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Guidelines for Priority Setting Between Measures with Practical Examples

Deliverable D3.5

SafetyCube

SafetyCube

Guidelines for Priority Setting Between Measures with Practical Examples

Work package 3, Deliverable 5

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Project Coordinator:
Professor Pete Thomas, Transport Safety Research Centre, Loughborough Design School, Loughborough University, Ashby Road, Loughborough, LE11 3TU, UK

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VIAS, Belgium

Report Author(s):
Heike Martensen, Stijn Daniels, Wouter Van den Berghe (VIAS), Wim Wijnen, Wendy Weijermars (SWOV), Laurent Carnis (IFSTTAR), , Jacques Saadé (CEESAR), Rune Elvik (TOI)

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Table of contents

Executive Summary

This deliverable gives an outline of the process of prioritising road safety measures. It should be used by policy makers to understand how they can use the SafetyCube Decision Support System (DSS) to choose between different countermeasures.

Candidates for countermeasures are mostly selected on the basis of crash analysis (either microscopic or macroscopic) or departing from specific risk factors. Both approaches are supported in the SafetyCube DSS. The number of casualties a countermeasure can save depends on the target group -- the number of cases on which the measure can possibly have an effect -- and the percentage reduction within that group. This can be expressed as CMF or as relative risk. If the measure is not implemented / used everywhere it also depends on the degree of usage, the penetration rate.

Three analyses of a countermeasure's economic efficiency are investigated: Cost- effectiveness analysis, cost utility analysis, and cost benefit analysis. It is concluded that *cost-benefit analysis* fits the purpose of prioritising between alternative countermeasures best. It allows the joint evaluation of measures' effectiveness in reducing crashes of different severity. Moreover, it provides information on the socio-economic return of countermeasures, and in principle allows to include side effects into the analysis. Although, the valuation of possible side effects of road safety measures was beyond the scope of SafetyCube, the presentation in terms of cost-benefit ratios allows for the post hoc inclusion of other impacts.

To help decision makers prioritize between different measures, the Decision Support System provides a *calculator for Economic Efficiency Evaluations (E^3)*. This E3 calculator combines input on the measures with input on the cost of crashes and calculates different indicators of economic efficiency. One of the major criticisms on cost-benefit analysis is that the outcomes are highly dependent on the costs that are assumed for crashes. SafetyCube has therefore dedicated large efforts to collecting, analysing, and harmonising the crash-cost estimates from European countries, also providing a set of European standard values, which was used for all SafetyCube example analyses.

DSS users can use the E^3 calculator to conduct their *own analysis*. They can choose to depart from a SafetyCube example analysis in which they change values according to their own situation. To determine the *crash costs*, they can select the target-country of their analysis and choose between the country's own reported values or a set of harmonised values for the target country. Users can also include *side-effects* if they have an estimate of their costs / benefits. A quick guide how to use the E^3 calculator is included, describing the input necessary from the user as well as the input and calculations provided by SafetyCube. Conducting a *sensitivity analysis* is shown exemplary in the SafetyCube examples and is advised for users who conduct their own analysis.

The *output* of the E^3 calculator consists of criteria of cost-effectiveness (the costs per prevented crash or casualty) and cost-benefit indicators. The *benefit-cost ratio* (benefits / costs) favours measures with the best value for money even if their actual benefits are relatively small, because they are implemented at a small scale. The *net-present value* (benefits – costs) favours measures with large benefits (even if they come at a relatively large cost). The *break-even* cost is the maximal cost for a countermeasure to still be economically efficient. It is relevant when the analysis is done without precise information on the cost of the countermeasure.

It is acknowledged, that data are not always available to perform a *full-scale* cost-benefit analysis including *all* aspects that are relevant for the choice between alternative measures. *Multicriteria decision analysis* denotes a group of systematic tools for decision making that allow taking several criteria into account – even if no monetary valuation (or other quantitative estimates) exist for them. Often these analyses involve the stakeholders in parts of the analysis process and also give information on how preferable different alternative measures are for each of them. The output of the Road Safety Decision Support System and the E3 calculator can be used in a multicriteria analysis as one of the indicators under consideration.

The DSS gives the end-user the building blocks for developing a road safety program. It is based on a taxonomy of risk factors and measures, it makes the user aware of different options to treat a problem, it indicates how well each approach has been found to work, and it contrasts the costs of each measure with its estimated effectiveness.

1 Introduction

This chapter describes the project and purpose of the deliverable. A short description of the work package that produced the deliverable is also provided.

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) economic efficiency analysis taking account of human and material costs.
2. Apply these methods to safety data and results 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 system approach with road safety stakeholders at the national level, EU and beyond having involvement at all stages.

1.1.1 Work Package 3

The objective of work package 3 is to define the methodological foundations of the road safety Decision Support System. The methodological guidelines developed are applied in Work Packages 4, 5, 6, and partly also 7 to identify and analyse road safety problems and measures addressing road users, road infrastructure, vehicles and measures for trauma care. A road safety decision support system should help policy makers identify important risk factors and the accidents, injuries and fatalities resulting from them; select measures by estimating their safety effects; and set priorities among measures on the basis of their costs and benefits.

To do so, results from different types of studies are collected for a broad range of risk factors and measures. The literature is reviewed for the decision support system. The studies are selected and prioritised by a systematic and documented literature search, they are "analysed" in terms of their research design and possible biases, and entered into a coding template capturing all relevant information for the Decision Support System (DSS) users. Studies addressing the same countermeasure or risk factor are summarised into a synopsis using the information contained in the coding template and other information from the literature review. Whenever possible the synopsis will result in a summary estimate of measure effectiveness (like a CMF – crash modification factor) and a description of how this varies across different conditions, or sub-types of the factor under investigation. The synopses also give an indication how well a risk factor or countermeasure has been studied.

To do so, Work Package 3 has produced the following deliverables describing

D3.1 The available data sources
D3.2 The crash cost collection, analysis, and harmonisation
D3.3 The methodological framework for the evaluation of risk factors and countermeasures
D3.4 The preliminary guideline for prioritisation

Where D3.4 forms the methodological basis for the present deliverable.

1.2 OBJECTIVE OF THE PRESENT DELIVERABLE

This deliverable gives an outline of the process of prioritising road safety measures. It should be used by policy makers to understand what they can do to choose between different countermeasures. The deliverable is meant to give an overview, rather than technical details. For details the readers are referred to other deliverables.

The prioritisation process starts with establishing the effectiveness of a measure. Different approaches to investigate the effectiveness are given with practical examples. For the economic efficiency evaluation, three methods are described (cost-effectiveness, cost-utility, and cost-benefit analysis). It is explained why the approach chosen for the SafetyCube Decision Support System is the cost-benefit analysis. It is acknowledged, however, that data to perform a full-scale cost-benefit analysis are not always available. Therefore, multicriteria analysis is discussed, a group of systematic tools for decision making that can also be based on categorical input values. The remainder of the deliverable is focused on how the economic efficiency evaluation is implemented in the SafetyCube DSS. It is explained which input SafetyCube provides and how users of the system can either adjust the SafetyCube analyses to their own situation or conduct new analyses.

2 Analysing the risks

Candidates for countermeasures are mostly selected on the basis of crash analysis (either microscopic or macroscopic) or departing from specific risk factors. Both approaches are supported in the SafetyCube DSS.

The SafetyCube DSS provides different ways to select countermeasures for evaluation. Each of these approaches is linked to a particular type of analysis that is taken as point of departure.

2.1.1 Crash analysis

One can differentiate between microscopic and macroscopic crash analyses. In ***microscopic*** analyses (also in-depth analysis), road crashes are analysed by multidisciplinary teams taking into account all available information (e.g. traces, deformations) and using advanced simulation methods to reconstruct the crash. To summarize the big variety of information, these analyses often result in typical ***crash scenarios***. In the DSS, the most frequent crash scenarios can be selected and they have been linked to countermeasures that are considered to have a positive effect in these situations.

In ***macroscopic crash analyses***, crashes are usually analysed in terms of characteristics that have been recorded by the police and are available for most countries. Typically these databases also allow an analysis of states, regions, and communities. Although such analyses usually do not give much detail about the crashes that happened, it is often interesting to compare the results with similar units (e.g., their neighbours) and identify ***road-user groups*** that have a too high share in the crash statistics. In the DSS, it is possible to select risk-factors and countermeasures that specifically apply to particular road user groups.

2.1.2 Risk analysis

Ideally, the search for countermeasures starts with the identification of risk-factors. The DSS supports this approach by giving a summary of the present knowledge on a broad range of risk-factors covering road-user behaviour, infrastructure, and vehicles. For each risk-factor it is described to whom/where it applies and what mechanisms are at work. The risk-effect on crashes is often quantified by *relative risk.* As an example, the probability to have a fatal crash when driving under the influence of amphetamines is estimated to be more than 5 times higher than the normal risk (Leblud, 2017). Which risk-factors are most important to tackle is also determined by the prevalence of a particular risk factor.

The SafetyCube DSS gives not only information for each risk-factor, but also leads the user to possible countermeasures. It is important to note that risk-factors and countermeasure to mend them do not necessarily come from the same domain. As an example, speeding (which is a problem of road-user behaviour) is linked to 6 types of behavioural countermeasures, 12 types of infrastructure countermeasures, and 6 types of vehicle countermeasures.

3 Effectiveness of a countermeasure

The number of casualties a countermeasure can save depends on the target group -- the number of cases on which the measure can possibly have an effect -- and the percentage reduction within that group. This can be expressed as CMF or as relative risk. If the measure is not implemented / used everywhere it also depends on the degree of usage, the penetration rate.

Once a number of candidate measures have been identified first it should be established whether they are effective at all. The DSS gives information about a broad range of countermeasures and is not restricted to those that have proven to be effective. If the best available knowledge did not prove the effect of a measure, or even indicated that it might be contra productive, the synopsis on the measure in question will say so.

To prioritise between different measures one needs an estimate how much they reduce the negative outcomes of road-crashes. For some measures it is possible to argue convincingly that they reduce crash risk, but still this reduction is difficult to estimate. As an example, if conducted well, training courses with traffic offenders who have driven under the influence of alcohol have been shown to reduce the recidivism rate if respecting a number of principles (see Nieuwhuis & Martensen, 2018). Although the increased crash risk of driving under the influence of alcohol is very well established (Elvik, 2009) , it is difficult to estimate how often recidivists have driven under the influence before they were caught by the police and how much they had drunk in each case. Moreover, the percentage of reduction of the recidivism varies substantially between studies. As a consequence, the effect of the measure is difficult to quantify with respect to crash frequency. See Chapter 5 for a discussion on prioritising in the absence of quantitative criteria. It is however, always better if a link between countermeasures and the reduction of crashes can be formally established and quantified.

To quantify the crash reduction due to countermeasures, one needs an estimate of the relative risk or a crash modification factor and the size of the group of target crashes to which a measure is directed. In some cases it is also necessary to know how often the measure is applied (the penetration rate of the measure).

3.1 RELATIVE RISK

A countermeasure in road safety is a protection factor that lowers the risk for a negative road safety outcomes: crashes and casualties. To estimate how much the risk is reduced, the *relative risk* is calculated: the probability to have a crash in the presence of a particular countermeasure relative to the probability to have a crash in its absence. In practice the relative risk is mostly estimated by an *odds ratio* (*OR*, see D3.3, Chapters 2 and 3 for details).

$$RR = \frac{P(Crash|MeasurePresent)}{P\ (Crash|MeasureAbsent)}$$

As an example, the relative risk of a seatbelt is 0.5 for fatal crashes (indicating that the probability of a fatal crash with a seatbelt is only half that without a seatbelt (Elvik, 2009)).

3.2 CRASH MODIFICATION FACTORS

A lot of research also departs from the comparison of groups where measures have been implemented to groups without the measure. Especially in studies concerning road design, there is a long research tradition which has led to the estimation of *crash modification factors* (*CMF*s). A CMF is the expected number of crashes with a countermeasure divided by the number expected without the countermeasure. In practice CMF's like relative risk is mostly estimated by *odds ratios*.

An example: chevron signs are widely used as safety devices to warn drivers of the severity of a curve by delineating the alignment of the road around that curve. Choi et al. (2015) found a CMF value for chevron signs of 0.721. This result showed that chevron signs had a positive effect on road safety because they caused an average reduction in the number of crashes of 27.9%

3.3 EFFECTIVENESS: PERCENTAGE REDUCTION

The effectiveness of a countermeasure is usually quantified by the percentage reduction of crashes in the target group (also called *preventive fraction*, e.g. Fildes et al., 2015; Zangmeister et al., 2007). The effectiveness can be based on either, CMF's or relative risks, which are both usually estimated by odds ratios. The effectiveness is given by:

$$E = (1 - OR) * 100$$

The effectiveness is thus the percentage of crashes that would be avoided among the crashes critical to the measure in question. A relative risk or CMF of 0.8 leads to E=20 and therefore indicates that the crashes in the target group could be reduced by 20%.

3.4 TARGET GROUP OF A COUNTERMEASURE

The target population of a counter measure is the number of crashes to which a safety feature was relevant. For an infrastructure measure, usually all crashes at the treated site (before treatment) would be considered within the target population. For vehicle systems, crash scenario's for which a countermeasure could be expected to help have to be differentiated from those for which no protective function can be expected from this particular countermeasure.

As an example, to study the effectiveness of autonomous emergency braking system (AEB), Fildes et al. (2015) investigated *rear-end collisions* and compared the rate of vehicles with AEB among the striking vehicle (the target crashes that could be helped by AEB) and the struck vehicles (non-target crashes). The effectiveness was calculated in 6 countries. This resulted in a significant safety effect, indicating that the odds for AEB equipped vehicles to be the striking car in a rear-end crash are reduced by 38%. This percentage has to be multiplied by the proportion of critical crash situations (rear-end crashes) to give an estimate of the percentage of the total crash population that could be prevented by the measure. Grover et al. (2008) estimated the number of target injuries per year for AEB in Europe (EU 25) to be of 709 fatalities, 12,453 serious injuries, and 506,805 slight injuries. If we take, for example, a mean effectiveness of 50% for fatal and severe injuries and a mean effectiveness of 5% for slight injuries, we can estimate that a total of 354 fatalities, 6,226 severe injuries, and 25,340 slight injuries could be saved.

3.5 INCREASING THE USE OF A MEASURE (PENETRATION RATE)

Sometimes there is an effective countermeasure with proven effectiveness, but its use is not optimal. Then a measure can be directed at increasing the use (also called penetration rate) of the measure. As an example, a Dutch seatbelt campaign raised the usage of seatbelts by 1.8% from 93.8% to 95.6% (Tamis, 2009). Wearing a seatbelt is estimated to reduce the probability of fatal injuries by 50% and of serious injuries by 45%. It is thus estimated that of the 214 Dutch annual fatalities, 3.6 can be prevented by this measure and of the 2832 serious injuries 39.7 (Aigner-Breuss, 2018).

To summarize, the number of casualties a countermeasure can save depends on the percentage reduction (or the preventive fraction); the size of the target group, and the penetration rate of the measure.

4 Economic efficiency evaluation

Three analyses of economic efficiency are discussed: cost-effectiveness analysis, cost-utility analysis, and cost-benefit analysis. It is concluded that cost-benefit analysis fits the purpose of prioritising between alternative countermeasures best. It allows the joint evaluation of measures' effectiveness in reducing crashes of different severity; it provides information on the socio-economic return of countermeasures; and in principle it allows to include side effects into the analysis.

Economic Efficiency Evaluation refers to analyses made for the purpose of identifying how to use scarce resources to obtain the greatest possible benefits of them. The main reason for doing efficiency assessment of road safety measures is to select countermeasures that produce the largest possible benefits for a given cost**. Cost effectiveness analysis** (CEA), **cost-utility analysis** (CUA) and **cost-benefit analysis** (CBA) seek to identify the cheapest way of improving road safety and are therefore tools to help choose the countermeasure which gives the highest return on investments.

4.1 COST EFFECTIVENESS ANALYSIS

The cost-effectiveness analysis (CEA) of a road safety measure gives the cost for the prevention of one crash or one casualty. If one wants to differentiate between crashes of different severity, different CEA's have to be done for each severity (e.g., fatal, serious, slight, and damage only crashes).

4.1.1 Examples

To address only one type of crash (or casualty) can be problematic, because some measures have a strong effect on severe crashes but a small or even reversed effect on crashes with slight injuries. For some it is the other way around. Of course it is more important to prevent crashes with live-threatening consequences. But how much more important? Should less severe crashes be included in the analysis? To illustrate this problem, Table 4.1 includes four road safety measures, listed from the most expensive to the least expensive. The measures are taken from a previous policy analysis for Norway (Elvik 2007) and the effects from the Handbook of Road Safety Measures (Elvik, 2009).

The four measures are median guard rail (cost 10 million), roundabout in a T-junction (cost 5 million), general rehabilitation of a road (cost 4 million) and installing a bike lane (cost 0.7 million). The costs refer to one unit, i.e. one kilometre of road or one junction. The upper half of the table shows the number of injuries influenced by each measure (target injuries). These are mean numbers intended to reflect the long-term expected number of injuries and are therefore stated with decimals. The lower half of the table shows the effect of each measure stated as percentage change in the number of injuries. It is seen that median guard rails reduce fatalities by 76 %, reduce serious injuries by 47 % and increase slight injuries by 13 %. Roundabouts also have a greater percentage effect on fatal and serious injuries than on slight injuries. For the other two measures, effects do not vary with respect to injury severity.

Table 4.1 Ranking of four road safety measures according to cost-effectiveness

	Number of injuries affected by measure				
Measure	**Fatalities**	**Serious injury**	**Slight injury**	**Total injury**	**Cost (million NOK)**
Median guard rails (per km)	1.74	4.58	15.47	21.79	10
Roundabout in T-junction (per junction)	0.58	2.76	28.77	32.11	5
General rehabilitation of road (per km)	0.24	0.77	4.76	5.77	4
Bike lane (per km)	0.07	0.39	4.02	4.48	0.7
	Percent effect of measure			**CE-ratio for all injuries**	**CE-ratio for fatalities**
Median guard rails	-76	-47	+13	0.146	0.132
Roundabout in T-junction	-49	-33	-31	2.023	0.057
General rehabilitation of road	-20	-20	-20	0.289	0.012
Bike lane	-13	-13	-13	0.832	0.013

The four measures are median guard rail (cost 10 million), roundabout in a T-junction (cost 5 million), general rehabilitation of a road (cost 4 million) and installing a bike lane (cost 0.7 million). The costs refer to one unit, i.e. one kilometre of road or one junction. The upper half of the table shows the number of injuries influenced by each measure (target injuries). These are mean numbers intended to reflect the long-term expected number of injuries and are therefore stated with decimals. The lower half of the table shows the effect of each measure stated as percentage change in the number of injuries. It is seen that median guard rails reduce fatalities by 76 %, reduce serious injuries by 47 % and increase slight injuries by 13 %. Roundabouts also have a greater percentage effect on fatal and serious injuries than on slight injuries. For the other two measures, effects do not vary with respect to injury severity.

Based on the effects, the number of injuries prevented can be estimated. For example, for median guard rails there are 1.74 target fatalities per kilometre of which 76% are prevented when a guard rail is implemented. This means that a kilometre of guard rails is expected to prevent $1.74 \cdot 0.76 = 1.32$ fatalities. The total number of injuries prevented is obtained by adding the number of prevented fatalities, the number of prevented serious injuries and the number of prevented slight injuries. For median guard rails, this sum is 1.46[1]. One might be surprised that the number of prevented casualties (injuries + fatalities) is in fact very close to the number of prevented fatalities. The reason is negative effect on slight injuries which reduces the total number of prevented casualties. To obtain the cost-effectiveness ratio the total number of injuries prevented is divided by the cost of the measure. This is shown in the table as CE-ratio for all injuries. It is seen that roundabouts is the most cost-effective measure and median guard rail the least cost-effective. When cost-effectiveness is estimated for the prevention of fatalities only, median guard rails is the most cost-effective measure and general rehabilitation of roads the least cost-effective.

[1] 1.74*0.75+4.58*0.47+15.47*(-0.13) = 1.32 + 2.15 +(- 2.01) = -1.46

4.1.2 Advantages and shortcomings

The cost-effectiveness criterion for priority setting has a number of advantages as well as shortcomings. The *advantage of the cost-effectiveness criterion is* that it highlights the safety effects of measures. It can also be considered an advantage that it does not require the use of crash costs (however, these are provided by SafetyCube, see Section 5.3.1 and the Appendix).

The major *shortcoming* concerns mostly the fact that cost-effectiveness can only address *one single criterion*. In the Table 4.1 it can be seen that some measures have a strong effect on severe crashes but a small or even reversed effect on crashes with slight injuries. For some it is the other way around. How should these benefits be weighted? Of course it is more important to prevent crashes with live-threatening consequences. But how much more important? Cost-effectiveness offers no indication how to combine these different criteria. In this context it should also be noticed that material damage of crashes is usually not taken into account in cost-effectiveness analysis at all. This is a serious shortcoming. For those countries that include material damage into their estimate of crash costs, this is one of the 3 largest components of the total costs (see Figure A1 in the Appendix on crash-cost estimates in Europe).

Furthermore, cost-effectiveness offers no possibility to compare the road-safety effect to that in other policy domains, for instance mobility or the environment. And finally, cost-effectiveness can only be used to compare different measures. The criterion does not say at what level of cost-effectiveness a measure becomes too expensive.

4.2 COST UTILITY ANALYSIS

In recent time there is a growing awareness that the burden of road crashes does not only concern road crash fatalities but to the same extent the number of serious injury casualties. While the costs in terms of human suffering might be smaller for injury crashes than for fatal crashes, the number is so much larger that in economic reasoning there can be a trade-off between the two and the reduction of injury crashes is more and more becoming its own objective rather than being considered a natural consequence of reducing fatal crashes.

Cost-utility analysis (CUA) is an economic assessment tool that allows inclusion of different crash outcomes in a single criterion. In CUA the road safety impacts resulting from a countermeasure are expressed in Quality Adjusted Life Years (QALYs). A QALY is a measure for the health impact that combines the impacts on mortality (fatalities) and morbidity (injuries). The measure for mortality impact is the number of years of life lost (YLL) saved and the measure for morbidity impacts is the years lived with disability (YLD) saved. For each fatality, the Years of Life Lost can be estimated by the difference between his/her life expectancy (based on a combination of age and gender) and his/her actual age. The total YLL saved can be estimated by summing up the YLL of all fatalities that are prevented by a measure. To be able to calculate the Years Lived in Disability (YLD) for none-fatal casualties, one additionally needs information on the type of injury to know for how many years consequences typically last and which weight is given to their severity. To calculate the QALYs a countermeasure can save, one needs more than the typically available figures of prevented fatalities, severe injuries, and slight injuries, but also information on the type of casualties (age and type of injury) that can be prevented. In cost-utility analysis the cost per QALY are calculated (similar to the cost per casualty saved in a cost-effectiveness analysis) and road safety measures can be ranked according to their 'cost-utility', that is by the cost per QALY.

The main advantage of a utility-analysis compared to a cost-effectiveness analysis is the fact that a different value is attached to fatalities, serious injuries and slight injuries, based on the number of life years lost and the health impact of injuries. Material damage of crashes can, however, not be taken into account in cost-utility analysis. Moreover, the other three shortcomings related to cost effectiveness analysis (1. Not taking material damage into account, 2 not offering an indication how much a measure can cost to be economically efficient, and 3 not being extendable to other policy domains), still hold for cost-utility analysis[2].

A major obstacle to conducting cost-utility analyses is the availability of QALY's. To derive QALY's from different types of casualties takes a complex estimation process that is even more complex than the monetary valuation of different severity outcomes and is available only for few countries (see D7.3 for more details).

4.3 COST-BENEFIT ANALYSIS

Cost-benefit analysis (CBA) is a formal analysis of the impacts of a countermeasure, designed to assess whether the advantages (benefits) of the measure are greater than its disadvantages (costs).

All relevant impacts should first be estimated in "natural" units. In a cost effectiveness analysis of road safety measures, this would be the number of crashes prevented – separately for different severities. In cost benefit analysis other outcomes, like the number of additional hours of travel or the reduction of fuel consumption can also be included. To make different impacts comparable, they all have to be converted to monetary terms, which are applying monetary valuations of the various impacts.

The main result of a cost-benefit analysis is a monetary estimate of the benefits and costs of a road safety measure. A measure is cost-effective if its benefits are greater than its costs. In general, the term costs refer to any negative impacts of a measure. By convention (and in the SafetyCube E^3 calculator), however, the costs of a measure are defined as the costs of implementation and other negative impacts are defined as negative benefits.

The objective of cost-benefit analysis is welfare maximisation. Welfare is maximised by maximising the difference between benefits and costs, the net present value.

4.3.1 Examples

As an example, consider the five road safety measures listed in **Table 4.2**. For each measure, three statistics showing its benefits are given: (1) Its effect on the number of fatalities, (2) Net present value = Benefits - Costs, (3) The benefit-to-cost ratio = Benefits / Costs. The measures have been sorted according to their effect on the number of fatalities (percentage reduction).

Which of these measures should be introduced first? Section control is the first choice, because it has the largest net present value (i.e., surplus of benefits to costs). In this example this measure also has the highest benefit-to-cost ratio (together with safety barriers). In order to see the difference between the rankings by using net present values and benefit-to-cost ratios, it is interesting to compare the results for chevron signs and dynamic speed limits. Although the benefit-to-cost ratio for dynamic speed limits is lower than the one for chevron signs, dynamic speed limits are still preferred because they result in a higher net present value. This seeming contradiction results from the fact a ratio does not account for the scale of a measure. Installing dynamic speed limits has a very high cost but an even higher benefit (in terms of prevented fatalities). As both – costs and benefits – are large numbers, the difference between the two (i.e. the net-present value) is very large in the case of dynamic speed limits, even if the ratio of costs and benefits is actually a lot smaller than that for other measures, where both the costs as well as the benefits are smaller.

[2] Note, however, that some other impacts (e.g. environmental) can also be expressed in QALYs.

According to these results road lighting should not applied as it has a negative net present value and therefore decreases welfare, i.e. the benefits are lower than the costs.

Table 4.2 Choice between five road safety measures based on net present value (based on Daniels & Papadimitriou, 2017)

Measure	Percentage reduction of fatalities (best estimate)	Total cost in EUR of measure per road/highway km (investment cost + net present value of annual costs)	Net present value in EUR (per road/highway km)	Benefit-cost ratio	Choice
Section control	56%	152 913 €	2 834 895 €	19.5	1
Road lighting	52% (accidents at night)	85 962 €	- 24 888 €	0.7	-
Safety barriers	46%	72 314 €	1 339 933 €	19.5	2
Dynamic speed limits	6%	490 192 €	31 548 €	1.1	3
Chevron signs[3]	2.6%	508 €	881 €	2.7	4

4.3.2 Decision rules

The net-present value will favour measures with large benefits even if they come at a relatively large cost, while the cost benefit ratio will favour measures with the best value for money, even if their actual benefits are relatively small (e.g., because they are implemented on a small scale). It is often advised to use the net-present value rather than the benefit-cost ratio as a decision rule in cost-benefit analysis (Boardman et al., 2011). The argument is that the benefit-cost ratio can be manipulated by putting negative side effects either in the denominator or in the numerator. In the SafetyCube E^3 calculator, however, side-effects are always entered as benefits (i.e. in the numerator).

If all measures have to be financed from the same budget, implementing the one with the highest *benefit-cost ratio* and then proceeding to implement the second highest, etc. until the budget is spent will ensure the best value for money for the budget under consideration.

Comparing measures on the basis of their *net-value* is meaningful only if they are implemented at a comparable scale as is the case for the examples in Table 4.2. As a consequence, CBA's should always be tailor-made for the implementation that is under decision. In SafetyCube a number of example analyses are given. To make them comparable with respect to the net-present value, they have to address the same number of units and the same time-horizon (see Chapter 6 how to adjust SafetyCube analyses).

[3] V-shaped symbols (often inverted) on signs to mark the location of the curve and to assist drivers in negotiation of the curve

4.3.3 Advantages and shortcomings

CBA is typically applied to help find efficient solutions to social problems that are not solved by the market mechanism. Typical characteristics of problems to which cost-benefit analysis is applied include (Elvik 2001):

- They involve public expenditures, often investments. Projects are sometimes financed by direct user payment, but more often by general taxation.
- There are multiple policy objectives, often partly conflicting and requiring trade-offs to be made. It is assumed that policy makers want solutions that realise all policy objectives to the maximum extent possible.
- One or several of the policy objectives concern the provision of a non-marketed public good, like less crime, a cleaner environment or safer roads.
- It is assumed that an efficient use of public funds is desirable, since these funds are scarce and alternative uses of them numerous.

There are however, some reservations that are frequently brought forward against CBA's. These will be discussed in some detail below.

Assigning a monetary value to life

Some people find the very idea of assigning a monetary value to lifesaving or to quality of life meaningless and ethically wrong. Human life, it is argued, is not a commodity that can be traded against other goods. However, the purpose of assigning a monetary value to human life is not to engage in trading in the usual sense of that term. The purpose is to provide *a guideline with respect to the amount of resources we would like to spend on the prevention of crashes or injuries.*

Human needs and value systems are complex and multi-dimensional. While safety is certainly one of the more basic human needs, it is not the only one, and no society would ever be able to spend more than a fraction of disposable resources on the prevention of crashes or injuries. How much to spend on the prevention of crashes or injuries will depend, and ought to depend, on how important people think this good is, seen in relation to all other goods they would like to see produced.

Low quality of crash-cost estimates

The outcomes of a CBA depend heavily on the assumed costs for the consequences of crashes. These estimates rely strongly on the methodology applied and even small changes can lead to big differences between the resulting crash-cost estimates and thus to the outcome of the CBA. In SafetyCube, we consider this indeed to be the most crucial problem of CBA and have therefore undertaken large efforts to collect the crash-cost estimates from European countries, to analyse which components these cost estimates contain and to provide additionally to the country's own estimate a harmonised estimate based on a common methodology in accordance with international guidelines. (See Section 6.3.1 and the Appendix).

Monetary valuation of side effects

One of the most emphasised advantages of CBA is that it can help find the right balance between safety and other possible objectives. CBA analyses how economically efficient a measure under investigation is with respect to a combination of objectives possibly from different policy domains (Hakkert & Wesemann, 2004). In principle many countermeasures have an effect on different objections. After all there is often a trade-off between safety and mobility (e.g, for licence withdrawal), personal comfort (e.g., for helmet wearing), traffic flow and travel time (e.g., for speed reduction), to name just a few examples. Side-impacts of road safety measures can also be positive, like the reduction of fuel consumption and CO_2 production for speed-reducing measures or the increased comfort for cyclists on cycle paths that are separated from motor traffic.

The economic valuation of possible other impacts is, however, out of the scope of the SafetyCube project. The evaluations of measures is tailored to their effect on road safety, if possible to their impact on the number of crashes and/or casualties. As a consequence, the evaluation of the balance between casualty reduction and other objectives, which is the core-objective of cost-benefit analysis, is not be possible within the DSS. One can argue that in that case one should better avoid the whole issue of estimating crash costs and work with cost-effectiveness or cost-utility analyses. The decision to conduct CBA's nevertheless was mainly based on two reasons: 1.) combining crash outcomes of different severity in one estimate and 2.) providing input for CBA's that do include other policy areas.

1.) Cost-effectiveness analysis compares measures' effectiveness with respect to remedying one particular type of crash (e.g. fatal crashes). Cost utility analysis is in principle able to address crash outcomes of different severity by transferring crash outcomes into loss of Quality Adjusted Life Years (QALYs). This however, takes an estimation process that is almost as difficult as the monetary valuation of different severity outcomes, which is available only for few countries. Neither cost-effectiveness, nor cost-utility analysis take material damage into account. So, for the time being, ***CBA is the only analyses that can be used widely to prioritise measures taking crashes of different severity into account***.
2.) Next to the results of CBA's the SafetyCube Decision Support system also contains a calculator in which the input of any given analysis can be adjusted or extended. If the user has estimates of the (monetary valuation of) side effects, these can be included into the analysis. Moreover, the resulting costs and benefits can still be compared with costs and benefits from other policy domains to decide which priority road-safety measures should have as compared to measures in other domains.

5 Beyond effectiveness and cost considerations

Multicriteria decision analysis denotes a group of systematic tools for decision making that allow taking multiple criteria into account – even if no monetary valuation (or other quantitative estimate) exist for them. Often these analyses involve the *stakeholders* in parts of the analysis process and also give information on how preferable different alternative measures are for each of them.

A requirement for a full-scale CBA to be undertaken is that all costs, safety effects and side effects can be expressed in monetary terms. This can become problematic when particular side effects or objectives have to be considered, which are difficult to quantify in an objective manner or for which no monetary values exist. Examples of such side effects or additional criteria are public acceptability, impact on local employability, environmental effects, technical risks, and speed of implementation. In principle, if such aspects are to be included in a traditional CBA, there are techniques to estimate their monetary values. This could be done by measuring the willingness to pay for each aspect in question. This approach is, however, often problematic. First of all, it may simply not be feasible at all to conduct a willingness to pay study for each aspect. Also, when using such an approach only one willingness to pay value is estimated for each aspect (e.g. by averaging over a large sample). This procedure ignores that different stakeholders assign different value to each aspect. In such circumstances, a multicriteria analysis (MCA) approach could be used.

5.1 MULTICRITERIA ANALYSIS

MCA was initially developed as an optimization method within operations research (Charness & Cooper, 1961). The basic principle is that different alternatives are evaluated on a set of criteria reflecting the decision-maker's objectives, and subsequently ranked on the basis of an aggregation procedure. Scores achieved do not necessarily need to be conveyed in monetary terms, but can simply be expressed in physical units or even in qualitative terms (De Brucker et al., 2011).

A recent example of the use of MCA in road safety is given by Sarrazin and De Smet (2014). They developed a methodology for an ex ante assessment of the road safety performance and other sustainable concerns of particular roads. They identified 13 criteria: Legibility and consistency of the infrastructure; Visibility of the infrastructure; Protection of the vulnerable roads users; Quality of the road pavement materials; Road design and safety equipment; Intersections; Safety on road works; Information and intervention services; Reduction of greenhouse gases emissions; Limitation of noise pollution; Ensure a good level of service; Limitation of the construction costs; and Limitation of the maintenance costs. For each criterion an indicator was developed.
The method was then applied to 10 alternatives for a particular case study: the redevelopment of a secondary road in a rural area with a multimodal traffic. Assuming that the score for certain criteria would be identical, only 6 criteria were retained. Initially, all 6 criteria were given an equal weight. The PROMETHEE method was used to calculate the best alternative, which proved to be quite robust when sensitivity analyses were performed.

Although the use of CBA is still widespread in transport projects decisions, there is an increased use of MCA techniques, which seems to be originating from the possibility to include aspects in the analysis for which no monetary valuation exists (Macharis & Bernardini, 2015).

5.2 MULTICRITERIA DECISION ANALYSIS (MCDA)

When MCA methods are used as part of a decision-making process, they are usually referred to as Multicriteria decision analysis (MCDA) methods (sometimes MCDA stands for 'Multicriteria Decision Aid'). There is a whole range of techniques which can be applied to conduct a MCDA (Macharis & Bernardini, 2015), often to be used in connection with a particular software. The most widespread methods used in the field of transport are multi-attribute theory variants (AHP, ANP, MAUT, MAVT, SMART, SMARTER, VISA), outranking methods (PROMETHEE, ELECTRE) and regime analysis (Turcksin et al., 2011). Based on a review of 276 articles using MCDA methods, Macharis & Bernardini (2015) concluded that the method mostly used is the Analytic Hierarchy Process (AHP) developed by Saaty (1988) or a variant of his hierarchical structured decision making.
Despite a large range and variety of MCDA methods existing, they all share some common principles and steps:

1. Identify the alternative solutions which are to be compared.
2. Identify and agree on the criteria for assessing the alternative solutions.
3. Define the indicators (and scales) that will be used to score or rank the performance of a solution for a particular criterion.
4. Define the weighting factors for the different criteria (i.e. indicate to what extent particular criteria are more important than others).
5. Calculate the indicator values and criteria scores for every solution.
6. Compare and rank the alternative solutions, based on their aggregated score on all criteria combined.
7. Undertake sensitivity analyses (in particular the effect of different weightings).
8. Decide on the preferred solution.

The solution can be a selection of the best alternative or a subset of alternatives, a classification, a ranking, or only a description of the alternatives without any ranking (Ampe et al., 2008).
MCDA methods can differ in terms of

- how the criteria are selected and defined
- how the criteria scales and underlying indicators are defined and calculated
- how the scores on indicators and criteria of the alternative solutions are compared
- how the weightings are applied
- and through what method the alternative solutions are finally ranked.

In its simplest form, an MCDA uses a utility function which is just an addition of the weighted scores for the criteria (Belton & Stewart, 2002):

$$V(a) = \sum_{i=1}^{m} v_i w_i(a)$$

whereby *V(a)* is the total value for alternative solutions a, $v_i(a)$ the score al alternative solution a for criterion *i* and w_i the weighting factor expressing the importance of criterion *i*.
Note that net Present Value that is calculated within a CBA (see Section 4.3.2) can be considered as a special case of a simple linear MCDA approach, where the criteria are the costs, benefits and side effects (expressed in monetary terms) and the weights -1 for the costs and the negative side effects, and +1 for the safety benefits and the positive side effects.

When defining indicators, it is important to define the appropriate scale (see e.g. Belton & Stewart, 2002). In general, interval scales are used for scoring the alternative solutions for a particular indicator. Interval scales require the identification of two reference points. There are different ways to select these reference points, e.g. using the lowest and highest scores of the alternative solutions, or using the worst or best imaginable scores. In the former case, the best alternative solution (for this indicator) could get a score of 100 and the worst one a score of 0. When several indicators are used to underpin a particular criterion, the scores on the different indicators need to be aggregated first. Again, there are several ways to do so, including the simple averaging of the different sub-scores.

It is also often challenging to define the weighting factors for each criterion. One way of doing so is the method of pairwise comparison. In this method, pairs of criteria are compared and one needs to indicate their relative importance (this can be binary or on a scale). These pairwise comparisons are done for all possible pairs of the criteria. These comparisons can be done in a consensus meeting of experts/stakeholders, or also in parallel by each individual expert or stakeholders. Based on the outcomes of these comparisons, an overall weighting can then be calculated (such calculations are often done by the software that is associated with particular MCDA methods). In general, the weights obtained are normalized so that their total value equals 1 or 100.

5.3 CRITERIA THAT CAN BE USED IN MCDA METHODS

Most peer reviewed literature on using MCDA in transport concerns large infrastructure works, in which road safety is only one of the many considerations. Examples of criteria that can be used (the first ones on this list will also be found in a typical CBA):

- Safety of vehicle occupants
- Safety of cyclists
- Safety of pedestrians
- Development costs
- Maintenance costs
- Costs for the user
- Travel time
- Flexibility of travel
- CO_2 emission
- Other pollution
- Noise
- Employment
- Trade balance
- Other local impact
- Public/social/political acceptability
- Technical feasibility
- Technology risks
- Security risks
- Costs for the users
- Comfort for the users
- Quality of services
- Aesthetics
- Speed of implementation
- Communicability

An important requirement for most MCDA methods to work properly is that the set of criteria are exhaustive, consistent and non-redundant (De Smet, 2006; Roy, 1996):

- Exhaustive means that there are no 'hidden' or 'implicit' criteria that could make a difference in the final decision. For instance, suppose that after application of the algorithms, two alternative solutions get an equal score. Yet, the decision-maker prefers clearly one of the two alternatives. This can be the result of the fact that an important criterion (e.g. speed of implementation, public acceptability) had not been included in the original list of criteria.

- Consistency refers to the need of alignment between the criteria and the preferences of the decision-maker (an increase in the score for a criterion should lead to a higher preference)
- Non-redundancy implies that the criteria should be independent from each other. For instance, if you would have two criteria "impact on local employment" and "impact on regional employment" the criteria are clearly interdependent.

Note that often it can be difficult to avoid some correlation between some of the criteria.

5.4 INVOLVING STAKEHOLDERS

Within a CBA, there is a single 'logic' and experts determine the value of the different components of the algorithm. MCDA methods allow to involve different perspectives and considerations. Stakeholders could be involved at the beginning of the process, by contributing to the identification of different criteria and the relative importance of each of these (weighting). This could be achieved through meetings seeking consensus and/or by using other methods (e.g. averaging the weightings of the different stakeholders).

Stakeholders could also be involved in the interpretation of the results, in particular of the sensitivity analyses undertaken. Moreover, it is possible to involve stakeholders even further. In a method developed and successfully implemented in transport projects by Macharis and others ("MAMCA – Multi-Actor Multicriteria Analysis, see e.g. Macharis, 2004 and Macharis e.a., 2012) all stakeholder can define their own criteria and weighting. In the MAMCA method, the criteria used are based on the stakeholders' (legitimate) objectives. For instance, representatives of cyclists may put forward cyclists' safety, whilst economic actors may value travel time highly and public servants the overall cost. Of course, some of these criteria could be common for all stakeholders, but the weighting may differ.

In the MAMCA method, it is still up to experts to calculate the indicator values and to determine the overall score for each alternative and for each of the stakeholders' set of criteria and weighting. The assessments for each stakeholder are then brought together and used as a basis for decision. In case the assessments converge, it is relatively straightforward to decide. In case they diverge, those in charge of the final decision will know in advance from which stakeholders' resistance is to be expected (and on what grounds).

5.5 USING THE SAFETYCUBE DSS FOR MULTICRITERIA DECISION ANALYSES

For each multicriteria decision that involves road safety, the Road Safety DSS is an important input tool. If the DSS does not provide an economic efficiency evaluation, the synopses can still help to make a rough estimate of their effectiveness. In particular the colour-codes dividing measures into "effective" (dark green), "probably effective" (light green), "unclear" (grey), and "not effective or even counterproductive" (red) can be used, either to generate scores or an entry criterion for measures to be included into the analysis.

If an economic efficiency analysis is provided for a particular counter measure, the total benefit (i.e. the sum of crash costs of all prevented crashes) is the optimal indicator for the road-safety effect already providing a weighting for the different outcome severities of the prevented crashes. Other indicators can be added to this.

6 Economic efficiency analysis in the DSS

A quick guide how to use the E3 calculator in the SafetyCube DSS to conduct an economic efficiency evaluation. The input necessary from the user and the input and calculations provided by SafetyCube are described.

6.1 INTRODUCTION

Economic efficiency evaluation (E^3) is included in the SafetyCube Decision Support System (DSS) by example analyses for a large range of measure and by the ***E^3 calculator***, that allows users to run their own analyses or adjust SafetyCube examples to their own situation. With the DSS being dedicated to give the best available knowledge for each countermeasure, this calculator is directed to evaluation of single measures, rather than programs of several countermeasures.

This E3 calculator combines information on countermeasures and information collected from countries: the crash costs, the relative frequency of crashes/casualties of different severities (i.e. how many severely injured are there for any fatality?), and the discount rate. This information will be available for each EU country or as a European standardised value.

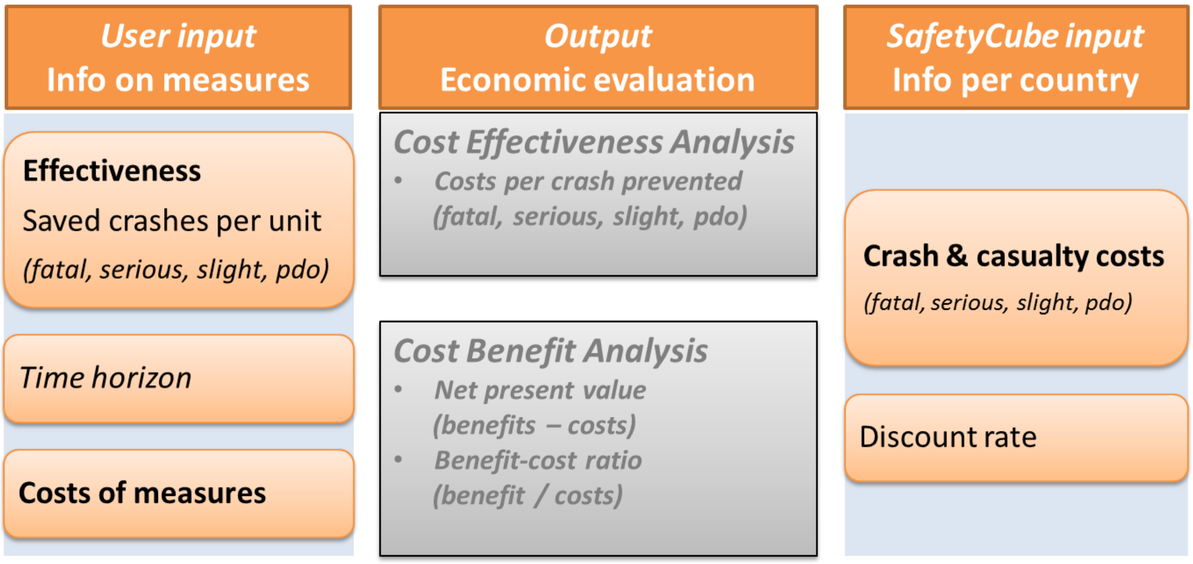


Figure 6.1 Inclusion of economic efficiency assessment into the Decision Support System.

As input to the E^3 calculator, the following is needed

- Costs of measures
  - Implementation costs
  - Annually recurrent costs
- Number of crashes / casualties prevented (for each level of severity)

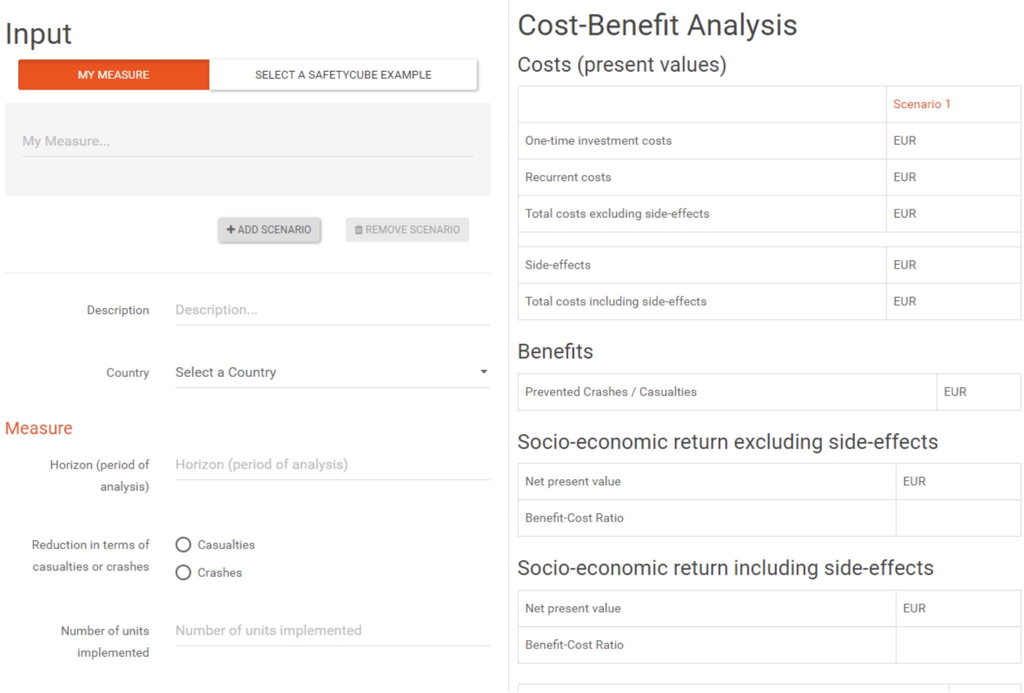
        - Target crashes of countermeasure
            - Fatal crashes/casualties
            - Serious crashes/casualties
            - Slight crashes/casualties
            - Property damage only crashes (not applicable for casualties)
        - Percent reduction
            - Reduction of fatal crashes/casualties
            - Reduction of serious crashes/casualties
            - Reduction of slight crashes/casualties
            - Reduction of property damage only crashes (not applicable for casualties)
- Time horizon (period considered for E3)

On the basis of this input and the crash or casualty costs, the calculator adds for each year within the time horizon the present value of all costs and benefits, resulting into the following outputs:

- **Number** of crashes / casualties **prevented** (per unit of implementation)
- **Cost effectiveness**: cost per prevented crash / casualty
    - Costs per prevented fatality / fatal crash
    - Costs per prevented severe injury / severe crash
    - Costs per prevented slight injury / light crash
    - Cost per prevented damage only crash (if applicable)
- Total benefits
- Cost-benefit analysis
    - **Benefit-cost ratio** (benefits/costs)
    - **Net effect** (benefits – costs)
    - **Break-even costs** for countermeasure

Two different types of analyses can be conducted in the calculator: 1.) own analysis, 2.) SafetyCube example. In the second case, the user can select one of the examples in the drop-down list and the calculator is filled with the values used in the SafetyCube analysis. The analysis is described in PDF file at the bottom of the page. Users can use the SafetyCube examples as a departing point for their own analysis.

6.2 USER INPUT



After giving the name and possibly a description of the measure, the country and the currency for the analysis has to be selected. This will determine the crash costs that are used and the currency in which the output is given. See 6.3.1 for the option to select SafetyCube crash cost estimates according to common methodology, rather than using countries own reported value.

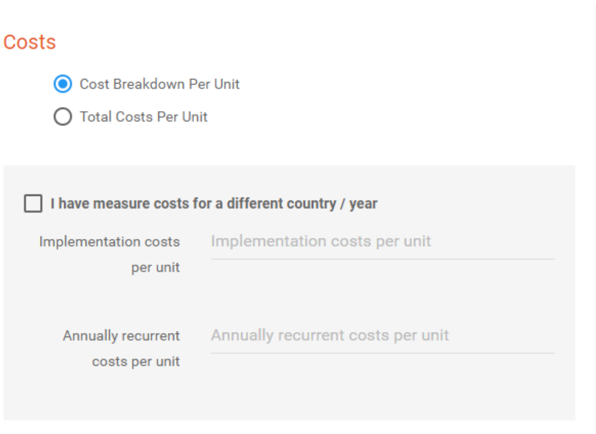
The *horizon* of the measure describes the life-time of a countermeasure in years (minimal 1). This way, the implementation costs of a measure are weighed against the benefits of prevented crashes over the whole lifetime of the measure. For infrastructure measures this can be up to 25 or 30 years. For other measures, e.g. awareness raising campaigns or educational activities the horizon is typically much shorter, often just one year.

An evaluation of a countermeasure can be based either on the prevention of *crashes* or *casualties*. It is assumed that an analysis of casualty-reduction addresses countermeasures for injury prevention and therefore does not entail any reduction of material damage.

Define a suitable *unit of implementation* of the measure. In the case of infrastructure measures, the appropriate unit will often be one junction or one kilometre of road, but it could also be a whole area. In the case of vehicle safety measures, the unit of implementation will usually be one vehicle. For police enforcement, the number of man-hours per year may be a suitable unit of implementation. For education and training, the unit cost will be the cost of training one participant. For public information, there are usually no meaningful units and the analysis will be based on total costs.

The number of *units implemented has to agree with the number of target-crashes*. E.g., if the analysis is based on the equipment of *one* vehicle, the target crashes have to be entered as the expected number *per vehicle*. If the analysis is based on all target crashes in a country, the fleet-size should be entered as the number of units.

6.2.1 Costs of the countermeasure



Costs of measures typically differentiate between implementation costs and annually recurrent costs.
Some road safety measures have only implementation costs. Building a roundabout might be an example. There are costs in building the roundabout, but once built, it will not generate new costs. It will have no, or at worst a negligible influence on road maintenance costs. Quite a few road safety measures have both implementation and annual recurring costs. Finally, some road safety measures (e.g., police enforcement) have mainly annually recurring costs.

If the split-up between total costs and annually recurring costs is unknown or there are no annually recurring costs, the DSS user can enter the "Total costs per unit". Note however, that future costs will not be *discounted* (see 6.2.2. and 6.2.3) if they are not entered as annually recurrent costs. Enter the year and the country in which the measure costs have been established and they will be converted to costs with 2015 price-level of the country chosen for the analysis above.

Costs of measures are often difficult to obtain. Using costs from literature can be a solution. The E3-calculator adjusts the costs based on the source country, source year and target country (see Figure 6.2).

Figure 6.2 DSS process for adjusting measure costs if costs entered stem from another country and/or another year.

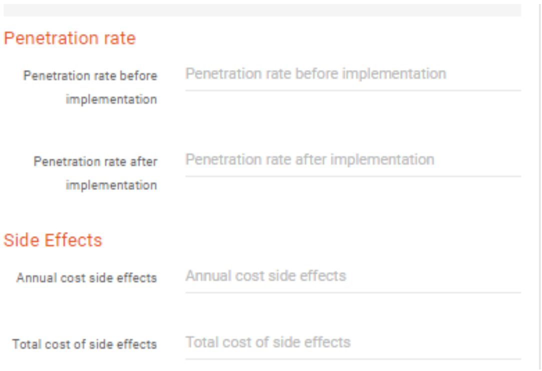
If no measure cost is entered, cost-benefit analysis results in ***break-even*** *cost* (the *maximal cost for a measure to be economically efficient*).

6.2.2 Prevented crashes

Prevented crashes (or casualties) are typically given by indicating the annual number of crashes that could possibly be affected by the measure (the target group) and the percentage reduction per year. The number of target crashes will certainly be different for each severity. If the user does not enter numbers for a particular category (e.g., property damage only (PDO) crashes) the suggestion of the calculator is based on the average rate in the target country (e.g., in Belgium, for each fatal crash, there are 7 serious, 59 slight and 472 PDO crashes). Note that the rates among the target crashes of a particular countermeasure can differ from the average rates in the country.
The effectiveness (***percentage reduction*** among the target crashes), can also differ per severity category. In the case of missing data and in absence of reasons otherwise, it is advised to assume equal reduction rates for each severity.

If *only* the total number of prevented crashes is known "Prevented crashes (total over all years)" should be checked and in the calculations, it is assumed that the prevented crashes are evenly distributed across the number of years indicated in the horizon.

Optimally, the input to the calculator differentiates between fatal, severe, slight, and PDO crashes. However, if the available information concerns either all injury crashes jointly or even all crashes with either injured or fatalities, this information can also be entered. In that case one needs to assume the same effectiveness for all categories that are joined. Please take care and ***never enter any severity categories twice***. As an example, if one has already entered the number of fatal crashes, serious injuries, and slight injuries separately, DO NOT ADD THEM UP entering them once more as "affected cases: slight, serious, fatal".



6.2.3 Penetration rate

Sometimes a measure can be directed at increasing the use (also called penetration rate) of another measure. Examples are directives that make certain vehicle protective features mandatory or campaigns that advocate the use of personal protective gear. To analyse this one needs -- additionally to the data on effectiveness -- the penetration rate (i.e. rate of use) before the measure and after. In the case of a horizon longer than one year, each year the same percentage of change is assumed.

6.2.4 Side effects

Side effects, or indirect costs of a measure, might be larger than the direct costs. As an example, consider the withdrawal of a drivers' licence. To withdraw a licence requires a formal decision, which must be written and communicated to the licence holder. The costs of this procedure are small. A driver who loses his or her licence, however, must either reduce travel or find other means of doing so than driving a car. This involves either a loss of benefit (mobility) and/or new expenditures, if public transport is used to replace trips made by car. The costs for the reduced mobility or measures replacing transport in the driver's own car are side effects that should be included in a CBA.

Side effects can also be positive. For instance, reducing driving speed is good for road safety but usually also reduces fuel consumption and CO_2 emission. In the SafetyCube calculator, side-effects can be included. The monetary valuation of side effects is always entered in the "benefits" side. In the case of indirect costs, this is a negative benefit.

In SafetyCube no side-effects were calculated. However, if users have their monetary value they can be entered into the analysis. All side effects are entered as benefits and have to be summed up before entering them into the E^3 calculator. In the case of indirect *costs* (negative side effects) these should be entered as negative benefits.

6.3 SAFETYCUBE INPUT

6.3.1 Crash costs

The outcome of each CBA depends strongly on the monetary valuation of crash outcomes. If crashes are estimated to be very costly, the benefits of the prevented crashes are more likely to exceed the costs of the countermeasures. The quality of the crash-cost estimates is consequently central to the quality of a CBA and their incomparability is one of the central criticisms to CBA. In SafetyCube, a lot of effort has therefore gone into the *collection, analysis, and harmonisation of European crash-cost* estimates.

Together with the EC H2020 project InDev, SafetyCube has undertaken the collection of crash costs from all European countries (see D3.2 for details). *First*, an overview was presented of the components that should be included in crash cost estimates according to the international guidelines. *Second*, information on costs of crashes and costs of casualties was collected by means of a survey to experts from each EU country. Estimates were collected separately for crashes and casualties and four severity levels were differentiated: fatal, serious injuries, slight injuries, and damage only (with the last category available for crash costs but not casualty costs). *Third*, for some countries not all cost components are included (e.g., some countries do not include human costs in their estimates), or there was no estimate at all for a particular outcome. Therefore, additionally to the country's own estimates (if available), SafetyCube produced component estimates based on *value transfer* from the mean component value of the other countries. This led to *estimates according to the common methodology* that make crash costs of different countries comparable. *Fourth*, the Standardized EU values for crash and casualty costs were based on the common-methodology estimates. This means that differences in price-level were retained, but differences in methodology were up-dated to the internationally advised common methodology.

The users of the SafetyCube Decision Support System (DSS) can choose whether to use the countries own reported crash costs (e.g., if the analysis is intended for official use within the country) or the crash costs estimated in SafetyCube applying the common methodology (e.g., if comparability to other countries is desired). To use the common-methodology estimate, scroll down in the list of countries and select the country name with the addition "COMMONMETHOD".

See the Appendix for more information on the difference between the countries own reported crash costs and the common-methodology estimates provided by SafetyCube.

6.3.2 Discount rate

Discounting makes values that occur at different moments in time comparable. The ***discount rate***, enables us to express all monetary values at different points in time in terms of what they would be worth in cash today. The present is considered as the reference point and the discount rate indicates the depreciation for future values. So, 100 Euro now is worth less in the future depending on the discount rate and the time period concerned. In practice, the discount rate is ***a percentage that is detracted from benefits and costs for each year that they are delayed into the future***. [4]

The process of discounting is the same for costs and benefits, which is important when they do not develop equally over time. Often a large part of the costs for a countermeasure is situated in the beginning, while the benefits are spread out more evenly across the years. In that case the benefits are more diminished by discounting than the (initial) costs. Generally speaking, long term projects will see their benefits more diminished than short term projects. A higher discount rate therefore usually favours short term projects.

Many countries have a "prescribed" discount rate, which will be used automatically when selecting that country. If no value was indicated by the country-expert, the European modal value of 2.5% is used.

6.3.3 Calculations

For each year of the horizon, the number of saved crashes (casualties) are calculated per severity category. The percentage reduction is considered to remain constant and the target group is diminished by the saved crashes in the previous years. Subsequently, for each year, the benefits (saved crashes * crash costs) and annually recurrent costs for the countermeasures are calculated

[4] Costs and benefits are brought to present by: $present\ value = \frac{actual\ value}{(1+discount\ rate)^{year}}$

and discounted. The implementation costs are assumed to take place in the present and are not discounted. Subsequently all saved crashes, costs, and benefits are summed up.

6.4 SENSITIVITY ANALYSIS

The results of economic efficiency analyses depend critically on the input values and consequently a sensitivity analysis is advised. Apart from the crash costs (which are imported from SafetyCube), the most influential parameters are the measure costs and the effectiveness of the measure. The estimates of a countermeasure's effectiveness usually come with a confidence interval. The upper and lower boundaries of this confidence interval can be used to mark the expected range of the true effectiveness. For the costs of a counter-measure there are often no estimates, but simply the costs from an earlier implementation (possibly corrected for inflation and price-level differences). To indicate the range in which the true costs can most likely be found, the example costs were either halved or doubled. So, for each SafetyCube example, the following variations were calculated:

- Low measure effect (lower boundary of confidence interval from source study)
- High measure effect (upper boundary of confidence interval from source study)
- High measure costs (+ 100%)
- Low measure costs (-50%)

These were combined to two scenarios:

- Worst case: low effectiveness + high costs
- Ideal case: high effectiveness + low costs

Users of the calculator are advised to create their own sensitivity analysis by repeating the original analysis with adjusted values.

6.5 OUTPUT

Cost-Benefit Analysis

Infrastructure safety management - Speed management & enforcement - section control

Section control on 1 km highway

Costs (present values)

	Scenario 1
One-time investment costs	68323 EUR
Recurrent costs	84589.56 EUR
Total costs excluding side-effects	152912 EUR
Side-effects	0 EUR
Total costs including side-effects	152912 EUR

Benefits

Prevented Crashes / Casualties	2987808.06 EUR

Socio-economic return excluding side-effects

Net present value	2834896.06 EUR
Benefit-Cost Ratio	19.54

Socio-economic return including side-effects

Net present value	2834896.06 EUR
Benefit-Cost Ratio	19.54

Break-even cost for measure (per unit)	2987808.06 EUR

A full description of the methods and data used in this example, as well as a sensitivity analysis, are available in the Cost-Benefit Analysis document:

The E3-calculator produces the following outputs:

- **Number** of crashes / casualties **prevented** (per unit of implementation)
- **Cost effectiveness**: cost per prevented crash / casualty
    - Costs per prevented fatality / fatal crash
    - Costs per prevented severe injury / severe crash
    - Costs per prevented slight injury / light crash
    - Cost per prevented damage only crash (if applicable)
- Cost benefit analysis
    - *Total benefit*
    - **Benefit-cost ratio** (benefits/costs)
    - **Net effect** (benefits – costs)
    - *Break-even costs* for countermeasure

The output of the calculator are a number of criteria and other indicators. The number of casualties (or crashes) prevented, the cost per prevented casualties (cost-effectiveness), the benefit-cost ratio, and the net-effect are all criteria that can be used to rank alternative measures. In Table 6.1, an overview is given over the conditions for use, the advantages and the shortcomings of each criterion. (For more background information see Chapter 4).

Table 6.1 Criteria in economic efficiency evaluation

Criterion	Conditions for use	Advantage	Shortcoming
Number of crashes/ casualties prevented	• Direct communication of effect	• Easily understood	• Not taking costs into account
Cost-effectiveness	• Focus an road safety effect • (No crash costs available)	• Easily understood • Comparison between road-safety measures possible to some extent.	• No differentiation by severity of outcomes. • No inclusion of side-effects. • No comparison with other policy domains possible.
CBA net-present value	• Valuation of all costs and benefits available	• Gives absolute size of the net-benefit. • Side-effects can be added. • Comparable to other policy domains.	• Depends on crash-cost estimates. • Depends on scale of analysis (number of units implemented)
CBA benefit-cost ratio	• Valuation of all costs and benefits available. • Maximisation of benefits for measures that have to be financed from the same budget.	• Indicates good value for money. • Side-effects can be added. • Comparable to other policy domains.	• Depends on crash-cost estimates.

A cost-benefit analysis results in two decision criteria (net-effect and benefit cost-ratio – see Section 4.3.2 for the difference between the two) and two other indicators: The total benefit and the break-even costs.
The *total benefit* is the sum of the costs of all prevented crashes or casualties. If side-effects are included the total benefits including and excluding side effects are given separately. As noted in Chapter 5, the total benefit (excluding side-effect) is the best measure of the road-safety effect, because it combines and weighs the prevention of crashes of different severity.

The *break-even cost* for the countermeasure is particularly interesting when the analysis is done exploratory without knowing the exact cost of implementing the measure. It is the cost for the countermeasure at which the benefit-cost ratio is one (and the net-effect 0) and gives an indication how much the countermeasure should maximally cost to still be economically efficient.

7 Conclusion

In the present deliverable, we have described different criteria for economic efficiency assessment of road safety counter measures, like the cost per saved casualty (cost effectiveness analysis), the cost per saved Quality-adjusted life year (QALY – cost utility analysis) and the balance of costs and benefits (net present value) and benefit-cost ratio in a cost-benefit analysis. It has been shown that at this moment cost benefit analysis offers the most complete framework for measure evaluation. Cost-utility analysis is for the time being difficult to apply because a lack of data, and for cost effectiveness analysis, it can be concluded that all resulting aspects can also be concluded from CBA, but not vice versa. Although it has also been shown that sometimes cost effectiveness analysis can be sufficient, it is concluded that a presentation in terms of cost-benefit analysis offers most flexibility to consider several criteria at the same time and for the DSS user to post-hoc include other aspects, like countermeasure side effects.

Cost-benefit analysis is based on welfare theory and requires the monetary valuation of all measure and crash impacts. It is important to understand that "costs" in this context do not necessarily refer to money actually spent. In the context of crash costs, it indicates the resources that are lost as a consequence of crashes, *as well as, loss of quality of life*. For some part the crash costs are based on costs of medical care, costs of repairing of material damage and other direct costs, but for the largest part, crash costs are human costs: the value that we are willing to pay to prevent human suffering that is caused by road safety crashes.

In cost-benefit analysis, the crash costs enter as benefits (because they are prevented) and the costs for measures are compared to them. For countermeasures the costs are mostly direct costs (i.e. resources used to implement the measure). The monetary valuation of side effects is beyond the scope of the SafetyCube project.

In the discussion of the principles of CBA, it is shown how the applied criterion and parameters can influence whether a countermeasure is considered efficient or not. A high discount rate favours short-term projects while a low discount rate gives projects a chance that only show benefits in the long term. It is also demonstrated that the CBA ratio (benefits/costs) does not necessarily "favour" the same measures as the net-effect (benefits – costs). The net-present value will favour measures with large benefits even if they come at a relatively large cost, while the cost benefit ratio will favour measures with the best value for money, even if their actual benefits are relatively small (e.g., because they are targeted at a small group of crashes).

In the SafetyCube Decision Support System (DSS) data on crash costs – collected in WP3 – are combined with data on safety effects and costs of countermeasures – collected in WPs 4, 5, 6, and 7. The system allows the inclusion of standard estimates by the researchers from WPs 4, 5, 6, and 7, as well as the replacement of these values by the user of the DSS (who might have more concrete costs for the specific case). For those countermeasures for which all required input-estimates exist, several criteria will be presented: the costs per avoided crash for different severity types (fatal, serious, light, damage only), the benefit-cost ratio and the net-effect.

In this way, the DSS gives the end-user the building blocks for developing a road safety program. It is based on a taxonomy of risk factors and measures, it makes the user aware of different options to treat a problem, it indicates how well each approach has been found to work, and it contrasts the costs of each measure with its estimated effectiveness.

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Appendix: Crash cost estimates

There are big differences in the crash-cost estimates of different countries. This can be due to differences in 1.) price-level, 2.) the methodology, 3.) welfare.

1.) Countries differ in price level, meaning that one can buy more for one Euro in one country than another. These differences can be corrected for by value transfer based on each country's purchasing power parity (PPP) factor.
2.) Among the different components of crash-cost estimates (see Figure A1) the human costs take a very large part. Human costs are mostly estimated by willingness to pay for preventing a particular crash outcome and result in a *value of a statistical life*. It makes a big difference whether a country includes this component in their cost estimates or not. Inclusion or non-inclusion of other subcomponents can also lead to substantially different crash-cost estimates.
3.) Different cost estimates can be due to real differences in the welfare of countries. The rich can afford to pay more for road safety than the poor. For example, the value of a statistical life in Sweden is more than 4 times larger than in Portugal (see D3.2). This means that a CBA in Sweden is much more likely to result in positive advice for a particular countermeasure than in Portugal.

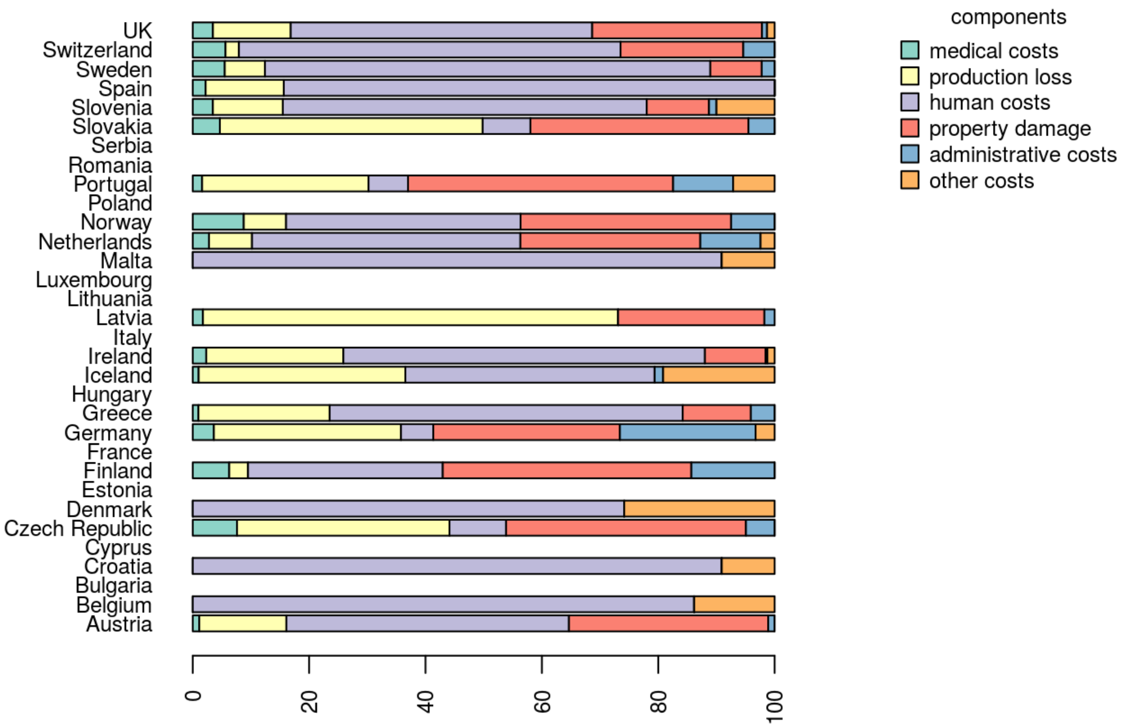

Figure A.1 Components of crash costs and their share in countries cost estimates (D3.2)

We can conclude that due to differences in crash costs, CBA's have different outcomes when applied in different countries. Most CBAs conducted for SafetyCube have been based on the European standardize crash costs that resulted from the estimation process based on the common methodology (D3.2). For countries for which components were missing, these have been estimated by value-transfer from the other countries. This means that real differences in welfare were taken into account, but differences in methodology were up-dated to the internationally advised common methodology (D3.2).

The users of the SafetyCube Decision Support System (DSS) can choose whether to use the countries own reported crash costs or the crash costs estimated in SafetyCube applying the common methodology (D3.2). In Figure A1, the ratio between the country's own crash costs and the common-methodology estimate is given. A number of countries had no estimates for some outcomes and the value transfer method was used to estimate these. For these countries no ratio can be calculated and the table contains "#Value". For the other fields, the colouring indicates the relation between the country's own value and that of the common-methodology estimate. White fields mean that the difference is negligible; blue fields mean that the countries own estimate is smaller (and therefore countermeasures are less likely to be judged as economically efficient), red fields mean that the country's own estimate is higher than those resulting from the common methodology.

Depending on the purpose of the analysis, the user should either use the country's own crash costs (if the analysis is intended for official use within the country) or the common-methodology estimates (if comparability to other countries is desired).

Ratio: Countrie's own value / common meth. est. value							
Country	Fatal crashes	Fatalities	PDO crashes	Serious injuries	Serious injury crashes	Slight injuries	Slight injury crashes
Austria	0.93	1.00	0.82	0.96	0.95	0.80	0.76
Belgium	#VALUE!	0.80	#VALUE!	0.99	#VALUE!	0.65	#VALUE!
Bulgaria	0.55	0.60	#VALUE!	0.73	0.81	2.09	2.00
Croatia	#VALUE!	0.82	#VALUE!	0.86	#VALUE!	0.69	#VALUE!
Cyprus	#VALUE!	0.45	#VALUE!	0.45	#VALUE!	0.36	#VALUE!
Czech Rep	#VALUE!	0.44	0.96	0.62	#VALUE!	0.63	#VALUE!
Denmark	#VALUE!	0.80	#VALUE!	1.11	#VALUE!	1.73	#VALUE!
Estonia	#VALUE!	1.24	#VALUE!	3.16	#VALUE!	1.34	#VALUE!
Finland	0.90	1.00	0.87	1.00	#VALUE!	0.98	#VALUE!
France	#VALUE!	1.30	1.14	1.21	#VALUE!	0.51	#VALUE!
Germany	0.02	0.51	1.05	0.38	0.06	0.18	0.35
Greece	0.96	1.05	0.77	0.77	0.69	1.63	1.45
Hungary	#VALUE!	0.95	1.44	1.65	#VALUE!	0.20	#VALUE!
Iceland	1.04	0.87	2.09	0.86	1.00	0.83	1.52
Ireland	1.04	1.02	0.73	1.01	1.26	0.97	1.04
Italy	0.00	0.62	#VALUE!	0.54	0.03	0.52	0.25
Latvia	#VALUE!	0.50	1.66	0.09	#VALUE!	0.01	#VALUE!
Lithuania	#VALUE!	0.44	#VALUE!	0.30	#VALUE!	#VALUE!	#VALUE!
Luxembou	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
Malta	#VALUE!	0.75	#VALUE!	0.79	#VALUE!	0.59	#VALUE!
Netherlan	#VALUE!	1.00	1.00	1.00	#VALUE!	0.24	#VALUE!
Norway	1.00	1.00	0.85	1.00	0.98	0.99	0.95
Poland	#VALUE!	0.36	4.27	3.22	#VALUE!	0.42	#VALUE!
Portugal	0.36	0.37	#VALUE!	0.45	0.48	1.29	1.28
Romania	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
Serbia	0.27	#VALUE!	#VALUE!	#VALUE!	0.27	#VALUE!	0.23
Slovakia	#VALUE!	0.30	1.06	0.42	#VALUE!	0.61	#VALUE!
Slovenia	0.02	1.05	1.01	0.99	0.05	0.85	0.32
Spain	#VALUE!	0.74	#VALUE!	0.91	#VALUE!	0.40	#VALUE!
Sweden	#VALUE!	1.02	0.81	1.36	#VALUE!	1.13	#VALUE!
Switzerlar	#VALUE!	0.99	#VALUE!	0.96	#VALUE!	0.54	#VALUE!
UK	0.88	0.88	0.69	0.86	0.85	0.62	0.71

Figure A.2 Ratio of crash and casualty costs supplied by each country and SafetyCube estimation based on common methodology. Blue fields indicate that country's estimate is smaller than common methodology estimate, red fields vice versa.