Economic evaluation of infrastructure related measures

Deliverable 5.3

SafetyCube

Economic evaluation of infrastructure related measures

Work package 5, Deliverable 5.3

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Executive summary

This Deliverable reports on the work in SafetyCube Task 5.3. This addresses one of the main objectives of WP5 by contributing to the evaluation of key infrastructure related road safety measures. This is achieved by collecting, assessing and analysing pertinent information in order to conduct **cost-benefit analyses (CBAs) for selected infrastructure related road safety measures**.

The analyses are based on the methodologies developed within SafetyCube WP3, namely: the methods for priority setting between different road safety measures, and in particular the methodology and tool for conducting CBAs (i.e. the "E³ Calculator) - given that CBA is the recommended method for measures priority setting.

A selection procedure was followed for **meaningful candidate topics for a CBA**. The selection criteria were as follows: first, among the 48 infrastructure measures examined within Task 5.2 of SafetyCube, the 35 measures that were assigned a green (effective) or light green (probably effective) colour code were considered. For these measures, a literature review was performed, in order to identify existing published CBAs that could be used as a basis for SafetyCube CBAs.

The studies found were analysed to identify usable data elements. The items of interest were those that should serve as input data to the E³ Calculator: target group, unit of implementation and time horizon, measures costs and measures safety effects. Lack of reliable information on these aspects resulted in dropping a measure from the CBA analyses - with the exception of measures costs, for which a "break-even" CBA could be conducted, reflecting the measure threshold cost value at which benefits and costs are equal.

Especially as regards the measures costs, apart from the literature search, resulting in a compilation of measures costs from different sources, dedicated inquiries were made to key infrastructure stakeholders to collect additional information; however, stakeholders mostly pointed towards existing publications that were already considered.

As regards crash costs, the improved SafetyCube estimates for EU countries were used in all CBAs.

Eventually, CBAs were carried out on 16 measures. In general, there were two options for conducting a CBA on the selected measures:

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

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

The CBA outputs concern both the measures Net Present Value, and the Benefit-to-Cost ratio (BCR). The results suggest large variations of the BCR, ranging from not cost-effective (e.g. automatic barriers at rail-road crossings, traffic calming) to highly cost-effective (e.g. chevron signs, rumble strips, safety barriers, section control, junctions channelization or conversion to roundabouts).

The results of any cost-benefit analysis are much dependent on the underlying assumptions. Effect estimates are – even in the best known cases – only known within a certain uncertainty margin. It is therefore useful to run a sensitivity analysis based on some alternative assumptions about the effects of the measure. For the vast majority of the CBA we ran sensitivity analyses that use some alternative effect estimates.

If available we used **the upper and lower limits of the 95% confidence intervals of the estimates**. In the ideal case these estimates were resulting from a meta-analysis, in other cases the used values result from one or two particular studies. The used values represent a (much) lower than expected and a (much) higher than expected effect respectively. Overall, this sensitivity analysis did not change the overall trend of the measures cost-effectiveness, with a few exceptions: dynamic speed limits, 30-zones and traffic signals were found not cost-effective under the low measure effect assumption (lower limit of the 95% CI).

Moreover, in order to reflect the inherent uncertainty of cost estimates we decided to include also two scenarios in which **the measure costs vary from a 'very low' (-50% of the estimate) level to a 'very high' (+ 100% of the best estimate) level**. The latter case concerns the, more frequent, case of measures cost under-estimation, while the former case may be most applicable to technology solutions, whose costs tend to decrease with increasing penetration or technology improvements. A few measures were found clearly sensitive to changes in the measure costs as their BCR values change from below 1 to above 1 throughout the different scenarios. Interestingly, it is mostly the same measures that were found sensitive in the safety effect sensitivity analysis (dynamic speed limits, 30-zones and traffic signals). Apart from these, also the BCR value of the installation/improvement of lighting is much dependent on the eventual measure cost.

The results were eventually analysed for two rather extreme scenarios:

- **a 'worst case' scenario** as a combination of a much worse than expected effect (in principle the lower limit of the 95% confidence interval of the effect estimate) and a higher than expected measure cost (i.e. the estimated cost +100%).
- **an 'ideal case' scenario** that is a combination of a much better than expected effect (upper limit of the 95% CI of the effect estimate) and a lower than expected measure cost (estimated cost -50%).

Even in these scenarios the measures examined remain consistently efficient (e.g. section control or rumble strips), or never become efficient (e.g. automatic barriers). Some other measures (e.g. 30 km/h zones or traffic signal installations) are clearly more susceptible to varying combinations of measure costs and effects.

The executed examples show that the assumptions on all three elements of a CBA can play a decisive role: the effectiveness of the measures, the costs of the measures and the size of the target group. The fragmentary information available in the literature resulted in several cases for **a combination of information sources to be used for a single CBA**. Although every effort was made by SafetyCube experts to use as consistent sources as possible, in several cases this was simply inevitable. Even in these cases, particular caution was put on the transparent and substantiated combination of information.

The **flexibility provided by the E³ tool**, which allows to transfer any cost value from any country to another (EU countries, USA, Canada, Australia) was exploited as much as possible, but with particular care to properly combine related information.

It should be stressed that **the dependency on all these assumptions is not as such a weakness of the method but rather a weakness of the data that are usually available**. In general, too little published literature is available on economic evaluations of traffic safety measures and more reliable data are needed to allow CBA of more infrastructure measures.

It is recommended to avoid relying on existing CBA results and transfer them to a different context, but in any particular case to complement the available information with the case-specific information on the measures target group, the likely safety effects, the measure costs and the circumstances in which they are applied.

List of abbreviations

AADT	Annual average daily traffic
BCR	Benefit-to-cost ratio
CARE	Community database on Accidents on the Roads in Europe
CBA	Cost-benefit analysis
CEA	Cost-effectiveness analysis
CI	Confidence interval
CUA	Cost-utility Analysis
CMF	Crash modification factor
DSS	Decision Support System
E^3	Economic Efficiency Evaluation
HGV	Heavy Goods Vehicle
NPV	Net Present Value
PPP	Purchasing Power Parity
PR	Percentage Reduction
QALY	Quality Adjusted Life Years
ROR	Run-off-road
WP	Work Package
WTP	Willingness To Pay
YLD	Years Lived with Disability
YLL	Years of Life Lost

1 Introduction

This chapter describes the overall project and the purpose of this Deliverable.

1.1 SAFETYCUBE

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

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

The core of the project is **a comprehensive analysis of accident risks and the effectiveness and cost-benefit of safety measures focusing on road users, infrastructure, vehicles and injuries framed within a systems approach** with road safety stakeholders at the national level, EU and beyond having involvement at all stages.

1.1.1 Work Package 5

The objective of the Work Package (WP) 5 is the in-depth understanding of infrastructure related accident causation factors and the identification and evaluation of the most appropriate related measures. **This WP will exploit a large amount of existing accident data (macroscopic and in-depth) and knowledge (e.g. existing studies) in order:**

i. to identify and rank risk factors related to the road infrastructure,
ii. to identify measures for addressing these risk factors,
iii. to assess the effects of measures.

WP5 will thus contribute to all the objectives of SafetyCube, as listed in section 1.1 above, from a road infrastructure viewpoint. WP5 includes **four distinct and complementary Tasks**, as follows:
Task 5.1. Identification of infrastructure related risk factors
Task 5.2. Identification of safety effects of infrastructure related measures
Task 5.3. Evaluation of key infrastructure related road safety measures
Task 5.4. Inventory of road infrastructure safety measures

More specifically, the WP started with the creation of an exhaustive list of risk factors and road safety measures specific to the road infrastructure (**taxonomy**). For all these elements, a set of basic pieces of information are available within the existing literature, e.g. a general description, a rough assessment of the safety effects (high / low or range of values, if known) and the related costs (high /

low, or unit costs if known), other effects (mobility, environmental etc.). The stakeholders' consultation taking place in WP2 is an additional source of basic information on the risk factors and measures.

This exhaustive list has been examined together with WP3 and WP8, in order to make a selection of risk factors and measures to be analysed and evaluated. It has been updated and improved several times through the course of the project, on the basis of literature review and analyses results.

For the selected risk factors and measures, the **methodologies and guidelines developed in WP3** (Martensen et al., 2017) are implemented and tested in the WP5 analyses. At the same time, care is taken – under the supervision of WP8 – that the conceptual framework of the analyses is consistent with the "systems" approach, that the combined effect of risks and measures related to more than one component of the system (user, infrastructure, vehicle) is taken into account.

Overall, **a mixture of methods and data sources** have been utilised following the WP3 methodologies:

- existing and new data sources (macroscopic or in-depth) are used for carrying out original analyses.
- existing studies are examined for carrying out meta-analyses or other types of analysis allowing for comprehensive syntheses of results (e.g. vote-count analysis) to estimate the effects of risk factors and the efficiency of road safety measures.
- The Economic Efficiency Assessment (E^3) Tool is used to carry out cost-benefit analyses of selected measures.

Eventually, WP5 will create an **inventory of evaluated road safety risks and measures** related to road infrastructure, with results from accident risk factors analysis and measures cost-efficiency assessment, to be integrated in the DSS system of WP8.

1.2 PURPOSE AND STRUCTURE OF THIS DELIVERABLE

This Deliverable reports on the work in Task 5.3. This addresses one of the main objectives of WP5 by contributing towards the evaluation of key infrastructure related road safety measures. This is achieved by collecting, assessing and analysing published information **in order to conduct cost-benefit analyses (CBAs)** for infrastructure related road safety measures. The current report focuses on identifying and evaluating infrastructure related measures by:

- **Overviewing of methodology:** the available methods for prioritizing measures, and a presentation of the Economic Efficiency Evaluation Tool.

- **Showcasing Data collection:** Following a structured methodology, essential data collection procedures are described. Certain technical approach principles are established as well.

- **Presenting cost-benefit and sensitivity results:** After the analyses are completed, resulting findings are presented for each identified measure which include CBAs for several scenarios (best estimate and "ideal" / worst cases).

1.2.1 Report structure

This report has five chapters. This chapter (**Chapter 1**) provides background information about the SafetyCube project and the current Work Package. **Chapter 2** describes methodological issues and the decided approach for conducting CBAs. **Chapter 3** details the data collection process and principles applied for prioritizing infrastructure related measures. **Chapter 4** considers infrastructure measures in turn, presenting the results of the CBAs. **Chapter 5** complements those findings by presenting sensitivity analyses for each measure previously described which include several possible scenarios ("ideal" and worst cases). **Chapter 6** concludes the report, summarizing the main findings and detailing the next steps.

Appendix A contains the full CBAs alongside break-even costs and possible side-effects.

1.3 RELATION TO OTHER SAFETYCUBE WORK PACKAGES AND OUTPUTS

The main results of deliverable 5.3 include a variety of systematically analysed infrastructure measure findings regarding costs and benefits. These findings will be documented and integrated in a similar form as the measure 'synopses' which were prepared as part of Task 5.2 and presented in Deliverable 5.2. The CBAs will be incorporated into the Safety Cube DSS and linked to corresponding road safety benefits of these measures. The CBAs presented in the report, however, form individual documents appended to this one and will be made available separately through the DSS.

Similar analyses of measures cost-effectiveness is carried out within Tasks 4.3 (Road user behaviour) and Task 6.3 (Vehicle), in accordance to the Systems approach that spans the whole SafetyCube project.

2 Methodology

This chapter provides a comprehensive overview of the methods used for carrying out efficiency assessment of road safety measures within SafetyCube Task 5.3, as developed within WP3. For full descriptions the reader is referred to Martensen et al. (2017), and Wijnen et al. (2016). Moreover, the procedure followed for carrying out the analyses is described.

2.1 OVERVIEW OF METHODS FOR PRIORITY SETTING

After assessing the different road safety measures and their estimated effects, it is important to define a methodology to assign levels of priority to each of the measures. This helps policy makers and other stakeholders to determine policies that make the most efficient use of resources. Priority can be assigned to the different measures by performing an economic assessment. There are three methodologies: cost-effectiveness analysis (CEA), cost-utility analysis (CUA) and cost-benefit analysis (CBA). This section briefly describes the tools and explains why a CBA is preferred. More information can be found in SafetyCube Deliverable 3.4 (Martensen et al., 2017).

2.1.1 Cost-effectiveness analysis (CEA)

In a cost-effectiveness analysis (CEA) a road safety measure can be evaluated as the number of crashes prevented by the measure per unit cost of implementing the measure.
The necessary information to conduct this analysis is the effectiveness of a measure per unit of implementation, the cost of implementing the measure and a definition of a unit of implementation.

The main advantage of a CEA is that less information is necessary to conduct the analysis. It is not necessary to have an estimation of the monetary value of a crash. On the other hand the CEA is limited to the economic evaluation regarding only one outcome of the measure (for example the number of prevented crashes). It is not possible to take into account the effect of the measure on different levels of severity of crashes, or the effect on different policy areas such as the environment or mobility.

CEA is useful to determine how to reach one specific policy objective (e.g. reducing the number of crashes) at the lowest costs.

2.1.2 Cost-utility analysis (CUA)

A cost-utility analysis (CUA) is an analysis in which the effect of a measure on different levels of severity of crashes can be taken into account. The impact of a measure on the health of traffic casualties can be expressed in Quality Adjusted Life Years (QALY). Fatalities are assessed by Years of Life Lost (YLL) avoided by implementing a road safety measure, while injuries are assessed by the Years Lived with Disability (YLD) that are saved. While a CEA calculates the cost per prevented crash a CUA calculates the cost per QALY, which combines the impact on fatalities and different injury severities. In that way road safety measures can be prioritised according to the cost-utility (cost per QALY).

The main advantage compared to CEA is that CUA allows including the effect of the measure on different severity levels of crashes. Different values can be assigned to them depending on the impact on YLL or YLD. A similar limitation of the CUA is that 'side effects', the impact of the measure in other policy areas, cannot be taken into account.

CUA is useful to determine how to reach multiple objectives which are related to each other (e.g. number of fatalities, serious injuries, slight injurie), at the lowest cost.

2.1.3 Cost-benefit analysis (CBA)

A cost-benefit analysis (CBA) allows the joint evaluation of the effectiveness of measures in reducing crashes of different severity and to provide information on the socio-economic return of countermeasures. Therefore a monetary value is assigned to each type of benefit that results from the measure. The sum of these monetary values is compared to costs of the measure. In a CBA two statistics can be calculated:

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

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

A CBA is often preferred above a CEA or a CUA because it is possible to take side effects - effects on other policy areas such as mobility or the environment - into account. As long as these effects can be monetarized, they can be included in a CBA. The determination of side effects is however not in the scope of the SafetyCube-project since the main focus is on road safety.

While CEA simply helps to find the cheapest way of realising one particular policy objective, the aim of CBA is to help find the right balance between safety and other possible objectives. Instead of interpreting one specific objective as absolute, CBA evaluates the economic benefits and costs of this objective in the context of other objectives.

2.2 THE ECONOMIC EFFICIENCY EVALUATION TOOL

Within the SafetyCube-project an Economic Efficiency Evaluation (E^3) calculator has been developed. This tool facilitates conducting a CBA. All necessary input information can be filled in by the user: the effectiveness of the measure, the target group and its costs. Monetary values of the benefits (the prevented crashes or casualties) for different severity categories are provided by the tool. Using this information, the economic efficiency of the measure is calculated by the E^3 calculator in terms of the NPV, the BCR or, in case there is no information on the measure costs, the break-even cost.

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

- Crash Modification Factor (CMF): A CMF is a multiplier that has to be applied to the number of crashes that occurred before the implementation of the measure. A CMF is used to estimate the number of crashes that (still) will occur when the measure is implemented. Thus it is an estimate of the expected effect of a measure.
- Effectiveness (E) or Percentage Reduction (PR) is defined by the formula E=PR=100*(1-CMF) and it represents the reduction of crashes after the measure is implemented.

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

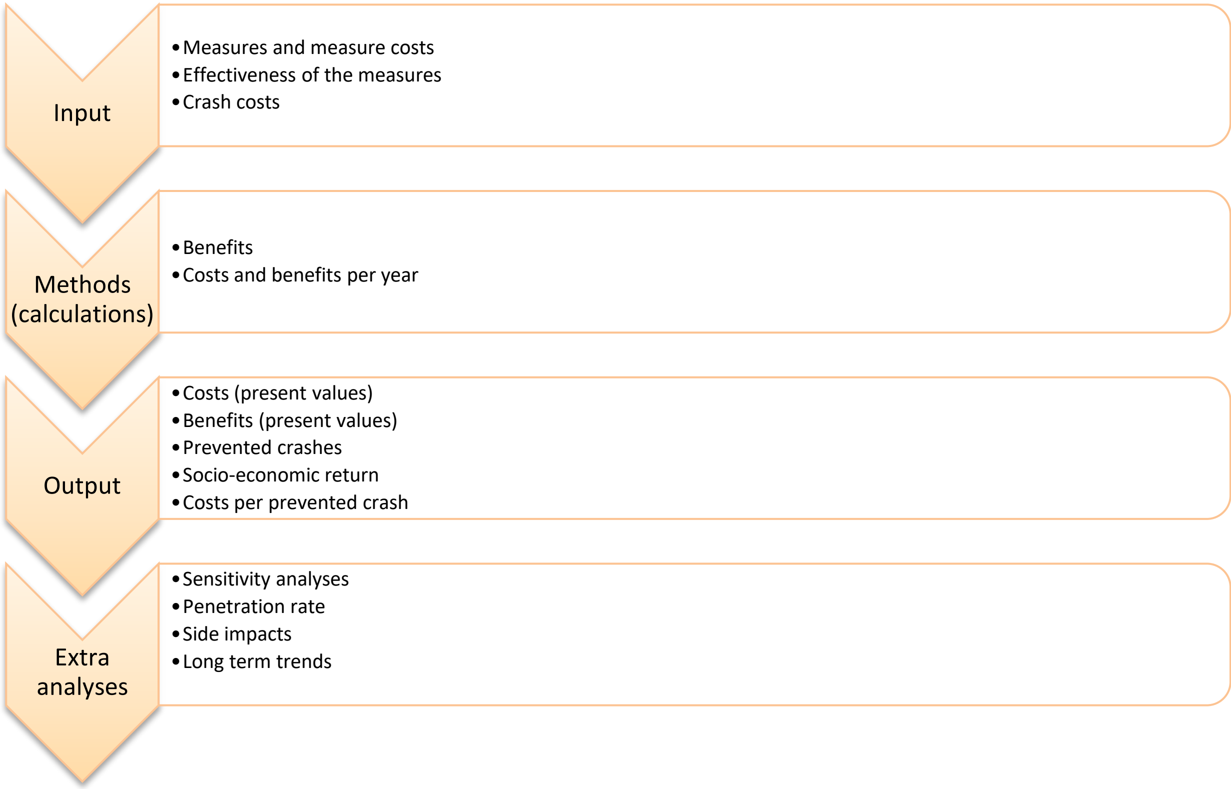

Figure 1. Overview of the SafetyCube E[3] Tool

2.2.1 Inputs

First it is important to consider whether a specific road safety measure or intervention is preventing crashes or casualties. In the E³ tool, all the measures that can prevent crashes are assessed as a reduction of crashes and it is recommended to take into account different levels of severity of crashes when estimating the effectiveness of the measures. That is due to the fact that the implementation of a certain measure can have different effects depending on the level of severity, and can thus lead to different benefits because the monetary value differs for each severity category.

Second, when including the costs of a road safety measure as an input to the E³ tool, implementation and maintenance costs have to be differentiated. The implementation cost is only paid one time, while the maintenance cost is a recurrent cost and should be expressed on a yearly basis. These costs differ per country. These costs have to be updated to 2015 since this is the year in which the costs of crashes (benefits) provided in the E³ tool, are expressed.

Another important input is the target group. This is the number of crashes on which the safety measure is expected to have an impact. In the tool, the target group should be specified for all the levels of severity for which there is information regarding the CMF. Moreover, the effectiveness (or percentage reduction) should be added for each severity level.

The number of crashes and an estimate of the value of the crash costs, per severity level, are provided by the E³ tool for each European country, and for all European countries together. The user can select the relevant data for the country they analyse and include the values as an input in the calculator.

2.2.2 Method

First of all, the benefits, depending on the level of severity, that result from the introduction of a measure, are calculated as follows.

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

Where, s= severity level.

The tool calculates the costs and benefits on a yearly basis considering by default a time period of 30 years (but different implementation periods may also be specified). First, the actual values of the implementation and maintenance costs are calculated. Then, a discount rate that can be chosen as an input is applied to obtain the present value of the costs as follows.

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

The benefits represent the number of prevented crashes per year due to the implementation of the measure. The number of prevented crashes can be filled in directly in the input, or will be calculated by multiplying the target group with the effectiveness. Next the benefits will be put in monetary values by multiplying the cost per crash with the number of prevented crashes.

2.2.3 Output

The output consists of the present values of the costs and benefits of implementing the measure over the selected time period (e.g. 30 years).
Net present value and benefit-to-cost ratio are also shown, calculated with the following formulas to estimate the socio-economic return of introducing the measures:

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

For measures with missing measure cost information, a break-even cost is calculated by the tool.

2.2.4 Other analyses

Extra analyses might be included in the tool. For example, sensitivity analyses, and side effects derived from the implementation of the measure.

2.3 ANALYSIS PROCEDURE

CBA was selected within the SafetyCube project as the common analysis method. The following steps were taken:

1) Selecting measures that were meaningful candidates for a CBA.
2) Executing CBA with the E3 calculator according to the previously established method.
3) Reporting the assumptions and the results in a synoptic document

First, a literature review was performed for the candidate topics of the SafetyCube infrastructure measures taxonomy, in order to identify available data sources and/or existing published CBAs that could be used as a basis for SafetyCube CBAs. The studies found were analysed to identify usable data elements. The items of interest were target group, unit of implementation, time horizon, measures costs and measures safety effects.

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

a) New CBA: this was the preferred option when a meta-analysis with confidence intervals of the estimate of the measure was available, as such an estimate is considered highly reliable and transferable. However, in such case no “perfectly matching” measure cost and target group were available and this information had to be found elsewhere and subsequently value-transferred to the generic context.

b) Adjustment of an existing CBA: if a reliable CBA was available, it was adjusted at least in two ways: first, with the improved SafetyCube crash costs estimates, and second, with the update of all figures and estimates to the reference year 2015.

After executing the CBA, all results and assumptions were summarized in a two page synopsis document. All synopses are included in Appendix A.

3 Input data for cost-benefit analysis

This chapter provides an overview of the information that was used as input for the cost-benefit Analyses (CBA). The first section 3.1 lists all the selected measures. The subsequent sections 3.2 and 3.3 provide information on the selected time horizons for the measures, the measure costs and the used values for the effect estimates. Section 3.4 explains the method used and the input data for the crash cost estimates.

3.1 SELECTED MEASURES

Following a common method, systematic information on the safety effects of 48 traffic safety measures was collected in Machata et al. (2017) (Deliverable 5.2 of WP5). The method included a literature search strategy, a 'coding template' to record key data and metadata from individual studies, and guidelines for summarising the findings (Martensen et al., 2017).

48 synoptic documents ***(synopses)*** were created, synthesising the coded studies and outlining the main findings in the form of a meta-analyses (where possible) or another type of comprehensive synthesis (e.g. vote-count analysis). In these synopses, each measure was assigned a colour code, which indicates how effective this measure is in terms of the amount of evidence demonstrating its impact on crash reduction. The code can be one of the following:

- Green: **Clearly reducing risk**. Consistent results showing a decreased risk, frequency and/or severity of crashes when this measure is applied.
- Light Green: **Probably reducing risk, but results not consistent**. Some evidence that there is a decreased risk, frequency and/or severity of crashes when this measure is applied but results are not consistent.
- Grey: **Unclear results**. Studies report contradicting effects. There are few studies with inconsistent or not verified results.
- **Red: Not reducing risk**. Studies consistently demonstrate that this measure is not associated with a decrease in crash risk, frequency or severity.

In total, 14 measures were given a Green code (e.g. speed management measures, work zone treatments, automatic barriers installation at rail-road crossings, delineation, road markings and traffic signs), 21 were given a Light Green code (e.g. convert junction to roundabout, median and roadside treatments, road safety audits and high risk sites treatments), 13 were given a Grey code (e.g. lane treatments, junctions re-alignment) and one measure received a Red code (namely the conversion of junctions to roundabouts, which was found to have negative effects for the particular case of cyclists safety).

For the purpose of the cost-benefit analyses, we started from the initial list of **35 measures that turned out to have a green or light green colour code** in Machata et al. (2017). Measures with a grey code were not considered to be meaningful candidates for CBA as cost-benefit analyses only make sense if some beneficial effect of the measure can be assumed. All these measures were reviewed and for each of them it was checked whether they could be the subject of a meaningful CBA. Subsequently a selection was made.

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

- Lacking information on measure costs
- Lacking or no consistent information on measure effectiveness
- Lacking information on the number or the nature of affected accidents

Table 1: Overview of selected measures for CBA

Measure	Colour code	CBA executed?
HGV traffic restrictions	Green	No
Road safety audits	Light Green	**Yes**
High risk sites treatment	Light	**Yes**
Speed limit reduction	Green	No
Dynamic speed limits	Green	**Yes**
Dynamic speed display signs	Green	No
Section control	Green	**Yes**
Speed cameras	Green	No
Installation of speed humps	Green	**Yes**
Implementation of 30 km/h-zones	Green	**Yes**
Creation of by-pass roads	Light Green	No
Installation of lighting & Improvement of existing lighting	Green	**Yes**
Workzones: Signage installation and improvement	Green	No
Implementation of rumble strips at centreline	Green	**Yes**
Installation of chevron signs	Green	**Yes**
Traffic sign installation; Traffic sign maintenance	Green	No
Convert at-grade junction to interchange	Green	No
Channelisation	Light Green	**Yes**
Sight distance treatments	Green	No
Automatic barriers installation	Green	**Yes**
Implementation of narrowings	Light green	No
School zones	Light green	No
Installation of traffic calming schemes	Light green	**Yes**
Road surface treatments	Light green	**Yes**
Increase median width	Light green	No
Change median type	Light green	No
Shoulder implementation (shoulder type)	Light green	No
Increase shoulder width	Light green	No
Safety barriers installation	Light green	**Yes**

Measure	Colour code	CBA executed?
Create clear-zone / remove obstacles & Increase width of clear-zone	Light green	No
Road markings implementation	Light green	No
Implementation of edgeline rumble strips	Light green	No
Variable message signs	Light green	No
Convert junction to roundabout	Light green	**Yes**
Installation of rail-road crossing traffic sign	Light green	No
Traffic signal installation	Light green	**Yes**

3.2 UNIT OF IMPLEMENTATION

The unit of analysis for the CBAs represents the dimensions of the area for which the CBA was executed. For infrastructural measures, three possible units of intervention occurred:

- **One location**, e.g. an isolated intersection. This was for instance used in the CBA's for high risk site treatment or conversion into a roundabout.
- **A road segment** where an infrastructural measure is implemented, often expressed per km. Examples can be found in the CBA's on road safety audits or dynamic speed limits
- **An 'area' of undefined size**, often a neighbourhood or some streets that have undergone a similar treatment. Examples of these can be found in the CBA's for 30-zones and area-wide traffic calming.

Table 2 contains an overview of the units of analysis that were used in every CBA.

3.3 TIME HORIZON

The time horizon in the CBA should equal as much as possible the real lifetime of the measure. For many road infrastructure measures **a time horizon of 25 years seems realistic** (Elvik et al., 2009). For some measures, often those that are **more technology-related** (e.g. section control) or those that are more **subject to wearing out** (e.g. rumble strips), a shorter horizon was taken at the discretion of the study coder.

No formal sensitivity analyses were done based on varying time horizons. Although it is not likely for most measures that changes in the applied time horizons within reasonable boundaries will deeply affect the outcomes of the cost-benefit analysis, the reader should keep in mind that time horizons are one of the input variables that eventually will determine the outcomes and therefore should be estimated with the best possible precision. Table 2 shows the applied time horizon for each of the selected measures.

3.4 INVESTMENT COSTS AND RECURRENT COSTS

Within the present Task, a thorough and dedicated literature review was carried out for the collection of information on infrastructure measures costs. This was not straightforward, as these costs are subject to large variation and are sometimes poorly documented in existing studies. Moreover, road authorities, who may possess such information, typically don't apply cost accounting and moreover are sometimes reluctant to share or publish this information.

Cost information SafetyCube WP5 was retrieved from various sources:

- **The Handbook of Safety Measures** (Elvik et al., 2009): a compilation of costs from the infrastructure road safety measures reported in the Handbook was made; most of the estimates concerned Norway, and may be transferred to other countries or the EU on the basis of PPP (Purchasing Power Parity) factors - although with caution.
- **Review of published studies** reporting on cost estimates of infrastructure measures; these mostly concerned CBAs in which the costs per unit of implementation were reported.
- Additional information was sought in less formal sources ("grey literature"), namely various infrastructure studies and projects reports - this was an exception to the general approach of SafetyCube to avoiding grey literature, and in some cases it was proved to provide useful information on measures costs (FHWA, 2017; Wijnen et al., 2010; ROSEBUD, 2005; CEDR, 2008 etc.).

The complete list of infrastructure costs information compiled within this Task can be found in Annex B.

Table 2 also presents an overview of the estimated investment costs and annually recurrent costs of the selected measures. To make a proper comparison possible, all measure costs are expressed in euro and are converted to average EU-28 PPP (Purchasing Power Parity) values for 2015. More information on the specific sources of the provided measure costs can be found in the CBA synopses in the annex. As mentioned above, the reader should be aware that cost estimates in general tend to be rather weakly documented and only sparsely available. Even in the best cases, only a few cost estimates were available. In those cases, priority was given to the most recent estimates, the ones that were most applicable to the European situation and the ones that come from the most reliable sources.

Just in two cases no measure costs could be found. In those cases no benefit to cost ratio could be calculated but a break-even cost was calculated. In all other cases a full CBA was executed and resulting BCR could be calculated.

Table 2: Overview of unit of analysis, time horizon and costs of the selected measures

Measure	Unit of analysis	Time horizon (in years)	Investm. cost per unit of analysis (in EUR EU-2015 PPP)	Annual costs per unit of analysis (in EUR EU-2015 PPP)	Total costs per unit of analysis (in EUR EU-2015 PPP)
Road safety audits - Light measure case	1 km	25	€ 79 189	-	€ 79 189
Road safety audits - Heavy measure case	1 km	25	€ 599 291	-	€ 599 291
High risk sites treatment	1 location (intersection)	25	€ 21 446	€ 1 960	€ 57 561
Dynamic speed limits	1 km	25	€ 311 070	€ 9 722	€ 490 192
Section control	1 km	15	€ 68 323	€ 6 832	€ 152 913
Installation of speed humps	1 area	25	€ 187 953	-	€ 187953
Implementation of 30-zones	1 area	25	€ 90 465	€ 1 199	€ 110 226
Installation of lighting & Improvement of existing lighting	1 km of ordinary road	25	€ 42480	€ 2360	€ 85962

Measure	Unit of analysis	Time horizon (in years)	Investm. cost per unit of analysis (in EUR EU-2015 PPP)	Annual costs per unit of analysis (in EUR EU-2015 PPP)	Total costs per unit of analysis (in EUR EU-2015 PPP)
Implementation of rumble strips at centreline	1 km	10	€ 987		€ 987
Installation of chevron signs	1 location (curve)	10	€ 429	€ 9	€ 504.
Channelization	1 location (intersection)	25	€ 150 000	€ 2 500	€ 196 061
Automatic barriers installation	1 location (level crossing)	25	€ 135 000	€ 4 000	€ 208 698
Installation of traffic calming schemes	1 area	25	€ 318 875	€ 15 944	€ 612 633
Installation of traffic calming schemes (b)	1 area	25	€ 5 389 225	-	€ 5 389 225
Road surface treatments	1 location (intersection)	5	-	-	-
Winter maintenance	1 location (intersection)	1			€ 519
Safety barriers installation	1 km	25	€ 39 070	€ 1 804	€ 72 314
Convert junction to roundabout	1 location (intersection)	25	€ 363 000	€ 5 000	€ 455 122
Traffic signal installation	1 location (intersection)	25	€ 48 309	€ 3 370	€ 98 285
Traffic signal installation - highways	1 location (intersection)	25	€ 123 580	€ 5 617	€ 206 874

3.5 SAFETY EFFECTS OF THE MEASURES

Table 3 reflects the used estimates of measures safety effects. Obviously, this is a highly important variable in any CBA and assumptions about this variable are likely to have decisive effects on the eventual outcomes.

In the ideal case **a meta-analysis of the safety effect** of the measure was available in the literature. This is not only interesting because a well performed meta-analysis tends to provide a reliable estimate of the effect of the measure but also because confidence intervals (usually 95 % CI) are available that quantify the level of uncertainty of the effects.

If a meta-analysis was not available, the absolute minimum requirement for conducting a CBA is that **at least one sufficiently reliable effectiveness evaluation** has been done that provides a quantitative effect estimate. For some measures no meta-analysis was available but a few studies with varying estimates of effectiveness were found back. In these cases it was left to the individual researcher's expert judgment either to run CBA's with each of these estimates or to select the estimate that seemed more reliable for a good reason, for instance because one study meets best the typical conditions of the measure (e.g. it's the only European study or it's a study that meets best the conditions where proper cost estimates are available for).

Apart from the best estimate of the effect, table 3 also includes the lower and upper limits of the CI for the selected infrastructure measures. Detailed information on the input variables that were used for the individual CBA's, including references to the original sources, are available in the CBA synopses, see Annex A.

Table 3: Overview of the safety effects used in CBAs of the selected measures

Measure	Unit of analysis	Crash effects (best estimates)	Crash effects (lower limit)	Crash effects (upper limit)
Road safety audits - Light measure case	1 km	Fatal injury crashes reduction: 60% Injury (Serious/Slight) crashes reduction: 60% PDO only crashes reduction: 60%	Fatal injury crashes reduction: 45.4% Injury (Serious/Slight) crashes reduction: 45.4% PDO only crashes reduction: 45.4%	Fatal injury crashes reduction: 74.6% Injury (Serious/Slight) crashes reduction: 74.6% PDO only crashes reduction: 74.6%
Road safety audits - Heavy measure case	1 km	Fatal injury crashes reduction: 60% Injury (Serious/Slight) crashes reduction: 60% PDO only crashes reduction: 60%	Fatal injury crashes reduction: 45.4% Injury (Serious/Slight) crashes reduction: 45.4% PDO only crashes reduction: 45.4%	Fatal injury crashes reduction: 74.6% Injury (Serious/Slight) crashes reduction: 74.6% PDO only crashes reduction: 74.6%
High risk sites treatment	1 location (intersection)	Fatal injury crashes reduction: 28% Serious injury crashes reduction: 28% Slight injury crashes reduction: 28% PDO only crashes reduction: 28%	Fatal injury crashes reduction: 23% Serious injury crashes reduction: 23% Slight injury crashes reduction: 23% PDO only crashes reduction: 23%	Fatal injury crashes reduction: 32% Serious injury crashes reduction: 32% Slight injury crashes reduction: 32% PDO only crashes reduction: 32%
Dynamic speed limits	1 km	Fatal injury crashes reduction: 6% Serious injury crashes reduction: 6% Slight injury crashes reduction: 18% PDO only crashes reduction: 18%	Fatal injury crashes reduction: -29% Serious injury crashes reduction: -29% Slight injury crashes reduction: +4% PDO only crashes reduction: +4%	Fatal injury crashes reduction: 32% Serious injury crashes reduction: 32% Slight injury crashes reduction: 30% PDO only crashes reduction: 30%
Section control	1 km	Fatal injury crash reduction: 56% Serious injury crash reduction: 56% Slight injury crash reduction: 30% PDO only crash reduction: 30%	Fatal injury crashes reduction: 42% Serious injury crashes reduction: 42% Slight injury crashes reduction:24 % PDO only crashes reduction: 24%	Fatal injury crashes reduction: 66% Serious injury crashes reduction: 66% Slight injury crashes reduction: 36% PDO only crashes reduction: 36%

Measure	Unit of analysis	Crash effects (best estimates)	Crash effects (lower limit)	Crash effects (upper limit)
Installation of speed humps	1 area	Accidents(fatal,serious,slight) reduction: 17%	Accidents(fatal,serious,slight) reduction: 8%	Accidents(fatal,serious,slight) reduction: 25%
Implementation of 30-zones	1 area	Fatal injury crashes reduction: 57% Serious injury crashes reduction: 26% Slight injury crashes reduction: 22%	Fatal injury crashes reduction: 17.2% Serious injury crashes reduction: 14.4% Slight injury crashes reduction: 13.7%	Fatal injury crashes reduction: 95.8% Serious injury crashes reduction: 38.1% Slight injury crashes reduction: 29.6%
Installation of lighting & Improvement of existing lighting	1 km of ordinary road	Fatal injury crash reduction in darkness: 52% All injury crash reduction in darkness: 26%	Fatal injury crash reduction in darkness: 45% All injury crash reduction in darkness: 19%	Fatal injury crash reduction in darkness: 59% All injury crash reduction in darkness: 33%
Implementation of rumble strips at centreline	1 km	Casualties (slight/serious/fatal) crashes reduction: 37% PDO only crashes reduction: 37%	Slight/serious/fatal injury crashes reduction: 31% PDO crashes reduction: 31%	Slight/serious/fatal injury crashes reduction: 42% PDO crashes reduction: 42%
Installation of chevron signs	1 location (curve)	Casualty crashes (slight/serious/fatal) reduction: 2.6% PDO only crashes reduction: 2.6%	Casualty crashes (slight/serious/fatal) reduction: 1.3% PDO only crashes reduction: 1.3%	Casualty crashes (slight/serious/fatal) reduction: 5.2% PDO only crashes reduction: 5.2%
Channelisation	1 location (intersection)	Accident reduction: 27%	Accident reduction: 4%	Accident reduction: 45%
Automatic barriers installation	1 location (level crossing)	Accident reduction: 68%	Accident reduction: 57%	Accident reduction: 76%
Installation of traffic calming schemes	1 area	Accidents(fatal,serious,slight) reduction: 15% PDO reduction: 15%	Accidents(fatal,serious,slight) reduction: 12% PDO accidents reduction: 12%	Accidents(fatal,serious,slight) reduction: 17% PDO accidents reduction: 19%
Installation of traffic calming schemes (b)	1 area	Accidents(fatal,serious,slight) reduction: 38%		
Road surface treatments	1 location (intersection)	21.3 % reduction total casualty crashes 15.3 % reduction high severity crashes (fatal/serious) 21.4 % other injury crashes		
Winter maintenance	1 km	12% reduction all injury crashes 35% reduction property damage crashes		

Measure	Unit of analysis	Crash effects (best estimates)	Crash effects (lower limit)	Crash effects (upper limit)
Safety barriers installation	1 km	Fatal injury crashes reduction: 46% Serious injury crashes reduction: 55% Slight injury crashes reduction: 55% PDO only crashes reduction: -100% (increase)	Fatal injury crashes reduction: 12% Serious injury crashes reduction: 42% Slight injury crashes reduction: 42% PDO only crashes reduction: -100% (increase)	Fatal injury crashes reduction: 67% Serious injury crashes reduction: 65% Slight injury crashes reduction: 65% PDO only crashes reduction: -100% (increase)
Convert junction to roundabout	1 location (intersection)	Fatal crashes reduction: 72% PDO crashes reduction: 0% Injury crashes reduction: 47%	Fatal crashes reduction: 42% PDO crashes reduction: -15% Injury crashes reduction: 41%	Fatal crashes reduction: 86% PDO crashes reduction: 17% Injury crashes reduction: 52%
Traffic signal installation	1 location (intersection)	Casualty crashes (slight/serious/fatal) reduction: 29% PDO only crashes reduction: 29%	Fatal injury crashes reduction: 14% Injury (Serious/Slight) crashes reduction: 14% PDO only crashes reduction: 14%	Fatal injury crashes reduction: 41% Injury (Serious/Slight) crashes reduction: 41% PDO only crashes reduction: 41%
Traffic signal installation - highways	1 location (intersection)	Casualty crashes (slight/serious/fatal) reduction: 29% PDO only crashes reduction: 29%	Fatal injury crashes reduction: 14% Injury (Serious/Slight) crashes reduction: 14% PDO only crashes reduction: 14%	Fatal injury crashes reduction: 41% Injury (Serious/Slight) crashes reduction: 41% PDO only crashes reduction: 41%

3.6 SAFETYCUBE CRASH COST ESTIMATES

Within SafetyCube, costs of crashes were estimated for individual EU countries as well as for the EU in total. First, by studying international guidelines and best practices, it was determined which cost components should be included and how each cost component should be estimated. Second, information on costs of crashes was collected by means of a survey among all EU countries. Third, by means of value transfer, costs were made more comparable between EU countries and an estimate of the total costs of crashes in the EU was provided. The three steps are discussed in more detail below. For more detailed information as well as actual estimates please see Deliverable 3.2 '*Crash cost estimates for European countries'* (Wijnen et al., 2017).

3.6.1 Crash cost components and methods to estimate them

Following international guidelines, like the COST313 guidelines (Alfaro et al., 1994), the following cost components are taken into account within SafetyCube:

- Medical costs (e.g. costs of transportation to the hospital, costs related to hospital treatment)
- Costs related to production loss
- Human costs
- Costs related to property damage (mainly vehicles)
- Administrative costs (e.g. police, fire department, insurances)
- Other costs (funeral costs, congestion costs)

Medical costs, costs related to property damage, and administrative costs should be calculated by means of the restitution costs method. This means that the actual costs - like costs of an overnight hospital stay or costs related to the reparation of a vehicle - need to be calculated. Costs related to production loss should be calculated by means of the human capital approach: production loss of a casualty is calculated by multiplying the period of time the casualty not able to work due to the crash with a valuation of the production per person per unit of time.

The (individual) willingness to pay (WTP) approach is recommended for the estimation of human costs. In this approach, costs are estimated on the basis of the amount individuals are willing to pay for a risk reduction. On the basis of a WTP study, the value of a statistical life (VOSL) is estimated. This VOSL is subsequently used to calculate human costs. Several alternative approached are in use for the calculation of human costs. In Germany and Australia for example, human costs are based on financial compensations that are awarded in courts or by law. Another approach is to deduct human costs from premiums people pay for life insurances or from public expenditures on improving road safety. These alternative approaches typically result in much lower values than those from WTP studies. Within SafetyCube, the (individual) WTP approach is recommended to estimate human costs, because this is the most theoretically sound method, in particular for use in cost-benefit analysis, and is common practice in many countries.

3.6.2 Collection of data on crash costs EU countries

By means of a survey, information was collected on costs of crashes in European countries. The data collection was a joint effort of the H2020 projects SafetyCube and InDeV. A working group, consisting of SafetyCube and InDeV partners, developed an excel-based questionnaire, asking for information concerning: costs per casualty and crash by severity level, total costs, costs per component, methods and definitions, and number of casualties. We asked for official cost figures used by governmental organizations. Questionnaires were prefilled by a responsible SafetyCube or InDeV partner using available information and then sent to experts in each country for a check and completion. Data from 31 European countries, out of the 32 initially included in the study, was obtained.

Within SafetyCube, the questionnaires were integrated into a SQLite database, consistency checks were carried out, and the data was standardized for currency, inflation and relative income differences between countries.

For all EU countries, except Romania, at least some information on costs of crashes was available. Reported costs per fatality vary between €0.7 million and €3.0 million per fatality. Reported costs per serious injury range from €28,000 to €959,000 and reported costs per slight injury range from €296 to €71,742. The total costs of crashes vary between 0.4% and 4.1% of the Gross Domestic Product (GDP). Although a better road safety performance should in principle result in lower crash costs, we found only a weak positive relation between mortality rate and costs as a percentage of GDP. Differences between countries are also due to methodological differences, like whether the WTP method is applied for the calculation of human costs.

3.6.3 EU Cost estimates using value transfer

Not all countries have information for all cost components and/or all severity levels. Some countries for example exclude property damage only (PDO) crashes. Moreover, not all countries produce cost estimates according to the international guidelines. Some countries for example, didn't apply the WTP approach for the calculation of human costs. Within SafetyCube, the value transfer method is applied to estimate standard cost values per casualty/crash type and to estimate total costs of crashes according to international guidelines for each EU country and for the EU in total.

The value transfer method uses cost estimates from countries whose estimates are consistent with international guidelines to estimate costs for countries that do not have cost information according to the guidelines. Basically, for each cost component, median values per casualty (fatality, serious injury, slight injury), and per crash (fatal, serious injury, slight injury and PDO) are determined, using data from countries that determined costs according to the international guidelines. These median values are subsequently used for countries that have no information for that cost component or did not use the recommended method.

Applying the value transfer method to all cost components, the 'standard' costs of a fatality are estimated at €2.3 million. Costs per serious and slight injury are estimated at 13% and 1% of the value of a fatality. Total costs according to the international guidelines in all EU countries individually as well as the EU in total were calculated. Table 4 shows the cost estimates for the EU countries as well as for the EU in total. For the 28 EU member states together, costs are estimated at about €270 billion if the results of the value transfer approach are applied. This corresponds to 1.8% of the GDP.

Table 4. Total costs (in Million Euro), calculated with transferred values for crashes (EUR2015, corrected for relative income differences using purchasing power parity (PPP), source: WIjnen et al., 2017).

Country	Total costs estimated on the basis of value transfer	Country	Total costs estimated on the basis of value transfer
Austria	€ 11,049	Latvia	€ 2,862
Belgium	€ 6,947	Lithuania	€ 1,043

Country	Total costs estimated on the basis of value transfer	Country	Total costs estimated on the basis of value transfer
Bulgaria	€ 2,855	Luxembourg	€ 236
Croatia	€ 3,147	Malta	€ 162
Cyprus	€ 282	Netherlands	€ 17,667
Czech Republic	€ 5,278	Norway	€ 2,447
Denmark	€ 1,113	Poland	€ 12,842
Estonia	€ 475	Portugal	€ 4,763
Finland	€ 2,605	Romania	€ 8,091
France	€ 30,431	Serbia	€ 3,939
Germany	€ 51,806	Slovakia	€ 1,414
Greece	€ 2,746	Slovenia	€ 828
Hungary	€ 4,295	Spain	€ 29,347
Iceland	€ 249	Sweden	€ 1,673
Ireland	€ 694	Switzerland	€ 6,279
Italy	€ 39,534	UK	€ 23,253
EU28 – Total (rounded)			**€ 267,000**
EU28 + 4 Total (rounded)			**€ 280,000**

Please note that the cost estimates are still an underestimation of the actual costs, because many countries have not corrected the numbers of casualties/crashes for underreporting. If unreported casualties and crashes are taken into account, we expect that total costs are in the order of magnitude of at least 3% of GDP.

4 Results of cost-benefit analyses

This chapter presents the results of the cost-benefit analyses (CBA). In total CBAs were executed for 16 different measures. All CBAs were done by means of the E^3 calculator. Section 4.1 provides and discusses the B/C ratios and net present values for all the selected measures. Section 4.2 treats the break-even analyses

4.1 BENEFIT-TO-COST RATIOS AND NET PRESENT VALUES

Using the E^3-calculator, benefit-to-cost ratios were calculated for all the selected measures. The results are provided in table 5. The table also contains a monetary estimate of the net present value per unit. All the values are expressed in euro (price level 2015, PPP EU-28).

BCR values above 1 indicate a favourable **benefit-to-cost ratio** (BCR). They are indicated in green. For example a BCR of 2 indicates that the calculated benefits of the measure are two times higher than the costs.

BCR values below 1 are indicated in red. They reflect a situation in which the measure benefits (in terms of the monetary value of the reduced number of accidents) are not likely to cover the measure costs. The smaller the value the larger the unbalance between costs and benefits. A BCR of 0.2 for instance indicates that the calculated measure costs are 5 times higher than the calculated benefits. Negative values for the BCR are only possible in case a measure is likely to cause an increase in the number of crashes. As the selected measures reflect measures that had a green ('effective' or a light green ('probably effective') colour code in the measure synopsis, negative values don't occur.

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

4.2 BREAK-EVEN COST FOR THE MEASURES

Break-even costs reflect the measure cost value at which benefits and costs are equal. They indicate the maximal costs for one unit of a measure to be still economically efficient. Using break-even costs is particularly interesting when no estimates or no reliable estimates are available of the measure costs. Although we could find cost estimates for most measures in WP5, it is still worthwhile to look at break-even costs as they indicate for every measure at what point – given an assumed effect on traffic safety – it starts to become cost-effective.

Table 5 provides the break-even costs for each measure. For the sake of clarity also the used best estimate for the measure cost is provided. This allows to easily assess the magnitude of the difference between the currently known best estimate of the measure cost and the break-even cost.

Table 5: B/C ratios and Net Present Values per unit for all the selected measures

Measure	Unit of analysis	Benefit-to-cost ratio (best estimate)	Net Present Value (in EUR EU-2015 PPP)	Total costs per unit of analysis (in EUR EU-2015 PPP)	Break-even measure cost (in EUR EU-2015 PPP)
Road safety audits - Light measure case	1 km	21.7	€ 1 641 482	€ 79 189	€ 1 720 671
Road safety audits - Heavy measure case	1 km	2.9	€ 1 121 380	€ 599 291	€ 1 720 671
High risk sites treatment	1 location (intersection)	16.1	€ 869 803	€ 57 561	€ 927 363
Dynamic speed limits	1 km	1.1	€ 31 548	€ 490 192	€ 521 739
Section control	1 km	19.5	€ 2 834 895	€ 152 913	€ 2 987 808
Installation of speed humps	1 area	18.2	€ 3 234 711	€ 187 953	€ 3 422665
Implementation of 30-zones	1 area	1.6	€ 66 038[1]	€ 110 226	€ 176 265[1]
Installation of lighting & Improvement of existing lighting	1 km	0.7	€ -24 888	€ 85962	€ 61073
Implementation of rumble strips at centreline	1 km	9.1	€ 7950	€ 987	€ 8938
Installation of chevron signs	1 location (curve)	2.7	€ 875	€ 504	€ 1379
Channelisation	1 location (intersection)	8.4	€ 1 452 858	€ 196 061	€ 1 648 919
Automatic barriers installation	1 location (level crossing)	0.05	-€ 197 399	€ 208 698	€ 11 299
Installation of traffic calming schemes	1 area	0.4	-€ 392 061	€ 612 633	€ 220 572
Installation of traffic calming schemes (b)	1 area	0.2	-€ 4 199 122	€ 5 389 225	€ 1 190 103
Road surface treatments	1 location (intersection)				€ 1 123 604
Winter maintenance	1 km	6.0	€ 2 609	€ 519	€ 3128
Safety barriers installation	1 km	19.5	€ 1 339 933	€ 72 314	€ 1 412 247
Convert junction to roundabout	1 location (intersection)	9.2	€ 3 749 171	€ 455 122	€ 4 204 293
Traffic signal installation	1 location (intersection)	1.1	€ 8731	€ 98 285	€ 107 016
Traffic signal installation - highways	1 location (intersection)	3.7	€ 559 388	€ 206 874	€ 766 263

[1] Converted from the obtained NPV (60 035) and break-even cost (160 241) in GBP to EUR by applying the PPP-conversion factor (see Martensen et al, 2016) of 1.1

5 Sensitivity analysis

In this chapter we present the results of sensitivity analyses that were made for all the measures concerned. Firstly, we check the consequences of scenarios in which the effects of the measures are lower or higher than initially expected. Subsequently we combine this information with scenarios on higher and lower measure costs in order to calculate two 'extreme' scenarios: a worst case and an ideal case. These scenarios help to assess the sensitivity of the analysed measures to some assumptions in the underlying data.

5.1 LOW EFFECTS AND HIGH EFFECTS

The results of any cost-benefit analysis are much dependent on the underlying assumptions about the effect of the concerned measure. However, effect estimates are – even in the best known cases – only known within a certain uncertainty margin. It is therefore useful to run a sensitivity analysis based on some alternative assumptions about the effects of the measure. The purpose is to show to which extent benefit-to-cost ratios are sensitive to changes in the underlying effect estimates. For the vast majority of the CBA we ran sensitivity analyses that use some alternative effect estimates.

If available we used **the upper and lower limits of the 95% confidence intervals of the estimates**. In the ideal case these estimates were resulting from a meta-analysis, in other cases the used values result from one or two particular studies. The used values represent a (much) lower than expected and a (much) higher than expected effect respectively.

Table 6 presents the results. BCR values above 1 indicate a favourable benefit-to-cost ratio. They are indicated in green. BCR values below 1 are indicated in red and indicate situations in which costs exceed the assumed benefits. The closer to zero, the stronger the distortion between costs and benefits.

Table 6: B/C ratio's in 3 scenarios with varying effect estimates

Measure	Benefit-to-cost ratio (best estimate)	Benefit-to-cost ratio (low measure effect)	Benefit-to-cost ratio (high measure effect
Road safety audits - Light measure case	21.7	16.4	27
Road safety audits - Heavy measure case	2.9	2.2	3.6
High risk sites treatment	16.1	13.2	18.4
Dynamic speed limits	1.1	-2.3	3.6
Section control	19.5	14.7	23.0
Installation of speed humps	18.2	8.6	26.8
Implementation of 30-zones	1.6	0.6	2.5
Installation of lighting & Improvement of existing lighting	0.7	0.5	0.9
Implementation of rumble strips at centreline	9.1	7.6	10.3
Installation of chevron signs	2.7	1.4	5.5
Channelisation	8.4	1.2	14.0
Automatic barriers installation	0.05	0.04	0.06
Installation of traffic calming schemes	0.4	0.3	0.4
Installation of traffic calming schemes (b)	0.2	-	-
Road surface treatments	-	-	-
Winter maintenance	6.0	-	-
Safety barriers installation	19.5	10.6	25.4
Convert junction to roundabout	9.2	8.1	10.2
Traffic signal installation	1.1	0.5	1.5
Traffic signal installation - highways	3.7	1.8	5.2

5.2 VARIATION IN THE ESTIMATES OF THE MEASURE COSTS

Costs of measures are generally poorly known. The sources of these estimates and their rigour are sometimes unclear. Other estimates are rather old. Some of the estimates may only apply to very particular conditions. When it comes to infrastructural measures variables such as road type, traffic volume, number of lanes, land use conditions etc., are likely to play an important role. Huge variations therefore tend to exist.

These huge variations are an important source of uncertainty that can considered to be on the same level as the uncertainty about the effect estimates. Logically, also the scenarios for the measure costs should clearly reflect the inherent uncertainties of the analyses. However, in contrast to the effect estimates that are for some measures relatively well established and formally assessed, this is not all the case for the costs of measures. For most cases only one or two estimates for the costs of the measures were available, which does not allow to express the uncertainty formally.

In order to reflect the inherent uncertainty of cost estimates we decided to include also two scenarios in which **the measure costs vary from a 'very low' (-50% of the estimate) level to a 'very high' (+ 100% of the best estimate) level**. These threshold values are to a certain extent arbitrary, but they are believed to reflect realistic boundaries for different reasons described below.

In many cases there are good reasons to presume that the currents estimates are rather low. Many estimates tend to include only direct 'out-of-pocket costs'. It is therefore more likely that real costs will be underestimated than overestimated. This explains the choice for the + 100% upper limit and also the 'skewness' of the used interval [-50%; +100%].

Although somewhat less likely, prices can also be overestimated. In particular for technology-based measures, decreasing prices of technology due to mass production, innovation, competition, efficiency improvements, etc., might lead to substantial reductions of measure costs, so there is a good reason not just to look at cost increases. For example, some authors have argued that 'permanent average speed camera sites were estimated to have cost up to £1.5m per mile in 2000 but in 2016 cost an average of £100,000 per mile'[2]

The results are provided in Table 7. BCR values above are indicated in green. BCR values below 1 are indicated in red. A few measures are clearly sensitive to changes in the measure costs as their BCR values change from below 1 to above 1 throughout the different scenarios.

[2] Owen, R., Ursachi, G. and Allsop, R., 2016. The Effectiveness of Average Speed Cameras in Great Britain. London, Royal Automobile Club Foundation for Motoring Ltd., http://www.racfoundation.org/assets/rac_foundation/content/downloadables/Average_speed_camera_effectiveness_Owen_Ursachi_Allsop_September_2016.pdf

Table 7: B/C ratio's in scenarios with varying measure costs (best estimate, low measure cost, high measure cost)

Measure	Benefit-to-cost ratio (best estimate)	Benefit-to-cost ratio (low measure cost -50%)	Benefit-to-cost ratio (high measure cost +100%)
Road safety audits - Light measure case	21.7	43.5	10.9
Road safety audits - Heavy measure case	2.9	5.7	1.4
High risk sites treatment	16.1	32.2	8.1
Dynamic speed limits	1.1	2.1	0.5
Dynamic speed display signs			
Section control	19.5	39.1	9.8
Installation of speed humps	18.2	36.4	9.1
Implementation of 30-zones	1.6	3.2	0.8
Installation of lighting & Improvement of existing lighting	0.7	1.4	0.4
Implementation of rumble strips at centreline	9.1	18.1	4.5
Installation of chevron signs	2.7	5.5	1.4
Channelisation	8.4	16.8	4.2
Automatic barriers installation	0.05	0.11	0.03
Installation of traffic calming schemes	0.4	0.7	0.2
Installation of traffic calming schemes (b)	0.2		
Road surface treatments	-	-	-
Winter maintenance	6.0	12.1	3.0
Safety barriers installation	19.5	39.1	9.8
Convert junction to roundabout	9.2	18.5	4.6
Traffic signal installation	1.1	2.2	0.5
Traffic signal installation - highways	3.7	7.4	1.9

5.3 A WORST CASE AND AN IDEAL CASE SCENARIO

Finally we define two rather extreme scenarios:

- **a 'worst case' scenario** as a combination of a much worse than expected effect (in principle the lower limit of the 95% confidence interval of the effect estimate) and a higher than expected measure cost (i.e. the estimated cost +100%).
- **an 'ideal case' scenario** that is a combination of a much better than expected effect (upper limit of the 95% CI of the effect estimate) and a lower than expected measure cost (estimated cost -50%).

The results of the CBA for these scenarios are reflected in Table 8.

Even in these scenarios the measures examined remain consistently efficient (e.g. section control or high risk site treatment), or never become efficient (e.g. automatic barriers on level crossings). Some other measures (e.g. 30 km/h zones or traffic signal installations) are clearly more susceptible to varying combinations of measure costs and effects.

Table 8: B/C ratio's in the 'best estimate' scenario and in two extreme scenarios ("ideal" and "worst" case)

Measure	**Benefit-to-cost ratio** (best estimate)	**Benefit-to-cost ratio** (worst case scenario = high cost + low effect)	**Benefit-to-cost ratio** (best case scenario = low cost + high effect)
Road safety audits - Light measure case	21.7	8.2	54.0
Road safety audits - Heavy measure case	2.9	1.1	7.1
High risk sites treatment	16.1	6.6	36.8
Dynamic speed limits	1.1	-1.2	7.2
Dynamic speed display signs			
Section control	19.5	7.3	46.1
Speed cameras			
Installation of speed humps	18.2	4.3	53.8
Implementation of 30-zones	1.6	0.3	5.1
Installation of lighting & Improvement of existing lighting	0.7	0.3	1.8
Implementation of rumble strips at centreline	9.1	3.8	20.5
Installation of chevron signs	2.7	0.7	10.9
Channelisation	8.4	0.6	28.0
Automatic barriers installation	0.05	0.02	0.12
Installation of traffic calming schemes	0.4	0.1	0.8
Installation of traffic calming schemes (b)	0.2		
Road surface treatments	-	-	-
Winter maintenance	6.0	-	-
Safety barriers installation	19.5	5.3	21.2
Convert junction to roundabout	9.2	4.0	20.4
Traffic signal installation	1.1	0.3	3.1
Traffic signal installation - highways	3.7	0.9	10.5

6 Discussion and conclusions

6.1 DISCUSSION

6.1.1 The obtained results

The results of the performed CBA provide the reader with relevant information about the balance between costs and benefits of the selected measures. The CBA documents themselves are added in Annex A and provide more details about the underlying assumptions and data. In the present report we listed the information on the individual analyses in synoptic tables that allow to compare the results for different measures. We tried as much as possible to express the outcomes (BCR, break-even costs) per unit, in order to enable comparisons between the different measures. The advantage of this approach is that information becomes clearly visible and easily available for almost any reader, even the one that is less familiar with the calculations in the background.

6.1.2 The followed approach

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

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

The principal tool for all the above-mentioned analyses was the **Economic Efficiency Evaluation (E^3) calculator** that has been developed in the SafetyCube project. A major advantage of this tool is that it enabled to standardise the input and output information. The use of the tool in its test phase also enabled to provide feedback that has been used to gradually improve it. Thanks to the availability of the tool, CBAs could be executed for 15 different measures. Just in two cases no cost information could be obtained and only break-even costs were calculated.

6.1.3 Challenges and limitations

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

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

Most importantly, the scarse and fragmentary information available in the literature resulted in several cases for **a combination of information sources to be used for a single CBA**. In particular, a safety effect from a meta-analysis, being the most reliable effectiveness estimate, needed to be combined with measure cost information from another source, and applied for a customised case (unit of implementation and target group or number of crashes / casualties affected). Although every effort was made by SafetyCube experts to use as consistent sources as possible, and limit the number of different sources to be combined in a CBA, in several cases this was simply inevitable, in order to produce a CBA estimate. Even in these cases, particular caution was put on the transparent and substantiated combination of information.

In other words, the **flexibility provided by the E³ tool**, which allows to transfer any cost value from any country to another (EU countries, USA, Canada, Australia) was exploited as much as possible, but with particular care to properly combine related information.

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

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

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

The E³ Calculator that will be available through the SafetyCube DSS is explicitly designed to meet this need, by allowing users to **customise any input value of the existing examples on the basis of more case-specific information**, or to perform one's own CBA with new data.

6.1.4 Further work

Clearly, no CBA results should just be transferred to whatever situation. Given the abovementioned limitations, any reader should use CBA values critically and make sure to check thoroughly any of the underlying assumptions before inferring results about the CBA values of a measure for other applications or settings.

All together the number of CBA on road infrastructure safety measures in the scientific literature so far is rather limited and much further work is needed to systematically assess costs and benefits of road safety measures. It deserves recommendation not just to carry out the work, but also to publish it more systematically in the literature.

6.2 CONCLUSIONS

The present report presents the results of cost-effectiveness analysis of infrastructure measures carried out within SafetyCube Task 5.3.

Following Task 5.2, in which 48 infrastructure measures were analysed and ranked in terms of their effectiveness (safety effects), as well as WP3, in which standard methodologies for measures priority setting and tools for carrying out economic evaluation were developed, Task 5.3 performed cost-benefit analyses of 16 selected road infrastructure safety measures.

The measures were selected on the basis of both the following criteria:

- Measures ranked with a green (effective) or light green (probably effective) colour code as per their safety effects
- For which there was sufficient information in one or more literature sources, as per: the measures safety effect, the measures cost per unit of implementation, and the target group / number of cases affected by the measures implementation.

The SafetyCube E[3] tool was used to perform cost-benefit analysis on the basis of the input data collected, and furthermore to perform sensitivity analysis of the CBA results for different measures costs and safety effects ranges.

Table 9 provides a synoptic overview of the results of the various CBA and ranks the analysed measures according to their costs and effectiveness. All values are based on the best estimates of effects and costs.

Table 9: Ranking of infrastructure measures according to the best estimates for costs (low/high) and effectiveness (low/high)

		Costs (per unit)	
		Low [Costs < 100.000 €/unit]	**High** [Costs ≥ 100.000 €/unit]
Effectiveness	**Low** [BCR < 2.0]	Installation of chevron signs Traffic signal installation Installation of lighting & Improvement of existing lighting	Automatic barriers installation Installation of traffic calming schemes (b) Installation of traffic calming schemes Dynamic speed limits Implementation of 30-zones
	High [BCR ≥ 2.0]	Road safety audits - Light measure case Winter maintenance Safety barriers installation High risk sites treatment Implementation of rumble strips at centreline	Road safety audits - Heavy measure case Installation of speed humps Traffic signal installation - highways Channelisation Convert junction to roundabout Section control

Despite the attempt to present the information in ways that allow the comparative assessment of the selected measures as per any key element of the CBA, one clear finding is that any comparative analysis must be addressed with much caution. One reason for this is that measures vary substantially in terms of units of implementation, are of application (e.g. intersections versus road segments, rural versus urban environments) and country of reference. Moreover many measures can be implemented in either lower or higher cost implementations. Furthermore one must be aware that even for measures in a similar context / unit of implementation, the uncertainty in the safety effects and costs as found in the literature is usually high. The present analysis placed particular focus on the sensitivity analysis, which was explicitly meant to reflect the extent of these uncertainties, and to provide an indication of what could be expected in terms of cost-effectiveness of each measure in different scenarios, including an "ideal" one and a "worst" one. These extreme scenarios mostly serve in revealing the "boundaries" of cost-effectiveness of a measure, e.g. will it be cost-effective even if the cost were seriously underestimated, and the safety effects overestimated at the same time? Will the measure be cost-effective if the costs are substantially reduced? And so on.

Details of each CBA are available in Annex A. The readers are encouraged to revisit the CBAs reported in the present Deliverable, by adjusting the input values with respect to their specific case / context, for a customised CBA. In general, it is strongly recommended to carefully review the assumptions of each one of the SafetyCube CBAs and adjust accordingly if necessary to better meet specific conditions. The E^3 calculator available in the SafetyCube DSS is explicitly designed to allow this type of adjustments in order to facilitate transferability of estimates by taking into account more case-specific data.

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Appendix A: CBA synopses

This appendix includes synopses of the executed cost-benefit analyses (CBA). These will also be available through the final version of the DSS. The following synopses are available:

1. Road safety audits
2. High risk sites treatment
3. Dynamic speed limits
4. Installation of section control
5. Installation of speed humps
6. Implementation of 30-zones
7. Installation of traffic calming schemes
8. Road surface treatments
9. Winter maintenance
10. Road lighting
11. Implementation of rumble strips at the centreline
12. Safety barriers installation
13. Installation of chevron signs
14. Channelisation
15. Convert junction to roundabout
16. Automatic barriers installation
17. Traffic signals installation

CBA: Road safety audits – Light measure case

Apostolos Ziakopoulos, NTUA, October 2017

ABSTRACT

Existing evaluation studies on the effects of road safety audits were analysed, and information was synthesized from several sources. The SafetyCube Economic Efficiency Evaluation (E3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 21.7 when audits are used in tandem with a light engineering measure which means that the benefits highly exceed the costs (for a heavy measure example and the resulting change in BCR, see the Appendix). The BCR is sensitive to changes in the underlying assumptions as shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: The original meta-analysis in the synopsis conducted by NTUA mentions a 60% (95% CI [-74.60%; -45.40%]) reduction in all crashes from audit implementation (Machata et al, 2017). This is corroborated by US-based FHWA (Ward, 2006) as well ("the average number of fatal and injury crashes at project sites that were audited fell by 1.25 crashes per year (from 2.08 to 0.83 crashes per year").

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

Measure Costs: The original Handbook (Elvik, 2009) mentions that the costs of road safety audits related to the time spent to make the audit range between 600 and 6,000 Euros per stage or between 700 and 2,500 Euros /km. This corresponds to about 0.1–1.0% of the construction costs or 4–7% of the planning costs. This seems to be corroborated by US-based FHWA (Ward, 2006), which states that the average cost of conducting RSAs ranges from $2000 to $5000. The average of that range is used ($3.500) as it applies to case and not site, after being converted for inflation (they are 2005 prices) and to Euros.

Additionally, every road safety audit has at least one measure that is implemented as a consequence: the price range of a light engineering measure (e.g. guardrail installation, clear zone creation, channelization implementation) is selected for the CBA. The figure provided for the implementation of guardrails along the roadside is used as an example: the cost is reported as 600,000 NOK in 2000 prices (Elvik, 2009). This is converted for inflation by applying the inflation conversion value of 1.63 and to Euros (EU-28 average) by dividing with the PPP conversion value of 12.87. No maintenance costs apply. This amounts to an extra implementation cost of 76,113 Euros/km (Total implementation costs: 79,189 €/km).

Time horizon: The applied time horizon for the measure is 25 years, as per standard measures analysis.

Area/Unit of implementation: The area that is examined is an average 1 km of guardrails on EU-28 secondary (rural) roads. This area is abstract due to the method of obtaining crash/km. Therefore all figures and the analysis apply per kilometre.

Number of cases affected: Crash number per km is (approximately) obtained via the division of the respective category with the rural network km of EU countries (no data available for property damage only crashes).

Source for crashes: Care, 2017 (2013 data was used to coincide with road network data year-wise).

Source for km: European Commission, 2016

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for road safety audits used in tandem with a light measure. It shows a B/C ratio of 21.7. This means that the benefits tend to highly exceed the costs.

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

Scenario	Input values	B/C ratio
Best estimate	All injury crashes reduction: 60% Implementation cost: 79,189 €/km Annual cost: 0.00 €/km Affected nr. of crashes per year: Fatalities: 0.0283/km Serious Injuries: 0.1357/km Slight Injuries: 0.9413/km	21.7

SENSITIVITY ANALYSIS

We used the upper and lower limits of the 95% confidence intervals of the estimates in Machata et al. (2017) to run a sensitivity analysis. The values represent a considerably lower/higher than expected effect, respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	All injury crashes reduction: 45.4%	16.4
High measure effect	All injury crashes reduction: 74.6%	27.0
Low measure cost (-50%)	Implementation cost: 39,594 €/km Annual cost: 0.00 €/km	43.5
High measure cost (+100%)	Implementation cost: 158,378 €/km Annual cost: 0.00 €/km	10.9

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	All injury crashes reduction: 45.4% Implementation cost: 158,378 €/km Annual cost: 0.00 €/km	8.2
Ideal case	All injury crashes reduction: 74.6% Implementation cost: 39,594 €/km Annual cost: 0.00 €/km	54.0

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CBA: Road safety audits – Heavy measure case

ABSTRACT

The previous analyses is complemented by an additional scenario where the measure is in the heavy engineering category (instead of the light measure example of the previous analysis). The improvement of 1 km of rural road via either improving the cross section or general upgrading is used as an example; the cost of both measures is equal and is reported as 4,700,000 NOK/km in 2000 prices (Elvik et al., 2002). This is converted for inflation by applying the inflation conversion value of 1.63 and to Euros (EU-28 average) by dividing with the PPP conversion value of 12.87. Maintenance costs are assumed to be zero. This amounts to an extra implementation cost of 596,215Euros/km (Total implementation costs: 599,291 €/km).

The resulting best estimate of the benefit-to-cost ratio (BCR) is 2.9. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for road safety audits used in tandem with a heavy measure. It shows a B/C ratio of 2.9. This means that although a more expensive solution is implemented, the benefits are still considerably higher than the costs from road safety audit implementation.

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

Scenario	Input values	B/C ratio
Best estimate	All injury crashes reduction: 60% Implementation cost: 599,291 €/km Annual cost: 0.00 €/km Affected nr. of crashes per year: Fatalities: 0.0283/km Serious Injuries: 0.1357/km Slight Injuries: 0.9413/km	2.9

SENSITIVITY ANALYSIS

The values of the previous analysis are used with the addition of the cost of the light measure. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	All injury crashes reduction: 45.4%	2.2
High measure effect	All injury crashes reduction: 74.6%	3.6
Low measure cost (-50%)	Implementation cost: 299,645 €/km Annual cost: 0.00 €/km	5.7
High measure cost (+100%)	Implementation cost: 1,198,582 €/km Annual cost: 0.00 €/km	1.4

Again, we define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost

-50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	All injury crashes reduction: 45.4% Implementation cost: 1,198,582 €/km Annual cost: 0.00 €/km	1.1
Ideal case	All injury crashes reduction: 74.6% Implementation cost: 299,645 €/km Annual cost: 0.00 €/km	7.1

CBA: High risk site treatment

Apostolos Ziakopoulos, NTUA, September 2017

ABSTRACT

Existing evaluation studies on the effects of high risk site treatment were analysed, and information was synthesized from several sources. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 16.1 which means that the benefits tend to highly exceed the costs. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: The updated handbook meta-analysis (Høye and Elvik, 2016) mentions a significant 28% reduction in injurious crashes (95% CI [-32%; -23%]) for both high risk sites and sections after reviewing and analysing several original studies.

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

Measure Costs: The original Handbook (Elvik, 2009) set average cost per site at 200,000 NOK. This is converted for inflation by applying the inflation conversion value of 1.38 (it is in 2005 prices) and to Euros (EU-28 average) by dividing with the PPP conversion value of 12.86. Regarding maintenance costs, no singular absolute source of information can be located; two reports place it at about 2500 USD, similarly converted by applying the inflation conversion value of 1.03 (it is in 2013 prices) and to Euros (EU-28 average) by multiplying with the PPP conversion value of 0.76.

Time horizon: The applied time horizon for the measure is 25 years, as per standard measures analysis.

Area/Unit of implementation: The area that is examined is the one investigated by the study providing crash mitigation figures: one treated roundabout site. Therefore all figures and the analysis apply per site.

Number of cases affected: Crash mitigation figures were reported by Meuleners et al. (2008), an Australian study, since it was the only one available from those providing actual crash numbers (before-after). In a paper conducting relevant analyses, they had reported mitigation factors very close to Elvik's (29.2% instead of 28%). PDO and casualty crash numbers were reported.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for DSL. It shows a B/C ratio of 16.1. This means that the benefits tend to highly exceed the costs.

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

Scenario	Input values	B/C ratio

Best estimate	Fatal injury crashes reduction: 28% Serious injury crashes reduction: 28% Slight injury crashes reduction: 28% PDO only crashes reduction: 28% Implementation cost: 21,446 €/site Annual cost: 1,960 €/site Affected nr. of crashes per year: Casualties (slight/serious/fatal): 1.3704 PDO[3]: 3.3778	16.1

SENSITIVITY ANALYSIS

We used the upper and lower limits of the 95% confidence intervals of the estimates in Høye and Elvik (2016) to run a sensitivity analysis. The values represent a considerably lower/higher than expected effect, respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Fatal injury crashes reduction: 23% Serious injury crashes reduction: 23% Slight injury crashes reduction: 23% PDO only crashes reduction: 23%	13.2
High measure effect	Fatal injury crashes reduction:32% Serious injury crashes reduction: 32% Slight injury crashes reduction: 32% PDO only crashes reduction: 32%	18.4
Low measure cost (-50%)	Implementation cost: 10,723 €/site Annual cost: 980 €/site	32.2
High measure cost (+100%)	Implementation cost: 42,891 €/site Annual cost: 3,920 €/site	8.1

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Fatal injury crashes reduction: 23% Serious injury crashes reduction: 23% Slight injury crashes reduction: 23% PDO only crashes reduction: 23% Implementation cost: 42,891 €/site Annual cost: 3,920 €/site	6.6
Ideal case	Fatal injury crashes reduction:32% Serious injury crashes reduction: 32% Slight injury crashes reduction: 32% PDO only crashes reduction: 32% Implementation cost: 10,723 €/site Annual cost: 980 €/site	36.8

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CBA: Dynamic Speed Limits

Stijn Daniels, VIAS, September 2017

ABSTRACT

An existing evaluation study on effects of dynamic speed limits on motorways in Flanders, Belgium (De Pauw et al., 2017) was revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 1.1 which means that the benefits tend to exceed the costs slightly. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: The only available before-and-after study (De Pauw et al., 2017) reports a significant reduction of 18% (95% CI [-4%; -30%] of injury crashes due to the presence of a dynamic speed limits (DSL) system on motorways in Flanders, Belgium.

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

Measure Costs: De Pauw et al. (2017) also contained cost information. The estimated implementation cost in this paper is 316 000 EUR (2010 prices) per kilometre. The estimated annual maintenance and operational cost is 9876 EUR (2010 prices) per kilometre. These costs apply to Belgium and are updated to 2015 values by applying the inflation conversion value of 1.07. Subsequently the values are converted to EU averages by multiplying with the PPP conversion value of 0.92.

Time horizon: The applied time horizon for the measure is 25 years.

Area/Unit of implementation: All costs and effects are expressed per kilometre of motorways that are equipped with dynamic speed limits. The study evaluated 59.5 km of motorways that are equipped with the system.

Number of cases affected: The affected number of casualties was retrieved from De Pauw et al. (2017). The study contains an estimate of the effect on the total number of injured people and a separate estimate on the effect on the number of serious injuries. For the CBA the effect on PDO crashes was assumed to be the same as the effect on the number of slight injury crashes. No side effects were taken into account.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for DSL. It shows a B/C ratio of 1.1. This means that the benefits tend to exceed the costs slightly.

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

Scenario	Input values	B/C ratio

Best estimate	Fatal injury crashes reduction: 6% Serious injury crashes reduction: 6% Slight injury crashes reduction: 18% PDO only crashes reduction: 18% Implementation cost: 311070 €/km Annual cost: 9722 €/km Affected nr. of crashes per year: Fatalities: 0.0447 (2.66/59.5 km) (De Pauw et al., 2017) Ser. Inj. 0.4021 Slight inj.: 1.6078 PDO[4]: 9.797	1.1

SENSITIVITY ANALYSIS

We used the upper and lower limits of the 95% confidence intervals of the estimates in De Pauw et al. (2017) to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Fatal injury crashes reduction: -29% Serious injury crashes reduction: -29% Slight injury crashes reduction: +4% PDO only crashes reduction: +4%	-2.3
High measure effect	Fatal injury crashes reduction: 32% Serious injury crashes reduction: 32% Slight injury crashes reduction: 30% PDO only crashes reduction: 30%	3.6
Low measure cost (-50%)	Impl. cost: 155535 €/km Annual cost: 4861 €/km	2.1
High measure cost (+100%)	Impl. cost: 622140 €/km Annual cost: 19444 €/km	0.5

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Fatal injury crashes reduction: -29% Serious inj. Crashes reduction: -29% Slight injury crashes reduction: 4% PDO only crashes reduction: 4% Impl. cost: 622140 €/km Annual cost: 19444 €/km	-1.2
Ideal case	Fatal injury crashes reduction:32% Serious inj. Crashes reduction: 32% Slight injury crashes reduction: 30% PDO only crashes reduction: 30% Impl. cost: 155535 €/km Annual cost: 4861 €/km	7.2

[4] In De Pauw et al. (2017) no information about PDO crashes is available. The estimated number of affected PDO crashes (9.797) is calculated by multiplying the number of slight injuries (1.6078) with (331370/54381), i.e. the proportion of PDO crashes to slight injuries for Belgium, i.e. the country of origin for the target crash data.

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CBA: Section Control

Stijn Daniels, VIAS, September 2017

ABSTRACT

A cost-benefit analysis on section control systems was executed based on effect estimates from the meta-analysis by Høye (2014), supplemented by cost estimates in Owen et al. (2016) and target crash estimates in Montella et al. (2012). The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio is 19.5 which means that the benefits clearly outweigh the costs. The sensitivity analyses show that this measure remains cost-effective in all scenarios, even in the worst case scenario.

INPUT INFORMATION

Case studied: Section control was found to significantly reduce the number of crashes in a meta-analysis (Høye, 2014) with estimated reductions in the number of crashes of 30% for the total number of crashes and 56% for crashes involving killed or severely injured victims.

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

Measure Costs: Owen et al. (2016) state that permanent average speed camera sites are estimated to have cost up to £1.5m per mile in 2000 but in 2016 cost an average of £100,000 per mile (which equals a cost of 68323 €/km (= 100 000 * 1.10 (GBP to EUR 2015)/1.61 (mile to km). They expect this evolution to continue as the cost of the technology falls and there is increased competition in the market. As no information could be retrieved about the annual maintenance or operation cost for the section control systems, we assumed these to be 10% of the initial investment cost, thus 6832€ annually.

Time horizon: The applied time horizon for the measure is 15 years.

Area/Unit of implementation: All costs and effects are expressed per kilometre of highways that are equipped with section control (average speed control) systems.

Number of cases affected: The affected number of casualties was retrieved from one of the studies where the meta-analysis of Høye was based upon (Montella et al., 2012), the one with the highest statistical weight. This study contained information for both severe and non-severe target crashes. For the CBA the effect on PDO crashes was assumed to be the same as the effect on the number of non-severe crashes. No side effects were taken into account.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for DSL. It shows a B/C ratio of 19.5 which means that the benefits clearly outweigh the costs.

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

Scenario	Input values	B/C ratio
Best estimate	Fatal injury crash reduction: 56% Serious injury crash reduction: 56% Slight injury crash reduction: 30% PDO only crash reduction: 30% Implementation cost: 68323 €/km Annual cost: 6832 €/km Affected nr. of crashes per year:	19.5

	Fatal crashes[5]: 0.08 Serious injury crashes[1]: 0.60 Slight injury crashes[6]: 0.45 PDO crashes[2]: 2.41	

SENSITIVITY ANALYSIS

We used the upper and lower limits of the 95% confidence intervals of the estimates in Høye (2014) to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Fatal injury crashes reduction: 42% Serious injury crashes reduction: 42% Slight injury crashes reduction:24 % PDO only crashes reduction: 24%	14.7
High measure effect	Fatal injury crashes reduction: 66% Serious injury crashes reduction: 66% Slight injury crashes reduction: 36% PDO only crashes reduction: 36%	23.0
Low measure cost (-50%)	Impl. cost: 34162 €/km Annual cost: 3416 €/km	39.1
High measure cost (+100%)	Impl. cost: 136646 €/km Annual cost: 13665 €/km	9.8

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Fatal injury crashes reduction: 42% Serious inj. Crashes reduction: 42% Slight injury crashes reduction: 24% PDO only crashes reduction: 24% Impl. cost: 136646 €/km Annual cost: 13665 €/km	7.3
Ideal case	Fatal injury crashes reduction:66% Serious inj. Crashes reduction: 66% Slight injury crashes reduction: 36% PDO only crashes reduction: 36% Impl. cost: 34162 €/km Annual cost: 3416 €/km	46.1

[5] Target severe crashes: 0.68 (= 0.3/km/year in after-period (observed number)/0.44 (best estimate of reduction) to obtain the target number on the treatment locations) (Montella et al., 2012). Applying the generic proportion (Italy) of fatal crashes to serious injury crashes (0.1294), these 0.68 crashes are assumed to consist of 0.68/1.1294 = 0.60 serious injury crashes and 0.08 fatal crashes.

[6] Target non-severe crashes: 2.86 (= 2.0/km/year in after-period (observed number)/0.70 (best estimate of reduction) to obtain the target number on the treatment locations) (Montella et al., 2012). Non-severe crashes include both slight injury crashes and PDO only crashes. Applying the generic proportion (Italy) of Slight injury crashes to PDO crashes (0.01141), these 2.86 crashes are assumed to consist of 2.86/1.1141 = 2.41 PDO crashes and 0.45 slight injury crashes

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CBA: Installation of speed humps

Christos Katrakazas, Claire Quigley, LOUGH, September 2017

ABSTRACT

A meta-analysis regarding the effects of the installation of speed humps on accidents (Høye, 2015) was revisited. The SafetyCube Economic Efficiency Evaluation (E3) Calculator was used. The resulting best estimate of the benefit-cost ratio (BCR) is 18.2 which means that the benefits tend to exceed the costs considerably. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis, however in all the scenarios it is shown that the installation of speed humps is a very cost-effective measure.

INPUT INFORMATION

Cases studied: The meta-analysis (Høye, 2015) reports a significant reduction of 17% (95% CI [-25%; -8%] of all crashes, as an effect of the implementation of speed humps. A case study on speed humps installation (49 speed humps) in one municipality of Athens, Greece is considered as regards the unit of implementation and the related costs (Yannis et al., 2005).

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

Measure Costs: The Greek case study reports a total cost of 187,953 EUR (converted from 1998 estimate for Greece to the 2015 value for EU-28), i.e. 3,836 EUR/speed hump. In the Handbook of Road Safety (Elvik, Hoye, Vaa, & Sorensen, 2009) a very similar value of 3,189 EUR /speed hump is reported (after related conversion from NOK 1996).

Time horizon: 25 years was assumed to be the time horizon for speed humps

Area/Unit of implementation: The example of 49 speed humps installation in one municipality of Athens, Greece is used (Yannis et al. 2005), and hence one (1) unit of implementation (1 municipality) was taken into account.

Number of cases affected: According to Yannis et al. (2005), the annual number of crashes with casualties in the examined municipality is 9 crashes (i.e. 0.184 crashes per speed hump).

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for speed humps for both studies. For the best estimate scenario the cost-benefit ratio was estimated at 18.2. This means that the benefits tend to exceed the costs considerably.

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

Scenario	Input values	B/C ratio
Best estimate	Accidents(fatal,serious,slight) reduction: 17% Implementation cost: 3,836 EUR /speed hump	18.2

SENSITIVITY ANALYSIS

We used the upper and lower limits of the effectiveness figures provided in the meta-analysis of (Høye, 2015) to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2 Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Impl. cost: 3,836 EUR /speed hump Accidents(fatal,serious,slight) reduction: 8%	8.6
High measure effect	Impl. cost: 3,836 EUR /speed hump Accidents(fatal,serious,slight) reduction: 25%	26.8
Low measure cost (-50%)	Impl. cost: 1,918 EUR /speed hump Accidents(fatal,serious,slight) reduction: 17%	36.4
High measure cost (+100%)	Impl. cost: 7.672 EUR /speed hump Accidents(fatal,serious,slight) reduction: 17%	9.1

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the highest value of estimated costs). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (the lowest value of estimated costs). The results of the CBA for these scenarios are reflected in Table 3.

Table 3 CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Impl. cost: 6,377 EUR /speed hump Accidents(fatal,serious,slight) reduction: 8%	4.3
Ideal case	Impl. cost: 1,918 EUR /speed hump Accidents(fatal,serious,slight) reduction: 25%	53.8

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SUPPORTING INFORMATION

Literature Search

A systematic literature search was conducted in June 2017. The database 'Scopus' was used to identify papers that contained cost-related information related to installing speed humps to improve road safety. The search terms used to identify papers which investigated the effectiveness of installing speed humps as a safety measure (see SafetyCube D5.2) were again used in this literature search. However, additional search terms (i.e. variations of 'cost' and 'cost-benefit analysis') were included to narrow down the papers to include only those containing cost-related information.

From this search, nine papers were identified which included cost-related search terms. After further investigation of these papers, four were found to have potential cost-related data for installing speed humps. After attempting to input information into the SafetyCube cost calculator from these four papers, it was found that none of them had enough relevant data for inputting into the SafetyCube cost calculator to be able to obtain any results.

The data from the meta-analysis included in the measures synopsis for speed humps (Høye, 2015, also see SafetyCube D5.2) was also investigated for relevant cost information. It was found that this data could be inputted into the cost calculator to provide results for estimated benefit-to-cost ratios for installing speed humps. Therefore in total, one paper was identified which had relevant cost information for inputting into the SafetyCube cost calculator.

CBA: Implementation of 30 km/h zones

Christos Katrakazas, Claire Quigley, LOUGH, September 2017

ABSTRACT

An existing cost-benefit and cost-utility analysis of mandatory 30km/h (20mph) zones in London (Peters & Anderson, 2013) was revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 1.6 which means that the benefits tend to exceed the costs slightly. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Cases studied: The available study reports a reduction of 57% [95%CI (17.2-95.8)] on fatal casualties, 26% [95% CI (14.4-38.1)] on seriously injured casualties and 22% [95%CI (13.7-29.6)] on slightly injured casualties as an effect of the implementation of 20mph zones. The CI intervals were obtained from the study of Grundy, Steinbach, Wilkinson, & Green, (2008), on which, the study of Peters & Anderson, (2013) was based on.

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

Measure Costs: The available paper reports a construction cost range of £75100-£75800. The average value of £75450 was used for the best-estimate result. The annual maintenance costs for the intervention were £1000. These costs apply to the UK in 2009 and was updated to 2015 values by applying the inflation conversion value of 1.09.

Time horizon: 25 years was assumed to be the time horizon for 20mph zones

Area/Unit of implementation: All costs and effects are expressed per area intervention, and hence one (1) unit of implementation was taken into account.

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

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for area-wide traffic calming. For the best estimate scenario, the benefit-to-cost ratio was estimated at 1.6. This means that the benefits exceed the costs slightly.

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

Scenario	Input values	B/C ratio
Best estimate (Peters& Anderson, 2013)	Fatal injury crashes reduction: 57% Serious injury crashes reduction: 26% Slight injury crashes reduction: 22% Implementation cost: 82241 GBP Annual maintenance cost: 1,090 GBP Affected nr. of casualties per year[7]: Fatal=0.006, Serious=0.039, Slightly injured=0.374 PDO number recommendation =4.914	1.6

SENSITIVITY ANALYSIS

We used the upper and lower limits of the cost figures for costs provided in the paper (Peters & Anderson, 2013) as well as the upper and lower limits of the effectiveness taken by (Grundy et al., 2008) to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected cost and effect respectively. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure cost (-50%)	Implementation cost: 41,120 GBP Annual maintenance cost: 545 GBP Fatal injury crashes reduction: 57% Serious injury crashes reduction: 26% Slight injury crashes reduction: 22%	3.2
High measure cost (+100%)	Implementation cost: 164,481 GBP Annual maintenance cost: 2,180GBP Fatal injury crashes reduction: 57% Serious injury crashes reduction: 26% Slight injury crashes reduction: 22%	0.8
Low measure effect	Implementation cost: 82,241 GBP Annual maintenance cost: 1,090 GBP Fatal injury crashes reduction: 17.2% Serious injury crashes reduction: 14.4% Slight injury crashes reduction: 13.7%	0.6
High measure effect	Implementation cost: 82,241 GBP Annual maintenance cost: 1,090 GBP Fatal injury crashes reduction: 95.8% Serious injury crashes reduction: 38.1% Slight injury crashes reduction: 29.6%	2.5

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the cost) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the cost) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

[7] The average values of the low- and high-casualty areas were estimated. These values are: Fatal=0.002, Serious=0.074, Slightly injured=0.547 (low casualty areas); Fatal=0.01, Serious=0.004, Slightly injured=0.201 (high casualty areas)

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Fatal injury crashes reduction: 17.2% Serious injury crashes reduction: 14.4% Slight injury crashes reduction: 13.7% Implementation cost: 164,481 GBP Annual maintenance cost: 2,180GBP	0.3
Ideal case	Fatal injury crashes reduction: 95.8% Serious injury crashes reduction: 38.1% Slight injury crashes reduction: 29.6% Implementation cost: 41,120 GBP Annual maintenance cost: 545 GBP	5.1

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SUPPORTING INFORMATION

Literature Search

A systematic literature search was conducted in June 2017. The database 'Scopus' was used to identify papers that contained cost-related information related to installing 20mph or 30mk/h zones. The search terms used to identify papers which investigated the effectiveness of installing 20mph or 30km/h zones as a safety measure (see SafetyCube D5.2) were again used in this literature search. However, additional search terms (i.e. variations of 'cost' and 'cost-benefit analysis') were included to narrow down the papers to include only those containing cost-related information.

From this search, three papers were identified which included cost-related search terms. After further investigation of these papers, two were found to have potential cost-related data for installing 20mph or 30km/h zones. After attempting to input information into the SafetyCube cost calculator from these two papers, it was found that both had enough relevant data for inputting into the SafetyCube cost calculator to be able to obtain results. However, as both papers referenced the same accident data from a previous study, the paper with the most detailed data was used for the cost-benefit analysis (Peters and Anderson, 2013).

CBA: Area-wide traffic calming

Christos Katrakazas, Claire Quigley, LOUGH, September 2017

ABSTRACT

A section of the road safety handbook (Elvik, Hoye, Vaa, & Sorensen, 2009) regarding the effects of the area-wide traffic calming on accidents, as well as a cost-benefit analysis of area-wide traffic calming in Greece (Yannis, Papadimitriou, & Evgenikos, 2005) were revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 0.2-0.4 which means that the costs tend to exceed the benefits slightly. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis, however in all the scenarios it is shown that the implementation of area-wide traffic calming is slightly not cost-effective a measure.

INPUT INFORMATION

Cases studied: The available study from (Elvik et al., 2009) reports a reduction of 15% [95%CI (-17%,-12%)] on all crashes, and a 15% reduction [95%CI (-19%,-12%)] on PDO crashes as an effect of the implementation of area-wide traffic calming. The study of Yannis et al., (2005) reports another significant reduction of 38% on all road accidents.

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

Measure Costs: The Handbook of Road Safety (Elvik et al., 2009), reports that the installation of an area-wide traffic calming scheme costs 2,000,000 NOK/area with annual maintenance costs around 100,000 NOK/area. This cost applies to Norway in 1996 and was updated to 2015 values by applying the inflation conversion value of 2.05. Subsequently the values are converted to EU averages (in EUR) by multiplying with the PPP conversion value of 0.08.

Regarding the study of Yannis et al., (2005), the implementation cost for area-wide traffic calming is reported as 3,192,956 EUR which applies to Greece in 1998. The values were also updated to 2015 values by applying the inflation conversion value of 1.35 and to EU averages by multiplying with the PPP conversion value of 1.25

Time horizon: 25 years was assumed to be the time horizon for area-wide traffic calming.

Area/Unit of implementation: All costs and effects are expressed per area intervention, and hence one (1) unit of implementation was taken into account.

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

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for area-wide traffic calming. For the best estimate scenario the benefit-to-cost ratio was estimated at 0.2-0.4. This means that the costs exceed the benefits.

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

Scenario	Input values	B/C ratio
Best estimate (Elvik et al., 2009)	Accidents(fatal,serious,slight) reduction: 15% PDO reduction: 15% Implementation cost: 318,875 EUR Annual maintenance cost: 15,944 EUR Affected nr. of crashes per year: Casualties(slight/serious/fatal):0.5/ million VKM PDO: 4.824/ million VKM	0.4
Best estimate (Yannis et al., 2005)	Accidents(fatal,serious,slight) reduction: 38% Implementation cost: 5,389,225 EUR Affected nr. of crashes per year: Casualties(slight/serious/fatal):1.4 PDO:10	0.2

SENSITIVITY ANALYSIS

We used the upper and lower limits of the effectiveness figures provided in the handbook of road safety (Elvik et al., 2009) to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Implementation cost: 318,875 EUR Annual maintenance cost: 15,944 EUR Accidents(fatal,serious,slight) reduction: 12% PDO accidents reduction: 12%	0.3
High measure effect	Implementation cost: 318,875 EUR Annual maintenance cost: 15,944 EUR Accidents(fatal,serious,slight) reduction: 17% PDO accidents reduction: 19%	0.4
Low measure cost (-50%)	Impl. cost: 159,437 EUR Annual cost: 7,972 EUR Accidents(fatal,serious,slight) reduction: 15% PDO accidents reduction: 15%	0.7
High measure cost (+100%)	Impl. cost: 637,750 EUR Annual cost: 31,887 EUR Accidents(fatal,serious,slight) reduction: 15% PDO accidents reduction: 15%	0.2

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Accidents(fatal,serious,slight) reduction: 12% PDO accidents reduction: 12% Impl. cost: 637,750 EUR Annual cost: 31,887 EUR	0.1
Ideal case	Accidents(fatal,serious,slight) reduction: 17% PDO accidents reduction: 19% Impl. cost: 159,437 EUR Annual cost: 7,972 EUR	0.8

REFERENCES

Elvik, R., Hoye, A., Vaa, T., & Sorensen, M. (2009). *The handbook of road safety measures 2nd Edition*. Emerald Group Publishing Limited.

Yannis, G., Papadimitriou, E., & Evgenikos, P. (2005). COST-BENEFIT ASSESSMENT OF SELECTED ROAD SAFETY MEASURES IN GREECE. In *Road Safety on Four Continents: 13th International Conference*.

SUPPORTING INFORMATION

Literature Search

A systematic literature search was conducted in June 2017. The database 'Scopus' was used to identify papers that contained cost-related information related to installing traffic calming schemes to improve road safety. The search terms used to identify papers which investigated the effectiveness of installing traffic calming schemes as a safety measure (see SafetyCube D5.2) were again used in this literature search. However, additional search terms (i.e. variations of 'cost' and 'cost-benefit analysis') were included to narrow down the papers to include only those containing cost-related information.

From this search, six papers were identified which included cost-related search terms. After further investigation of these papers, only one was found to have potential cost-related data for traffic calming schemes which were relevant for inputting into the SafetyCube cost calculator.

The data from the meta-analysis included in the measures synopsis for traffic calming schemes (Elvik et al, 2009, also see SafetyCube D5.2) was also investigated for relevant cost information. It was found that this data could be inputted into the cost calculator to provide results for estimated benefit-to-cost ratios for traffic calming schemes. Therefore in total, two papers were identified which had relevant cost information for inputting into the SafetyCube cost calculator.

CBA: Road Surface Treatment

Vesna Marinko, AVP, October 2017

INTRODUCTION

An existing evaluation study on effects of road treatment (Hussein et al., 2016) was revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The *break-even costs* indicate the maximal costs that one unit of a measure can have to still be economically efficient.

We had one good before-and-after study available on the effect of road treatment restricted to 136 intersections in a metropolitan region of Melbourne, Australia, by Hussein et al. (2016). Table 1 summarises the characteristics, strengths and weaknesses and main effect estimates of the study.

Table 1. Effects estimates that can be used for the cost-benefit analysis.

Study	Study type	Study scope	Relevance for Europe	Strengths/ Weaknesses (S/W)	Best effect estimates
Hussein et al. 2016	Before-after study	136 intersections; period 2005-2010	Moderate relevance; study conducted in Australia, EB approach	**S:** Large scale study 136 intersections with > 5 years before and after period. **W**: No good separate estimate for fatal crashes or serious injury crashes.	21.3 % reduction total casualty crashes 15.3 % reduction high severity crashes (fatal/serious) 21.4 % other injury crashes

The only available before-and-after study on the effect of road treatment (Hussein et al., 2016) does not separate estimates for fatal crashes and serious injury crashes, but still is a good example for obtaining information on benefits of road treatment. We chose to use the Hussein et al. 2016 for our estimates on benefits of road treatment (resurfacing).

INPUT INFORMATION

Case study: Our case (road resurfacing) dealt with Australia. We made so-called "general-analysis" and used EU as a value for country and EUR as a currency. Therefore we copied the crash cost information about EU to the Input map.

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

Measure costs: In cost-benefit s analysis for road treatment (resurfacing) no measures costs have been filled in. Therefore no BCR and NPV could be calculated, so the "break-even costs" have been estimated.

Time horizon: The applied time horizon for the measure is 5 years.

Area/Unit of implementation: Number of units implemented on which we provided crash information is 136 intersections.

Number of cases affected:

- 1290 casualty crashes (slight/serious/fatal) per year (the target number of crashes reflects situation in year 2016 in which no treatment was recently done; data from Australian authorities)
- property damage crashes because this value was suggested by the E-3 calculator
- effectiveness percentage: *plus* 21 to indicate the 21.3% reduction in total casualty crashes based on study of Hussein et al. 2016
- effectiveness percentage: *plus* 15 to indicate the 15.3% reduction in injury crashes based on study of Hussein et al. 2016

RESULTS

Table 2 provides the input values and the final result.

Table 2. Output map, Road treatment (resurfacing), Australia

COST-BENEFIT ANALYSIS		
Costs (present values)		
One-time investment costs	-	EUR
Recurrent costs	-	EUR
Total costs excluding side-effects	-	EUR
Side-effects	-	EUR
Total costs including side-effects	-	EUR
Benefits		
Prevented Crashes	152810191	EUR
Socio-economic return excluding side-effects		
Net present value	152.810.191	EUR
Cost-benefit ratio	#DEL/0!	
Socio-economic return including side-effects		
Net present value	152.810.191	EUR
Cost-benefit ratio	#DEL/0!	
Break-even cost for measure (per unit)	1.123.604	EUR
COST-EFFECTIVENESS ANALYSIS		
Prevented crashes		
Fatal	0,0	
Serious	0,0	
Slight	0,0	
PDO	0,0	
Serious & slight	0,0	
Fatal / serious / slight	1354,5	

As we haven't filled in any measure costs, no BCR and NPV can be calculated. So we used break-even costs for estimation; the value 1.123.604 EUR is the maximal cost that one unit of a measure can have to still be economically efficient.

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CBA: Winter maintenance

Vesna Marinko, AVP, September 2017

ABSTRACT

An existing evaluation study on effects of winter maintenance (Høye & Bjørnskau, 2013) was revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. A benefit-to-cost ratio (BCR) > 1 indicates that a measure is economically efficient. The resulting best estimate of the BCR is 6.0 which means that the benefits tend to exceed the costs.

INPUT INFORMATION

Case study:

Table 1 summarises the characteristics, strengths and weaknesses and main effect estimates of an existing evaluation study on effects of winter maintenance (Høye & Bjørnskau, 2013)

Table 1. Effects estimates that can be used for the cost-benefit analysis.

Study	Study type	Study scope	Relevance for Europe	Strengths/ Weaknesses (S/W)	Best effect estimates
Høye & Bjørnskau 2013	Meta-analysis	Salting roads (introduction or cessation of salting the entire winter season)	High relevance	**W:** No good separate estimate for fatal or serious injury crashes.	12% reduction all injury crashes 35% reduction property damage crashes

The study (Høye & Bjørnskau, 2013) does not provide separate estimates for fatal crashes and serious injury crashes, but still is a good example for obtaining information on benefits of winter maintenance.

Our case (road resurfacing) dealt with Norwegian. Therefore we copied the crash cost information about Norway to the Input map.

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

Measure costs: In our cost-benefit s analysis for winter maintenance we used 64.884.800 NOK (6,919,572.7 EUR) as total costs over the whole period evaluated since we couldn't split up the costs into total initial costs and annual costs. Costs had to be updated to 2015 using our E^3 calculator. These costs apply to Norway and are updated to 2015 values by applying the inflation conversion value of 2.14.

Time horizon: The applied time horizon for the measure is 1 year.

Area/Unit of implementation: Number of units implemented on which we provided crash information is 10.000,00 km.

Number of cases affected:

- 305 casualty crashes (slight/serious/fatal) per year (the target number of crashes reflects situations in year 1995 in which the measure was applicable but not yet taken; data from Institute of Transport Economics, Oslo, Norway)
- property damage crashes because this value was suggested by the E-3 calculator
- effectiveness percentage: *plus* 35 to indicate the 35% reduction in property damage crashes based on Høye 2013 meta-analysis
- effectiveness percentage: *plus* 15 to indicate the 15% reduction in injury crashes based on Høye 2013 meta-analysis.

RESULTS

Table 2 provides the input values and the result estimated benefit-to-cost ratio for DSL. It shows a B/C ratio of 6.0. This means that the benefits tend to exceed the costs slightly.

Table 2. Output map, Winter maintenance, Norway

COST-BENEFIT ANALYSIS		
Costs (present values)		
One-time investment costs	-	NOK
Recurrent costs	-	NOK
Total costs excluding side-effects	64.884.800	NOK
Side-effects	-	NOK
Total costs including side-effects	64.884.800	NOK
Benefits		
Prevented Crashes	390976313	NOK
Socio-economic return excluding side-effects		
Net present value	326.091.513	NOK
Cost-benefit ratio	6,0	
Socio-economic return including side-effects		
Net present value	326.091.513	NOK
Cost-benefit ratio	6,0	
Break-even cost for measure (per unit)	39.098	NOK
COST-EFFECTIVENESS ANALYSIS		
Prevented crashes		
Fatal	0,0	
Serious	0,0	
Slight	0,0	
PDO	8409,2	
Serious & slight	0,0	
Fatal / serious / slight	45,8	
Costs per prevented crash		
Fatal	#DEL/0!	NOK
Serious	#DEL/0!	NOK
Slight	#DEL/0!	NOK
PDO	7.716	NOK
Serious & slight	#DEL/0!	NOK
Fatal / serious / slight	1.418.247	NOK

It can be seen that benefit-to-cost ratio (BCR) is estimated to be 6.0 which means that a measure is economically efficient. It is expected that in one year 8.409,2 PDO crashes will be prevented.

SENSITIVITY ANALYSIS

We used 50% lower cost of measure and 100% higher cost of measure to run a sensitivity analysis. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 3: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure cost (-50%)	Total costs: 75.800 NOK/km (8.083,61 €/km)	12.1
High measure cost (+100%)	Total cost: 56.850 NOK/km (6.062,71 €/km)	3.0

We define a 'worst case' scenario as a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined as a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 4: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Injury crashes reduction: 15% PDO only crashes reduction: 35% Total cost: 56.850 NOK/km (6.062,71 €/km)	3.0
Ideal case	Injury crashes reduction: 15% PDO only crashes reduction: 35% Total costs: 75.800 NOK/km (8.083,61 €/km)	12.1

REFERENCES

Høye, A. & Bjornskau T., (2013). Winter maintenance. The Handbook of Road Safety Measures, Norwegian (online) version

CBA: Road lighting

Annelies Schoeters, Vias institute, October 2017

ABSTRACT

An exemplary cost-benefit analysis for the installation of road lighting was conducted using data from Høye (2014), Høye et al. (2017) and Perkins et al. (2015). The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 0.7 which means that the costs exceed the benefits. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: The effectiveness estimate for the installation of road lighting on unlit roads is retrieved from the meta-analysis by Høye (2014). In this study the estimated effect of road lighting on fatal crashes during darkness, is a reduction of 52% (95% CI [-59%, -45%]). The effect on injury crashes during darkness is a reduction of 26% (95% CI [-33%, -19%]).

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

Measure Costs: In the Handbook of Road Safety Measures by Høye et al (2017) the costs for the installation of road lighting is given per kilometre. There is a distinction between ordinary roads and motorways. Since the number of affected cases could only be retrieved from a study (Perkins et al., 2015) in which the type of road is not specified, we will use the costs of road lighting for ordinary roads. The implementation costs are 450,000 NOK (2009) per kilometre and the annual recurrent costs are 25,000 NOK (2009). Correcting for inflation by the factor 1.18 (from 2009 to 2015) results in 531,000 NOK implementation costs and 29,500 NOK. Correcting for the exchange rate and the price level by the factor 0.08 (from Norway to EU-28) results in 42,480 EUR implementation costs and 2,360 EUR annual recurrent costs.

Time horizon: In accordance with most infrastructure-related measures, the applied time horizon for the measure is set at 25 years.

Area/Unit of implementation: The costs and the target group are defined per kilometre of ordinary road that was unlit and where road lighting is installed.

Number of cases affected: The affected number of casualties was retrieved from Perkins et al. (2015). The study evaluated the effect of reduced street lighting on road traffic injuries in 62 local authorities in England and Wales. Data on the number of casualties during darkness on unlit roads per kilometre is very limited. As a proxy we use the number of crashes that occurred on the roads in this study when road lighting was switched off. The road lighting was switched off on 946 kilometre road during three years. In this period 298 casualties were registered. This results in an average of 0.105 casualties per year per kilometre.

No side effects were taken into account.

RESULTS

Table 1 provides the input values and the resulting estimated benefit-to-cost ratio for the installation of road lighting. It shows a B/C ratio of 0.7. This means that the costs exceed the benefits.

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

Scenario	Input values	B/C ratio
Best estimate	Casualties (slight/serious/fatal) reduction: 26% Implementation cost: 42,480 €/km Annual cost: 2.360 €/km Affected nr. of crashes per year: Slight/serious/fatal casualties: 0,105	0.7

SENSITIVITY ANALYSIS

We used the upper and lower limits of the 95% confidence intervals of the estimates in Hoye (2014) to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Casualties (slight/serious/fatal) reduction: 19% Implementation cost: 42,480 €/km Annual cost: 2,360 €/km	0.5
High measure effect	Casualties (slight/serious/fatal) reduction: 33% Implementation cost: 42,480 €/km Annual cost: 2,360 €/km	0.9
Low measure cost (-50%)	Casualties (slight/serious/fatal) reduction: 26% Implementation cost: 21,240 €/km Annual cost: 1,180 €/km	1.4
High measure cost (+100%)	Casualties (slight/serious/fatal) reduction: 26% Implementation cost: 84,960 €/km Annual cost: 4,720 €/km	0.4

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Casualties (slight/serious/fatal) reduction: 19% Implementation cost: 84,960 €/km Annual cost: 4,720 €/km	0.3
Ideal case	Casualties (slight/serious/fatal) reduction: 33% Implementation cost: 21,240 €/km Annual cost: 1,180 €/km	1.8

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CBA: Implementation of rumble strips at centreline

Davide Shingo Usami, CTL, September 2017

ABSTRACT

An existing evaluation study on the effects of centreline rumble strips in USA (Lyon et al., 2015) was revisited. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 1.0 which means that the benefits tend to be equal to the costs. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: A meta-analysis carried out in 2015 is available in The Handbook of Road Safety Measures (online version) (Høye, A., 2015). The meta-analysis reports a significant reduction of 37% (95% CI [-42%; -31%] of target accidents (i.e. head-on, ROR to the left, sideswipe with vehicle in the left-hand side oncoming lane) due to the implementation of centreline rumble strips.

Crash costs: The updated SafetyCube estimates for 2015 for Europe were used (see SafetyCube Deliverable 3.2). It is assumed the measure is implemented in the same conditions as in EU.

Measure Costs: Cost information are available for Norway and for USA (Lyon et al., 2015). The estimated implementation cost for Norway is 40 000 NOK (2004 prices) per kilometre. For USA, according to information provided by three States, rumble strip costs range from 620 $ per km to 2 480 $ per km (2014). These costs assume there are no maintenance costs. As Norway might be an outlier as compared to the rest of Europe, for this case it was decided to consider the average of the 3 USA cost figures. Subsequently the values are converted to EU averages by multiplying with the PPP conversion value of 0.08.

Time horizon: According to Lyon et al. (2015) the service life could be considered between 7- and 12-years. The applied time horizon for the measure is the average value (rounded-off): 10 years.

Area/Unit of implementation: All costs and effects are expressed per kilometre of roadway equipped with centreline rumble strip.

Number of cases affected: The affected number of crashes was retrieved from Lyon et al. (2015). The study contains an estimate of the target crash rates (Head-on and Sideswipe-Opposite-Direction, run-off-road to the left accidents are not included in these estimates) in three States ranging between 0.08 and 0.16 target crashes per mile per year (0.05-0.10 crashes/km per year). These values refer to all severities. The average value is considered for the CBA (0.068) and a percentage of 69% of PDO crashes was assumed[8]. The effect on PDO crashes was assumed to be the same as the effect on the total crashes. No side effects were considered in the analysis.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for rumble strips at centreline. It shows a B/C ratio of 9.1. This means that the benefits are much higher than the costs.

[8] In Lyon et al. (2015) no information about the percentage of PDO crashes in target crashes is available. From the available data the percentage of total PDO crashes is among 69% (for Kentucky) and 45% (for Pennsylvania). A conservative value of 69% of the estimated percentage of PDO crashes has been considered and used in the analysis.

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

Scenario	Input values	B/C ratio
Best estimate	Casualties (slight/serious/fatal) crashes reduction: 37% PDO only crashes reduction: 37% Implementation cost: 987 €/km Annual cost: - €/km Affected nr. of crashes per km per year: Casualties (slight/serious/fatal): 0.021 PDO: 0.047	9.1

SENSITIVITY ANALYSIS

We used the upper and lower limits of the 95% confidence intervals of the estimates in the meta-analysis (Høye, 2015) to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Slight/serious/fatal injury crashes reduction: 31% PDO crashes reduction: 31%	7.6
High measure effect	Slight/serious/fatal injury crashes reduction: 42% PDO crashes reduction: 42%	10.3
Low measure cost (-50%)	Impl. cost: 494 €/km Annual cost: - €/km	18.1
High measure cost (+100%)	Impl. cost:1 975 €/km Annual cost: - €/km	4.5

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Slight/serious/fatal injury crashes reduction: 31% PDO crashes reduction: 31% Impl. cost:1 975 €/km	3.8
Ideal case	Slight/serious/fatal injury crashes reduction: 42% PDO crashes reduction: 42% Impl. cost: 494 €/km	20.5

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CBA: Automatic barriers

Severin Stadlbauer, KFV, September 2017

ABSTRACT

An existing meta-analysis on the effects of the installation of automatic barriers at rail-road crossing including international literature (Elvik, 2009) was revisited. For further analysis the SafetyCube Economic Efficiency Evaluation (E³) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 0.05 which means that the costs tend to exceed the effects. The BCR is not sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis (estimates are below 0 in all scenarios).

INPUT INFORMATION

Case studied: The only available meta-analysis (Elvik, 2009) reports a significant reduction of 68% (95% CI [57%; 76%] of crashes due to the installation of barriers at level crossings that previously only had warning signs (international studies included).

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

Measure Costs: Implementation costs are based on an article from Elvik et al. (2009). The estimated cost in this paper is € 135 000. Information regarding annual costs could not be found, hence € 4 000 (approx. 3% of implementation costs) was assumed to be appropriate.

Time horizon: The applied time horizon for the measure is 25 years.

Area/Unit of implementation: All costs and effects are expressed per rail-road crossing. The installation of barriers relate to level crossings that previously only had warning signs

Number of cases affected: The number of casualties was calculated using the number of total passive level crossings in the EU and the number of accidents happening there. The number of crossings is from the European Union Agency for Railways (2016). The number of crashes is derived from the European Railway Agency (2012).

RESULTS

Table 1 provides the input values and the estimated benefit-to-cost ratio for automatic barriers. It shows a B/C ratio of 0.05. This means that costs exceed the benefits in this case.

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

Scenario	Input values	B/C ratio
Best estimate	Accident reduction: 68% Implementation cost: 135 000 € per crossing Annual cost: 4 000 € per crossing Affected nr. of crashes per year: 0,007	0,05

SENSITIVITY ANALYSIS

The upper and lower limits of the 95% confidence intervals of the estimates in Elvik (2009) were used to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Subsequently the effect is calculated for cases in which the measure costs are lower or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Accident reduction: 57%	0,04
High measure effect	Accident reduction: 76%	0,06
Low measure cost (-50%)	Impl. cost: 67 500 € Annual cost: 2 000 €	0,11
High measure cost (+100%)	Impl. cost: 270 000 € Annual cost: 8 000 €	0,03

A 'worst case' scenario is defined as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Accident reduction: 57% Impl. cost: 270 000 € Annual cost: 8 000 €	0,02
Ideal case	Accident reduction: 76% Impl. cost: 67 500 € Annual cost: 2 000 €	0,12

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CBA: Safety barrier installation

Apostolos Ziakopoulos, NTUA, September 2017

ABSTRACT

Existing evaluation studies on the effects of safety barrier installation were analysed, and information was synthesized from several sources. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 19.5 which means that the benefits tend to highly exceed the costs. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: The updated handbook meta-analysis (Høye and Elvik, 2016) mentions a significant 46% reduction in fatal crashes (95% CI [-67%; -12%]) and a significant 55% reduction in fatal crashes (95% CI [-65%; -42%]) after reviewing and analysing several original studies. This figures are reported to apply to flat and downward sloping roadside terrain; they were preferred because they were statistically significant.

There is no PDO crash reduction to be obtained for the CBA. Furthermore, safety barriers are assumed to not reduce the percentage of damage-only crashes as a measure, but rather to mitigate the consequences of more serious crashes. <u>A decision was made to consider the reduction in fatal and injury as an equivalent increase in PDO crashes based on the numbers provided.</u> This is performed by calculating the number of accidents from the previous categories and summing them as PDO crashes with an increase that is coded as '-100%' crash reduction.

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

Measure Costs: An average cost is obtained from the original Handbook (Elvik, 2009) by dividing the cost for the first five categories (numbers are per km). This is 406,000 NOK per km as one-time investment and 18,750 NOK. These are converted for inflation by applying the inflation conversion value of 1.24 (it is in 2001 prices) and to Euros (EU-28 average) by dividing with the PPP conversion value of 12.86.

Time horizon: The applied time horizon for the measure is 25 years, as per standard measures analysis.

Area/Unit of implementation: The area that is examined is an average 1 km of safety barriers on EU-28 secondary (rural) roads. This area is abstract due to the method of obtaining crash/km. Therefore all figures and the analysis apply per kilometre.

Number of cases affected: Crash number per km is (approximately) obtained via the division of the respective category with the rural network km of EU countries.

Source for crashes: Care, 2017 (2013 data was used to coincide with road network data year-wise). Source for km: European Commission, 2016

Several assumptions have been made, including disregarding AADT which the Handbook mentions is very significant, since relevant data would be very hard and time-consuming to locate. As an indication, the Handbook mentions that benefits start to exceed costs for safety barrier installation if AADT > 3000.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for DSL. It shows a B/C ratio of 19.5. This means that the benefits tend to highly exceed the costs.

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

Scenario	Input values	B/C ratio
Best estimate	Fatal injury crashes reduction: 46% Serious injury crashes reduction: 55% Slight injury crashes reduction: 55% PDO only crashes reduction: -100% (increase) Implementation cost: 39,070 €/km Annual cost: 1,804 €/km Affected nr. of crashes per year: Fatalities: 0.0283/km Ser. Inj. 0.1357/km Slight inj.: 0.9413/km PDO[9]: 0.6054/km	19.5

SENSITIVITY ANALYSIS

We used the upper and lower limits of the 95% confidence intervals of the estimates in Høye and Elvik (2016) to run a sensitivity analysis. The values represent a considerably lower/higher than expected effect, respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Fatal injury crashes reduction: 12% Serious injury crashes reduction: 42% Slight injury crashes reduction: 42% PDO only crashes reduction: -100% (increase)	10.6
High measure effect	Fatal injury crashes reduction: 67% Serious injury crashes reduction: 65% Slight injury crashes reduction: 65% PDO only crashes reduction: -100% (increase)	25.4
Low measure cost (-50%)	Implementation cost: 19,535 €/km Annual cost: 902 €/km	39.1
High measure cost (+100%)	Implementation cost: 78,140 €/km Annual cost: 3,609 €/km	9.8

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

[9] Only as an equivalent increase: all casualty crash reductions are assumed to be PDO crash increases.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Fatal injury crashes reduction: 12% Serious injury crashes reduction: 42% Slight injury crashes reduction: 42% PDO only crashes reduction: -100% (increase) Implementation cost: 78,140 €/km Annual cost: 3,609 €/km	5.3
Ideal case	Fatal injury crashes reduction: 67% Serious injury crashes reduction: 65% Slight injury crashes reduction: 65% PDO only crashes reduction: -100% (increase) Implementation cost: 19,535 €/km Annual cost: 902 €/km	21.2

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4. CARE database/Date of query: September 2017

CBA: Installation of chevron signs

Apostolos Ziakopoulos, NTUA, September 2017

ABSTRACT

Existing evaluation studies on the effects installation of chevron signs were analysed, and information was synthesized from several sources. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 2.7 which means that the benefits tend to considerably exceed the costs. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: There was no meta-analysis available to provide a collective estimate for chevron sign installation. Therefore the safety effect is obtained from Montella (2009), who examined 15 sites and reported a reduction of 2.6% for chevron signs only. The confidence intervals that are provided are not statistically significant, so for the sensitivity analysis the best and worst cases similar to cost variations will be used instead.

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

Measure Costs: Chevron sign cost obtained by McGee and Hanscom (2006) at approximately $500 per set of 10 (average appropriate for a curve). $10 for annual maintenance is assumed based on information from the same document.

Time horizon: The applied time horizon for the measure is 10 years, which is comparable with other signage/markings measures analysis.

Area/Unit of implementation: One set of chevron signs (usually about 10) installed at a curve. It is assumed that one curve warranting chevron signs exists per km for the purpose of this analysis.

Number of cases affected: Montella (2009) also reports crash reduction per km per year:

Injury crashes/km-year=0.7 and PDO crashes/km-year=1.5.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for DSL. It shows a B/C ratio of 2.7 which means that the benefits tend to considerably exceed the costs.

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

Scenario	Input values	B/C ratio
Best estimate	Casualty crashes (slight/serious/fatal) reduction: 2.6% PDO only crashes reduction: 2.6% Implementation cost: 429 €/curve Annual cost: 9 €/curve Affected nr. of crashes per year: Casualty crashes (slight/serious/fatal): 0.7/km PDO only crashes: 1.5/km	2.7

SENSITIVITY ANALYSIS

We used upper and lower descriptive estimates from the results of Montella (2009) to run a sensitivity analysis. The values represent a considerably lower/higher than expected effect, respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect (-50%)	Casualty crashes (slight/serious/fatal) reduction: 1.3% PDO only crashes reduction: 1.3%	1.4
High measure effect (+100%)	Casualty crashes (slight/serious/fatal) reduction: 5.2% PDO only crashes reduction: 5.2%	5.5
Low measure cost (-50%)	Implementation cost: 215 €/curve Annual cost: 4 €/curve	5.5
High measure cost (+100%)	Implementation cost: 859 €/curve Annual cost: 17 €/curve	1.4

We define a 'worst case' scenario as a combination of a much worse than expected effect (-50% expected effect) and a higher than expected measure cost (i.e. the estimated effect +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (+100% expected effect) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Casualty crashes (slight/serious/fatal) reduction: 1.3% PDO only crashes reduction: 1.3% Implementation cost: 859 €/curve Annual cost: 17 €/curve	0.7
Ideal case	Casualty crashes (slight/serious/fatal) reduction: 5.2% PDO only crashes reduction: 5.2% Implementation cost: 215 €/curve Annual cost: 4 €/curve	10.9

REFERENCES

1. Montella, A. (2009). Safety evaluation of curve delineation improvements: empirical Bayes observational before-and-after study. Transportation Research Record: Journal of the Transportation Research Board, (2103), 69-79.
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CBA: Channelisation

Severin Stadlbauer, KFV, September 2017

ABSTRACT

An existing meta-analysis on the effects of channelisation (installation of left turn lanes at crossroads) including international literature (Høye, 2013) was revisited. For further analysis the SafetyCube Economic Efficiency Evaluation (E³) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 8.4 which means that the effects tend to exceed the costs. The BCR is slightly sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: The only available meta-analysis (Høye, 2013) reports a significant reduction of 27% (95% CI [4%; 45%] of crashes due to the installation of left turn lanes at crossroads (international studies included).

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

Measure Costs: Implementation costs are based on Elvik et al. (2004) as cited in Yannis et al. (2008). The estimated cost in this paper is € 150.000 (including inflation). Information regarding annual costs could not be found, hence € 15.000 (less than 2% of implementation costs) were assumed to be appropriate.

Information regarding annual costs could not be found, hence € 15.000 (3% of implementation costs) were assumed to be appropriate.

Time horizon: The applied time horizon for the measure is 25 years.

Area/Unit of implementation: All costs and effects are expressed per left-turn lane installation. The installations relate to crossroads.

Number of cases affected: The number of cases is based on a study on the installation of left-turn lanes from Newstead & Corben (2001) included in the synopsis. The authors reported that in five years and at three sites 41 crashes happened.

RESULTS

Table 1 provides the input values and the estimated benefit-to-cost ratio for channelisation. It shows a B/C ratio of 8.4. This means that benefits exceed the costs in this case.

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

Scenario	Input values	B/C ratio
Best estimate	Accident reduction: 27% Implementation cost: 150.000 € per crossing Annual cost: 2.500 € per crossing Affected nr. of crashes per year: 2,7	8,4

SENSITIVITY ANALYSIS

The upper and lower limits of the 95% confidence intervals of the estimates in Høye (2013) were used to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Subsequently the effect is calculated for cases in which the measure costs are lower or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Accident reduction: 4%	1,2
High measure effect	Accident reduction: 45%	14,0
Low measure cost (-50%)	Impl. cost: 75.000 € Annual cost: 1.250 €	16,8
High measure cost (+100%)	Impl. cost: 300.000 € Annual cost: 5.000 €	4,2

A 'worst case' scenario is defined as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Accident reduction: 4% Impl. cost: 300.000 € Annual cost: 5.000 €	0,6
Ideal case	Accident reduction: 45% Impl. cost: 75.000 € Annual cost: 1.250 €	28,0

REFERENCES

Høye, A., 2013. Channelisation, The Handbook of Road Safety Measures, Norwegian (online) version, URL : http://tsh.toi.no/index.html?21716.

Newstead, S., Corben, B., 2001. Evaluation of the 1992-1996 Transport Accident Commission Funded Accident Blackspot Treatment Program in Victoria, Monash University Research Centre.

Yannis, G., Evgenikos, P., Papadimitriou, E., 2008. Best Practices on Cost - Effective Road Safety Infrastructure Investments, URL : http://www.cedr.fr/home/fileadmin/user_upload/Publications/2008/e_Road_Safety_Investments_Report.pdf.

CBA: Roundabouts

Severin Stadlbauer, KFV, September 2017

ABSTRACT

An existing meta-analysis on the effects of the conversion of junctions to roundabouts (general effect) including international literature (Elvik, 2015) was revisited. For further analysis the SafetyCube Economic Efficiency Evaluation (E_3) Calculator was used. The resulting best estimate of the benefit-to-cost ratio (BCR) is 9.2 which means that the effects tend to exceed the costs. The BCR is not sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

INPUT INFORMATION

Case studied: The only available meta-analysis (Elvik, 2015) reports a significant reduction of 72% (95% CI [42%; 86%] of fatal crashes due to the conversion of junctions to roundabouts (no specification presented). Furthermore injury crashes got reduced by 47% (95% CI [41%; 52%], while PDO crashes did not show any changes with a 0% reduction (95% CI [-15%; 17%]).

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

Measure Costs: Implementation costs are based on Pokorny (2011). The estimated cost in this paper is € 300.000 (without inflation). Information regarding annual costs could not be found, hence € 5.000 (1% of implementation costs) were assumed to be appropriate.

For implementation and yearly costs cost scenarios of 50% lower cost of measure and 100% higher cost of measure were set.

Time horizon: The applied time horizon for the measure is 25 years.

Area/Unit of implementation: All costs and effects are expressed per roundabout installation. The installations do relate to conversions in general, including different junction types.

Number of cases affected: The value is based on a mean value for different junction types from Flannery & Elefteriadou (1999) included in the synopsis and represents the number of crashes per year at treatment sites.

RESULTS

Table 1 provides the input values and the estimated benefit-to-cost ratio for roundabouts. It shows a B/C ratio of 9.2. This means that benefits exceed the costs in this case.

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

Scenario	Input values	B/C ratio
Best estimate	Fatal crashes reduction: 72% PDO crashes reduction: 0% Injury crashes reduction: 47% Implementation cost: 363.000 € per crossing Annual cost: 5.000 € per crossing Affected nr. of crashes per year: 5,9	9,2

SENSITIVITY ANALYSIS

The upper and lower limits of the 95% confidence intervals of the estimates in Elvik (2015) were used to run a sensitivity analysis. The values represent a (much) lower than expected and a (much) higher than expected effect respectively. Subsequently the effect is calculated for cases in which the measure costs are lower or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Fatal crashes reduction: 42% PDO crashes reduction: -15% Injury crashes reduction: 41%	8,1
High measure effect	Fatal crashes reduction: 86% PDO crashes reduction: 17% Injury crashes reduction: 52%	10,2
Low measure cost (-50%)	Impl. cost: 181.500 € Annual cost: 2.500 €	18,5
High measure cost (+100%)	Impl. cost: 726.000 € Annual cost: 10.000 €	4,6

A 'worst case' scenario is defined as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Fatal crashes reduction: 42% PDO crashes reduction: -15% Injury crashes reduction: 41% Impl. cost: 726.000 € Annual cost: 10.000 €	4,0
Ideal case	Accident reduction: 45% Impl. cost: 75.000 € Annual cost: 1.250 €	20,4

REFERENCES

Flannery, A., Elefteriadou, L., 1999. A Review of Roundabout Safety Performance in the United Sates, URL : http://www.ite.org/traffic/documents/CCA99A33.pdf.

Elvik, R., 2015. The Handbook of Road Safety Measures, Norwegian (online) version, URL : http://tsh.toi.no/index.html?21728.

Pokorn, P., 2011. Cost - Benefit Analysis for the Implementation of Four-arm Roundabouts in Urban Areas, DOI: 10.2478/v10158-011-0004-x.

CBA: Traffic signal installation

Apostolos Ziakopoulos, NTUA, September 2017

ABSTRACT

Existing evaluation studies on the effects of traffic signal installation were analysed, and information was synthesized from several sources. The SafetyCube Economic Efficiency Evaluation (E^3) Calculator was used. For county signals, the resulting best estimate of the benefit-to-cost ratio (BCR) is 1.1 which means that the benefits slightly exceed the costs. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis. An additional analysis for highways in provided in the Appendix.

INPUT INFORMATION

Case studied: The updated handbook meta-analysis (Høye and Elvik, 2016) mentions a significant 29% reduction in injurious crashes (95% CI [-41%; -14%]) after traffic signal installation.

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

Measure Costs: The original Handbook (Elvik, 2009) mentions average implementation cost for traffic signal installation for county roads as 430,000 NOK and annual maintenance costs at 30,000 NOK. In both cases, they are converted for inflation by applying the inflation conversion value of 1.445 (they are 1995 prices) and to Euros (EU-28 average) by multiplying with the PPP conversion value of 0.078.

Time horizon: The applied time horizon for the measure is 25 years, as per standard measures analysis.

Area/Unit of implementation: The area that is examined is the one investigated by the study providing crash mitigation figures: 4-armed junctions. (35 junctions examined in the study).

Number of cases affected: For county analysis, crash numbers were obtained from Jensen and ApS, (2009), for 4-legged intersections only.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for DSL. It shows a B/C ratio of 1.1. This means that the benefits tend to slightly exceed the costs.

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

Scenario	Input values	B/C ratio
Best estimate	Casualty crashes (slight/serious/fatal) reduction: 29% PDO only crashes reduction: 29% Implementation cost: 48,309 €/junction Annual cost: 3,370 €/junction Affected nr. of crashes per year: Casualties (slight/serious/fatal): 10.607/junction PDO: 5.393/junction	1.1

SENSITIVITY ANALYSIS

We used the upper and lower limits of the 95% confidence intervals of the estimates in Høye and Elvik, (2016) to run a sensitivity analysis. The values represent a considerably lower/higher than expected effect, respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Fatal injury crashes reduction: 14% Injury (Serious/Slight) crashes reduction: 14% PDO only crashes reduction: 14%	0.5
High measure effect	Fatal injury crashes reduction: 41% Injury (Serious/Slight) crashes reduction: 41% PDO only crashes reduction: 41%	1.5
Low measure cost (-50%)	Implementation cost: 24,154 €/junction Annual cost: 1,685 €/junction	2.2
High measure cost (+100%)	Implementation cost: 96,617 €/junction Annual cost: 6,741 €/junction	0.5

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%). Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Fatal injury crashes reduction: 14% Injury (Serious/Slight) crashes reduction: 14% PDO only crashes reduction: 14% Implementation cost: 96,617 €/junction Annual cost: 6,741 €/junction	0.3
Ideal case	Fatal injury crashes reduction: 41% Injury (Serious/Slight) crashes reduction: 41% PDO only crashes reduction: 41% Implementation cost: 24,154 €/junction Annual cost: 1,685 €/junction	3.1

REFERENCES

1. Elvik, R., Hoye, A.; Vaa, T., Sorensen, M. (2009). The handbook of road safety measures. 2nd Edition. Emerald, Bingley, UK
2. Høye, A., Elvik, R., (2016). The handbook of road safety measures, Norwegian (online) version.
3. Jensen, S. U., & ApS, T. (2009). Safety Effects of Intersection Signalization: a Before-After Study. Trafitec, Denmark.

In Appendix:

1. Agent, K. R., & Green, E. R. (2008). Crash History After Installation of Traffic Signals (Warranted vs. Unwarranted).

CBA: Traffic signal installation on highways

ABSTRACT

The previous analysis is complemented by an additional scenario of traffic signal installation for highways; this amounts to different implementation and annual costs. The original Handbook (Elvik, 2009) mentions average implementation cost for traffic signal installation at 1,100,000 NOK and annual maintenance costs at 50,000 NOK per national highway junction. In both cases, they are converted for inflation by applying the inflation conversion value of 1.445 (they are 1995 prices) and to Euros (EU-28 average) by multiplying with the PPP conversion value of 0.078. For highway analysis, crash numbers per year were obtained from Agent and Green (2008) for 4-legged intersections of the USA.

The resulting best estimate of the benefit-to-cost ratio (BCR) is 3.7. The BCR is sensitive to changes in the underlying assumptions as it is shown by the sensitivity analysis.

RESULTS

Table 1 provides the input values and the result estimated benefit-to-cost ratio for DSL. It shows a B/C ratio of 3.7. This means that the benefits considerably exceed the costs for highways.

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

Scenario	Input values	B/C ratio
Best estimate	Casualty crashes (slight/serious/fatal) reduction: 29% PDO only crashes reduction: 29% Implementation cost: 123,580 €/junction Annual cost: 5,617 €/junction Affected nr. of crashes per year: Casualties (slight/serious/fatal): 1.16/junction PDO: 2.17/junction	3.7

SENSITIVITY ANALYSIS

We used the upper and lower limits of the 95% confidence intervals of the estimates in Høye and Elvik, (2016) to run a sensitivity analysis. The values represent a considerably lower/higher than expected effect, respectively. Subsequently the effect is calculated for cases in which the measure costs are lower of or higher than estimated. Table 2 presents the results.

Table 2: Sensitivity analyses

Scenario	Input values	B/C ratio
Low measure effect	Fatal injury crashes reduction: 14% Injury (Serious/Slight) crashes reduction: 14% PDO only crashes reduction: 14%	1.8
High measure effect	Fatal injury crashes reduction: 41% Injury (Serious/Slight) crashes reduction: 41% PDO only crashes reduction: 41%	5.2
Low measure cost (-50%)	Implementation cost: 61,790 €/junction Annual cost: 2,809 €/junction	7.4
High measure cost (+100%)	Implementation cost: 247,160 €/junction Annual cost: 11,235 €/junction	1.9

We define a 'worst case' scenario as a combination of a much worse than expected effect (i.e. the lower limit of the 95% CI) and a higher than expected measure cost (i.e. the estimated cost +100%).

Also an 'ideal case' scenario is defined which is a combination of a much better than expected effect (upper limit of the 95% CI) and a lower than expected measure cost (estimated cost -50%). The results of the CBA for these scenarios are reflected in Table 3.

Table 3: CBA for worst case and ideal case scenarios

Combined Scenario	Input values	B/C ratio
Worst case	Fatal injury crashes reduction: 14% Injury (Serious/Slight) crashes reduction: 14% PDO only crashes reduction: 14% Implementation cost: 247,160 €/junction Annual cost: 11,235 €/junction	0.9
Ideal case	Fatal injury crashes reduction: 41% Injury (Serious/Slight) crashes reduction: 41% PDO only crashes reduction: 41% Implementation cost: 61,790 €/junction Annual cost: 2,809 €/junction	10.5

Annex B: Infrastructure measures costs

Measure (as in taxonomy)	Specification	Unit of impl.	Impl. Costs fix	Impl. Costs Lower Limit	Impl. Costs Upper Limit	Annual maintenance / operation cost	Currency	Country	Year	Source
Access Control	-	1 site	1,000,000	-	-		EUR	Italy	2005	Augeri, M. G., Colombrita, R., Certo, A. L., Greco, S., & Matarazzo, B. (2005). Multi-Criteria Analysis to Evaluate Road Safety Measures and Allocate Available Budget. In 3° Convegno Internazionale SIIV (pp. _-_).
Automatic Barriers Installation	-	1 crossing	-	500,000	-		EUR	Germany	2016	Deutsche Bahn (2016). Bahnübergänge: Wo Straße und Schiene sich kreuzen.
Automatic Barriers Installation	Upgrade of semi-barrier	1 crossing	350,000	-	-		EUR	Germany	2016	Deutsche Bahn (2016). Bahnübergänge: Wo Straße und Schiene sich kreuzen.
Automatic Barriers Installation	-	1 crossing	-	200,000	300,000		AUD	Australia	2003	Cairney (2003). Prospects for improving the conspicuity of trains at passive railway crossings. ARRB Transport Research Ltd.
Automatic Barriers Installation	Four-Quad Gates	1 crossing	-	125,000	350,000		USD	USA	2001	Cooper, D. L., & Ragland, D. R. (2007). Driver behavior at rail crossings: cost-effective improvements to increase driver safety at public at-grade rail-highway crossings in California. Safe Transportation Research & Education Center.
Automatic Barriers Installation	Signals, Gates and Bells in general	1 crossing	-	80,000	300,000		USD	USA	1998	Fambro et al. (1998). Highway Rail Grade Crossings. Texas Transportation Institute.
Automatic Barriers Installation	-	1 crossing	-	100,000	200,000		USD	USA	1999	Hull, S. J. (1999). Selecting Railroad Crossing Safety Projects using Predicted Accident Rates and Benefit Cost Analysis. Indiana Department of Transportation.
Automatic Barriers Installation	Two gates with light	1 crossing	150,000	-	-		USD	USA	2007	Ogden, B. D. (2007). Railroad-Highway Grade Crossing handbook-Revised Second Edition 2007 (No. FHWA-SA-07-010).
Automatic Barriers Installation	Four-quadrant gates	1 crossing	-	1,250,000	250,000		USD	USA	2007	Ogden, B. D. (2007). Railroad-Highway Grade Crossing handbook-Revised Second Edition 2007 (No. FHWA-SA-07-010).
Automatic Barriers Installation	Flashing lights and gates	1 crossing	223,564	-	-		USD	USA	2014	Rezvani, A. Z., Peach, M., Thomas, A., Cruz, R., & Kemmsies, W. (2015). Benefit-Cost methodology for highway-railway grade crossing safety protocols as applied to transportation infrastructure project prioritization processes. Transportation Research Procedia, 8, 89-102.
Channelisation	-	1 site	150,000	-	-		EUR	Italy	2005	Augeri, M. G., Colombrita, R., Certo, A. L., Greco, S., & Matarazzo, B. (2005). Multi-Criteria Analysis to Evaluate Road Safety Measures and Allocate Available Budget. In 3° Convegno Internazionale SIIV (pp. _-_).
Channelisation	Installation of traffic islands on the main road		-	25,000	1,650,000		EUR	Norway	2004	Elvik et al. (2004) as cited in Yannis, G., Papadimitriou, E., & Evgenikos, P. (2011, June). Effectiveness of road safety measures at junctions. In Proceedings of the 1st International Conference on Access Management, Athens.

Measure (as in taxonomy)	Specification	Unit of impl.	Impl. Costs fix	Impl. Costs Lower Limit	Impl. Costs Upper Limit	Annual maintenance / operation cost	Currency	Country	Year	Source
Channelisation	Left-turn lane at T-junction	1 junction	65,000	-	-		EUR	Norway	2004	Elvik et al. (2004) as cited in CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Channelisation	Left-turn lane at crossroad	1 junction	100,000	-	-		EUR	Norway	2004	Elvik et al. (2004) as cited in CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Channelisation	Full channelisation at crossroad	1 junction	1,300,000	-	-		EUR	Norway	2004	Elvik et al. (2004) as cited in CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Channelisation	Full channelisation at crossroad	1 junction	1,650,000	-	-		EUR	Norway	2004	Elvik et al. (2004) as cited in CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Convert 4-leg junction to staggered junction	-	1 junction	-	130,000	1,300,000		EUR	Norway	2004	Elvik et al. (2004) as cited in Yannis, G., Papadimitriou, E., & Evgenikos, P. (2011, June). Effectiveness of road safety measures at junctions. In Proceedings of the 1st International Conference on Access Management, Athens.
Convert Junction to Roundabout	-	1 junction	400,000	-	-		EUR	Italy	2005	Augeri, M. G., Colombrita, R., Certo, A. L., Greco, S., & Matarazzo, B. (2005). Multi-Criteria Analysis to Evaluate Road Safety Measures and Allocate Available Budget. In 3° Convegno Internazionale SIIV (pp. _-_).
Convert Junction to Roundabout	-	1 junction		-	-		BRL	Brazil	2008	Bezerra, B., Romao, M., & Ferraz, A. (2010, July). Benefit-cost analysis of roundabouts in a Brazilian city regarding to the number and severity of traffic accidents–a case study. In 12 th World Conference on Transport Research Society. Portugal.
Convert Junction to Roundabout	-	1 junction	-	650,000	1,300,000		EUR	Various	2008	CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Convert Junction to Roundabout	T-arm to roundabout	1 junction	650,000	-	-		EUR	Various	2008	CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Convert Junction to Roundabout	Crossroad to roundabout	1 junction	450,000	-	-		EUR	Various	2008	CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Convert Junction to Roundabout	Mini roundabout	1 junction	12,000	-	-		EUR	Ireland	2007	CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Convert Junction to Roundabout	Crossroad to roundabout	1 junction	141,630	-	-		USD	USA	2013	Corliss, D., & Kang, M. W. Roundabout Feasibility for Improving a University Campus Intersection, Using Microscopic Traffic Simulation Approaches.

Measure (as in taxonomy)	Specification	Unit of impl.	Impl. Costs fix	Impl. Costs Lower Limit	Impl. Costs Upper Limit	Annual maintenance / operation cost	Currency	Country	Year	Source
Convert Junction to Roundabout	Crossroad to roundabout	1 junction	225,000	-	-		USD	USA	2003	Lenters, M. (2003). Roundabout Planning and Design for Efficiency & Safety Case Study: Wilson Street/Meadowbrook Drive/Hamilton Drive--City of Hamilton. In The Transportation Factor 2003. Annual Conference and Exhibition of the Transportation Association of Canada.(Congres et Exposition Annuels de l'Association des transport du Canada).
Convert Junction to Roundabout	T-arm to roundabout	1 junction	1,250,000	-	-		NOK	Norway	2001	SWOV (2001). Cost-benefit analysis of measures for vulnerable road users. Promotion of Measures for Vulnerable Road Users Contract No. RO-97-RS.2112
Convert Junction to Roundabout	Crossroad to roundabout	1 junction	1,500,000	-	-		NOK	Norway	2001	SWOV (2001). Cost-benefit analysis of measures for vulnerable road users. Promotion of Measures for Vulnerable Road Users Contract No. RO-97-RS.2112
Convert Junction to Roundabout	Mini roundabout	1 junction	47,735	-	-		USD	USA	2001	Waddell, E., & Albertson, J. (2005, May). The Dimondale Mini: America's First Mini-Roundabout. In National Roundabout Conference.
Convert Junction to Roundabout	Mini roundabout	1 junction	12,000	-	-		EUR	Various	2011	Yannis, G., Papadimitriou, E., & Evgenikos, P. (2011, June). Effectiveness of road safety measures at junctions. In Proceedings of the 1st International Conference on Access Management, Athens.
Convert Junction to Roundabout	-	1 junction	-	450,000	1,300,000		EUR	Ireland	2007	Yannis, G., Papadimitriou, E., & Evgenikos, P. (2011, June). Effectiveness of road safety measures at junctions. In Proceedings of the 1st International Conference on Access Management, Athens.
convert junction to roundabout	-	1 junction	350,000	-	-	1,000	USD	USA	2005	Zetland, D. (2008) Roundabouts in Davis. A comprehensive policy analysis.
Convert Junction to Roundabout	Crossroad to roundabout (at 2002 prices)	1 junction	300,000	-	-		EUR	Czech Republic	2002	Pokorný, P. (2011). Cost-Benefit Analysis for the Implementation of Four-arm Roundabouts in Urban Areas. Transactions on Transport Sciences, 4(1), 25.
Rail-Road Crossing Traffic Sign	STOP signs at passive crossings	1 crossing	-	1,200	2,000		USD	USA	2007	Ogden, B. D. (2007). Railroad-Highway Grade Crossing handbook-Revised Second Edition 2007 (No. FHWA-SA-07-010).
STOP / YIELD signs installation	-	1 junction	-	240	280		USD	USA	2010	Preston, H., & Barry, M. (2010). Minnesota's Best Practices for Traffic Sign Maintenance/Management Handbook, Including Insight on How to Remove Unnecessary and Ineffective Signage (No. Report No. 2010RIC10, Version 1.1).
STOP / YIELD signs installation	2 STOP signs (1990)	1 junction	280	-	-		USD	USA	1990	Bretherton Jr, W. M. (1999). Multi-way stops – The research shows the MUTCD is correct! In Transportation Frontiers for the Next Millennium: 69th Annual Meeting of the Institute of Transportation Engineers (No. Publication No. CD-006).

Measure (as in taxonomy)	Specification	Unit of impl.	Impl. Costs fix	Impl. Costs Lower Limit	Impl. Costs Upper Limit	Annual maintenance / operation cost	Currency	Country	Year	Source
STOP / YIELD signs installation	Conversion from two-way to all-way stop control	1 junction	5,000	-	-		USD	USA	2010	Simpson, C. L., & Hummer, J. E. (2010). Evaluation of the conversion from two-way stop sign control to all-way stop sign control at 53 Locations in North Carolina. Journal of Transportation Safety & Security, 2(3), 239-260.
Cycle path treatments	Bike lane	1 km	1,000,000				NOK	Norway	2007	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Cycle path treatments	Bike track	1 km	8,000,000			38,000	NOK	Norway	2007	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Upgrade road to motorway	Building motorway	1 km	101,400,000				NOK	Norway	2007	Ulstein, H., Syrstad, R. S., Seeberg, A. R., Gulbrandsen, M. U., & Welde, M. (2017). Evaluering av E6 Østfold. Delprosjektene Åsgård–Halmstad og Svingenskogen–Åsgård, samt samlet Utbygging.
Creation of by-pass road	Building bypass roads	1 km	20,000				NOK	Norway	1996	
	Building urban arterial roads	1 km	288,000,000				NOK	Norway	1993	Elvik, R. (1996). Enhetskostnader for veg- og trafikktekniske tiltak. Arbeidsdokument TST/0722/96. Oslo, Transportøkonomisk institutt.
Channelisation	Left turn lane, three leg junction	1 junction	500,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Channelisation	Minor road channelization, three leg junction	1 junction	200,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Channelisation	Full channelization, three leg junction	1 junction	1,200,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Channelisation	Left turn lane, four leg junction	1 junction	800,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Channelisation	Minor road channelization, four leg junction	1 junction	400,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Channelisation	Full channelization, four leg junction	1 junction	1,650,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Convert junction to roundabout	Converting three-leg junction to roundabout	1 junction	4,820,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
Convert junction to roundabout	Converting four-leg junction to roundabout	1 junction	3,470,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.

Measure (as in taxonomy)	Specification	Unit of impl.	Impl. Costs fix	Impl. Costs Lower Limit	Impl. Costs Upper Limit	Annual maintenance / operation cost	Currency	Country	Year	Source
	Changing geometric layout of junction	1 junction	6,000,000				NOK	Norway	1996	Elvik, R. (1996). Enhetskostnader for veg- og trafikktekniske tiltak. Arbeidsdokument TST/0722/96. Oslo, Transportøkonomisk institutt.
Convert at-grade junction to interchange	Building interchange (grade-separated)		40,000,000				NOK	Norway	1996	Elvik, R. (1996). Enhetskostnader for veg- og trafikktekniske tiltak. Arbeidsdokument TST/0722/96. Oslo, Transportøkonomisk institutt.
High risk sites identification	Black spot treatment	1 junction	200,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
	Improving cross section of rural roads	1 km	4,700,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
Create clear-zone / remove obstacles	Roadside safety treatments	1 km	255,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
	General upgrading of rural roads	1 km	4,700,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
Safety barriers installation	Guardrail alongside of road	1 km	600,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
Installation of median	Median guardrail	1 km	860,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
	Erecting fence to keep animals away from road	1 km	275,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
	Building animal crossing site with road lights	1 site	100,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Removal of sight obstructions	Sight clearance for earlier detection of animals	1 km	40,000				NOK	Norway	2005	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Increase horizontal curve radius (curve re-alignment)	Treatment of hazardous curves	1 curve	38,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
Installation of road lighting	New road lighting, ordinary roads	1 km	450,000			25,000	NOK	Norway	2009	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Installation of road lighting	New road lighting, motorways	1 km	1,250,000			100,000	SEK	Sweden	2009	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
2+1 roads	2+1 roads	1 km	2,300,000			90,000	SEK	Sweden	2009	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.

Measure (as in taxonomy)	Specification	Unit of impl.	Impl. Costs fix	Impl. Costs Lower Limit	Impl. Costs Upper Limit	Annual maintenance / operation cost	Currency	Country	Year	Source
Traffic calming schemes	Urban traffic calming (typical size of area)	1 area	2,000,000			100,000	NOK	Norway	1996	Elvik, R. (1996). Enhetskostnader for veg- og trafikktekniske tiltak. Arbeidsdokument TST/0722/96. Oslo, Transportøkonomisk institutt.
	Environmental streets	1 km	19,000,000				NOK	Norway	2000	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Woonerfs implementation	Converting a street to pedestrian street	1 km	4,000,000				NOK	Norway	1996	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
	Establishing priority roads	1 km	40,000				NOK	Norway	2017	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
STOP / YIELD signs installation	Stop or yield signs in junctions	1 junction	10,000				NOK	Norway	2017	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Road markings implementation	Road markings for stop or yield	1 junction	3,000				NOK	Norway	2004	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Traffic signals installation	Installing traffic signals, three-leg junction	1 junction	1,112,000			60,123	NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
Traffic signals installation	Installing traffic signals, four-leg junction	1 junction	1,600,000			60,123	NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
	Installing midblock signals at pedestrian crossing	1 crossing	340,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
Speed humps	Installing speed hump	1 hump	20,000				NOK	Norway	2011	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Narrowings	Installing narowings (chicanes)	1 chicane	40,000				NOK	Norway	2011	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
	Installing raised pedestrian crossing	1 crossing	100,000				NOK	Norway	2011	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
	Building pedestrian bridge or tunnel	1 crossing	4,980,000				NOK	Norway	2000	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Implementation of rumble strips at centerline	Centre or shoulder rumble strips	1 km	40,000				NOK	Norway	2004	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Implementation of edgeline rumble strips	Centre or shoulder rumble strips	1 km	40,000				NOK	Norway	2004	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.

Measure (as in taxonomy)	Specification	Unit of impl.	Impl. Costs fix	Impl. Costs Lower Limit	Impl. Costs Upper Limit	Annual maintenance / operation cost	Currency	Country	Year	Source
Implementation of marked crosswalk	Marking a pedestrian crossing	1 crossing	5,000				NOK	Norway	1995	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
	Installing refuge in pedestrian crossing	1 crossing	10,000				NOK	Norway	1995	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Variable message signs: incident / accident warning	Variable message signs	1 site	150,000				NOK	Norway	2000	Elvik, R., & Rydningen, U. (2002). Effektkatalog for trafikksikkerhetstiltak. TØI rapport, 572.
Automatic barriers installation	Automatic gates at railroad-highway grade crossings	1 crossing	800,000			7,500	NOK	Norway	1995	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
Speed cameras	Speed cameras	1 camera	800,000			100,000	NOK	Norway	2014	Høye, A., et al., (2017). The Handbook of Road Safety Measures. Online edition (in Norwegian). Institute of Transport Economics, Oslo.
30-zones implementation	Sustainable safe redesign of zone 30	1 km		20,000	40,000	0	EUR	The Netherlands	2003	Wijnen, W., & Vis, M. A. (2010). Effectiviteit en kosten van verkeersveiligheidsmaatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.
Cycle path treatments	Bike track (separated)	1 km	55,000			550	EUR	The Netherlands	2002	Wijnen, W., & Vis, M. A. (2010). Effectiviteit en kosten van verkeersveiligheidsmaatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.
Implementation of rumble strips at centerline	Installation of overridable median	1 km	2,000			20	EUR	The Netherlands	2000	Wijnen, W., & Vis, M. A. (2010). Effectiviteit en kosten van verkeersveiligheidsmaatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.
Installation of median	Installation of median	1 km	2,500				EUR	The Netherlands	2008	Wijnen, W., & Vis, M. A. (2010). Effectiviteit en kosten van verkeersveiligheidsmaatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.
Shoulder implementation (Shoulder type)	Semi-paved shoulders	1 km	25,000				EUR	The Netherlands	2003	Wijnen, W., & Vis, M. A. (2010). Effectiviteit en kosten van verkeersveiligheidsmaatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.
Create clear-zone / Remove obstacles	Clear zones	1 km	270,000			0	EUR	The Netherlands	2003	Wijnen, W., & Vis, M. A. (2010). Effectiviteit en kosten van verkeersveiligheidsmaatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.
Convert junction to roundabout	Convert junction into a roundabout	1 junction	400,000			-1,200	EUR	Belgium	2000	Delhaye, E. (2003). Kosten-baten analyse van het vervangen van een geregeld kruispunt door een rotonde. Tijdschrift voor economie en management, 47(4), 577-606.

Measure (as in taxonomy)	Specification	Unit of impl.	Impl. Costs fix	Impl. Costs Lower Limit	Impl. Costs Upper Limit	Annual maintenance / operation cost	Currency	Country	Year	Source
Convert junction to roundabout	Convert junction into a double-lane roundabout	1 junction	600,000			-1,200	EUR	The Netherlands	2010	Wijnen, W., & Vis, M. A. (2010). Effectiviteit en kosten van verkeersveiligheidsmaatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.
	Speed tables at intersections	1 junction	15,000				EUR	The Netherlands	2010	Wijnen, W., & Vis, M. A. (2010). Effectiviteit en kosten van verkeersveiligheidsmaatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.
Convert junction to roundabout	Construction of a roundabout	1 junction	587,500				GBP	United Kingdom	2000	Cambridgeshire city Council: Road Safety Plan Annual Review (2000), as cited in ECMT (2001). Economic evaluation of road traffic safety measures: report of the 117th round table on transport economics, Paris, 26-27 Oct 2000.
Traffic signals installation	Traffic signal installation	1 junction	86,956				GBP	United Kingdom	2000	Cambridgeshire city Council: Road Safety Plan Annual Review (2000), as cited in ECMT (2001). Economic evaluation of road traffic safety measures: report of the 117th round table on transport economics, Paris, 26-27 Oct 2000.
Safety barriers installation	Implementation of safety barriers	1 km	127,308				EUR	France	2008	CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Safety barriers installation	Implementation of safety barriers	1 km		185,000	220,000		EUR	The Netherlands	2008	CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Sight distance treatments (horizontal alignment)	Sight triangle improvements	1 junction	6,800				EUR	Sweden	1980	CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
Speed humps	Speed humps	1 site	700				EUR	Italy	2008	CEDR (2008). Best Practice for Cost-Effective Road Safety Infrastructure Investments'. Routes/Roads, (340).
	Pedestrian crossings	1 crossing	12,397				USD	Serbia	2009	iRAP (2009), as cited in Challenge Bibendum (2011). White paper making the business case for road safety investment to achieve sustainable road mobility. Berlin, Michelin, retrieved 2 Aug 2017
Increase shoulder width	Widening shoulders	1 km	18,950				USD	Serbia	2009	iRAP (2009), as cited in Challenge Bibendum (2011). White paper making the business case for road safety investment to achieve sustainable road mobility. Berlin, Michelin, retrieved 2 Aug 2017
traffic calming schemes	Calming traffic	1 km	35,714				USD	Serbia	2009	iRAP (2009), as cited in Challenge Bibendum (2011). White paper making the business case for road safety investment to achieve sustainable road mobility. Berlin, Michelin, retrieved 2 Aug 2017

Measure (as in taxonomy)	Specification	Unit of impl.	Impl. Costs fix	Impl. Costs Lower Limit	Impl. Costs Upper Limit	Annual maintenance / operation cost	Currency	Country	Year	Source
Land use regulations improvement	Regulating side commercial activity	1 km	8,696				USD	Serbia	2009	iRAP (2009), as cited in Challenge Bibendum (2011). White paper making the business case for road safety investment to achieve sustainable road mobility. Berlin, Michelin, retrieved 2 Aug 2017
Create clear-zone / remove obstacles	Removal of road safety hazards	1 km	26,316				USD	Serbia	2009	iRAP (2009), as cited in Challenge Bibendum (2011). White paper making the business case for road safety investment to achieve sustainable road mobility. Berlin, Michelin, retrieved 2 Aug 2017
Section control	Section control system on arterial roads	1 km	73,500				EUR	Belgium	2017	59 ANPR-camera's erbij op invalswegen (In Belgian) Retrieved from: http://www.hln.be/regio/nieuws-uit-mechelen/59-anpr-camera-s-erbij-op-invalswegen-a3222417/
Dynamic (weather-variant) speed limits	Dynamic speed limit system on motorways	1 km	316,000			9,876	EUR	Belgium	2015	De Pauw, E., Daniels, S., Franckx, L., & Mayeres, I. (2017). Safety effects of dynamic speed limits on motorways. Accident Analysis & Prevention.