, this age group has a relatively high share in the numbers of MAIS3+ causalities. National crash statistics show that 0-17 years are often injured as pedestrians and to a lesser extent as cyclists. Most relevant injuries are skull-brain injuries other than concussions, open head wounds and facial injuries and femur shaft and knee/lower leg fractures.
- **Spinal cord injuries**; these injuries result in lifelong disability and are relatively common among car occupants
- **Knee/lower leg fractures** and **femur shaft fractures**; these injuries are most common among powered two wheelers and relatively common among younger casualties.

Cyclists and 0-17 year olds are the relevant groups concerning vulnerable road users and are therefore further discussed.

Key risk factors contributing to crashes of cyclists

Analysis of in-depth datasets is available for four countries, England, Germany, The Netherlands and Spain. In total, this sample includes 327 cases where a cyclist sustained a MAIS 3+ injury in a collision on the road.

One of the most common collision types for cyclists in the MAIS 3+ sample are collisions where a road user does not give or get given right of way in a traffic situation, further referred to as 'crossing or turning' collisions. The collision opponent is in around 75% of the cases a motorised vehicle. Crossing collisions are dominated with factors related to perception and conflict but also have significant levels of legal (disobeying signs, signals, rules) and attention factors (distraction, inattention) compared to other crash types. At fault drivers have more perception factors (expecting. looking, planning) than cyclists, whereas cyclists at fault have more injudicious actions (disobeying signals, signs or laws) than drivers.
Another relevant group of crashes is single bicycle crashes. These crashes are particularly evident in the German and Dutch datasets. Single bicycle crashes happen mostly on straight sections. Causation factors vary but the largest group of these factors can be connected to distraction and information admission, where relevant information could have been acquired by the cyclists but was not.

Finally, vision obscuration also appears to be a relevant factor. The recorded occurrence of vision obscuration in the MAIS3+ cyclist sample is around seven times the baseline dataset value for all collision types.

Key risk factors contributing to crashes of 0-17 year olds

Analysis of in-depth datasets is available for three countries, England, German and Spain. In total, this sample includes 200 cases where a 0 to 17-year-old road user sustained a MAIS 3+ injury but was not killed in a collision on the road.
The in-depth data showed relatively many casualties among pedestrians and two-wheelers. Considering pedestrians, crossing type collisions (controlled and uncontrolled crossing points, midblock crossing and crossing of vehicle paths at junctions) and collisions with cars appear to be more common among 0-17 year old pedestrians than among other age groups.
The English data shows that pedestrians within the 0 to 17 sample are likely to have causation factors assigned that are related to the broad groups of 'perception' and 'conflict'. *This causations group covers elements relating to the pedestrian expecting, looking or planning, but is most often associated with causation factors relating to vision obscuration.* In the German data the causation factors related to young road users, the majority of which are pedestrians, are associated with

human failures. This general group covers a range of more specific factors, including 'information admission' factors such as a wrong focus of attention of attention hindered due to physiological conditions.

The most common type of collisions for two wheelers were accidents when crossing or turning, both of which are over represented in the 0 to 17 sample compared with older age groups in both the German and English data. Data from England indicates that this large group of crashes is associated with rider error or reaction (i.e. failed to look properly, poor turn or manoeuvre or junction issues) and by a smaller element of factors relating to behaviour or inexperience (i.e. careless, reckless, nervous or aggressive riding). Contrary to the pedestrian crashes there does not appear to be vision/obscuration issues related to these crashes. Further analysis of these causation codes indicates that two wheelers are much more commonly associated with 'looked but did not see' errors, incorrect anticipation of the speed or path of another vehicle or misjudgements of vehicle movement than other road users.

These analyses give additional information about causation factors for two vulnerable road user groups: cyclists and 0-17-years-olds and can be used for identifying countermeasures. Measures addressing these factors such as red light cameras (cyclists, disobeying rules) can be searched for in the DSS.

4 Road user related safety measures

This chapter demonstrates: which are the road user related measures addressed in the inventory, the type of information the DSS user will find per study and the type of information the DSS user will find in a synopsis. Furhtermore, the main results for the evaluated countermeasures are presented

4.1 ROAD USER RELATED SAFETY MEASURES ADDRESSED

A taxonomy for road user related safety measures[8] was developed analogous to the one for risk factors.
The initial approach to generate a comprehensive list of road user measures was to collect measures for each of the considered risk factors and continuously expand this list – based on the expertise of the consortium. For further completion, the starting point (risk factors in the first place) was altered to measures per road user group and per type of measure such as 'law and enforcement' or 'rehabilitation'. While different approaches were tested, it was decided to structure the taxonomy based on measure types, which resulted in five global categories, similar to the categorisation used in the project 'Supreme' (van Schagen & Machata, 2010):

1. Law and enforcement
2. Education and voluntary training
3. Driver training and licensing
4. Fitness to drive assessment and rehabilitation
5. Awareness raising and campaigns

As stated in chapter 1.2, Vulnerable Road Users (VRU) are of special interest to the SafetyCube project, therefore, dependent on the measure type VRU are included on various levels of the taxonomy or in the corresponding synopses, respectively.

The full taxonomy is presented in Table 17 to Table 21. It should be noted that the taxonomy is not exhaustive.

Table 17: Taxonomy of road user related road safety measures related to law and enforcement

Type of measure	Road user, risk factor, combination	Specific measure
Law and enforcement	Law and enforcement, speeding	Police enforcement, speeding
	Law and enforcement, drink driving or riding	Random breath testing
		DUI checkpoints, selective breath testing

[8] Within the SafetyCube project 'measure' refers to any intervention that is taken to reduce the risk, the frequency or the consequences of road accidents. Measures can have a direct influence on the risk or the frequency of an accident occurring, on the consequences of the accident (e.g. severity), or more indirectly by influencing a Safety Performance Indicator (SPI) which itself has a causal link to crashes or severity (e.g. speed); this, however, is often difficult to observe in isolation.

Type of measure	**Road user, risk factor, combination**	**Specific measure**
		Lowering BAC limits
		BAC limits for specific groups (novice or professional drivers)
	Law and enforcement, drugged driving or riding (illegal)	Enforcement of drugged driving or riding
	Law and enforcement, aggressive and unsafe driving or riding	Police enforcement, aggressive driving
	Law and enforcement, fatigue, professional drivers	Hours of service regulation
	Law and enforcement, distraction	Laws restricting cell phone use (handheld)
		Laws restricting cell phone use (hands-free)
		Police enforcement, cell phone use
	Law and enforcement, seatbelt	Seat belt law and safety effects
		Police enforcement, seatbelt use
	Law and enforcement, child restraint	Child restraint law and safety effects
	Law and enforcement, protective clothing	Protective clothing
	Law and enforcement, helmet, cyclists	Helmet wearing law
		Law on helmet standards
		Safety effect of helmets
	Law and enforcement, helmet, PTW	Helmet wearing law
		Law on helmet standards
		Safety effect of helmets
	Law and enforcement, red light running	Safety cameras, red light cameras
		Police enforcement, red light running
	Fines, demerit point system and general patrolling	Fines and penalties
		Demerit point system
		General police enforcement and patrolling

Table 18: Taxonomy of road user related road safety measures related to education and voluntary training or programmes

Type of measure	Road user, risk factor, combination	Specific measure
Education and voluntary training or programmes	Education of children, pre-school and primary school	Pedestrians
		Cycling
		General road safety
	Education of adolescents, secondary school	Pedestrians
		Cycling
		General road safety
	Education of young, novice drivers and riders	Driving
		PTW riding
		General road safety
	Education of elderly	Pedestrians
		Cycling
		Driving
		PTW riding
		General road safety
	Education of general population	Usage and fitting of child restraint
		Pedestrians
		Cycling
		PTW riding
		Driving
		Hazard perception
		Adverse conditions (weather, light)
		Unsafe or risky behaviour
		Rewarding programmes
		General road safety
	Professional drivers	Truck
		Bus, coach
		Car, van
		General road safety

Table 19: Taxonomy of road user related road safety measures related to driver training and licensing

Type of measure	Road user, risk factor, combination	Specific measure
Driver training and licensing	Formal pre-licence training	Duration of driver training
		Content of driver training
		Driving test
	Graduated driver licensing and probation	Overall effect of graduated driver licensing
		Speed restriction
		Night-time driving restriction
		Passenger restriction
		Other driving restriction
	Health requirements for initial registration	Private vehicles (car, PTW)
		Commercial vehicles (truck, bus, taxi)
	Required age for initial registration	Required age for initial registration
	Accompanied driving or riding	Accompanied driving or riding

Table 20: Taxonomy of road user related road safety measures related to fitness to drive assessment and rehabilitation law and enforcement

Type of measure	Road user, risk factor, combination	Specific measure
Fitness to drive assessment and rehabilitation	Fitness to drive and rehabilitation of offenders	Fitness to drive assessment
		Rehabilitation
		Alcohol interlock
	Fitness to drive and rehabilitation of young offenders	Fitness to drive assessment
		Rehabilitation
	Fitness to drive, medical referrals	Dementia
		Medical referral, other
	Fitness to drive and rehabilitation of elderly drivers	Fitness to drive assessment, screening
	Fitness to drive and rehabilitation of professional drivers	Fitness to drive assessment, screening

Table 21: Taxonomy of road user related road safety measures related to awareness raising and campaigns

Type of measure	Road user, risk factor, combination	Specific measure
Awareness raising and campaigns	Campaigns on speeding and inappropriate speed	Speeding and inappropriate speed
	Campaigns on distraction	Distraction
	Campaigns on driving under the influence of alcohol or drugs	Driving under the influence of alcohol or drugs
	Campaigns on fatigue	Fatigue
	Campaigns on seatbelt use	Seatbelt use
	Campaigns on child restraint use	Child restraint use
	Campaigns on helmets, protective clothing and visibility	Helmet, protective clothing and visibility
	Campaigns on aggressive, inconsiderate and unsafe behaviour	Aggressive, inconsiderate and unsafe behaviour
	Road safety campaigns, general	Road safety campaigns, general

4.2 CODED STUDIES

The coding of the selected studies and the incorporation of these studies into the DSS was done analogue to the risk factors. The process is described in chapter 3.2.
The following figures and table provide some characteristics (years of publication, orgin, study design) of the coded studies.

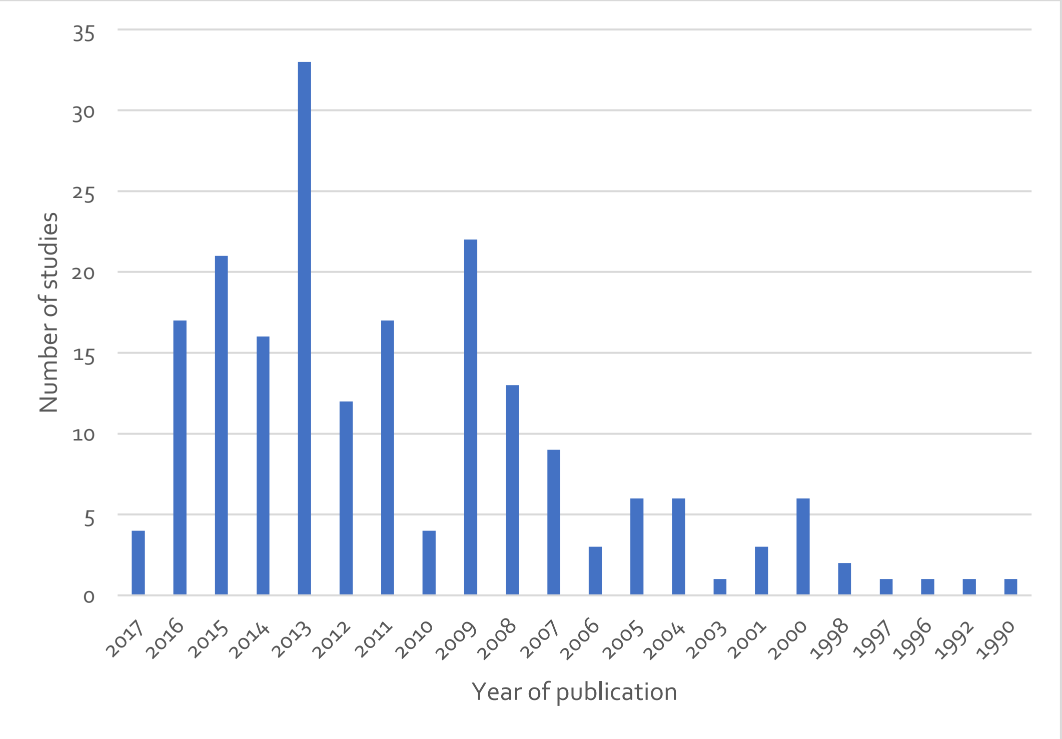

Figure 8: Publication year of the included studies

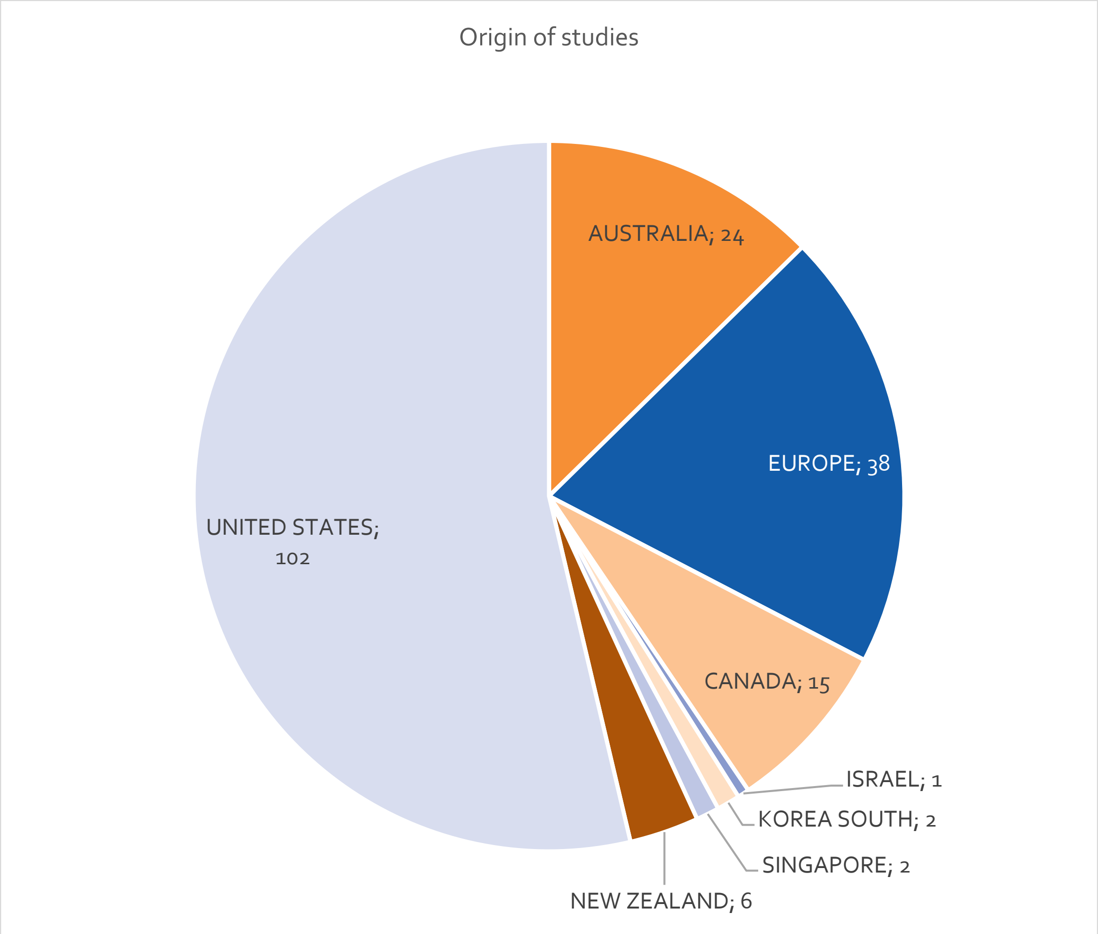

Figure 9: Origin of the included studies

Table 22: Study design of the included studies

Type of study	Number of studies
Quasi-experimental	46
Before-after	44
Meta-analysis	28
Observational	19
Experimental	9
Time-series	9
Emperical bayes	8
Cohort	6
Simulation	4
Cross-sectional	4
Case-control	4

Intervention modelling	3
Longitudinal	3
Full bayes	1

4.3 ROAD SAFETY MEASURE SYNOPSES

Analogue to the risk factors the main findings of the examined road safety measures are provided as 'synopses' (see chapter 2.2.3), which will also be available through the DSS. Within the synopses, each countermeasure (or group of measures) was analysed systematically on basis of scientific studies and is further assigned to one of four levels of effectiveness (marked with a colour code, see chapter 2.2.3).

26 synopses based on about 240 individual studies were produced. In a further step, the quality of the synopses was checked by reviewers (see chapter 6.1). Now, 21 synopses have passed the quality assurance process and the abstracts and colour codes of these are presented in Appendix B.

- B1 Law and enforcement – Lowering BAC limits (general and for novice drivers)
- B2 Law and enforcement – Mobile phone use
- B3 Increasing traffic fines
- B4 Hours of service regulation for commercial drivers
- B5 Demerit point systems
- B6 Red light cameras
- B7 Licence suspension
- B8 Education – Pedestrian skills training for children
- B9 Education – Non-statutory training for novice drivers
- B10 Driver training and licensing – Formal pre-license training, graduated driver licensing and probation
- B11 Alcohol interlock
- B12 Rehabilitation courses as measure for drink-driving offenders
- B13 Age-based screening of elderly drivers
- B14 Fitness to drive assessment tools for medical referrals
- B15 Effectiveness of road safety campaigns
- B16 Awareness raising and campaigns – Seatbelts
- B17 Awareness raising and campaigns – Child restraint
- B18 Awareness raising and campaigns – Driving under the influence
- B19 Awareness raising and campaigns – Speeding
- B20 Awareness raising and campaigns – Aggressive and inconsiderate behaviour
- B21 Education and training – Hazard perception training

4.4 ECONOMIC EVALUATION OF ROAD USER RELATED MEASURES

For further priority setting an economic evaluation was conducted. Measures which were categorised as effective (colour code green or light green) were screened if an economic evaluation could be calculated. 12 measures qualified regarding available information for this procedure (see Table 23) and exemplary economic evaluation were conducted. Within SafetyCube the economic evaluation principally is done by executing cost-benefit analyses (CBA). For this purpose, an 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 standardize the input and output information.

Table 23: Screening of road user related measures for economic evaluation

Measure	Colour code	CBA conducted	Reason not to conduct CBA
Law and enforcement – General police enforcement of speeding	Preliminary green[9]	Yes	-
Law and enforcement – DUI checkpoints, selective and random breath testing	Preliminary green	Yes	-
Law and enforcement – Seatbelt wearing	Green	Yes	-
Law and enforcement – License suspension	Green	No	Effectiveness estimates from the US only No (good) cost estimates
Fitness to drive assessment and rehabilitation – Alcohol interlock	Green	Yes	-
Education and voluntary training – Hazard perception training	Green	Yes	-
Law and enforcement – BAC limits (for novice drivers)	Light green	No	No (good) cost estimates
Law and enforcement – Red light cameras	Light green	Yes	-
Law and enforcement – Increasing traffic fines	Light green	No	Strong variation of measures of effectiveness No (good) cost estimates
Law and enforcement – Hours of service regulations for commercial drivers	Light green	No	Effectiveness estimates from the US only No (good) cost estimates
Law and enforcement – Demerit point systems	Light green	No	No (good) cost estimates
Education and voluntary training – Child pedestrian training	Light green	Yes	-
Formal pre-license training – Graduated driver licensing	Light green	Yes	-
Fitness to drive assessment and rehabilitation – Rehabilitation courses	Light green	No	Effectiveness estimate only for recidivism rates
Fitness to drive assessment and rehabilitation – Medical referrals	Light green	No	CBA on subtopic 'Mandatory eyesight test'
Fitness to drive assessment and rehabilitation – Mandatory eyesight testing	No synopsis	Yes	-
Awareness raising and campaigns – Seatbelt wearing	Light green	Yes	-
Awareness raising and campaigns – Child restraint	Light green	Yes	-
Awareness raising and campaigns – Drink-driving	Light green	Yes	-
Awareness raising and campaigns – Aggressive and inconsiderate behaviour	Light green	No	Heterogeneity of analysed campaigns and no CBA suitable for update found
Awareness raising and campaigns – Campaigns in general	Light green	No	Heterogeneity of meta-analysed campaigns
Awareness raising and campaigns – Speeding and inappropriate speed	Light green	No	Heterogeneity of analysed campaigns and no CBA suitable for update found

The results, underlying assumptions and data of the performed cost-benefit-analyses are documented for each selected measure separately. The following analyses can be can be found in Appendix C.

- C1 Police enforcement of speeding
- C2 Random breath tests and DUI checkpoints
- C3 Seatbelt enforcement
- C4 Alcohol interlock program

[9] Synopses with a preliminary colour code are currently under review by the internal Quality Assurance Committee.

- C5 Hazard perception training
- C6 Red light cameras
- C7 Graduated driver licensing
- C8 Mandatory eyesight tests
- C9 Child pedestrian training
- C10 Seatbelt campaign
- C11 Booster seat campaign
- C12 Drink-driving advertising campaign

4.5 MAIN RESULTS FROM EFFECTIVENESS AND EFFICIENCY

The results of the road user related road safety measure evaluation are presented in the respective synopsis, which can be assessed by the DSS. In this chapter, the effectiveness and the efficiency are summarized and illustrated with some examples.

For most of the 21 road user related measures analysed, the results show a positive effect on road safety (Table 24). These are categorized either as effective (colour code green) or as probably effective (colour code light green).

Three measures qualified for the colour code green, where results of the studies included clearly indicate a reduction in the road safety risk: laws and enforcement of seatbelt wearing, licence suspension and alcohol interlock. As an example, for alcohol interlock research shows (including a recent meta-analysis) a reduction of the recidivism rate while the device is installed in the vehicle (Nieuwkamp et al., 2017). It should be noted this effect is not sustainable (not the primary aim of the measure); once the devices are removed, recidivism rates increase towards their initial level.

Most of the evaluated measures (15 measures) are labelled as probably effective. While the studies analysed do offer evidence that these measures are effective, there are also some problems in terms of mixed results, study design or number of studies available. Furthermore, this category was chosen due to a weak direct link between accident reduction and measure. One example for this are road safety campaigns. The defined outcome measures to account for campaign effects are often 'indirect' like intended behaviour or attitudes. Even though there is evidence concerning the influence of these constructs on actual behaviour, there are always also other determining factors (e.g. situational factors) that cannot be accounted for.

One of the selected countermeasures was classified as ineffective or counterproductive (colour code red). Age-based screening of all elderly drivers for fitness to drive has not been found to reduce fatalities. At the same time, there are indications that it might increase fatalities among elderly pedestrians and the average risk per licensed (elderly) driver (Martensen, 2017).

Only two measures (Law and enforcement – mobile phone use, Education – none statutory training for novice drivers) had to be assigned to the colour code grey, which means that no valid conclusions about the effect on road safety could be drawn due to mixed results or an insufficient number of available studies. Contradictory findings have been reported on laws and enforcement for restricting mobile phone use report (Theofilatos, 2017). For "none statutory training for novice drivers" the available evidence does not support that there is a reliable link between voluntary training and skill improvement/risk reduction: five analysed studies show a mixture of significant and none significant results, and differences in methodologies prevent the comparison of results (Talbot, 2017).

Table 24: Overview of analysed Road user related measures synopses by colour code

Topic	Effective	Probably effective	Unclear results	Ineffective or counterproductive
Law and Enforcement	• Laws and enforcement for seatbelt wearing • License suspension	• Lowering BAC limits (general and novice drivers) • Increasing traffic fines • Hours of service regulations for commercial drivers • Demerit point systems • Red light cameras	• Mobile phone use	
Education and voluntary training/programs	• Hazard perception training	• Pedestrian skills training	• None statutory training for novice drivers	
Driver training and licensing		• Formal pre-license training, graduated driver licensing and probation		
Fitness to drive assessment and rehabilitation	• Alcohol interlock	• Fitness to drive assessment tools for medical referrals • Rehabilitation courses as measure for drink-driving offenders		• Age-based screening of elderly drivers
Awareness raising and campaigns		• Road safety campaigns in general • Seatbelt campaigns • Child restraint campaigns • Driving under the influence campaigns • Speeding campaigns • Aggressive and inconsiderate behaviour campaigns		

The efficiency was addressed by economic evaluation of road user related safety measures. Within SafetyCube this was principally done by executing cost-benefit analyses (CBA) (see chapter 2.2.4). A cost-benefit analysis (CBA) allows the joint evaluation of the effectiveness of measures in reducing crashes of different severity and to provide information on the socio-economic return of countermeasures. Therefore a monetary value is assigned to each type of benefit that results from the measure. The sum of these monetary values is compared to costs of the measure. In a CBA two statistics can be calculated:

1. the net present value (NPV) = Benefits – Costs
2. the benefit-to-cost ratio (BCR) = Benefits / Costs.

If the benefits are greater than the costs, a measure is cost-effective. For the NPV this means a value higher than 0 and for the BCR this means a value higher than 1. Measures can be ranked or prioritized based on the NPV or BCR.

Most of the assessed road user related measures have a benefit-to-cost ratio (CBR) that is higher than 1. This means that the benefits outweigh the costs and are economically efficient. The conducted calculations show a wide range of benefit-to-cost ratios (BCR) between 1 and 125.1

(Table 25). For only one measure, mandatory eye-sight testing for drivers between 45 and 69 years old, the BCR is 0.5., which means that it is not economically efficient.
Further the break-even costs are presented in Table 25. These 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 the measure costs are available. This was the case for the topic hazard perception training.

Table 25: Benefit-to-cost ratio and Net present value for selected measures, benefit-to-cost ratios higher than 1 are marked in green, lower than one in red.

Measure	**Unit of analysis**	**Total costs per unit of analysis** (in EUR EU-2015 PPP)	**Benefit-to cost ratio (Best estimate)**	**Net present value** (in EUR EU-2015 PPP)	**Break-even measure cost** in EUR EU-2015 PPP)
Law and enforcement – General police enforcement of speeding	One area of enforcement with a total length of 88 km.	€5,856,879	1.0	€122,489	€5,979,369
Law and enforcement – DUI checkpoints, selective and random breath testing	DUI testing for 100,000 drivers for a year	€3,284,143	7.3	€20,732,246	€24,007,389
Law and enforcement – Seatbelt wearing	One country, increase of seatbelt enforcement by factor 2	€5,173,139	1.4	€2,030,188	€7,077,153
Fitness to drive assessment and rehabilitation – Alcohol interlock	Participation of a serious offender in an alcohol interlock programm	€3,068	10.9	€131,281,642	€32,130
Education – Hazard perception training	One harzad perception training	-	-	€120,155	€120,155
Law and enforcement – Red light cameras	One red light camera on an intersection, 253 implemented units	€109,400	3.7	€71,491,929	€388,358
Formal pre-license training – Graduated driver licensing	One training intervention	€132,620	125.1	€16,462,021	€16,594,642
Fitness to drive assessment and rehabilitation – Mandatory eyesight test	One visual mandatory eyesight test and treatment if necessary and possible	€47	0.5	-2,782,968	€24

Measure	Unit of analysis	Total costs per unit of analysis (in EUR EU-2015 PPP)	Benefit-to cost ratio (Best estimate)	Net present value (in EUR EU-2015 PPP)	Break-even measure cost in EUR EU-2015 PPP)
Education and voluntary training – Child pedestrian training	One child pedestrian training	€574,689	2.6	€935,422	€1,510,111
Awareness raising and campaigns – Seatbelt	One national seatbelt campaign	€468,832	42.2	€19,300,582	€19,769,414
Awareness raising and campaigns – Child restraint	One nationwide booster seat programme 4-8-years old	€463,980	4.6	€1,671,196	€2,135,176
Awareness raising and campaigns – Drink-driving	One drink-driving advertising campaign	€862,157	2.1	€932,113	€1,794,270

The most important limitation of using cost-benefit analyses is its dependence on the underlying assumptions about the measure effectiveness, the target group and the measure costs. Therefore, the CBAs were accompanied by a sensitivity analysis. Sensitivity analyses are performed using different rates of effectiveness of the measure in preventing crashes, and different values for measure costs. It could be shown that conducting such an analysis the benefit-to-cost ratio still remains above 1 for the majority of the measures. Additionally, it was possible to estimate a best and worst-case scenario (with a lower effectiveness estimate and higher costs) for five measures. The worst-case scenario indicates a BCR above 1 for three out of five measures, where these analyses were possible to conduct:

- Drink-driving checkpoints and breath testing
- Alcohol interlocks
- Seatbelt campaigns

The results of these CBAs can be used by policymakers, but – given the limitations – the values should be used carefully and with a critical eye. The assumptions that are made should be checked thoroughly. Furthermore, it is recommended 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.

Table 26: Overview about the results of the sensitivity analyses

Measure	**BCR** (best estimate)	**BCR** (low measure effect)	**BCR** (high measure effect)	**BCR** (low measure cost -50%)	**BCR** (high measure cost +100%)	**BCR** (worst case scenario)	**BCR** (ideal case scenario)
Law and enforcement – General police enforcement of speeding	1.0	0.7	1.3	2.0	0,5	0.4	2.6
Law and enforcement – DUI checkpoints, breath testing	7.3	5.7	9.4	14.6	3.7	2.9	18.8
Law and enforcement – seatbelt wearing	1.4	1.1	1.8	2.8	0.7	0.5	3.5
Fitness to drive assessment and rehabilitation – Alcohol interlock	10.9	5.8	13.8	21.7	5.4	2.9	27.5
Law and enforcement – Red light cameras	3.7	-	4.2	7.3	1.8	-	-
Formal pre-license training – Graduated driver licensing	125.1	-	-	250.3	62.6	-	-
Fitness to drive assessment and rehabilitation – Mandatory eyesight test	0.5	-	-	1.5	0.3	-	-
Education and voluntary training – Child pedestrian training	2.6	-	-	5.3	1.3	-	-
Awareness raising and campaigns – Seatbelt	42.2	34.8	50.9	84.3	21.1	17.4	101.9
Awareness raising and campaigns – Child restraint	4.6	-	-	9.2	2.3	-	-
Awareness raising and campaigns – Drink-driving	2.1	-	-	4.2	1.0	-	-

5 Challenges and limitations

There were several challenges and limitations involved to arrive at 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, vehicle). And some are specifically related to the aim of quantifying the effect of *road user* related risk factors and measures.
For a more in-depth discussion of the methodological approach of SafetyCube, please see deliverable 3.3, which will be published early 2018.

5.1 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. This may occur due to one of the following reasons:

- Lack of evidence: insufficient number of (high-quality) studies could be identified to develop a topic synopsis or a topic might be to recent to assess its effect.
- Complexity of topic such as safety culture
- Time constraint and limited resources.

Risks versus measures

A challenge within the task of identifying studies to be included in the repository of risk factor studies was to separate risk factors from countermeasures. For example, studies on speeding are often designed to record e.g. accidents before and after the establishment of a certain speeding measure (e.g. increase of fines). So, the study is at the same time assessing the risk factor and the corresponding measure. Also, protective devices such as a bicycle helmet can either be interpreted as a safety measure. Its absence poses a risk of more severe injuries, however. In these cases, studies have been interpreted as a measure rather than a risk factor.

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 vote count or literature review was completed. For road user related topics, only a few meta-analyses could be carried out. Oftentimes, this is related to the vast variety of used outcome measures in scientific studies (see also 5.2).

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 demonstrated the consequences of changing some basic assumptions on measure costs, effectiveness or target group. The assumptions made should be checked thoroughly before applying the presented figures to other contexts.
Moreover, very little information is available regarding quantified side effects of measures. Thus, they were not considered in the 12 conducted analyses.

5.2 ROAD USER RELATED CHALLENGES

The discussion of the following challenges is to a certain extent also applicable to the topic areas "infrastructure" and "vehicles", however, these aspects are particularly severe for the area of road users. 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 human decision making and behaviour come into play. Therefore, complementary qualitative information is provided in the individual synopses. It is highly recommended to consider these aspects when using the DSS.

Presence, extent and stability of risk factors

The presence or absence of some risk factors such as fatigue is not absolute but rather a state on a continuum which can vary over time (other than an airbag which is either built in or not). Many road user related risk factors are furthermore not directly observable, such as a drunk driver (other than a roundabout which is visible). This requires the presence and extent of such risk factors to be inferred based on indicators, which are (more or less) stable over time, such as the blood alcohol concentration (unstable even in the short term) or outcomes of psychometric test (stable, at least in the medium term). Given these characteristics of many road user related risk factors complicates their quantification.

Confounding factors

Furthermore, human road safety risk factors tend to not occur as independent, distinct phenomenon but sometimes have similar or overlapping characteristics which makes it difficult to distinguish them or they interact with other (human) factors relevant for road safety. For example:

- Speeding can also be interpreted as aggressive driving
- Whereas drink-driving is a risk factor per se, it can encourage the driver to engage in further risky behaviour.
- Certain diseases, which are detrimental for road safety require medication, which might pose further risk.
- Driving while tired can evoke the desire to arriving faster at the destination.

"Confounding factors" also concerns road safety measures. They are not always implemented separately, one at a time, but oftentimes in a set of measures. In before-after studies to evaluate the effectiveness of a measure it therefore might remain unclear to which extent a single measure contributes to the effect (if confounding factors are not considered carefully in the research design).

Non-standardised measures

Some road user related groups of measures exist or are implemented in variations. Many different activities to raise awareness can be a component of a e.g. drink-driving campaign. Even though the outcome measure of numerous studies might be the same and thus comparable, the evaluated

campaign might be very different in terms of duration, specific target group, (combination of) media etc. Hence, the comparability of the effectiveness outcomes is sometimes questionable.
This limitation also applies e.g. to educational measures and trainings (if not standardised).

Actual contribution to accidents occurrence and SPIs

Some of the above outlined challenges are contribution to the fact that we are frequently dealing with studies which are investigating the effect of a risk factor or countermeasure on alternative outcome measures or safety performance indicators (SPI) rather than on actual accident occurrence, such as performance in a simulator, results of psychometric tests or self-reported behaviour. When looking at accident statistics in retrospect, there are a lot of intermediary factors which should be controlled for. While the considered SPIs are either assumed or known to be linked to road safety or accident involvement, the relationship is still indirect and cannot always be quantified.
As already discussed earlier, road safety strategies often do not rely on single measures but rather a combination of some (e.g. change of law combined with awareness raising campaign), which complicates the assessment of a single measure.

Cost-benefit analysis

The afore discussed limiting aspects also pose consequences for the potential to conduct cost-benefit-analyses (CBA) for countermeasures in the realm of road users. A CBA can only be conducted if the savings potential in terms of accident reduction (or reduction of injury severity) is known. Even though, there is a plausible link between safety performance indicators and accident occurrence, an alternative outcome measure is not suitable for this kind of economic assessment. It is the reliable measure of effectiveness that is lacking most of the time. But to determine the costs of measures is also not always straightforward.
For some of the SafetyCube measures the time horizon is disputable. The time horizon refers to the duration (in years) that the measure in question is effective. But how long is a pedestrian training for children effective? Until certain cognitive abilities are fully functional? Until adolescence? Only very short-term? This kind of underlying assumptions should be considered carefully and are made transparent in the CBA documents available through the DSS.
Furthermore, the fact that some groups of measures are not standardised, as e.g. argued above for road safety campaigns, is limiting the potential for CBA. It was refrained e.g. from using the outcome of a meta-analysis since campaigns are highly heterogeneous, even if the tackle the same risk factor (e.g. drink-driving campaigns).

SafetyCube's deliverable 4.3 provides detailed information on CBA of road user related countermeasures (Daniels et al., 2017).

6 Building the inventory of road user related risks and measures

Methodological approach and main challenges

6.1 QUALITY ASSURANCE (QA) PROCESS

The literature search, study coding and synopses creation for a particular risk factor or a measure was completed generally within the same SafetyCube partner organisation. In order to guarantee a comprehensive selection of studies per topic, low probability of coding errors, consistency within and between synopses a set of comprehensive QA criteria and procedures are set for each type of DSS contents.

Quality of coded studies

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. Moreover, a quality control procedure was established in which all risk factors and safety measures were allocated to a primary and a secondary coding partner. The primary coding partner undertook the literature search, selected the papers for coding and coded these studies. The initial coded studies for each partner where shared between primary and secondary coding partners to confirm coding decisions. Once there was agreement on the coding of the initial studies, the rest of the studies were coded without sharing between the primary and secondary coding partners unless the studies were complicated or caused problems for the coders. These more complex studies which proved were discussed between the primary and secondary coding partner so as to reach consensus. Coders had the opportunity to have more than one study checked if they were uncertain.

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, inappropiate values and inconsistencies. In case of mistakes that cannot easily be solved, specific requests can be submitted to the related coders to discuss issues.

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.

Quality of efficiency analysis

Efficiency analysis was supported by using a common tool: the *Economic Efficiency Evaluation* (*E^3*) *calculator*. The SafetyCube E^3 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 document, which was reviewed by one expert to check assumptions made, ensure readability as well as consistency of information within and between the CBAs and their documentation.

6.2 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.

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 bicycle helmets is provided below:

☐ Differences between effects	Effect 1	Effect 2	Effect 3	Effect 4	Effect 5
Injury nature	Fracture; Internal; Open Wou	Fracture; Internal; Open Wou	Fracture; Internal; Open Wou	Fracture	Fracture
Injury severities	Moderate	AIS 3	AIS 4	AIS 3	AIS 3; AIS 4
Injury - Cases	Hospital; Head	Hospital; Head	Hospital; Head	Hospital; Head	Hospital; Head
Injury - Controls	Non-Head; Minor head	Non-Head; Minor head	Non-Head; Minor head	Non-Head; Minor head	Non-Head; Minor head
Measure of effect/association	Odds ratio	Odds ratio	Odds ratio	Odds ratio	Odds ratio
Specifications	Odds for wearing a helmet	Odds for wearing a helmet	Odds for wearing a helmet	Odds for wearing a helmet	Odds for wearing a helmet
Estimate	0.5060	0.3790	0.2570	0.4370	0.2170
Standard error of estimate					
Statistic [name(parameters)=x]					
p-value	<0.0001	<0.0001	<0.0001	0.1710	<0.0001
Sample size (x or n1=x1; n2=x2)	n (cyclist casualties)= 6745	n (cyclist casualties)= 6745	n (cyclist casualties)= 6745	n (cyclist casualties)= 6745	n (cyclist casualties)= 6745
Confidence level	0.9500	0.9500	0.9500	0.9500	0.9500
Lower limit	0.3880	0.2670	0.1480	0.1300	0.1320
Upper limit	0.6590	0.5360	0.4480	1.4660	0.3570
Adjustment variables/Covariates	Speed limit; Collision vehicle	Speed limit; Collision vehicle	Speed limit; Collision vehicle	Speed limit; Collision vehicle	Speed limit; Collision vehicle
Conclusion	Significant positive effect on	Significant positive effect on	Significant positive effect on	Non-significant effect on roa	Significant positive effect on

Figure 10 Example of coded template (results sheet) effect of bicycle helmets

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.

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.

6.3 LINKING RISKS AND MEASURES

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.

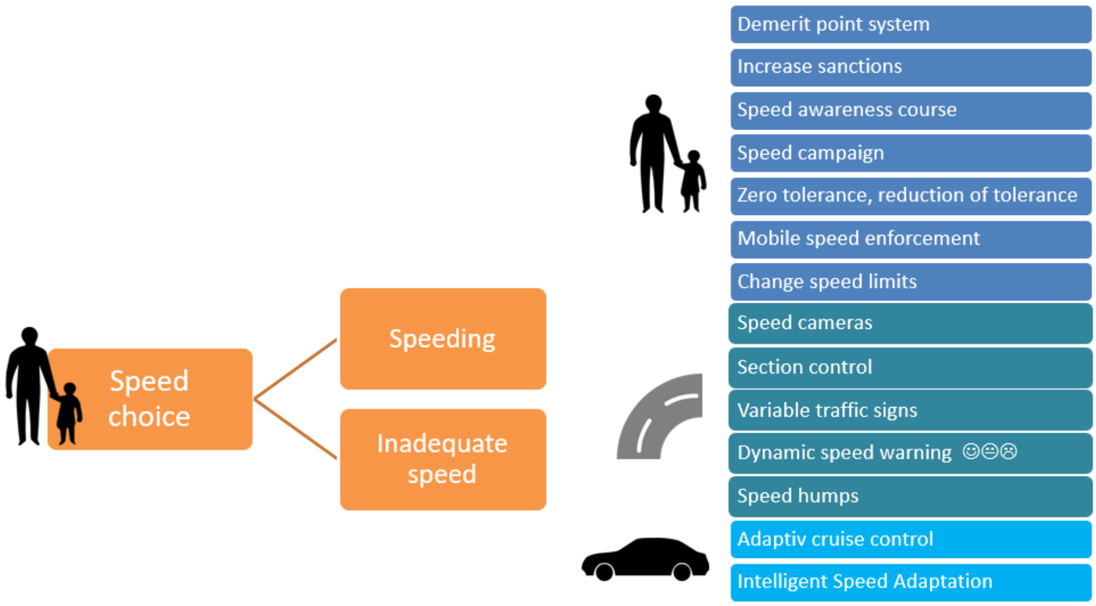

Figure 11: Example of linking between the risk factor speed choice (road user related) and the related measures from different areas (road user related, infrastructure, vehicle).

7 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.

Using the inventory for gaining information on road user related risks and measures the necessary research assumptions, as well as some involved limitations as described in chapter 5 should be considered, such as the inclusion criteria for studies. The main criterion for inclusion of studies in the DSS was that each study provides a quantitative estimate of the effect. Therefore, key studies providing qualitative information might not be contained in the DSS.
Further, it should to be noted that the included road user related risks or measures cannot be exhaustive due to several reasons such as lack of evidence or time constraint and limited resources.

Measuring the effectiveness of measures and quantifying human aspects in traffic is challenging for various reasons as described in chapter 5. However, these challenges highlight the importance of evidence based decision making and the need for evaluation studies especially for road user related measures, where modification of human behaviour is addressed.

List of Abbreviations

BAC	Blood Alcohol Concentration
BCR	Benefit-to-cost ratio
CBA	Cost-Benefit Analysis
CBR	Cost-Benefit Ratio
CMF	Crash Modification Factor
DSS	Decision Support System
DUI	Driving Under the Influence
EVT	Education and Voluntary Training
GDL	Graduated Driver Licensing
HGV	Heavy Goods Vehicle
ISA	Intelligent Speed Adaption
IVIS	In-Vehicle Information System
LGV	Large Goods Vehicle
PPP	Purchasing Power Parity
RLC	Red Light Camera
SPI	Safety Performance Indicator
TRACE	Traffic Accident Causation in Europe
VRU	Vulnerable Road User(s)
WP	Work Package

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Appendix A: Risk factor colour codes and abstracts[10]

A1 Driving under the influence: legal and illegal drugs
A2 Red light running
A3 Risk taking – Overtaking
A4 Risk taking – Close following
A5 Distraction – Cell phone use – Handheld
A6 Distraction – Cell phones – Texting
A7 Distraction – Music and entertainment systems
A8 Distraction – Operating devices
A9 Distraction – Cognitive overload, inattention
A10 Distraction – Conversation with passengers
A11 Fatigue – Not enough sleep, driving while tired
A12 Fatigue – Sleep disorders – Sleep apnea
A13 Functional impairment – Hearing loss
A14 Functional impairment – Vision loss
A15 Diseases and disorders – Diabetes
A16 Personal factors – Sensation seeking
A17 Emotions – Aggression, anger

A1 Driving under the influence: Legal and illegal drugs

COLOUR CODE: RED

Many legal and illegal drugs have a significant negative effect on crashes and driving performance. When combined with other drugs or alcohol, the negative effect on road safety is even larger.

ABSTRACT

'Drugs' is a very general term which refers to countless numbers of substances. They can have positive or negative effects on efficiency, reflexes, concentration, sleeping etc. More specifically, substances having physiological effects on the human body and behaviour are defined as psychoactive drugs. In the context of road safety, they could present a major danger when driving a vehicle. In this synopsis, the main types of drugs are assessed to determine their impact on road safety. Legal drugs studied were divided into benzodiazepine and medicinal opiates. Illegal drugs were divided into amphetamines, benzodiazepines, illicit opiates, and cannabinoids (tetrahydrocannabinol, THC). The literature inventory highlighted that driving under the influence of drugs is a well-studied subject, with hundreds of papers found. The results show that the main legal and illegal drugs have a negative impact on road safety. They increase crash risk, injury severity and fatal crash rate, and they reduce the general ability to drive. When combined with alcohol or other

[10] The colour code explanations and abstracts of road user related risk factors were first published in SafetyCube's deliverable 4.1. All synopses underwent an internal quality assurance procedures and some have been updated accordingly. Therefore, some of the here presented contents differ from deliverable 4.1. The most recent versions will always be the ones available through the DSS.

drugs, the negative effects are even larger. Considering that more than 10% of fatal accidents could be linked to drug use, it is important to systematically monitor their use in traffic and increase the enforcement.

A2 Traffic rule violations – Red light running

COLOUR CODE: RED

Road safety experts agree that red light running is a risk factor since it is a demonstrable causal factor in part of the crashes and since it demonstrably leads to two basic types of traffic conflicts at intersections: right-angle and left turn-opposed conflicts. Red light running is associated with very severe crash outcomes (fatality or serious injury).

ABSTRACT

Red light running is a risky traffic violation leading to traffic conflicts at intersections that may result very serious injury. Crashes related to red light running compose a substantial part of urban road safety. It has been estimated that pedestrians' relative crash risk is eight times higher when they cross an intersection at red light instead of green (or yellow) light. Another study estimated a 10 to 15 times increase in fatal crash risk for all transport modes due to red light running. Red light running is fairly scarce amongst drivers (a few drivers per 1,000 vehicles), but fairly frequent among cyclists and pedestrians (percentages may run up to over 50% at specific days, times and locations). Red light running is influenced by several factors, including age and gender, static and dynamic characteristics of the intersection, day and time, and weather. Most research has been done in busy, large metropolitan city areas in China, Europe and the USA.

A3 Risk taking – Overtaking

COLOUR CODE: YELLOW

Research shows compared to other vehicle manoeuvres (risky) overtaking tends to increase accident severity. Regarding accident frequency however it seems that only a small share of crashes occurs while overtaking another vehicle. In addition, some situational factors (traffic volume, speed) and driver characteristics (age, gender) seem to influence (the frequency of) risky overtaking.

ABSTRACT

Overtaking is known as one of the most complex manoeuvres for road users. From studies in the international literature, it appears indeed that compared to other vehicle manoeuvres, (risky) overtaking significantly increases accident severity, however regarding accident frequency – although associated with a higher crash risk in one study – it seems that only a small share of crashes occurs while overtaking another vehicle. Moreover, studies indicate that various situational factors and driver characteristics – especially age – seem to influence (the frequency of) risky overtaking: younger drivers tend to be more likely to engage in risky overtaking manoeuvres, than older drivers. This seems to be also the case for other situational factors (traffic volume, speed) and driver characteristics (gender).

A4 Risk taking – Close following behaviour

COLOUR CODE: YELLOW

Although following too closely is seen as one of the main reasons for rear end crashes, studies that evaluate the risk of this behaviour in connection to accidents are rare. However, if headway distances are so short that it is no longer possible to stop in time in the case of an emergency stop, it can be presumed as risky. Quite a proportion of drivers engage in such a behaviour. Results of one study indicate a higher crash risk for short headways.

ABSTRACT

Headway is the distance from a following vehicle to a lead vehicle in a traffic following situation. A minimum headway distance of two seconds to the vehicle in front is generally recommended as safe. Considerably shorter headways for a longer period are seen as risky and addressed as tailgating. Headway distance is mainly measured in seconds (time headway), which is independent from velocity, or meters (headway distance). The prevalence of close following behaviour in traffic differs considerably depending on the location, traffic situation, time of the day and type of measurement (prevalence of risky drivers, prevalence of driving time).
Studies which evaluate the risk of this behaviour in connection to accidents are rare. One naturalistic driving study shows an increased crash risk for close following behaviour with a low prevalence of this behaviour present in the driving condition. Several driving characteristics and situational factors such as age, personality, weather and presence of roadworks seem to have an effect on the choice of headway distance.

A5 Cell phone use – Handheld

COLOUR CODE: RED

Handheld cell phone use for conversation creates negative impacts on road safety, with a very large number of studies presenting findings to support that. Those studies have good levels of quality, and are overall consistent in their results.

ABSTRACT

The use of handheld cell phones induces a level of distraction to the person driving. This distraction translates to slower reaction times to events, increased percentages of time with eyes off the road, speeding, increased number of crashes and near misses. and also increased crash injury severities. Thirteen high quality studies, including four meta-analyses, regarding various related topics were coded. On a basis of both study and effect numbers, it can be argued that handheld cell phone use creates negative impacts on road safety, with most factors being statistically significant. Some studies, however, reported no statistically significant relation of cell phone use to various road safety variables (including behavioural factors) or even positive effects from overcompensation. The presence of meta-analyses makes the results generally transferable.

A6 Cell phone use – Texting

COLOUR CODE: RED

Texting creates negative impacts on road safety with a large number of studies presenting findings to support that. Those studies have good levels of quality, and are overall consistent in their results.

ABSTRACT

The use of cell phones for texting induces a level of distraction to the person driving. This distraction translates to an increase of accidents and near misses, injury severities, reaction times to events, percentage of time with eyes off the road, speeding, and to inconsistencies in driving behaviour. Eight high quality studies regarding various texting topics were coded. On a basis of both study and effect numbers, it can be argued that texting via cell phones or other devices creates negative impacts on road safety, with most factors being statistically significant. Some studies reported no statistically significant relation of texting to various road safety variables (including behavioural factors). The presence of meta-analyses makes the results generally transferable.

A7 Distraction – Music and entertainment systems

COLOUR CODE: GREY

The effects of listening to music while driving have been suspected to link to accidents, and thus many scientific studies have been conducted to investigate the matter. The coded studies have good quality, but they fail to settle to a common conclusion for the effects of this risk factor, or in some cases even reach opposite results. As there is a balance between positive and negative effects, and there are many uncertainties, the overall impact of listening to music while driving must be characterised as unclear.

ABSTRACT

The employment of music for entertainment while driving induces a level of distraction to the person driving. The specific impacts of these distractions vary, but in general music has an unclear impact on road safety. While in absolute numbers many of the effects of this risk factor are detrimental, there are many beneficial impacts as well, and a considerable number of variables remain statistically non-significant (not sufficiently) related to music. Driver behaviour variables such as speed and (lateral) positioning are affected. There is evidence to support that overcompensation occurs by certain drivers, but whether the overall, collective effects of this risk factor are negated is still unclear. The results of the analysis are generally transferable. The majority of the studies were quasi- or experimental studies with the capability to investigate various behavioural variables.

A8 Operating devices

COLOUR CODE: GREY

The effects of operating devices while driving have been suspected to link to accidents, and thus many relevant scientific studies have been conducted to investigate the matter. The coded studies have good levels of quality, however, they fail to settle to a common conclusion for the effects of these risk factor. As there are both positive and negative effects, and a lot of uncertainties, the overall impact of operating devices is characterised as 'unclear', which might turn into 'probably risky' if indirect indicators are taken into account.

ABSTRACT

The use or operation of various devices (generally IVIS) while driving induces many distractions to the person driving. The specific impacts of these distractions vary, but in general it can be assumed that driver behavioural variables are affected. Six high quality studies regarding various IVIS topics were coded. On a basis of both study and effect numbers, it can be argued that operating devices have an unclear impact on road safety, with most factors not being statistically significant. There were cases, however, that reported increased crash counts and reaction times to events (e.g. bicycle appearance) when distracted by IVIS. The results are moderately transferable.

A9 Distraction – Cognitive overload, inattention

COLOUR CODE: YELLOW

The effects of inattention due to daydreaming or state of mind (e.g. pondering and cognitive overload) while driving have been suspected to link to accidents. The coded studies have good levels of quality and decent consistency, though there are some unclear areas. As there are more detrimental effects to road safety than beneficial ones, the overall impact of these factors is characterised as probably risky.

ABSTRACT

The inattention of drivers through loss of focus, daydreaming or state of mind induces a level of distraction to the person driving. On a basis of both study and effect numbers, it can be argued that inattention while driving has a likely detrimental effect on road safety. The specific impacts of these distractions vary, but they are negative and in general it can be assumed that driver behavioural variables such as perception and braking performance are affected. There are some positive results that show reduced injury severity or increased perception, but these occur mainly due to overcompensation, and the effects and are limited. The results of the analysis are generally transferable with caution. The majority of the studies were observational/case control studies which investigated past accident data.

A10 Conversation with Passengers

COLOUR CODE: RED

The meta-analyses carried out showed that conversation with passengers (both adults and children) has a negative impact on road safety. There is also evidence that conversation with passenger slows down reaction times and increases injury severity, but more studies are needed to further support this statement.

ABSTRACT

Conversation and other interactions with passengers induce a level of distraction to the person driving. This distraction translates to slower reaction times to events or to increased severity of driver injuries in accidents. On a basis of both study and effect numbers, it is observed that a consistent non-negligible proportion of road accidents is caused by driver conversation with passengers in the vehicle. The results of the meta-analyses carried out confirmed this trend and showed that this proportion is significant. In general, findings for this risk factor are transferable, though caution and care against oversimplification are always required.

A11 Fatigue – Not enough sleep, driving while tired

COLOUR CODE: RED

Most studies suggest that in general sleepiness/fatigue increases the risk of road traffic accidents. However, the wide range of methodologies used makes it difficult to compare results.

ABSTRACT

Fatigue is examined in terms of drivers who have not had enough sleep or more generally driving while feeling tired irrespective of how this was caused. Fatigue and road traffic accident risk is studied and measured in a variety of different ways in the scientific literature. This includes both directly observing fatigue symptoms and more commonly using self-report methodologies to capture information on sleep habits and sleepiness while driving. Both accidents and near miss events are focussed on, and participants have been recruited directly following a road traffic accident or at a stop point during a journey. There appears to be relatively strong evidence for sleepiness at the wheel/not having enough sleep increasing the risk of professional drivers being involved in safety critical events. For car drivers, when participants report actually falling asleep at the wheel (or display drowsy behaviour), the risk of having a road traffic crash is substantially higher. However, differences between sleepy and alert drivers are sometimes small or non-significant and the variation in methodologies make comparisons between studies problematic.

A12 Fatigue – Sleep disorders – Obstructive sleep apnea

COLOUR CODE: RED

Studies consistently show that untreated Obstructive Sleep Apnea is associated with increased risk for road traffic accidents.

ABSTRACT

Obstructive Sleep Apnoea (OSA) is where the muscles and tissue in the airway collapse during sleep and cause the airway to be blocked. This can cause the sufferer to partially wake repeatedly through the night. OSA can therefore result in sleep deprivation and feelings of sleepiness during the day. The severity of OSA is measured using the Apnea-Hypopnoea Index (AHI) which gives a score of the number of apnea (airway collapse) episodes that occur per hour. Studies usually include a group of participants with untreated OSA and a control group and the number of accidents experienced in each group, as measured by self-report or police registry, is compared. The studies examined here, in general, suggest that a driver is 2-3 times more likely to have been involved in an accident if suffering from untreated OSA with the risk of truck drivers with OSA being potentially higher. However, although the measure of OSA is often objective, self-report methodologies are commonly used to gather information on accidents which may lead to accident risk being under or over stated.

A13 Functional impairment – Hearing loss

COLOUR CODE: GREY

Reduced hearing, or hearing loss, is generally not considered to reduce road safety, but there is limited and inconsistent research on the subject. There is a lack of studies that quantify the effect of hearing loss on road safety in terms of crash risk, and overall, they cannot show a clear association between hearing loss and increased crash risk.

ABSTRACT

Hearing loss is one of the most frequent sensory deficits, of which prevalence increases with age. Research regarding the effect of hearing loss on road safety is limited, and the empirical findings are inconsistent. Studies that quantified the effect of reduced hearing on road safety in terms of crash risk are rare. The few studies that have been identified do not show a clear association between reduced hearing and increased crash risk. The studies have used approaches similar to case-control, which means that the crash rates of individuals with hearing loss (cases) are compared with crash rates of individuals without hearing loss (controls). Study deficiencies are that the degrees of hearing loss are not measured among the participants, or that the degrees are not classified in the same way across studies. Reduced hearing is commonly correlated with increased age, but the majority of studies control for this in the analysis. It is possible that drivers gradually adopt compensation or adaptation strategies as the hearing becomes more and more reduced. Such strategies may reduce negative effects from hearing loss on their driving.

A14 Functional impairment – Vision loss

COLOUR CODE: YELLOW

The current knowledge about visual impairments and crash risk suggests that visual acuity is very weakly associated with crash risk, while contrast sensitivity, visual field, and in particular cognitive aspects of vision have better evidence for their relevance to road safety.

ABSTRACT

The current knowledge about visual impairments and elevated crash risk suggests that visual acuity (generally tested during application for a driving license) is very weakly associated with crash risk, while contrast sensitivity, visual field, and cognitive aspects of vision have some, or thorough, evidence for their relevance to road safety. Impaired vision is much correlated with increased age and the elderly. Therefore, several studies focus on road users 50 years of age or older. With advanced age, other medical and functional co-morbidities follow that are potential confounders in the relationship between vision and road safety – in particular cognitive impairments. The majority of studies have used case-control approaches, usually meaning that the crash rates of individuals with vision impairments (cases) are compared with crash rates of individuals without vision impairment(s) (controls).

A15 Diseases and disorders – Diabetes

COLOUR CODE: YELLOW

Studies generally show a (slightly) elevated crash risk. However, effects are not always statistically significant. Many studies have low quality, e.g. because they did not adjust for exposure or mileage. Furthermore, the results are possibly compromised by national countermeasures, e.g., some countries impose driving restrictions on drivers with insulin-treated diabetes. When the higher risk diabetes drivers are not allowed to participate in traffic, this will affect the overall risk of diabetes identified in that country.

ABSTRACT

This synopsis discusses the effect of diabetes on road safety. Diabetes mellitus is a group of metabolic diseases characterised by defects in insulin secretion, insulin action, or both. Studies generally show a (slightly) elevated risk for drivers with diabetes, although differences are often not statistically significant. Two main approaches have been used to study the relationship between diabetes and crash risk. The most common approach compares crash rates of individuals with diabetes with crash rates of individuals without diabetes. The less common approach first distinguishes between drivers who have and who have not been involved in a crash, and then compares the prevalence of diabetes in these two groups. Most research has been done in the USA, Canada, and Europe. Most of the research is on private drivers; very few studies are on commercial drivers.

A16 Personal factors – Sensation seeking

COLOUR CODE: YELLOW

Studies generally show an association between sensation seeking and self-reported risky driving and self-reported crashes. However, the independent effect of sensation seeking is generally small, and the causal relationship is not always clear. Moreover, in nearly all studies the association may be inflated by research biases and, hence, overestimated.

ABSTRACT

Sensation seeking is a personality trait that steers people at “varied, novel, complex and intense sensations and experiences” and at “accepting the physical, social, legal, and financial risks for the sake of such experiences”. Sensation seeking can have an immediate, direct effect on driving behaviour and crashes because sensation seekers are more inclined to look for new, exciting and intense sensations of, for example, driving fast and recklessly. Generally, the results show that sensation seeking is associated with self-reported risky driving behaviours, such as speeding, risky overtaking, alcohol-impaired driving, driving with multiple passengers, and with self-reported crash-

involvement. Various studies show that this effect is robust after control for demographic and other personality variables. However, the independent effect of sensation seeking is generally small, its causal interpretation is not always clear, and in nearly all survey research the reported association may be inflated or exaggerated by research biases. In summary, although there is fairly consistent evidence that sensation seeking is linked to risky driving behaviours and road crashes, the independent, direct effect of sensation seeking is rather small and may be overestimated.

A17 Emotions – Anger, aggression

COLOUR CODE: YELLOW

The relationship between emotion and crash risk varies depending on the mode of measurement (simulator, questionnaire, different decision-making tests, self-reported crashes etc.). Moreover, emotions are induced in different ways (by pictures and videos, emotional recall, traffic events etc.) and their prevalence can only be concluded from self-ratings. Therefore, results are inconsistent but show a tendency to an elevated crash risk, though not always statistically significant.

ABSTRACT

There is no consensus about an unambiguous definition for emotion. However, in common speech, it is any relatively brief mental experience with intensity and a high degree of pleasure or displeasure (Cabanac, 2002). Most research in this field is based on the appraisal theory. According to appraisal theory, the particular judgments about a stimulus cause emotion (Scherer et al., 2001). Studies generally indicate a (slightly) higher risk for drivers who show emotion, typically anger or aggression, while driving, although differences are often not statistically significant. Most research has been done in Europe and USA and was conducted at universities with students as participants. Only car drivers have been investigated. There is no information on vulnerable road users. Due to the kind of study interests, studies with control groups (in the sense of "neutral" emotions) are rare.

Appendix B: Road safety measure colour codes and abstracts[11]

B1 Law and enforcement: Lowering BAC limits (general and for novice drivers)

COLOUR CODE: LIGHT GREEN

The effects of laws introducing BAC limits are mostly positive in reducing crash frequency and reducing especially the number of mainly alcohol-related fatal/injury accidents. The per-se law, together with enforcement and other DWI laws, has a deterrent power that discourages offences. Furthermore, the coded studies have some good levels of quality and consistency. On the other hand, many studies showed no effect on road safety and two studies indicated an increase of fatal crashes. For the reasons mentioned above, the overall impact of BAC laws is characterized as light green (effective).

ABSTRACT

Laws limiting blood alcohol concentration have been introduced worldwide in order to diminish the frequency of alcohol-related fatal/injury crashes. These laws (and their implementation) aim to discourage drivers from drinking and driving. Zero tolerance laws were introduced for young drivers,

[11] The colour code explainations and abstracts of road user related measures were first published in SafetyCube's deliverable 4.2. All synopses underwent an internal quality assurance procedures and some have been updated accordingly. Therefore, some of the here presented contents differ from deliverable 4.2. The most recent versions will always be the ones available through the DSS.

in order to address the issue of driving while impaired among inexperienced drivers. The implementation of these laws, either alone or combined with other DWI laws and enforcement, affects the level of road safety and causes a reduction in the number of crashes. Ten high quality studies involving lowering BAC limits were coded. On the basis of both study and effect numbers, it can be argued that limiting BAC for drivers create positive impacts on road safety. However, some scarce cases reported opposite results, indicating increases in total crashes.

B2 Law and enforcement: Mobile phone use

COLOUR CODE: GREY

The effects of implementing laws and increasing enforcement against mobile phone use while driving are mixed. To date, studies have shown positive, positive without statistical evaluation, non-significant and even negative effects.

ABSTRACT

Laws and enforcement against mobile phone use while driving are widely used as safety measures to prevent drivers from talking, texting or dialling while driving. In that context, fifteen high quality studies were coded. In general, there is some indication that laws and enforcement have a positive impact on road safety and most specifically on self-reported and observed mobile phone use while driving. However, in a number of studies, statistical evaluation is absent and some other studies indicate non-significant and even negative effects. Meta-analyses showed a negative effect of laws on drivers' mobile phone use and furthermore, there is no evidence of a reduction in crashes or fatalities. Consequently, on a basis of both study and effect numbers, it can be argued that the evidence for a road safety effect of laws and enforcement against mobile phone use is far from conclusive. This topic needs further investigation and statistical evaluation.

B3 Increasing traffic fines

COLOUR CODE: LIGHT GREEN

There is evidence that higher fines are associated with less traffic violations, but effects may be limited in time and place.

ABSTRACT

Penalties for traffic violations, e.g. in the form of fines, are part of the traffic law enforcement chain. According to deterrence theory, a sufficiently high chance of detection of a violation and a sufficiently high penalty will deter road users from committing traffic violations. This synopsis describes the effects of fine increase on several road safety indicators. Studies on fines and road safety have linked the increase in fines to changes in traffic violations, changes in recidivism (re-offending), and changes in crashes. A 2016 meta-analysis indicated that fine increases between 50 and 100% are associated with a 15% decrease in violations; that fine increases of up to 50% do not influence violations, and that fine increases over 100% are associated with a 4% increase in violations and thus tend to be counterproductive. The effects of a fine increase on recidivism are mixed, but the more severe and frequent offenders do not seem to be influenced by a fine increase. An increase of fines was associated with a 5-10% reduction in all crashes, and a 1-12% reduction in fatal crashes. In general, studies had insufficiently controlled for confounding factors and results should be interpreted cautiously. Moreover, most studies looked at the effect immediately after a change in fines and at places with high enforcement levels. Therefore, the possibility that the reported effects are limited in time and place cannot be excluded.

B4 Hours of service regulation for commercial drivers

COLOUR CODE: LIGHT GREEN

Some but not all studies indicate that regulations concerning driving times and rest time or hours of service have reduced commercial driver fatigue and fatigue-related accidents. The impact of hours of service regulations on fatigue and accident risk depends upon multiple factors, including enforcement and monitoring, economic market pressure, and types of affected driver schedules.

ABSTRACT

'Driving hour and rest time' or 'hours of service' (HOS) regulations are regulations that limit when and for how long drivers of commercial goods or passenger vehicles are allowed to drive and/or work during a particular period. The purpose of these regulations is to reduce driver fatigue and to reduce fatigue-related accidents. The levels of enforcement of these regulations were found to vary and to be low in many countries. Both in Europe and the USA high violation levels of the regulations have been noted. In Europe, there is no direct evidence that HOS regulations have reduced average driving times, driver fatigue, or accidents. In the USA, the evidence of the safety effectiveness of HOS regulations is mixed. Both positive and negative findings have been reported, in terms of change in driving and rest time, sleep, and accidents. There is evidence that increased or improved monitoring or enforcement of HOS regulations leads to higher compliance and more safety.

B5 Demerit point systems

COLOUR CODE: LIGHT GREEN

There is some indication that Demerit Point Systems can reduce road safety risk, however in practice the effects wear off rather quickly.

ABSTRACT

With a demerit point system, demerit points are meted out to traffic offenders in addition to the normal penalty. Generally, more demerit points are meted out when the offence is more serious. If a defined points' limit is exceeded, suspension of the licence follows. In most cases the traffic offender needs to prove that he is capable of driving safely by following a driving course or by some other measure. A 2012 worldwide meta-analysis indicated that demerit point systems have a positive effect in reducing the number of traffic violations as well as the number of accidents, fatalities and injuries. However, the effects appeared to wear off in less than 18 months. This is probably due to low or decreasing levels of enforcement resulting in a small chance that traffic offences are detected. It can be expected that point systems achieve longer lasting safety effects when enforcement levels are sufficiently high and sustained over time. In addition, a demerit point system can be expected to be more effective when the system includes a broad scope of major dangerous traffic violations (speed, alcohol, red light, use of seat belts/helmet/child restraints, dangerous overtaking, priority rules, headway distance), when intermediate measures (such as warning letters and educational measures) are targeted at specific groups of offenders, and when the point system, including its communication and administration, is simple, transparent and fair.

B6 Red light cameras

COLOUR CODE: LIGHT GREEN

Studies indicate that red light cameras decrease right-angle crashes, but at the same time increase rear-end and other types of crashes. Since rear-end crashes are often associated with less severe injury than right-angle crashes, it may be assumed that the net effect on road safety is positive.

ABSTRACT

Red light cameras (RLCs) are one of several possible countermeasures against red light running. Red light running is a risky traffic violation since it is associated with very serious, high injury crashes. Besides red light cameras, other countermeasures may include improving the driver's view of the intersection, converting intersection to roundabout, producing a raised intersection or improving the traffic signal phasing. A 2013 meta-analysis indicated that RLCs decrease right-angle injury collisions by 33%, but at the same time increase injury rear-end collisions by 19%. Several North-American studies after the meta-analysis, one European study and one Korean study, have confirmed that RLCs reduce right-angle crashes, but at the same time increase rear-end crashes and other types of crashes. Since rear-end crashes are often associated with less severe injury than right-angle crashes, it may be assumed that the net effect on road safety is positive. RLCs have been found to achieve larger road safety effects when red light violations are deliberate, when intersections have a high proportion of right-angle crashes and a lower proportion of rear-end crashes, when cameras are signposted, and when cameras are in continuous operation rather than rotational.

B7 Licence suspension

COLOUR CODE: GREEN

Studies indicate that licence suspension (or licence revocation) is an effective measure for reducing violations and crashes of (repeat) offenders.

ABSTRACT

In most countries, a licence suspension means a temporary withdrawal of the privilege to drive a motorised vehicle. Most often after a fixed period of time and after fulfilling certain conditions (e.g. paying a fee, and/or participating in a rehabilitation programme), the driving privileges will be restored. There are two basic ways in which licence suspension may improve road safety. First, the threat of licence suspension may motivate drivers to improve their traffic behaviour and to abstain from risky driving. Second, licence suspension temporarily removes risky drivers from traffic. Studies indicate that licence suspension (and also licence revocation) is effective in reducing crashes and violations of repeat offenders. A 2004 meta-analysis estimated that licence suspension or revocation measures reduce crashes and violations of suspended offenders by 17% and21% respectively. A 2009 meta-analysis indicated that administrative licence suspension laws reduce all fatal accidents by 4%. It should be added that for specific groups of offenders, such as drink-drivers, other sanction measures, in particular the alcohol-interlock measure, is likely to produce larger road safety benefits than licence suspension. Also, the combination of licence suspension and other measures, such as rehabilitation programmes or vehicle impoundment, is likely to perform better than licence suspension as a single measure.

B8 Education – Pedestrian skills training for children

COLOUR CODE: LIGHT GREEN

There is some evidence, including a meta-analysis, that behaviour based education/training for children in pedestrian skills can improve the skills that children require to cross the road. However, some studies had mixed results and those with follow up results suggested that the benefit of training may reduce over time.

ABSTRACT

There is some evidence, including a meta-analysis, that behaviour based education/training for children in pedestrian skills can improve the skills that children require to cross the road. However, it is not clear how sustained this improvement is over time, and the age of the children undertaking training may have an impact on its success. There may also be an increased risk when skills are beginning to be learned until children fully master them. Education/training has been linked to reduced numbers of accidents involving child pedestrians. However, this has not been studied recently and therefore the link between education/training and accidents is unclear for more recent studies.

B9 Education – Non-statutory training for novice drivers

COLOUR CODE: GREY

The five analysed studies report a mixture of significant and none significant results, and differences in methodologies prevent the comparison of results. The available evidence does not support that there is a reliable link between voluntary training and skill improvement/risk reduction.

ABSTRACT

The accident risk of young (aged <25 years old) and novice drivers is greater than that of the general driving population. Five studies focusing on education and voluntary training for young/novice drivers were examined. Their focus was on skills improvement (cognitive and vehicle handling) and on reducing risky behaviour such as speeding and driving under the influence of alcohol. Training was a mixture of on road and simulator training as well as classroom based training. Skills/behaviour/attitudes were assessed using on-road or simulated driving tests or questionnaires. Not all results were compared with an independent control group, and self-assessed behaviour or attitudes may not represent actual behaviour. Results showed a mixture of significant and non-significant findings for both driving skills and reducing risky behaviour. There was insufficient evidence to establish a link between the education/training reported here and improved skills and reduced risky behaviour.

B10 Driver training and licensing – formal pre-license training, graduated driver licensing and probation

COLOUR CODE: LIGHT GREEN

Graduated driver licensing (GDL) seems to be effective in improving 16 to 17 year-old drivers' road safety, but the results are less consistent for older drivers, aged 18 to 20 years. In the majority of the coded studies, the implementation of a strict GDL entails a reduction of the crash rate (overall, fatal, or injury-related). However, in a few studies the effect is not significant, and sometimes opposite. Regarding the formal pre-license training, it seems that completing a mandatory specific training or a computer-based training improves road safety and simulated driving performance. However, it has also been shown that an intensive driving course and time-discount were detrimental for novice drivers' road safety.

ABSTRACT

Young drivers are disproportionately represented in motor vehicle collisions. Graduated driver licensing (GDL) programmes and a probationary licence were progressively introduced in several countries worldwide since the early 1970s in order to reduce fatal crashes and high-risk behaviours of teen drivers. The 34 reviewed studies (four meta-analyses and thirty original papers) focused on the effect of the GDL and formal pre-license training (FPLT) on learner and novice drivers' road safety. Before-after studies or time series analyses (21), cohort studies (4), longitudinal or observational studies (2), and quasi-experimental or experimental studies (3) were used to investigate the effect of GDL and FPLT on crash rate (overall, fatal, leading to severe injury, occurring during the night, or in presence of passengers) and traffic violations. Most of the studies were conducted on car drivers from the United States (n = 21). It is important to note that only two studies focused on powered two wheelers showing a lack of investigation on these at-risk road users. The results tend to indicate that GDL and FPLT have a general positive effect on road safety, but some inconsistent results were noted regarding drivers of 18 years and older. More specifically, GDL and FPLT appear to reduce crash rates for younger drivers and, consequently, for their passengers and other road users. They also appear, to a small extent, to improve driving behaviour. However, these effects are sometimes reversed for older drivers (>18 years).

B11 Alcohol interlock

COLOUR CODE: GREEN

The results of the research on the effectiveness of the alcohol interlock are positive in terms of reducing recidivism. However, once the device is uninstalled, the recidivism rates become comparable to those in the control group. Therefore, the effect on road safety is positive, but only while the device is installed.

ABSTRACT

For many years, drink-driving has posed a serious threat to road safety. That threat can be countered most efficiently by preventing drunk drivers from driving. An alcohol interlock can verify whether or not a driver's Blood Alcohol Concentration (BAC) is lower than the maximum threshold set by the legislator. If the driver's BAC exceeds that threshold, the vehicle will not start, and as a result prevents driving. In relevant studies, the recidivism rates are typically compared between offenders who had an alcohol interlock installed (experimental group) and those who did not (control group). Such a comparison can be carried out during the period while the device is installed and/or during a follow-up period after the device is removed. The results from a recent meta-analysis show that installing an alcohol interlock reduces recidivism risk by 75%. However, in a follow-up period after the alcohol interlock is removed, recidivism risk is only decreased by 7% compared to the control group. That difference is not statistically different from those who had not installed an alcohol interlock. A similar pattern of results also emerges from most recent studies. Alcohol interlocks do what they promise to do: while installed they reduce the risk on drink-driving. However, once removed the recidivism rates increase towards their initial level.

B12 Rehabilitation courses as measure for drink-driving offenders

COLOUR CODE: LIGHT GREEN

The most recent studies indicate that rehabilitation courses – if properly performed – can reduce the likelihood of recidivism. There are, however, also studies that did not find an effect.

ABSTRACT

The main purpose of rehabilitation courses is to reduce recidivism with respect to drink-driving offences. Such a course is educational or psychologically oriented, and typically organised in small groups. Recent studies were analysed. The main outcome variable in all of these studies was recidivism for 'driving under the influence of alcohol' (DUI) in the 2 to 3 years following the course. Participants were compared to non-participants (e.g., DUI-offenders who were charged with a more traditional sentence such as a prison sentence). The results show that rehabilitation courses for DUI-offenders – if properly performed – can reduce recidivism and thus have a positive effect on road safety. Important characteristics of a course are a focus on behavioural change (i.e. concrete plan of what to do when a relapse is imminent) rather than simply providing information. Furthermore, it should be spread over at least several weeks. A meta-analysis of the six most recent studies with an acceptable methodology suggests that rehabilitation courses can reduce recidivism by 40%. The present meta-analysis is more positive than previous ones, as several older studies found no effect or an effect that disappeared very quickly. The difference could be due to an improvement in the courses evaluated in the more recent studies. A general weakness of almost all studies in this area lies in the comparison of programme participants to non-participating DUI-offenders, who did either not qualify for the programme or not volunteer for it. The control group usually has a-priori a higher risk on recidivism which would add to the effect of the course. Matching or statistical methods help to correct for this – but one can never be sure whether all differences have been taken into account.

B13 Age-based screening of elderly drivers

COLOUR CODE: RED

Although studied by a number of good quality studies, age-based screening of all elderly drivers for fitness to drive has not been found to reduce fatalities. At the same time, there are indications that it might increase fatalities among elderly pedestrians and the average risk per licensed (elderly) driver.

ABSTRACT

Due to the increased numbers and mobility of elderly drivers in most industrialised countries, there has been a growing concern to assure the fitness of elderly drivers. Therefore, many countries have introduced additional re-licensing requirements like vision tests, medical check-ups, or on-road driving tests for all drivers from a certain age on (most often 70 years). From a scientific point of view there is no indication that age-based screening of elderly drivers improves road safety. Although a good number of studies from Europe, Canada, and Australia have investigated this effect in the last decade, no effect of increased safety was found. On the contrary, there are indications that the measure might have two unwanted side-effects: (1) increased accident risk per licensed driver, and (2) an increase of pedestrian fatality rate. However, studies from the United States indicate that obliging drivers to appear in person for licence renewal, rather than allowing re-licensing on-line or per mail has a beneficial effect on the number of fatal crashes involving elderly drivers.

B14 Fitness to drive assessment tools for medical referrals

COLOUR CODE: LIGHT GREEN

A number of the evaluated off-road tests appear to have some potential for predicting driving performance, and for identifying drivers who do not require an "on-road fitness to drive" assessment. However, most of the studied tests are not sufficiently accurate to predict on-road performance as a replacement for on-road assessment.

ABSTRACT

The overall aim of fitness to drive assessment is to determine whether a driver with functional impairments will be able to drive a car, and where limitations are detected, determine how these can be compensated for. This synopsis reviews studies evaluating whether off-road assessment tools can replace on-road testing (at least partly) in this process. None of the evaluated tests (N=14) perfectly predicts driving performance. Thus, none would be able to fully replace on-road driving assessment. Drive-Safe/DriveAware and SMC Tests have the highest reported sensitivity and specificity. These have the potential to eliminate the need for on-road testing for a substantial proportion of the tested drivers. However, replication studies are required, particularly because the results depend on the composition of the tested group.

B15 Effectiveness of road safety campaigns

COLOUR CODE: LIGHT GREEN

There is some indication that campaigns are beneficial for road safety on various levels. Meta-analyses show an association with accident reduction, increased safe behaviours and risk awareness. However, for other outcome variables such as drink-driving or safety relevant attitudes, no such effect was found. Furthermore, meta-analysed studies vary strongly, mainly regarding the design of the evaluated campaigns.

ABSTRACT

Road safety communication campaigns aim at informing, persuading and motivating people to change attitudes and behaviour and ultimately at improving road safety.
Two meta-analyses on campaigns with various road safety themes showed an association with a reduction of accident occurrence (9%) as well as a favourable change in (observed and self-reported) seat belt use (+25%), yielding behaviour (+37%), speeding behaviour (-16%) and risk comprehension (+16%). No significant changes are indicated, however, for drink-driving behaviour, favourable road safety attitudes and knowledge. Often, when road safety campaigns are implemented, they are accompanied by increased enforcement. Accounting for this factor, a decrease in accidents can still be found in a meta-analysis due to campaigns solely, however, a smaller one (10% vs. 13% for campaigns combined with enforcement).

B16 Awareness raising and campaigns – Seatbelts

COLOUR CODE: LIGHT GREEN

Results consistently show that seatbelt campaigns, in combination with legislation and/or police enforcement, increase seatbelt use. As seatbelt use reduces injury severity significantly, this will have a positive impact on road safety. The stand-alone effect of seatbelt campaigns could not be determined.

ABSTRACT

The main purpose of seatbelt campaigns is to encourage car occupants to use seatbelts. Meta-analyses evaluating mainly studies from the 1980s or early 1990s showed a significant positive average effect on seat belt use (an increase of 15 to 25%). Studies, conducted in recent years, indicate a minor increase of general observed seatbelt usage (+1.8%-6.4%). This can be attributed to an already high baseline rate. Furthermore, it should be noted that all analysed seatbelt campaigns were accompanied by strong enforcement activities or law changes. Therefore, it is not clear to what extent the effects are attributable to the campaign itself. Moreover, transferability to European countries might not be possible as most coded studies were carried out in the USA.

B17 Awareness raising and campaigns – Child restraint

COLOUR CODE: LIGHT GREEN

Results show that child restraint campaigns have significant positive effects on child restraint use. However, most campaigns do not indicate long-term effects. Furthermore, only a few studies on evaluations of child restraints could be found and the quality of some studies was not satisfactory.

ABSTRACT

The main purpose of child restraint campaigns is to promote the safety of children in vehicles by using child restraints.
Results provide some indication that campaigns on child restraint usage have positive effects on road safety. Studies which measure observed child restraint use show a significant increase between 12% and 28%. Self-reported child restraint use increases between 23% and 30%. No clear statement can be drawn on influencing knowledge and attitudes as studies use different theoretical approaches and measurements. However, there are some indication that knowledge and some attitudes can be improved by campaigns.
Results should be considered carefully, as the methodology of some studies is quite poor. Furthermore, the identification of long term effects has not been adequately studied.

B18 Awareness raising and campaigns – Driving under the influence

COLOUR CODE: LIGHT GREEN

There is some indication that drink-driving campaigns have a positive impact on attitudes towards drink-driving and even on the related accident occurrence. There is less evidence of the effectiveness of designated driver programmes.

ABSTRACT

The main purpose of DUI (Driving Under the Influence) campaigns is to raise awareness regarding impaired driving as well as to promote sober driving. Results provide some indication that drink-driving campaigns can have positive effects on road safety. One out of two meta-analyses showed an association with crash reduction. A further meta-analysis and other individual studies with indirect outcome measures showed mixed results. While self-reported drink-driving behaviour did not considerably change, attitudes towards drink-driving were favourably influenced to some extent. Designated driver programmes (assigning someone to not drink and drive and to bring others home safely) seem to have lower potential to prevent drink-driving. However, most of the coded individual studies focus on young drivers and to some extent on passengers aged up to 34 years. Thus, conclusions can only be drawn regarding this age group. Furthermore, it should be noted that some analysed DUI campaigns were accompanied by enforcement activities. Therefore, it is not clear to what extent the effects are attributable to the campaign itself.

B19 Awareness raising and campaigns – Speeding

COLOUR CODE: LIGHT GREEN

Results show that anti-speeding campaigns can have significant positive effects on road safety (behaviour). However, some campaigns are combined with enforcement activities, while others do not indicate long-term effects or do not take other indirect effects, like changes in traffic, into account.

ABSTRACT

The main purpose of speeding campaigns is to raise awareness regarding speeding and inappropriate speed, that is speed not adapted to the prevailing traffic, road or weather conditions. Results provide some indication that speeding campaigns have a positive effect on road safety. A meta-analysis showed a significant 16% reduction in speeding. While one individual study reported a 30-45% decrease of fatalities and significant changes in attitudes and behaviour, some other studies did not find any significant changes either in actual behaviour, or in attitudes.
Further, it should be noted that some analysed speeding campaigns were accompanied by enforcement activities. Therefore, it is not clear to what extent the effects are attributable to the campaign itself.

B20 Awareness raising and campaigns – Aggressive and inconsiderate behaviour

COLOUR CODE: LIGHT GREEN

There is some indication that campaigns addressing aggressive, unsafe or inconsiderate behaviour in road traffic have a positive impact on accident occurrence and self-reported (un)safe and (in)considerate behaviour.

ABSTRACT

The main purpose of campaigns addressing aggressive, unsafe or inconsiderate behaviour in road traffic is to raise awareness as well as to promote considerate behaviour towards other road users. Results provide some indications that campaigns targeting aggressive or inconsiderate behaviour can have positive effects on road safety. Some studies indicate an association with the number of killed and injured car passengers, non-fatal and severe injuries or at fault accidents. However, campaign evaluations with indirect outcome measures showed rather mixed results: significant reduction in speeding, non-significant change in unsafe behaviour and rule violations.
Furthermore, it should be noted that the studies considered are quite different regarding the exposure variable(s) (different aims and resources of campaigns) and outcome measures, and have at least minor limitations: combining a campaign with other road safety measures is often seen and a detailed documentation of evaluation methods is missing in some cases.

B21 Education and training – Hazard perception training

COLOUR CODE: GREEN

The results from the available literature indicate that hazard perception training/education can significantly improve the hazard perception skills of drivers as well as reduce accident rates and speeds. As most of the studies performed statistical analyses, and the vast majority of the results were statistically significant, there is evidence that hazard perception training brings about enhanced hazard avoidance skills. Consequently, drivers who have undertaken hazard perception training are less likely to cause accidents or drive with high speeds, thus it can be concluded that hazard perception training reduces road safety risk.

ABSTRACT

Hazard perception training aims to enhance the ability of road users to detect and avoid hazards through education or additional training, which is not mandatory, as part of licensing or graduate licensing programmes. For this synopsis, the effects of hazard perception training on road safety were investigated based on ten studies in a relatively wide range of countries. In addition to the effects on hazard perception skills, some studies investigated the effect of training on accident rates and vehicle speeds among car drivers, PTW riders and pedestrians. The dominant approaches to derive the effects of training was the use of driving simulators and quasi-experiments. The results demonstrated that the hazard perception ability of road users is significantly enhanced. Furthermore, in three studies regarding accident rates and vehicle speed, it was revealed that drivers who undertook hazard perception training caused less accidents and drove with lower speeds. In conclusion, hazard perception training appears to significantly enhance road safety.

Appendix C: Cost-benefit analyses of road safety measures – abstracts

C1 Police enforcement of speeding

ABSTRACT

Existing evaluation studies on the effects of general police enforcement and speeding were analysed, and information was synthesized from several sources. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 1.0 which means that the benefits tend to match the costs invested. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

C2 Random breath tests and DUI checkpoints

ABSTRACT

Existing evaluation studies on the effects of random breath tests and DUI (Driving Under the Influence) checkpoints were analysed, and information was synthesized from several sources. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 7.3 which means that the benefits considerably exceed the costs invested. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

C3 Seatbelt enforcement

ABSTRACT

An existing evaluation study on effects of seatbelt enforcement in Norway (Elvik et al., 2009) was revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 1.4 which means that the benefits exceed the costs. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis. Except for two cases, the worst-case scenario and the doubling of measure costs, where the lowest effectiveness estimate is combined with the highest cost, the BCR remains higher than 1.

C4 Alcohol interlock program

ABSTRACT

An existing cost-benefit analysis on the effect of an alcohol interlock program in the Netherlands (SWOV, 2009) is revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 10.9 which means that the benefits substantially exceed the costs. The sensitivity analysis shows that while the BCR is sensitive to changes in the underlying assumptions, the ratio remains higher than 1, which means that the measure remains economically efficient.

C5 Hazard perception training

ABSTRACT

Two existing evaluation studies on cost-benefit effects of hazard perception training in the UK (Crundall, Andrews, Van Loon, & Chapman, 2010) and in Spain (Di Stasi, Contreras, Cándido, Cañas, & Catena, 2011) were used for this report. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. A benefit-to-cost ratio (BCR) was not possible to be calculated as neither of the papers included cost estimates. Although there is evidence that hazard perception training is generally low-cost (e.g. Vlakveld et al., 2011; White, Cunningham & Titchener, 2011), because the corresponding financial requirements concern the acquisition of a driving simulator or a PC, no estimates are given even in official reports such as Grayson & Sexton (2002). However, as figures for prevented crashes were given in Crundall, Andrews, Van Loon & Chapman (2010) and Di Stasi et al. (2011) break-even cost could be calculated.

C6 Red light cameras

ABSTRACT

To perform a cost-benefit analysis (CBA) on red light cameras, safety estimates from a meta-analysis on international red light camera studies (Høye, 2013) were used, and information on the costs of operating a red light cameras (i.e. costs of purchase, installation, maintenance of cameras and cost of administrative and judicial processing of red light offenders) were obtained from Belgian authorities.

The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) of red light cameras is 3.7. This means that in a time span of ten years the (expected) benefits exceed the costs with a ratio of 3.7 to 1.

The first sensitivity analysis checked the effects of two scenario's in which the costs of installation and the recurrent annual costs were either much lower or much higher than the author's estimates. If the measure costs were only 50% of the estimated ones, the BCR would increase to 7.3. If the measure costs were twice as high as the estimated ones, the BCR would decrease to 1.8 which still means that the benefits exceed the costs.

An additional sensitivity analysis was done by using the effect estimates of a European study instead of the meta-analyses by Høye (2013) as it could be argued that the latter is mainly reflecting effects from US and Australian studies. Using the results of De Pauw et al. (2014) yielded slightly different results with an estimated BCR of 4.2.

C7 Graduated driver licensing

ABSTRACT

An evaluation study on cost-benefit effects of graduated driver licensing (GDL) in the USA (National Academies of Sciences Engineering and Medicine; & Transportation Research Board, 2008) was revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 125.1 which means that the benefits tend to exceed the costs considerably. The sensitivity analysis indicates that this is also the case even with an 100% increase in measure costs.

C8 Mandatory eyesight tests

ABSTRACT

An existing cost-benefit analysis on the effect of mandatory eyesight testing in Norway (Vlakveld et al., 2005) is revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 0.5 (excluding side-effects) which means that the costs exceed the benefits and the measure is not economically efficient. Taking into account the side effects (on mobility, commercial transport and the environment) the measure becomes even less efficient with a BCR of 0.2.

C9 Child pedestrian training

ABSTRACT

An existing evaluation study on effects of child pedestrian training in the USA (National Academies of Sciences Engineering and Medicine & Transportation Research Board, 2008) was revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-cost ratio (BCR) is 2.6 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. However, in both the low-cost and high cost scenarios it is shown that child pedestrian training remains economically efficient.

C10 Seatbelt campaign

ABSTRACT

An exemplary cost-benefit analysis (CBA) for seatbelt campaigns was conducted using as a basis the evaluation study on a Dutch seatbelt campaign (Tamis, 2009). The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 44.6 which means that the benefits exceed the costs. The sensitivity analysis indicates that even when calculating a worst-case scenario, the benefits outweigh the costs.

C11 Booster seat campaign

ABSTRACT

An exemplary cost-benefit analysis for booster seat campaigns was conducted using data from NCHRP (2008). The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 4.6 which means that the benefits exceed the costs. The sensitivity analysis indicates that this is also the case even with an 100% increase in measure costs.

C12 Drink-driving advertising campaign

ABSTRACT

An existing evaluation study from the US on cost-benefit outcomes of an advertising campaign tackling drink-driving among young drivers (Murry et al., 1996) was revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used to update the figures. The resulting best estimate of the benefit-to-cost ratio (BCR) is 2.1 which means that the benefits exceed the costs. A sensitivity analysis with 100% increase and 50% decrease in measure costs suggests that the campaign is not sensitive to changes in the underlying assumptions. An increase of 100% in measure costs, however, results in a BCR of 1, which indicates neither exceeding costs nor benefits.