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AM (Accepted Manuscript)

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Kaiser, S., E. Aigner-Breuss, Heike Martensen, Rachel Talbot, and Athanasios Theofilatos. 2019. "Road User Related Risks and Measures – Evidence Based Decision Support for Road Safety Policy". figshare.  
<https://hdl.handle.net/2134/31901>.

## Road user related risks and measures – evidence based decision support for road safety policy

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### Abstract

The EU-funded SafetyCube<sup>†</sup> project aims at facilitating decision making in road safety by providing systematically analysed and assessed scientific evidence on risk factors and countermeasures. While this is done for the areas infrastructure, vehicle and road users, this paper focus solely on the latter. The project outcomes are available online and are targeted at actual decision makers as well as researchers. Various stakeholders were consulted to identify hot topics and the needs of practitioners. The accessible database currently contains about 450 individual study outcomes and synopses with condensed information for 49 road risks (e.g. speeding, drink-driving, fatigue) and measures (fitness to drive, education, enforcement, campaigns, etc.) associated with all kinds of road users (vehicle drivers, cyclists, pedestrians, elderly, young, commercial drivers). In a further step, cost-benefit will be assessed on the basis of the effectiveness of countermeasures. While vehicle and infrastructure related risks and measures are well suited for effect quantification, this is a challenging endeavour for road users for many reasons.

*Keywords:* road safety risks, road safety measures, human risk factors, evaluation, crash risk

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<sup>†</sup> This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 633485

## 1. Introduction

The overall objective of the SafetyCube project, which received funding from the European Commission within Horizon 2020, is to create an online inventory of evaluated road safety risk factors and measures based on scientific, quantitative evidence. Eventually, the aim is to provide decision makers with scientific evidence to tackle road safety problems efficiently. This information is being prepared for both a scientific and a non-scientific audience and will be retrievable through the “Road Safety Decision Support System” (Road Safety DSS; [www.roadsafety-dss.eu](http://www.roadsafety-dss.eu)).

Most risk factors in road traffic are attributable to human behaviour (e.g. speeding) or human characteristics (e.g. age). While SafetyCube also assesses vehicle and infrastructure related risks and measures, this article focuses exclusively on the human aspects of road safety risks and countermeasures. These relate not just to car drivers but to all road user groups, i.e. powered two-wheeler (PTW) riders, cyclists, pedestrians, truck and commercial drivers. Vulnerable road users (VRU) are also considered, namely the elderly, children and young road users, pedestrians, cyclists and PTW riders.

While the evaluation of quantified effects makes various risk factors and countermeasures more comparable, quantifying the effect of certain human aspects, such as age or educational measures, is especially challenging.

## 2. Method

To arrive at an inventory of evaluated road safety risks and measures, a method was developed which was applied in a standardised manner to risks and measures in all categories: road user, infrastructure and vehicle. However, there are a few aspects that are unique to the realm of humans, since behaviour and personal traits oftentimes cannot be observed in simple cause-effect relations to explain road safety outcomes – as will be explained later on.

The process comprised the following steps, each of which will be explained in more detail below:

- Identification of human related risk factors and measures and creation of taxonomies
- Stakeholder consultation to identify ‘hot topics’
- Systematic literature search for studies on safety effects of risk factors and measures
- Coding of identified studies
- Analysis of safety effects on basis of coded studies
- Summarised effects and conclusion in synopses per analysed risk factor or measure

These tasks were conducted in sequence for 1) Human related risk factors and then 2) Human related road safety measures.

### 2.1. Identification of risk factors and measures, systematization in taxonomies and stakeholder priorities

Various pre-existing classifications of road safety risk factors and countermeasures can be found in the literature. 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 and measures were created. The first step was to collect all risk factors and measures known and reported in literature, group these thematically and differentiate them further. The taxonomies of risk factors and measures both follow a three-level structure – from global to specific. An example is presented in Figure 1, the full taxonomies can be found in Talbot et al. (2016) and Theofilatos et al. (2017), respectively.

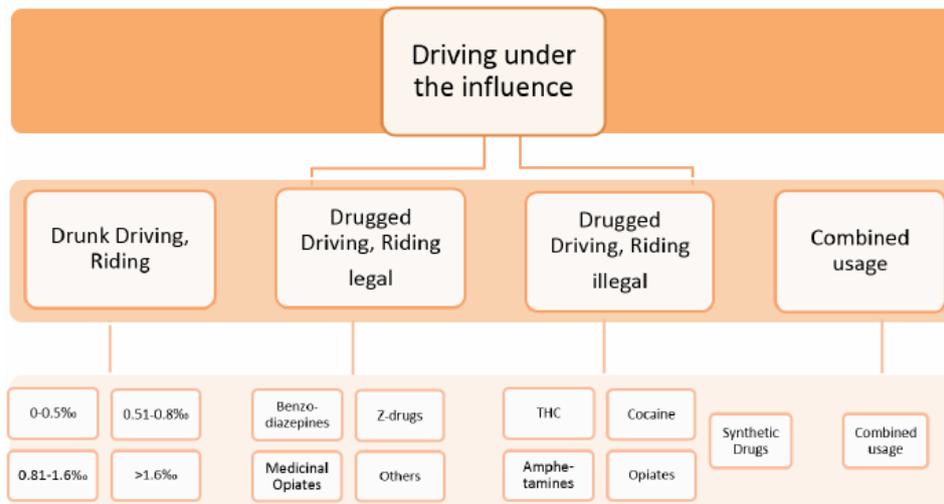


Fig. 1: Example of differentiation of a risk factor, specified on three levels of detail

In order to control for completeness of risk factors and measures 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 and measures. The collected information was assessed in terms of count analyses. To identify further ‘hot topics’ in road safety, policy papers and outcomes of previous projects were screened for highlighted and pressing topics. Furthermore, measures that tackle those risk factors which were assessed as ‘risky’ or ‘probably risky’ (see section *Analysis of coded studies and summary in ‘synopses’* for explanation) were prioritised.

## 2.2. Systematic literature search and selection of scientific studies on safety effects

A standardised literature search was carried out for the most important risk factor and most promising countermeasure topics. Various predetermined criteria were applied to find scientific studies reporting on quantitative safety effects of risks and measures. The databases searched were Scopus, Google Scholar, Web of Science, Science direct, DokDat and PubMed. All search terms and query types used are documented in so-called ‘synopses’. Following the search for and reading of literature regarding each of the topics, the taxonomies had to be amended slightly, especially for the subcategories (second and third level).

The criteria for selecting studies were predefined. The most important criteria were (1) studies which examined the impact of a risk factor (e.g. drink-driving, fatigue) or countermeasure (e.g. lowering BAC limits, campaigns) on road safety indicators in a quantitative manner and (2) the quality of the research in the identified studies. Priority was given to pre-existing meta-analyses as well as to more recent studies, studies published in English, number of citations and the peer-reviewed status. and studies from Studies from Europe, US, Australia, Canada were likewise given preference over other countries. Some of the defined criteria were applied less rigorously across the topics and adjusted depending on the numbers of studies which the search produced. Whereas there is a great number of studies on the effects of e.g. speeding, the effects of emotions on road safety is less well covered by quantitative studies.

Ideally, road safety outcomes are measured in terms of the number or share of accidents caused (risks) or prevented (measures). However, this is – especially when it comes to road users – not always easy to measure. In most cases, risk factors represented by road users (such as sensation seeking or fatigue) are not either present or absent but present to a certain extent and with variation over time, respectively. Furthermore, the contribution of a risk factor to accident probability is sometimes mediated and not direct: 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 human related measures, the challenges are similar. The crucial effect of a nationwide road safety campaign to promote safe behaviour, for example, is difficult to determine since there are other influencing factors present which can only be partly controlled for, such as seasonal effects or further road safety measures implemented at the same time.

These are just some examples of the challenges which had to be considered in the selection of appropriate studies. Many studies document safety performance indicators which are known or assumed to have a crucial impact on road safety as outcome variable(s) instead of actual changes in accidents. Accordingly, studies which document alternative outcome measures have also been taken into consideration. Studies using the following methods and outcome measures were included:

- 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

### *2.3. Coding of identified studies on the safety effects of risk factor and measure topics*

The aim of coding studies on risk factors and measures in a standardised and systematic way is firstly to provide decision makers with relevant, comparable information retrievable via the Road Safety DSS and secondly to prepare the evidence for each topic for further analysis and conclusion. All relevant information from each study was entered into a template to facilitate the processing of the data gathered. The design of this 'coding template' accommodated the variety and complexity of different study designs and allows the following information to be entered for each study:

- Road system element (road user, infrastructure, vehicle) and level of taxonomy (so that users of the DSS will be able to find information on topics they are interested in)
- Basic information on the study (title, author, year, source, origin, abstract, etc.)
- Road user group examined (pedestrians, cyclists, car drivers, etc.)
- Study design (experimental, before-after, time series, etc.)
- Variable(s) of exposure to risk or countermeasure
- Outcome variable (e.g. number of injury crashes, self-reported speed behaviour, etc.)
- Type of effects and the effects themselves (including corresponding measures, e.g. confidence intervals or standard deviation)
- Biases
- Summary

### *2.4. Analysis of coded studies and summary in 'synopses'*

Whenever possible, study outcomes per topic were assessed by means of vote-count-analysis or meta-analysis. However, due to the enormous range of outcome measures, this was not always possible. Review type analyses were therefore conducted alternatively. For each topic, results and background information are summarised and provided as 'synopses' which include two separate sections, one targeted at policy stakeholders, the other at a scientific audience. For purposes of transparency, the literature search and study selection process is documented in the section 'supporting documents'. Finally, each of the analysed topics was 'colour coded', i.e. assigned a rating that would provide users of the decision support system with an initial impression at first glance.

## **3. Human related risk and measure assessment in the field of road safety**

In total, 25 synopses have been produced based on 186 individual risk assessment studies. The topics of the synopses include speeding, driving under the influence, risk taking, fatigue, distraction, functional impairment, insufficient skills and knowledge, misjudgement and observation errors, traffic rule violation, aggression/anger, diseases (diabetes) and personal factors such as sensation seeking and attention deficit hyperactivity disorder (ADHD). A further 24 synopses based on 250 studies are available on the effectiveness of measures and cover the following topics: law and enforcement, education and voluntary training, licencing and testing, fitness to drive assessment, screening and rehabilitation and awareness raising and campaigns. Wherever meaningful and possible, age, as one of the stakeholder priorities, and mode of transport are addressed in each of the synopses.

### 3.1. Human related risk factors

To provide an initial indication of the level of evidence that a risk factor has a negative effect on road safety, each risk synopsis was assigned a colour code. *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].

Based on the analyses conducted, the following human related risk factors are assessed as *risky* (colour code red), showing that the risk factor has a negative effect on road safety:

- Driving under the influence (alcohol and drugs)
- Speeding and inappropriate speed
- Red light running
- Fatigue due to sleep disorders and sleep apnea
- Distraction due to mobile phone use (handheld and texting)

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 and van Schagen, 2016a)

Another good example is the risk factor fatigue due to sleep disorders and sleep apnea (Talbot and Filtner, 2016). Obstructive Sleep Apnoea (OSA) is where the muscles and tissue in the airway collapse during sleep and cause the airway to be blocked. To examine the risk for road accidents, studies usually include a group of participants with untreated OSA and a control group and compare the number of accidents experienced in each group, as measured by self-report or police registry. Studies show that a driver is two to three times more likely to be involved in an accident if he/she suffers from untreated OSA. For truck drivers, this risk is potentially higher.

A further ten risk factors were categorised as *probably risky* (colour code yellow). In these cases, there is some evidence these risk factors have a negative effect on road safety but also some problems in terms of mixed results, study design or number of studies available. These risk factors are:

- Risk taking (overtaking, close following)
- Functional impairment (cognitive impairment, vision loss)
- Diseases and disorders (diabetes)
- Personal factors (sensation seeking, ADHD)
- Emotions (anger and aggression)
- Red light running
- Fatigue due to not enough sleep/driving while tired
- Distraction due to conversation with passengers
- Distraction outside of vehicle
- Distraction due to cognitive overload and inattention

It should be noted that some of these risks are more difficult to measure, making it also more difficult to establish links between the presence of the risk factor and the risk of accident risk. 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 and Pilgerstorfer, 2016).

For other risk factors in this category, only a weak association with negative road safety outcomes has been found. In the case of the risk factor diabetes, for example, the studies examined generally show a (small) elevated risk of accident but the reported effects are not always statistically significant (Goldenbeld and van Schagen, 2016b). Few of the analysed risk factors were labelled as unclear (colour code grey). For those that were coded grey, there was not enough evidence to draw valid conclusions about their effect on road safety. For instance, the studies analysed

for the risk factor distraction due to music and entertainment systems showed mixed effects (positive, negative and non-significant) (Ziakopoulos et al., 2016).

### 3.2. Human related road safety measures

Based on the evaluated risks, related countermeasures were likewise identified and analysed<sup>1</sup>. Human related road safety measures were categorized into five main areas: *law and enforcement, education and voluntary training, licencing and testing, fitness to drive assessment, screening and rehabilitation* as well as *awareness raising and campaigns*.

For most of the 24 human related measures analysed, the results show a positive effect on road safety (see Fig. 2). For seven of the countermeasures, the results of the studies included indicate a reduction in the road safety risk. Given their proven effectiveness they were assigned the colour code 'green'. These measures stem mainly from the law and enforcement category, but also the fitness to drive assessment and screening and rehabilitation categories. For example, the alcohol interlock measure was labelled green since research results (including a recent meta-analysis) show a reduction of the recidivism rate while the device is installed in the vehicle (Nieuwkamp et al, 2017). However, it should be noted that this effect appears only while alcohol interlocks are installed; once they are removed, recidivism rates increase towards their initial level.

The conclusion for 13 human related measures analysed was that they are 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. Most road safety campaigns, for instance, fall in this category, often due to a weak direct link between accident reduction and campaigns. For example, campaigns addressing aggressive, unsafe or inconsiderate behaviour on the roads aim at raising awareness and promoting considerate behaviour towards all other road users and thus contributing to reducing accidents in the long run (Eichhorn and Kaiser, 2017). The studies analysed indicate that such campaigns have positive effects to a certain extent on road safety, reporting mostly a significant reduction in accident occurrence and self-reported (un)safe and (in)considerate behaviour. However, mixed results are shown for specific aggressive or unsafe driving behaviours like speeding, tailgating or not yielding to other road users (significant reduction in speeding, non-significant change in unsafe behaviour and rule violations). Further, the campaign evaluation studies differ considerably with regard to exposure variables and outcome measures.

Only one of the selected countermeasures was classified as ineffective or counterproductive (colour code *red*). Age-based screening of elderly drivers has been introduced in many countries to assure their fitness to drive (Martensen, 2017). However, the studies analysed from Europe, Canada and Australia showed that age-based screening of elderly drivers does not increase road safety. A reduction in fatalities has not been found, while the results even indicate an increase in the average risk per licensed (elderly) driver and also an increase in fatalities among elderly pedestrians.

For two of the selected measures, mixed results or an insufficient number of available studies meant that no valid conclusions about their effect on road safety could be drawn (colour code *grey*). For instance, studies on *laws and enforcement for restricting mobile phone use* report contradictory findings (Theofilatos, 2017): while there is some indication that laws and enforcement have a positive impact on self-reported and observed mobile phone use while driving, whereas meta-analyses show no effects when it comes to a reduction in accidents or fatalities.

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<sup>1</sup> It should be noted that an effective treatment of a risk factor related to a specific element of the road system may not always be related to that particular element, but to a different one. For example, drink-driving is a behavioural problem related to the driver, but the solution may be a technical device – the alcohol ignition interlock (Martensen et al., 2017).

<i>Topics</i>	<b>Effective</b>	<b>Probably effective</b>	<b>Unclear results</b>	<b>Ineffective or counterproductive</b>
<b><i>Law and Enforcement</i></b>	<ul style="list-style-type: none"> <li>• General police enforcement, speeding</li> <li>• DUI checkpoints, selective and random breath testing</li> <li>• Laws and enforcement for seatbelt wearing</li> <li>• Licence suspension</li> </ul>	<ul style="list-style-type: none"> <li>• BAC limits, BAC limits for novice drivers</li> <li>• Increasing traffic fines</li> <li>• Hours of service regulations for commercial drivers</li> <li>• Demerit points systems</li> <li>• Red light cameras</li> </ul>	<ul style="list-style-type: none"> <li>• Laws and enforcement for mobile phone use (handheld, hands-free)</li> </ul>	
<b><i>Education and voluntary training/programmes</i></b>	<ul style="list-style-type: none"> <li>• Hazard perception training</li> </ul>	<ul style="list-style-type: none"> <li>• Child pedestrian training</li> </ul>	<ul style="list-style-type: none"> <li>• Non-statutory training for novice drivers</li> </ul>	
<b><i>Driver training and licencing</i></b>		<ul style="list-style-type: none"> <li>• Formal pre-licence training, graduated driver licencing and probation</li> </ul>		
<b><i>Fitness to drive assessment and rehabilitation</i></b>	<ul style="list-style-type: none"> <li>• Alcohol interlock</li> <li>• Rehabilitation</li> </ul>	<ul style="list-style-type: none"> <li>• Medical referrals</li> </ul>		<ul style="list-style-type: none"> <li>• Age-based screening of elderly drivers</li> </ul>
<b><i>Awareness raising and campaigns</i></b>	<ul style="list-style-type: none"> <li>• Seatbelt campaigns</li> </ul>	<ul style="list-style-type: none"> <li>• Campaigns in general</li> <li>• Child restraint campaigns</li> <li>• DUI campaigns</li> <li>• Speeding campaigns</li> <li>• Aggressive and inconsiderate behaviour campaigns</li> </ul>		

Fig. 2 overview of the effectiveness of the analysed human related road safety measures analysed in SafetyCube

#### 4. Discussion and conclusions

Within the project SafetyCube, human related risk factors and countermeasures have been systematically analysed and assessed with regard to their effect on road safety. While there have been many thematic reviews for single risks or measures, the work conducted provides a comprehensive overview and comparison for all of the most important road safety issues. The project provides decision makers and other stakeholders of all kinds with evidence that is easily accessible.

The analyses of various risk factors allow conclusions to be drawn on the prioritisation of countermeasures. The results indicate a wide range of human related road safety measures which can be categorised as effective or probably effective. National Technical University of Athens from to all areas (law and enforcement, education and training, driver training and licencing, fitness to drive assessment and rehabilitation as well as road safety campaigns). On the other hand, age-based screening has been clearly assessed to be counterproductive: this measure produces side effects (e.g. an increase in pedestrian accidents), yet there is no evidence of any kind of positive effect on road safety.

In a next step, the most promising measures will be assessed in terms of their cost effectiveness and cost-benefit ratio in order to further facilitate the decision process. All project results will be retrievable via [www.roadsafety-dss.eu](http://www.roadsafety-dss.eu) by March 2018 and can be demonstrated at TRA.

It is crucial to note that quantifying human aspects in traffic can be a challenging endeavour on many levels. Some risk factors involve deliberate behaviour (e.g. drink-driving); others are generic (e.g. age). Oftentimes, such risk factors are hard to link to actual accidents, since their presence is not always objectively identifiable in retrospect (e.g. emotions) or it is unclear to what extent a particular factor contributed to an accident. Furthermore, some human related risk factors tend to be inter-related and evoke further risks (e.g. age, alcohol, speed). Many corresponding studies use alternative outcome measures other than accidents (e.g. risk behaviour, task performance or self-reported accident history) to quantify the effect of a risk factor or countermeasure. And when it comes to

the evaluation of countermeasures, there is also the additional challenge of combined activities such as increased enforcement accompanied by campaigns, where the isolated effect of either measure is hard to determine.

Ultimately, these challenges highlight the importance of evidence based decision making as well as the provision of background knowledge (as provided in the synopses) beyond mere numbers – especially when it comes to modification of human behaviour.

## Acknowledgements

This paper is based on work carried out within the SafetyCube project of the H2020 programme of the European Commission (Grant number 633485). The information and views set out in this paper are those of the authors and may not reflect the official opinion of the European Commission.

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