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## **Deliverable D.6.1 Impact Evaluation Methodology - Project PIONEERS - Protective Innovations of New Equipment for Enhanced Rider Safety**

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## D.6.1 Impact Evaluation Methodology

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## Abstract

The main goal of the PIONEERS project is to improve the safety of Powered-Two-Wheelers by providing an integrated approach to rider protection considering on-rider (Personal Protective Equipment) and on-board systems.

The four main pillars that have been built inside the PIONEERS project regarding the figure of the PTW rider are:

- To achieve a deep understanding of the injuries sustained by the riders
- To increase the performance of safety systems
- To develop better test and assessment methods
- To increase the awareness and the usage rate of PPE.

The implementation of the PIONEERS' main results will contribute to reducing PTW fatalities up to 25% in 2025 and injuries by defining test methods to develop protective systems and on-board systems to reduce impact severity. The development of new testing methods and products will strengthen European leadership in the PTW industry.

In order to assess if this major conclusion of the PIONEERS project is being fulfilled and to quantify the benefit that has been achieved from the completion of the activities specified in the previously-mentioned pillars, an Impact Evaluation methodology has been developed in this document.

By performing an extensive literature review and adapting the achieved results to the scope of the PIONEERS project, a methodology to assess both the Economical and Safety Benefits of the proposed PTW safety countermeasures (that have been developed in PIONEERS) has been elaborated.

The methodology that has been developed to evaluate the economic benefits is based on the outcome of the SafetyCube project (SafetyCube). In the PIONEERS project, measures which will be evaluated concern the reduction of casualties and are the following:

- Motorcycle leg protector
- Scooter leg protector
- Airbag jacket
- PTW-PPE communication system
- PreCrash Braking System

The selected horizon considered in the study is of 10 years.

The evaluation framework of the benefits in terms of road safety (mitigated accidents, reduction of morbidity and severity of injuries) can be decomposed in three parts:

- The evaluation of the benefits due to on-board system which aims to reduce impact speed mainly a Pre-Crash Braking (PCB). This evaluation is based on in-depth accident database from IFSTTAR-LMA and UNIFI In-Safe. One hundred crash kinematics will be first reconstructed. Then new kinematics which include the effect of the PCB are calculated in order to estimate the new impact speed. A parametric study will be carried out to simulate different PCB effects considering various Field Of View (from 10° to 70°), range (from 30m to 90m), PTW deceleration (between -2 m/s<sup>2</sup> and -8m/s<sup>2</sup>), etc.
- The evaluation of the benefits due to passive safety system like new PPE (airbag jacket, etc.) or lateral on-board protection. This work is firstly based on the establishment of the originally risk curves based on current accident database, and secondly on the establishment of the new risk curves after introducing the protective level of the passive safety systems. This work needs input from WP1, WP3, WP4 and WP5 in particular to provide risk curves and the levels of protection of the passive systems. The new injury level could be estimated by considering three approaches: a pessimistic approach which will consider the minimal level of protection offered by the passive safety systems, an optimistic one which will consider the maximal level of protection and a mean approach which will consider the average level of protection.
- The evaluation of the benefits due to both on-board and passive safety systems. This work is based on the methodology already described in the literature by (Roth and Stoll, 2011) or (Lubbe, 2012).

The Impact Evaluation Methodology that is described in this deliverable can be used as main input to task 6.2 of the PIONEERS Project, where the Impact Analysis calculation will be made, and the benefit analysis conclusions will be withdrawn.

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## Abbreviations and Acronyms

Acronym	Definition
ABS	Anti-lock Braking System
AEB	Automatic Emergency Braking
AIS	Abbreviated Injury Scale
CARE	Community database on Accidents on the Roads in Europe
CASR	Centre for Automotive Safety Research
CFS	Car-following scenario
CISAP	Centre for Innovation and Safety of Powered Two Wheelers, University of Florence
CPR	Crash Pulse Recorders
CRS	Crossing Scenario
DCA	Definition for Classifying Accidents
DIANA	Spanish In-depth accident database
DGT	National accident statistics from Spain (Dirección General de Tráfico)
DOE	Design of Experiment
DSS	Decision Support System
EB	Enhanced Braking
EDA	French in-depth accident study by IFSTTAR (Etudes Détaillées d'Accidents)
ESC	Electronic Stability Control
FOV	Field Of View
GDP	Gross Domestic Product
GIDAS	German In-Depth Accident Study
HGV	Heavy Goods Vehicle
ICD	International Classification of Disease
ICECI	WHO International Classification for External Causes of Injuries
IGLAD	Initiative for the global harmonization of accident data
InDev	In-depth Understanding of Accident Causation for Vulnerable Road Users

InSAFE	In-depth Study of accidents in Florence (University of Florence)
ISS	Injury Severity Score
KSI	Killed and seriously injured
LKA	Lane Keeping Assist
MAEB	Motorcycle Autonomous Emergency Braking
MAIDS	Motorcycle Accidents In Depth Study
MAIS	Maximum Abbreviated Injury Scale
MICIMS	Monash University Accident Research Centre
NHTSA	National Highway Traffic Safety Administration (USA)
NeuRA	Neuroscience Research Australia
OECD/OCDE	Organisation for Economic Co-operation and Development (OECD; French: Organisation de coopération et de développement économiques, OCDE)
PCB	Pre-Crash Braking
PISa	Powered Two Wheeler Integrated Safety
PPE	Personal Protective Equipment
PTW	Powered Two-Wheeler
RAIDS	Road accident in-depth accident studies, Department for Transport, UK
SafetyCube	Safety CaUsation, Benefits and Efficiency
SENIORS	Safety ENhanced Innovations for Older Road userS
STRADA	Swedish Traffic Accident Data Acquisition
VSL	Valuation of a Statistical Life



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# 1 Introduction

Protective Innovations of New Equipment for Enhanced Rider Safety (PIONEERS) is a Horizon 2020 project that aims to reduce the number of Powered-Two-Wheeler fatalities and severely injured by increasing the safety, performance, comfort and usage rate of Personal Protective Equipment and the development of new on-board safety devices.

One of the objectives of this project is to assess the safety and economic benefits of the new safety systems and the new testing methods developed throughout the course of this work. In order to obtain this information the PIONEERS Project has decided to perform a literature review to draw up which benefits can be assessed and how they can be calculated. In addition, the methodology from an economical point of view will be based on the cost of injuries resulting from motorcycle crashes.

Furthermore, since the introduction of new safety systems may affect the PTW road accident fatalities data, a methodology to evaluate the safety benefits in terms of injury criteria will be done throughout this work. In this case, both active and passive safety systems will be analysed considering several accident scenarios according to the work done in the Work Package 1 of the PIONEERS project.

## 2 Economic Evaluation Methodology

The main goal of this task is to develop a methodology for the evaluation framework of the benefits that can be achieved by implementing the project results in terms of safety (avoided or mitigated accidents, reduction of morbidity and severity of injuries) and from an economic point of view.

### 2.1 Literature Review

A literature review was carried out in order to know the state of the art and develop a methodology for the economic benefit assessment that could be applied for powered to wheelers.

On one hand, the National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of transportation published a report reviewing “The Economic and Societal Impact of Motor Vehicle Crashes, 2010 (Revised)” (NHTSA). This document specifies that, in 2010 the total economic cost of motor vehicle crashes in the United States was of \$242 billion, which is equivalent to approximately \$784 for every person living in the United States and 1.6 percent of the U.S. Gross Domestic Product. These values account for the lifetime economic costs for 32.999 fatalities, 3.9 million non-fatal injuries and 24 million damaged vehicles. If, additionally, quality-of-life valuations regarding motor vehicle crashes are also considered, the total value of societal harm from crashes in the U.S. in 2010 rises to \$836 billion.

This first cost-estimation highlights the need to include an economic evaluation of the safety benefits introduced by the implementation of injury prevention countermeasures due to vehicle crashes.

Also, in the same report, the NHTSA states that in 2010 motorcycle crashes cost \$12.9 billion in economic impacts and \$66 billion in societal harm in the United States. As a general conclusion, the report states (about motorcycle crashes) that: “Compared to other motor vehicle crashes, these costs are disproportionately caused by fatalities and serious injuries”.

As motorcycles are the most hazardous form of motor transportation (due to the lack of protection provided by vehicle structure, lack of internal protection by restraint systems, high speeds, etc.) the safety and economic benefit of implementing safety measures on Powered-Two-Wheelers is extremely high.

An example of this is shown on the previously-mentioned report by NHTSA, where it is stated that the estimated economic savings attributed to Motorcycle Helmet Use in the U.S. from 1975 to 2010 is of over \$60 billion and are currently still saving approximately \$2.7 billion in economic costs annually.

As mentioned in “Deliverable 4.3 - Benefit Analysis” of the European Commission H2020 project (SENIORS) Safety ENhanced Innovations for Older Road userS and the method used by (Wallbank, 2016), economic benefit of casualty reductions can be estimated by means of the valuation of a statistical life (VSL). The VSL methods are based on willingness to pay to avoid injury and are related to the Gross Domestic Product (GDP) of the country under consideration. These costs per country are referred to as crash and casualty costs in the following sections when referring to the Economic Safety Benefit Methodology to be used in the PIONEERS project.

Another methodology to do an economic evaluation of the safety benefits of a countermeasure is by using the cost-of-illness method. This method would include the costs for labor loss, funeral, property damage, transport delays, medical expenses and administrative costs. Although this method is a perfectly good alternative for the evaluation of the economic safety benefit, it does imply gathering information that is more difficult to find on a country-by-country basis. Also, as the resulting cost is not based in the GDP per capita, it is not possible to easily keep the results updated or compare them between countries.

Because of this, and due to the fact that (Bhalla D, 2013) states that the VSL method is preferred by economists, this will be the method to be used in the Economic Safety Benefit Methodology explained below.

The main principle to calculate the socio-economic cost is to convert injuries into cost using a monetary measure of human and material crash harm. The monetary values used for valuing the different types of injury are often estimated by applying a simple percentage of the Statistical Value of Life (Carnis, 2018). It can be based, like in the SafetyCube project (see below), on the estimation of the cost of DALY/QALY, years of life lost and years with a disability, calculated according to a hierarchical typology of injuries. In (Zaloshnja E, 2004), the unit costs per injury are reported by body part in order to allow a more accurate estimation of the social costs of motor vehicle crashes. The cost take into account parameters like the medically related costs, the police and fire (emergency) services, the property damage, the lost wage-work and the lost household work, legal costs, insurance administration costs, and the value of lost quality of life.

Other works can take into account other parameters like age, gender, the socio-professional category or an accurate decomposition of the time spent in work, leisure or other activities (H., 1983), (S.L, 1974), (Thedie J., 1958).

## 2.2 Evaluation Methodology

The methodology that has been developed to evaluate the economic benefits in terms of safety is based on the outcome of the SafetyCube project (SafetyCube).

### 2.2.1 SafetyCube Project

Safety CaUsation, Benefits and Efficiency (SafetyCube hereinafter) was a European Commission supported Horizon 2020 project aimed at supporting policy-makers and stakeholders in their decision-making regarding the selection of safety measures to be implemented. This was done by developing an innovative road safety Decision Support System (DSS). This tool makes it possible to generate the required information to select the most economically efficient (from a safety stand-point) approaches to consider when studying measures to reduce casualties and/or prevent crashes.

The SafetyCube DSS includes an Economic Efficiency Analysis calculator known as SafetyCube DSS E<sub>3</sub> calculator. The E<sub>3</sub> calculator takes input from the user, regarding the implementation of safety measures, and input generated in the SafetyCube project, regarding safety costs per country in the European Union, to generate an economic evaluation of the implementation of each studied measure. This can be generated either for each EU country or as a mean for the entire European Union.

A table chart showing the SafetyCube input and outputs may be found below:

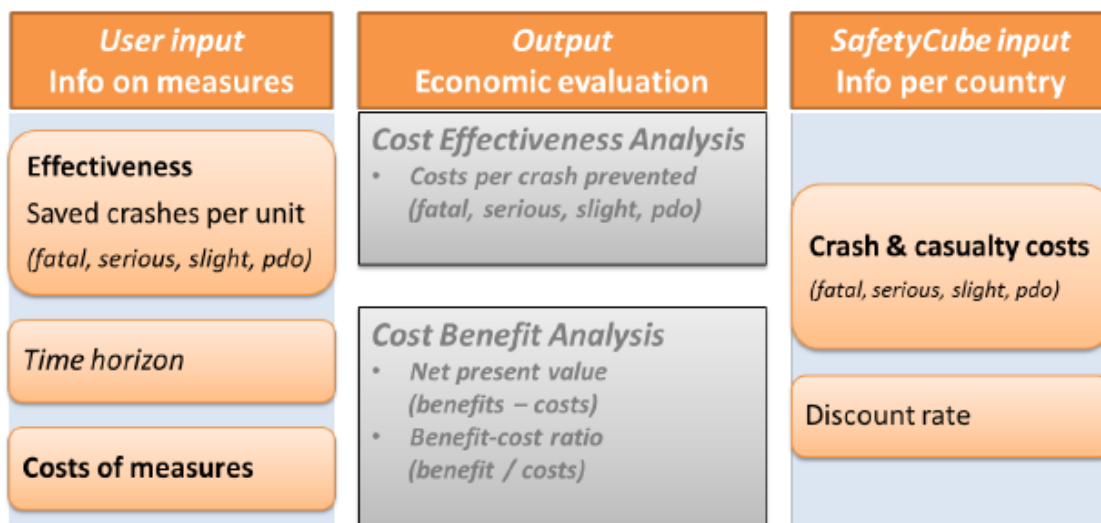


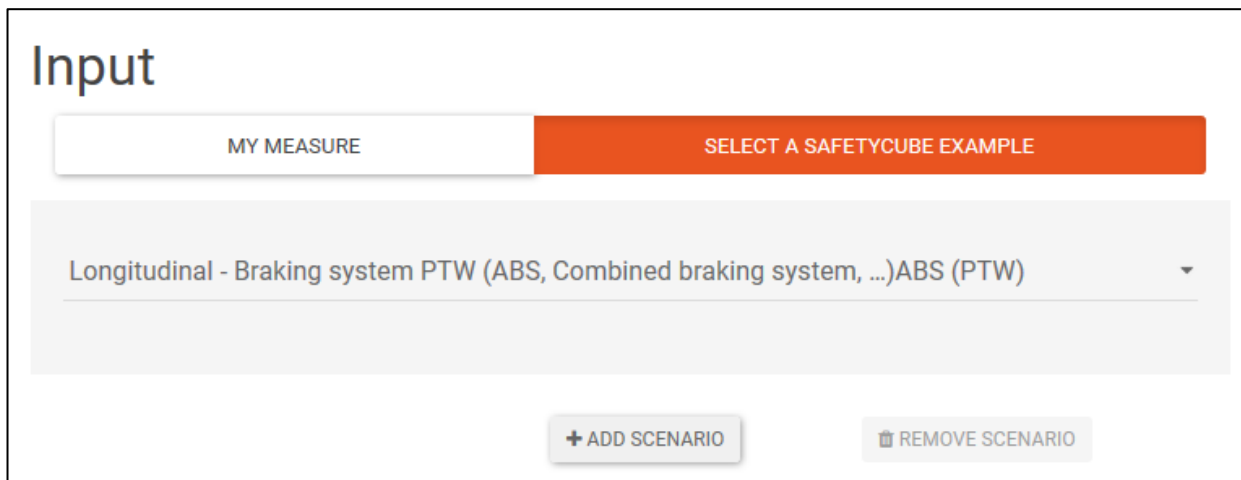
Figure 1: Table of SafetyCube DSS E<sub>3</sub> calculator input and outputs

The input and output of the SafetyCube DSS E<sub>3</sub> calculator will be explained in detail in the following sections.

## 2.2.2 Economic Calculation Inputs

In order to start the calculation of the Economic Safety Benefit of the new safety measures that have been developed in the PIONEERS project, it is necessary to access the SafetyCube (DSS). This tool makes it possible to both look into existing examples of safety benefit analysis that have been developed in the SafetyCube project or evaluate a different measure, using the tool for further research purposes.

For illustration purposes of this section, the following measure has been selected from the SafetyCube Example List: “Longitudinal – Braking system PTW (ABS, Combined braking systems, ...) ABS (PTW)”



The screenshot shows the 'Input' section of the SafetyCube DSS Calculator. At the top, there are two buttons: 'MY MEASURE' and 'SELECT A SAFETYCUBE EXAMPLE'. Below these is a dropdown menu with the selected example: 'Longitudinal - Braking system PTW (ABS, Combined braking system, ...)ABS (PTW)'. At the bottom, there are two buttons: '+ ADD SCENARIO' and 'REMOVE SCENARIO'.

Figure 2: Extract from SafetyCube DSS Calculator. Selection of SafetyCube Example “Longitudinal – Braking system PTW (ABS, Combined braking systems, ...) ABS (PTW)”

The main inputs that will be required in order to use the SafetyCube DSS calculator tool for the Economic Safety Benefit Calculation are the following:

- Measure to apply
- Country
- Horizon (period of analysis)
- Reduction in terms of casualties or crashes
- Number of units implemented
- Costs
- Safety
- Penetration rate
- Side effects

The data required in order to fill-in each of these inputs is explained in the following pages.

## Input

MY MEASURE
SELECT A SAFETYCUBE EXAMPLE

Longitudinal - Braking system PTW (ABS, Combined braking system, .. ▾

+ ADD SCENARIO
REMOVE SCENARIO

---

Description
1 PTW ABS

Country
EU ▾

### Measure

Horizon (period of analysis)
13

Reduction in terms of casualties or crashes

 Casualties  
 Crashes

Number of units implemented
33000000

### Costs

Cost Breakdown Per Unit

Total Costs Per Unit

Implementation costs per unit
400

Annually recurrent costs per unit
0

Figure 3: Extract from SafetyCube DSS Calculator. Selection of SafetyCube Example “Longitudinal – Braking system PTW (ABS, Combined braking systems, ...) ABS (PTW)”

#### Measure to apply:

First of all, a title and description of the measure to be evaluated must be included. In the case of the PIONEERS project, all the different safety measures that are considered in the project will be evaluated one by one, as the SafetyCube tool is not considered to evaluate several measures at the same time.

These measures are, namely:

- Motorcycle leg protector
- Scooter leg protector
- Airbag jacket
- PTW-PPE communication system
- PreCrash Braking System

#### Country:

Select the country to be assessed for the study. The tool also makes it possible to select the European Union as a whole. In the cost-benefit analysis to be performed in the PIONEERS project, the country of the study can either be selected to be the European Union as a whole or any of the main countries for which accidentology data is available.

#### Horizon (period of analysis):

The horizon of the measure is the life-time of the analyze countermeasure in years. The minimal life-time allowed by the DSS calculator is 1 year.

It has been decided that, for the methodology to be implemented in the PIONEERS Economic Safety benefit evaluation, the same horizon will be used for all the studied measures. This procedure makes it easier to do a back-to-back economic benefit comparison between measures.

The selected horizon to be included in the study is of 10 years. This has been decided because it is a reasonable amount of time to consider a new measure to be developed and incorporated into new European regulation. Furthermore, the choice of 10 years is also consistent with Deliverable 1.3. of this project, where a Future trends analysis is carried out for a duration of 10 years.

#### Reduction in terms of casualties or crashes:

In this section, the type of reduction to be considered must be included. The two available options are the reduction in casualties and the reductions in crashes.

The pre-crash activation measures that are included in this project are considered to have passive safety objectives as they are triggered once the collision is known to be unavoidable. Therefore, they have been developed to reduce the risk of injury during the crash and not to try to avoid the collision.

For this reason, all studied measures in this analysis will be evaluated against the reduction of casualties, as they all aim exclusively at improving injury prevention.

#### Number of units implemented:

To define the number of implemented units, a unit of implementation must be defined. In the case of the PIONEERS project, the unit of implementation will be motorcycles.

Taking this into account, the number of units implemented will be the motorcycle fleet-size of the country to be studied. Therefore, when imputing the data of the target crashes in the country, the data corresponding to this same country's fleet-size shall be used as input of the SafetyCube DSS Calculator.

For example, if the target crashes in Spain are used to generate the cost-benefit analysis study, the number of units implemented shall correspond to the motorcycle fleet-size in Spain.

#### Costs of the countermeasure

Typically, the costs associated to a countermeasure are split between the initial implementation costs and the annually recurrent costs. The SafetyCube DSS Calculator makes it possible to either input the cost of the countermeasure as a total cost, in case that there are no yearly recurring costs, or they are not known by the researcher.

If a limited amount of data is available, the calculator offers the possibility to input these amounts according to data from a different country to that of the analysis. On the other hand, if this data is not known and left blank in the calculator, the cost-benefit analysis will result in the maximal cost for a generic measure to be economically efficient.

#### Safety Benefits

In this section, the user must choose if the safety benefits of the studied measure shall either be expressed as a reduction of affected crashes or prevented crashes per year or as a total value.

Once this option has been selected, data from accident statistics must be included. The tool asks for the number of target fatalities/ fatal crashes, serious injuries / serious injury crashes and slight injuries / slight injury crashes. Then, the percentage of reduction in each group (fatalities, serious injuries and slight injuries) must be added for the studied countermeasure.



### Definition of Crashes Affected or Crashes Prevented

- Express safety effect as percentage reduction and number of target crashes/casualties per year
- Express safety effect as number of prevented crashes/casualties (total over all years)

#### Number of target crashes/casualties per year

Fatalities / fatal crashes	4223.31
Serious injuries / serious injury crashes	52804.7
Slight injuries / slight injury crashes	83827.1
PDO	PDO
Affected Casualties Slight Serious	Affected Casualties Slight Serious
Affected Casualties Slight Serious Fatal	Affected Casualties Slight Serious Fatal

#### Effectiveness (percentage reduction in target group)

Fatalities / fatal crashes	0.32
Serious injuries / serious injury crashes	0.29
Slight injuries / slight injury crashes	0.18
PDO	PDO
Effectiveness Casualties Slight Serious	Effectiveness Casualties Slight Serious
Effectiveness Casualties Slight Serious Fatal	Effectiveness Casualties Slight Serious Fatal

Figure 4: Extract from Safety Benefit Section of the SafetyCube DSS Calculator.  
SafetyCube Example “Longitudinal – Braking system PTW...”

Penetration rate:

The penetration rate shall only be filled-in if the studied measure can be directed at encouraging the use of another measure. In this case, these parameters may be left empty.

Side effects:

If the indirect costs (positive or negative) of the studied measure are known, they shall be added in this section as total (sum of all indirect costs). The value shall be negative if it is a cost and positive if it is a benefit.

### 2.2.3 Other Implicit SafetyCube Inputs

As mentioned in section 2.2.1, the SafetyCube DSS E<sub>3</sub> calculator uses additional input to the one to be indicated by the user. The SafetyCube Project provided the tool with implicit input, based on safety-related cost parameters in all countries of the European Union. This input is mainly based on the following three categories: Crash costs, discount rate and calculations.

Crash costs:

The SafetyCube project, together with the InDev (In-depth Understanding of Accident Causation for Vulnerable Road Users; also funded by the European Commission – H2020) collected the crash costs for all European countries. This data is extremely relevant as, when crashes are very costly, the benefits of reducing casualties or preventing crashes have a high possibility of exceeding the costs of implementation; and vice versa.

Discount rate:

The input named as discount rate represents the depreciation of the value of a cost or benefit over the passing of time. As an example, 1000 EUR today are for sure going to be less valuable in 5 years than they are now. SafetyCube incorporates the discount rate for all countries in which this data was available. For the remaining EU countries, a modal value of 2.5% is considered.

Calculations:

Additional calculations are done by the SafetyCube DSS E<sub>3</sub> calculator to account for the amount of saved crashes from previous years over the duration of the horizon.

Also, note that the data from one EU country can be extrapolated into the analysis done in another country or to the mean for the EU, accounting for financial differences between countries, inflation rates over the years, etc.

## 2.2.4 SafetyCube Outputs

The output of the cost-benefit analysis provided by the SafetyCube DSS calculator for the previously mentioned SafetyCube example regarding AEB for Power-Two-Wheelers may be seen in Figure 5.

Firstly, the costs for implementing the studied countermeasure are listed. These are shown by starting with the initial cost for implementing the measure, followed by the sum of the recurrent costs during the entire duration of the horizon. Next, these two values are added resulting in the total direct costs associated to the implementation of the measure. Finally, the indirect costs (only if included as input to the tool, not automatically generated) are listed and added to the overall direct costs, resulting in the total costs of measure implementation according to this analysis.

The value corresponding to the financial benefits (103470609759.15 EUR in this example) is the total of the addition of all the costs that are attributed to the casualty prevention over the duration of the horizon (13 years in the example shown in the following figure).

Next, the socio-economic return is given. This amount gives the result of the actual cost-benefit analysis. In this case the value is positive, which comes to show that the costs for this measure are lower than the economical safety benefit. This can also be seen in the fact that the benefit-cost ratio is bigger than one (7.84 in this case). In this example, as no side-effects were included in this example, the values including the side-effects are the same as those excluding side-effects, as none had been entered.

Finally, the break-even costs are given. SafetyCube DSS calculates the maximum cost that the countermeasure could have in order for its implementation to be economically efficient.

<b>Cost-Benefit Analysis</b>	
<b>Longitudinal - Braking system PTW (ABS, Combined braking system, ...)ABS (PTW)</b>	
1 PTW ABS	
<b>Costs (present values)</b>	
	<b>Scenario 1</b>
One-time investment costs	13200000000 EUR
Recurrent costs	0 EUR
Total costs excluding side-effects	13200000000 EUR
Side-effects	0 EUR
Total costs including side-effects	13200000000 EUR
<b>Benefits</b>	
Prevented Crashes / Casualties	103470609759.15 EUR
<b>Socio-economic return excluding side-effects</b>	
Net present value	90270609759.15 EUR
Benefit-Cost Ratio	7.84
<b>Socio-economic return including side-effects</b>	
Net present value	90270609759.15 EUR
Benefit-Cost Ratio	7.84
Break-even cost for measure (per unit)	3135.47 EUR

Figure 5: Extract from Cost-Benefit Analysis Output from the SafetyCube DSS Calculator. SafetyCube Example “Longitudinal – Braking system PTW...”

## 3 Safety Benefits Methodology

The main goal of this part is to develop a methodology for the evaluation framework of the benefits that can be achieved by implementing the project results in terms of road safety: avoided or mitigated accidents, reduction of morbidity and severity of injuries. The benefits evaluation can be decomposed in three parts:

- The evaluation of the benefits due to on-board system which aims to reduce impact speed mainly a Pre-Crash Braking (PCB)
- The evaluation of the benefits due to passive safety system like new PPE (airbag jacket, etc.) or lateral on-board protection.
- The evaluation of the benefits due to both on-board and passive safety systems.

The literature review either the description of the methodology which is given hereafter will be decomposed following these three parts.

### 3.1 Literature Review

#### 3.1.1 Pre-Crash systems evaluation

In the PIONEERS project, only passive safety systems which aim to reduce injuries are considered and no specific active safety system which aim to avoid the accident. In particular on-board systems are considered in Pioneers like a Pre-Crash Braking in order to reduce the impact speed in case of unavoidable crash. Nevertheless, a PCB has similarities with active safety systems like Autonomous Emergency Braking (AEB). Indeed, AEB aims to avoid or mitigate the accident while the PCB aims to only mitigate it. So it appears interesting to analyze the literature which concern the evaluation of active systems such AEB. The following part concerns mainly the description of previous works dealing with the evaluation of benefits of active safety systems like Automatic Emergency Braking. Since these kinds of systems are developed for cars, trucks and PTW, it will be detailed below studies which concerns one of these vehicle.

#### **Head on collisions between passenger cars and heavy good vehicles (HGV): Injury risk function and benefits of Autonomous Emergency Braking (AEB)**

(Johan Strandroth, 2012)

This paper seeks to correlate risk for moderate and severe injuries (MAIS2+ : Maximum Abbreviated Injury Scale 2+) with reduction of velocity ( $\Delta V$ ) that an AEB could provide.

The purpose of this study is to improve road safety as well as limiting number of injured. There are three ways to do so. It is possible to try and reduce 1) the number of crashes, 2) the injury risk or 3) the change of velocity ( $\Delta V$ ). When infrastructural measures cannot be taken because road environment improvements have already been made, new systems placed in vehicles can be introduced.

Three main systems can be quoted:

- Electronic Stability Control (ESC), helps on low-friction surfaces.
- Lane Keeping Assist (LKA) warns the driver or steers actively when the vehicle is shifting way from its lane.
- Autonomous Emergency Braking (AEB is currently rather used for car-to-pedestrian and rear-to-end collisions on passenger cars than head-on collisions).

Usually, braking is the preferred way during head on collisions in lower speeds and steering is preferred in higher speeds for collision avoidance. Nonetheless, when the crash is unavoidable, braking always ensure mitigation of the accident and reduction of injuries.

Hence this study is focus on AEB for HGV. Literature already exists for car-to-pedestrian collisions, rear-to-rear and frontal collisions for passenger cars but remains very scarce for HGV-to-cars.

The method used in this paper was the following:

- 1- Data on accidents had to be gathered in order to establish risk functions. The later curves were developed based on Swedish Traffic Accident Data Acquisition (STRADA): 70 in depth fatal cases, with enough details to investigate which scenarios were the most suitable for an AEB, 240 000 Crash Pulse Recorders from Folksam database where delta V was known, and GIDAS (German In-Depth Accident Study) database. Risk functions were plotted as the proportion of injured in interval of change of velocity.
- 2- In depth data were analyzed to find the possible closing speed and delta V reduction with AEB with a given functionality.
- 3- The delta V reduction was applied to the risk exposure from the CPR-data (which means shifting the exposure to the left, Fig.1 )
- 4- Then the injury reduction was calculated based on the derived risk curve.
- 5- Finally, the decrement of severe accidents per year in Sweden through national statistic was estimated.

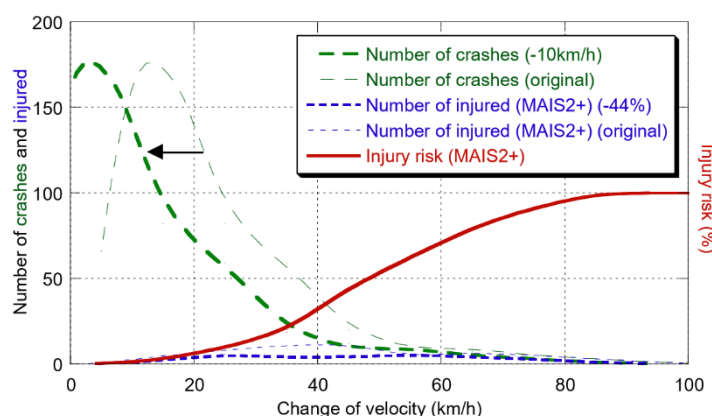


Figure 6: Reduction in injured occupant due to reduced delta V

AEB was relevant in 91% of the cases. Average additional braking time was 0,73s.

Results showed a MAIS2+ reduction of 73% for a speed reduction of 30km/h when both vehicles are equipped with the AEB and a MAIS2+ reduction of 52% for a speed reduction of 18 km/h when just the HGV is equipped.

This would translate to a reduction from 4% to 6% of all MAIS2+ injuries in passenger cars occurring in Sweden per year.

## **Evaluation of an Autonomous Braking System in Real-World PTW Crashes**

(Giovanni Savino, 2012)

PISa, (Powered Two Wheeler Integrated Safety) is a European project that aims to reduce number of injuries and their severity in PTW (Powered Two Wheelers) field by developing an autonomous braking system.

The purpose of this study is to re-assess whether or not the AEB (Autonomous Emergency Braking) system, with the specific characteristics identified in PISa, is effective. A preliminary analysis was carried out at the end of the project when the design and development was done. This new evaluation conducted by CISAP (Centre for Innovation and Safety of Powered Two Wheelers, University of Florence) was based on 58 real PTW crash cases, each of the cases were classified in ACs (Accident Configuration) of which 16% were car-following scenario (CFS), 53% crossing scenario (CRS), 12% were single-vehicle scenarios and 19% other scenarios. These cases represented various types of environment and involved various types of vehicle.

### *AEB features:*

An AEB should slow down the motorcycle to reduce the impact speed when a crash is impending, even if the rider has a very late reaction. To this end, the system must detect every obstacle that could lead to a collision. It works thanks to a laser scanner placed in the front fairing of the motorcycle which can perceive obstacles regardless of the weather. It can detect up to 3° of pitch angle, 8° of roll angle and scan a 100° wide area with 200m radius.

When an emergency braking is triggered –when a collision is unavoidable-, an independent braking system mounted on the right side front disk is activated while the other front disk is under control. However in this investigation, the AEB was able to apply rear braking too, and in addition, an ABS (Anti-lock Braking System) and an EB (Enhanced Braking) were added. EB is activated when the rider applies the brakes and increases the braking force in order to reach the maximum deceleration allowed by the road-tire friction conditions.

The braking is triggered when both the minimum braking distance and the minimum swerving distance are reached (i.e., reaching the condition of inevitable collision) as long as the threshold value of 10° for the roll angle is not exceeded. This value of 10° was determined via multibody simulations of braking maneuver in curves, applying a target deceleration of 4m/s<sup>2</sup>.

CISAP and previous PISa review both evaluated the applicability of the AEB with a score from 0 to 4 and 0 to 5 respectively, rating each case (in different configuration) depending on the scenarios, what the safety system would have done and its effects on the accident.

CISAP and PISa ratings are equivalent for a score of 3. The system is considered fairly applicable for this score and hardly applicable for a lower score.

Results show that the CISAP criteria allow the application of the system in more cases than PISa (approximately 30% higher) regardless of the MAIS classes.

Depending on the type of scenario, AB was applicable in 89% in CFS (Car-Following Scenario) and 86% in CRS (Crossing Scenario).

Benefits were estimated thanks to speed curves where the speed reduction could be visualized according to the different rider behaviors tested (early braking before theoretical AB activation, late braking, or no reaction at all). The speed reduction ranged from 14% up to 50%.



Even when the potential benefits were sometimes lower than the theoretical curves in some specific scenarios, this update CISAP evaluation confirms the first PISa review. Difference between the two estimations comes from better knowledge of the system and the way to apply it as well as new consideration of application, i.e. Slow-crossing vehicle scenario. The benefits of the EB and ABS functions were also re-assessed, participating to significant speed reduction: 34% in CFS and 33% in CRS in average.

These promising results require nevertheless more investigation on a larger database with some specific interest to the influence of AB on a PWT with a non-zero roll angle and particular scenario: slow crossing obstacles.

### **Assessing the Potential Benefits of the Motorcycle Autonomous Emergency Braking Using Detailed Crash Reconstructions**

(Giovanni Savino, 2013)

AEB on passenger cars is ongoing, but mostly for car-to-car rear end crashes or car-to-pedestrians and car-to-cyclists. Less progress was made in PTWs field. ABS (Anti-lock Braking) was only introduced in 1980's and the first MAEB prototype was developed in 2009 in the PISa project. (Powered Two Wheeler Integrated Safety). The purpose of this study was to determine whether or not the use of a MAEB (Motorcycle Autonomous Emergency Braking) system in fatal rear-end crashes could lead to a reduction of injury risks and other benefits. However, the consequences may not be only beneficial. An additional risk may arise from the system itself. This paper tried to identify this risk and appraise the potential benefits of the system in the field of PTWs (Powered Two Wheelers).

The MAEB functionalities derive from the PISa project in which it was developed. A laser scanner mounted in the front fairing of the vehicle detects obstacles, it is processed and then the last time to brake is calculated. The rider is warned before the crash becomes unavoidable then, if he still does not react, the system brakes automatically, providing a 0.3g deceleration. If the rider does react, maximum braking force is applied at that point, which is similar to EB (Enhanced Braking). The MAEB is a combination of AB (autonomous braking), ABS (Anti-lock Braking system) and EB.

To this aim, seven crashes were selected from the Swedish national database (STA: Swedish Transport Administration). Those fatal crashes involved motorcycles equipped with an ABS (Anti-lock Braking System) following a car. Each of them was simulated in a virtual environment. The trajectories, road scenario and environment were reconstructed according to the information from the database. Then, different configurations were tested as developed in the DOE (Design of Experiment): in real condition (no MAEB) versus with the assistance of MAEB and with the MAEB versus with an ABS. Furthermore, a range of different rider behaviors (reaction times), initial lateral position and initial speed of the PTW were tested in order to check if such changes could incur criticalities.

Results show that for all the seven cases, MAEB was relevant and was triggered in 5 out of 7. It provided a speed reduction ranging from 0 to 4 m/s, depending on the case and configuration. No negative side effects from the system, implying a possible additional threat, were to be noticed. Though, even if it confirms that MAEB effectiveness seem promising, more investigation should be carried out. Indeed, the sample of cases in this study was very limited (number of cases, cases not necessarily representative of all countries, all configurations...) and further attention should be put into additional matters, for instance the impact of swerve attempts on the ineffectiveness of MAEB.



## **A robust estimation of the effects of motorcycles autonomous emergency braking (MAEB) based on in-depth crashes in Australia**

(Giovanni Savino, 2016 )

Previous research has shown the potential benefits of MAEB, based on computer simulations derived from in-depth crashes investigation. However, there may be some inaccuracies due the hypotheses of the evaluation. Indeed, the MAEB was considered ideal, and limitations of the post-crash investigation may lead to some imprecisions.

Two main sources of errors are possible: uncertainties in the initial conditions and the type of obstacle detection system considered in the simulations.

This study aims to evaluate the sensitivity of previous estimations to variations and assess their reliability. It draws on data from in-depth reports of real crash cases from 3 independent Australian crash investigation studies: the Monash University Accident Research Centre (MICIMS), the Neuroscience Research Australia (NeuRA), and the Centre for Automotive Safety Research (CASR) consisting of 123, 80 and 51 cash cases.

The method involved the following phases: create a shortlist of all potential cases where the MAEB was applicable, and then establish baseline simulations for each case to generate variants by randomly altering the initial conditions and/or assuming a more realistic obstacle detection system and finally assess the potential benefits of the MAEB by analysing the speed reduction.

Every case was classified as scenarios according to DCA (Definition for Classifying Accidents) codes. 22 DCA scenarios were identified as applicable which represents 45% of all cases from the data set previously described. For these cases MAEB triggered for all of them but one and provided a speed reduction ranging from 1% to 32% (9% in average).

MAEB was triggered in 98% of all the variants generated in the different DCA considered and leading to a crash. Only two DCA showed a MAEB activation lower than 80% for the variants generated. Application of a more realistic MAEB with limitation of detection time / radius / range / refresh rate, affected negatively only 7% of overall cases. Moreover, when the conditions changed, only two specific scenarios showed higher sensitivity.

Finally, this study provided useful information regarding the sensitivity of the approximations made in the simulation and proved them to be accurate despite the different limitations of existing technologies even when MAEB triggered late before the impact point.

## **Issues and challenges for pedestrian active safety systems based on real world accidents** (H. HAMDANE, 2015)

The scope of this research concerns pedestrian active safety. Several primary safety systems have been developed for vehicles in order to detect a pedestrian and to avoid an impact. These systems analyze the forward path of the vehicle through the processing of images from sensors. If a pedestrian is identified on the vehicle trajectory, these systems employ emergency braking and some systems may potentially employ emergency steering. Methods for assessing the effectiveness of these systems have been developed. But, it appears difficult to determine the relevance of these systems in terms of pedestrian protection. The general objective of this research was to test the response of these systems in many accident configurations.

The first step consisted of gathering a sample of a hundred of accidents involving vehicles with pedestrians. These accidents were provided from accident databases of two laboratories IFSTTAR-LMA and University of Adelaide-CASR. Data of these accidents were recorded in sufficient detail from in-depth investigation which enables reconstructing the trajectory of the vehicle and pedestrian prior to the collision. The second step was to analyze qualitatively and quantitatively the data of the selected accidents. These accidents were reconstructed to simulate the pre-crash conditions. From this accident reconstruction, factors relevant to the primary safety of pedestrians were deduced.

The next step consisted of coupling the vehicle dynamic behavior with a primary safety system in order to confront these systems to real accident configurations. The potential of these systems is studied by verifying the feasibility of deploying an autonomous emergency maneuver during the timeline of the accident and according to the vehicle dynamic capabilities: i.e. verifying the possibilities in terms of crash avoidance. Based on this procedure, three modeling methods were developed: a first method testing a system to each accident configuration and two others using graphs of evaluation from a parametric study realized on a generic system. The results of the three methods were then discussed. This methodology will be used by IFSTTAR in the framework of the Pioneers project to evaluate the benefits of a PCB on the PTW.

### 3.1.2 Passive safety systems evaluation

#### **Motorcyclist injury risk as a function of real-life crash speed and other contributing factors**

(Chengkai Ding, 2019)

While biomechanical limits and the relationship between speed and injury outcome has been extensively investigated for car occupants and pedestrians, research analyzing this relationship for motorcyclists remains limited. The aim of this study was to address this issue by developing multivariate injury risk models for motorcyclists that estimate the relationship between speed and injury severity. For that purpose, motorcycle injury crashes from the German In-Depth Accident Study (GIDAS) database for the period 1999–2017 (n=1037) were extracted. Different models were tested using logistic regression and backwards elimination of non-significant variables. The best fitting model in the current study included relative speed, type of crash opponent, impact location on the motorcycle and impact mechanism of the rider during the crash. A strong and significant relationship between relative speed and injury severity in motorcycle crashes was demonstrated (see figure 7).

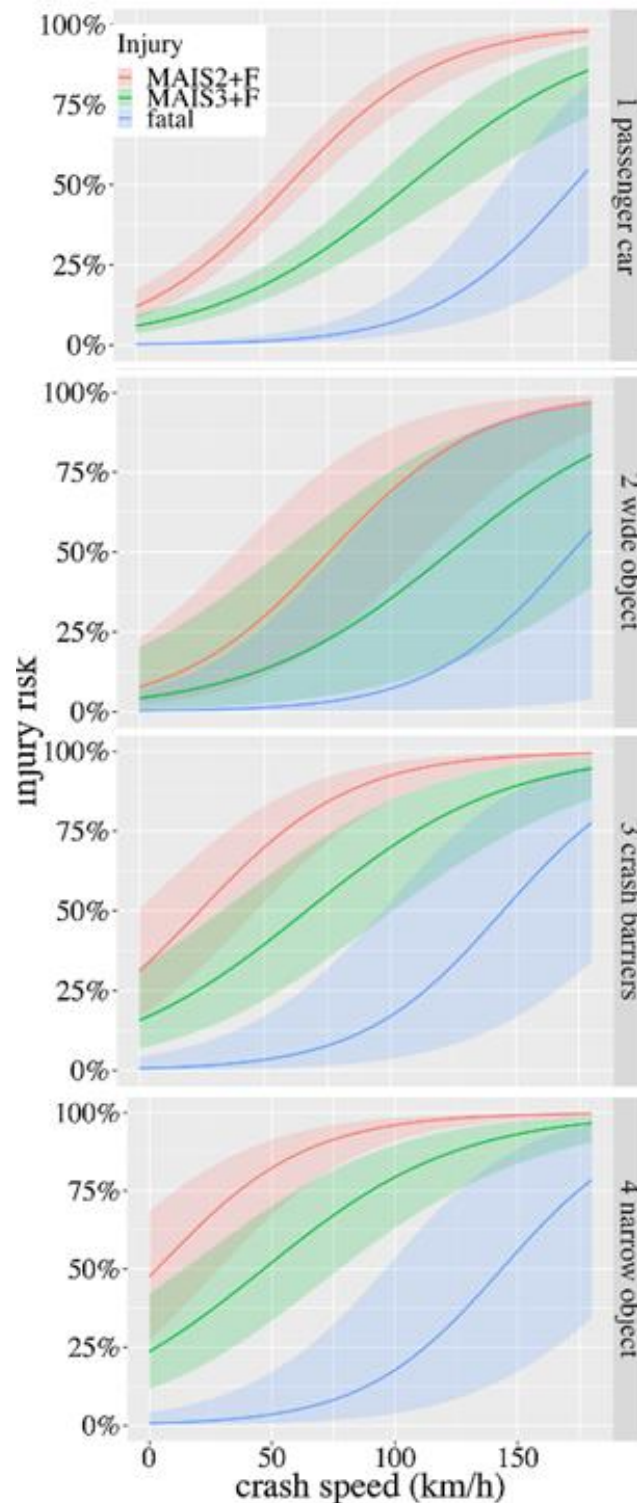


Figure 7: Injury risk curves for different crash opponents

At 70 km/h, the risk for at least serious injuries in collisions with wide objects, crash barriers and narrow objects was 20%, 51%, and 64%, respectively. Further, it was found that head-on collisions between motorcycles and passenger cars, with both vehicles traveling at 60 km/h (a relative speed at 120 km/h), present 55% risk of at least serious injury to the motorcycle rider.

More research is needed to fully understand the boundary conditions needed to design a safe road transport system for motorcyclists. However, this study provides important insights into the relationship between speed and injury severity for riders in various crash situations. The results may be useful in the discussion of appropriate speed limits and in determining the benefits of countermeasures which aim to reduce crash speed.

In the framework of the Pioneers project, it is expected to establish such risk curves, if possible for different segment bodies, in order to evaluate the benefits for different PPE.

### **3.1.3 Integrated safety evaluation**

#### **Towards an integrated pedestrian safety assessment method**

(Nils Lubbe, 2012)

#### **Assessment of integrated pedestrian protection systems with AEB and passive safety components**

(Mervyn Edwards, 2015)

An integrated safety system is one which consists of both active (like on-board system) and passive safety devices. This work aims to define a methodology which integrates active and passive assessments and takes into account the influence that the active safety system has on the boundary conditions for the passive safety system.

The current study is focused on developing a methodology to assess integrated pedestrian systems but the same process could be used in the framework of the PIONEERS project to evaluate benefits of PTW safety systems. The relevant elements which have to be taken into account for an integrated evaluation are the following:

For active safety:

- The results of tests performed on active safety system (like tests realized by Euro NCAP for warning or autonomous braking)
- The speed
- The scenario of the accident situation

The benefits are evaluated in terms of impact speed reductions that is to say avoided or mitigated accidents.

For passive safety:

- The body region which is tested and injured
- The speed of the tests
- The impact angles and the impact area

The benefits are evaluated in terms of injury risk reduction at chosen AIS level.

The proposed assessment methodology suggested in this work consists of five steps and can be summarized as follows (see Figure 8):

1. Active safety testing: Exposure / velocity curve shift

Driver warning and autonomous emergency braking systems are assessed with respect to their ability to reduce impact velocity. Analysis of accident data are used to define representative test scenarios. These test scenarios are weighted corresponding to their contribution to injury occurrence. From each test scenario the typical speed reduction over the whole range of impact speeds are derived. Using this information, the exposure – velocity curves for the corresponding accident scenario are adjusted to account the effect of the active safety system.

2. Passive safety testing: Impactor measurement

Tests are conducted at one or several speeds and impact angles to estimate impactor injury criteria measurements for the relevant vehicle speeds identified in step 1. Impact points are chosen according to the impact distribution of the pedestrian population.

3. Calculation of injury: Injury risk

Injury criteria measurements from step 2 are converted into an injury estimate for tested body regions using injury risk curves and velocity-exposure data from step 1. Injury risk curves need to be made available for all injury severity levels.

4. Calculation of cost: Socio-economic cost

Injury risks for tested body regions are converted into costs for individual injuries as presented in the part 2 of this report.

5. Vehicle assessment: Weighting and summing

In the last step, costs are weighted to account for non-tested body regions. These costs are summed to give overall socio-economic cost of vehicle fitted with active and passive safety systems. This total cost is subtracted from a baseline cost representing a typical vehicle to express the socio-economic cost in terms of a saving or benefit.

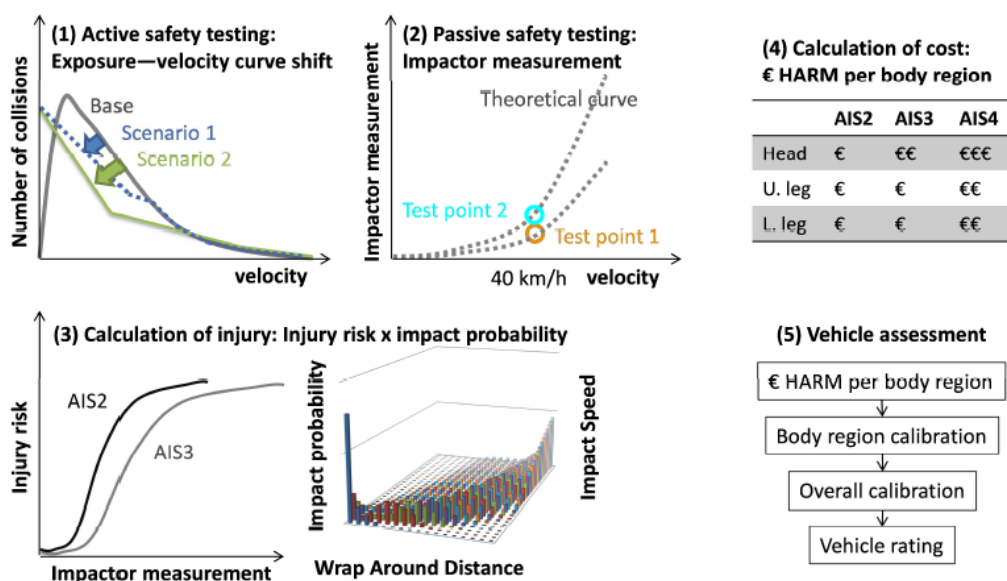


Figure 8: Integrated Pedestrian Safety Assessment in five steps

This has been described in “Integrated Pedestrian safety assessment: a method to evaluate combinations of active and passive safety systems” (Roth F, 2011) and in (Lübbe, 2015).

A similar method called Assessment method Predicting Effectiveness of integrated Fußgängerschutzsysteme (PreEffect-iFGS) to assess the combined effects of active and passive safety systems for pedestrian safety has been previously described by (Schramm, 2011) and Roth and Stoll (2011) and is illustrated in Figure 9.

An injury-risk curve at MAIS2+ level for any type of pedestrian injury was calculated from accident data in GIDAS for the average fleet car as the baseline for comparison (grey dashed line in Figure 9). Vehicle safety is given in reference to injury risk of an average fleet car at a selected test speed (illustrated for 50 km/h in Figure 9). Passive safety systems are assumed to reduce injury risk at the given test speed, while active safety systems are assumed to reduce collision velocity. The reduction of injury risk from the employment of passive safety systems is calculated based on the sets of injury risk curves for different Euro NCAP scores. The blue solid line in Figure 9 represents the injury risk curve for the passive protection level given in the top left of Figure 9.

A small reduction in injury risk can be identified comparing the grey dashed (lower passive protection level) and blue solid injury risk curves. This reduction is attributed to passive safety systems. Active safety system injury risk reduction is calculated from the change in collision velocity. In the figure, the active safety system reduced impact speed from 50 to 35 km/h. This reduction, following the solid blue injury risk curves, is associated with a reduction in injury risk.

A specific test procedure to obtain speed reduction for an active safety system is not described; an outline is given of how to obtain these reductions from system simulation of the active safety system under assessment. In a later version, it was suggested that a similar system could be chosen from a library of active safety system simulations based on specifications such as sensor field of view. This library would contain pre-defined speed reductions for a set of simulated active safety systems. The integrated safety benefit for the combination of active and passive safety systems is the sum of active and passive system risk reduction.

The main advantage of this method is that it covers injuries to all the body regions.

However, this method also has its limitations. The probability of impacting the test points and the change of this probability with impact speed is not modeled. The choice of injury severity level and reference car performance is somewhat arbitrary, and benefits are calculated at one reference speed only. Additionally, the “injury-shift method” lacks validation and a loss of information occurs when combining local (head, upper leg, lower leg) injury risk to a global MAIS risk for passive safety system testing. The depicted injury risk curve at the MAIS2+ level indicates a substantial injury risk at zero velocity, which is explainable from the data and methods used but unlikely to accurately represent reality. As for the other methods, uncertainty is not explicitly modeled.



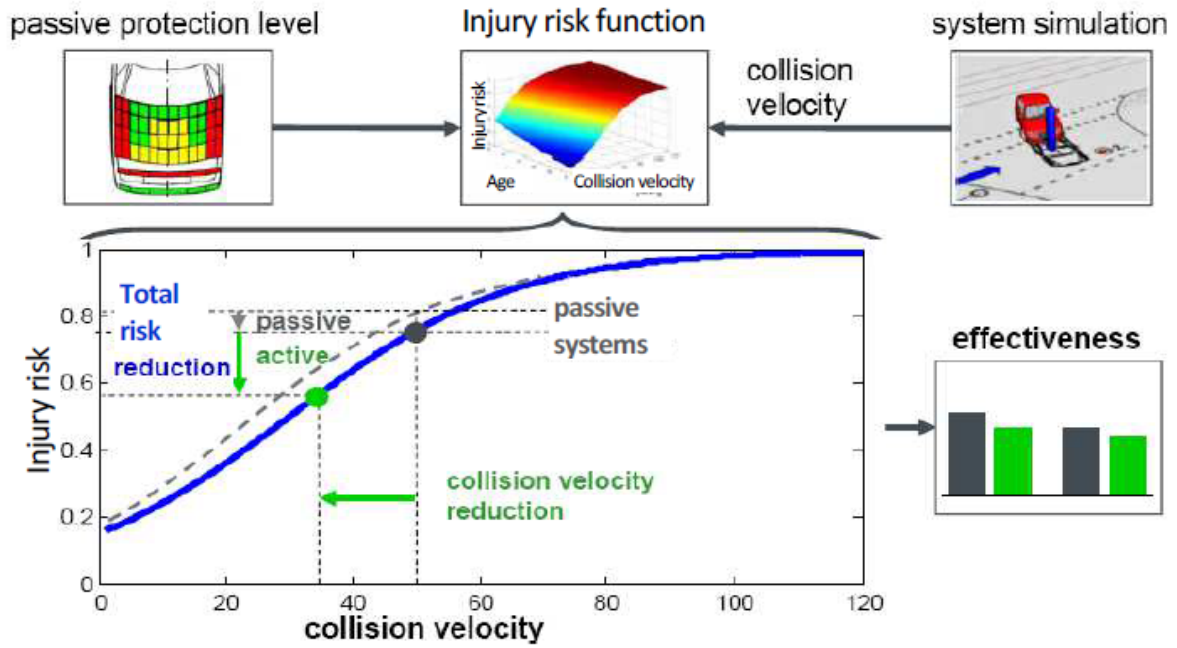


Figure 9: Integrated pedestrian safety assessment method from Roth and Stoll (2011)

## 3.2 Methodology

Following the structure defined in the literature review section, the new testing methods in terms of road safety to mitigate accidents and reduce morbidity and severity of injuries will be defined in this work. Thus, this chapter will concern to the reduction of the impact speed with Pre-Crash Braking (PCB) system, the use of passive safety systems such as new Personal Protective Equipment (PPE) or lateral on-board protections and the methodology used to test the integration of all the mentioned solutions.

### 3.2.1 Pre-Crash Systems

To obtain a more robust evaluation of the effects of PCB, a common methodology for the evaluation of the Pre-Crash Braking system for motorcycles is defined hereunder. Each crash case is analyzed by UNIFI and IFSTTAR so that, the common methodology adopted, as well as the differences due to the different in-house software tools, are depicted.

#### 1. Materials

The methodology leans on a convenient sample of detailed real crashes selected from the datasets. Each crash case report should include detailed crash scenario descriptions (date, hour and place where it happened), path description of the vehicles involved, configuration of the road, marks (skid, scrape, paint...), degradation of the vehicles and interviews of witnesses and the subjects involved. These reports are very informative, and typically enable great accuracy in reconstructing the crash. Further details are collected; like including helmet and protective garment possibly worn, weather conditions, technical information about the vehicles, etc.

The complete materials should consists of L1 and L3 vehicles against cars and others in accident scenarios AS1, AS2, AS3 and AS4 as defined in Deliverable1.1 of Pioneers (see table below). From the whole database, accidents where the rider lost control before the crash occurred should be removed.

Table 1: Scenarios defined in T.1.1 of the Pioneers project

Accident scenario	L1 vs		L3 vs		Single PTW accidents	
	Car	others	Car	others	L1	L3
Use case 1 <b>URBAN</b>	AS1-U	AS2-U	AS3-U	AS4-U	AS5-U	AS6-U
Use case 2 <b>RURAL</b>	AS1-R	AS2-R	AS3-R	AS4-R	AS5-R	AS6-R

#### 2. Methodology

The method to evaluate the PCB should be based on in-depth accident. The kinematics will then be reconstructed by using in-house software from IFSTTAR and UNIFI. The trajectories of the vehicles involved in the accident need to be calculated and their kinematics identified on a detailed map from a few seconds before the collision to a few seconds after. This information is then displayed on a detailed map. Concerning speed profiles, both PTW and opponent vehicle maneuvers are modeled as combinations of constant speed segments and constant acceleration segments.



Then, the motorcycle is set as a reference in the scene and the opponent vehicle location and trajectory are defined with respect to the motorcycle position, paying special attention in setting the correct synchronization of the trajectories. Initial position and time of synchronization have to be set in order to obtain the correct point of impact between the two vehicles.

Once the crash scene is reconstructed, a parametric study should be carried out to simulate the PCB effects. The parameters considered in the tests and their range is listed in Table 2:

Table 2: Parameters variation

Parameter	Level	Step
FOV (Field Of View)	[10°, 70°]	15°
Range	[30m, 90m]	15m
Deceleration	[-2 m/s <sup>2</sup> , -8 m/s <sup>2</sup> ]	1 m/s <sup>2</sup>
Triggering	[early, standard]	

A detection cone representing the FOV (Field Of View) is added to the motorcycle to allow the calculation of the moments when the other vehicle is detected whether or not an obstacle is hiding the view. Representation of the previous description is given in Figure 10.

The range is the distance to which the AEB can detect. Different deceleration applied by the latter should be tested from -2m/s<sup>2</sup> up to -8m/s<sup>2</sup> incremented with a step of 1m/s<sup>2</sup>.

Furthermore, two PCB triggering algorithms are analyzed. On one hand the “standard” triggering approach deploys the PCB intervention as soon as the impact becomes physically inevitable. To do so, a dedicated look up table should be adopted. On the other hand, the ‘early’ intervention approach deploys PCB when the collision becomes inevitable with any combination of maneuvers with constant decelerations of up to 7 m/s<sup>2</sup>.

If it’s the case that the variation of these selected parameters represents an unaffordable number of computations, other parameters and/or ranges must be selected.

In the model from Figure 10, a passenger car is represented by a rectangle with 5 points, one at each corner and one in the geometrical center. At each step of the simulation time, a calculation shows if the opponent vehicle is seen in the motorcycle point of view. The variable  $t_{\text{visible}}$  (s) saves the moment for each point when it becomes visible. This allows grading the level of visibility of the vehicle with a mark from 0 to 5, where 3 meaning at least half of the vehicle is visible.

The variable  $t_{\text{LTTB}}$  is the Last Time to Brake and the moment when the PCB can be triggered. In baseline conditions, the parameter TTC is defined as the difference between  $t_{\text{crash}}$ , time of crash, and  $t_{\text{LTTB}}$ . PCB deployment occurs when the following conditions are both met: a) the opponent vehicle is visible; b) the last time to brake has passed.

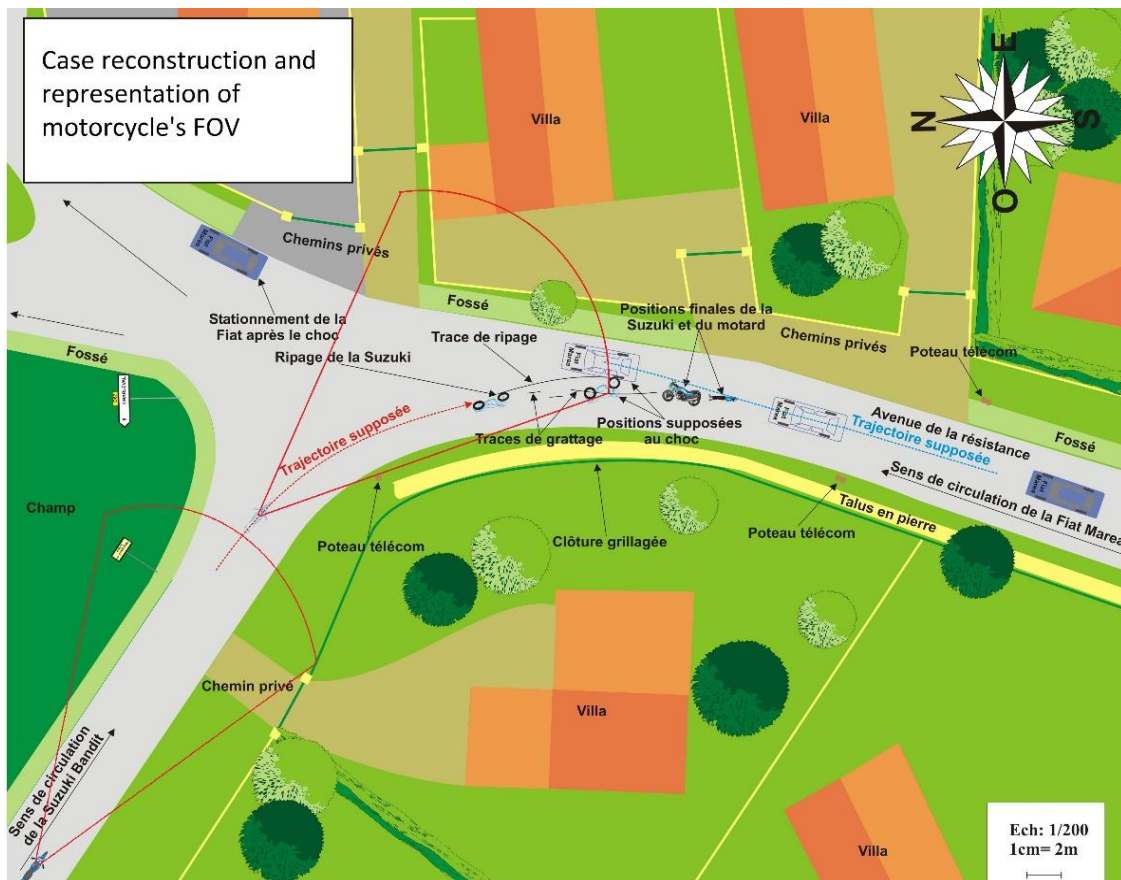


Figure 10: Display of the FOV cone in addition to the crash reconstruction map

### 3. Expected results

Considering all the assumptions and estimations, the results of the methodology can be evaluated thanks to the calculation of the reduction of the speed at the time of impact. If it becomes null, the accident will be considered avoided, mitigated with a reduction of speed and no effect if the speed is unaltered.

#### **Differences between the specific methodologies used by IFSTTAR and UNIFI**

IFSTTAR simulations include every obstacle and vehicles involved in the crash, whereas UNIFI simulations only consider the host PTW and one colliding opponent vehicle.

As an additional parameter for the tests, IFSTTAR simulations consider whether or not an obstacle is hiding the view. Obstacle is equal to 1 if they are considered as such which means that they are obstruction to visibility. It is equal to 0 if they are considered totally transparent.

In UNIFI simulations, the trajectories of both host PTW and opponent vehicle are schematized as combinations of straight segments and constant radius curves. Transitions between a straight and a curve are modeled with short segments having constant curvature rate.

### 3.2.2 Passive Safety Systems

Two kinds of passive safety systems will be evaluated in the framework of the PIONEERS project:

- PPE but mainly thorax protection like airbag jacket
- On-board system protection for lateral impact. (motorcycle/scooter leg protector)

So, two body regions are concerned by this evaluation: thorax and lower leg.

The evaluation of the benefits due to these passive safety systems will be based by developing injury risks function for motorcyclists that estimate the relationship between speed and injury severity on these body parts.

According to the literature review, the evaluation of the benefits for the passive safety systems will be decomposed in two steps:

- First, the establishment of the originally risk curves based on current accident database as proposed by (Ding et al., 2019)
- Secondly, the establishment of the new risk curves after introducing the protective level of the passive safety systems as proposed by (Lubbe, 2012; Edwards, 2015)

Concerning the first step, according to the previous studies developed above in the literature review, the parameters which have to be taken into account are the following: impact or relative speed, type of crash opponent, impact location on the motorcycle and impact mechanism of the rider during the crash.

One of the main important points to establish such injury risks curves is to have at our disposal enough data concerning this information. So a request has been expressed to the WP1 of the PIONEERS project in order to provide needed data to elaborate three kinds of risk curves:

- General injury risk curves linked to the whole body of the rider (MAIS of the rider).
- Risk curves for the lower leg during a lateral impact against an opposite vehicle in order to evaluate benefits of a lateral protection on the PTW (lateral airbags or bar)
- Risk curves for the trunk (thorax+ abdomen) in order to evaluate benefits of a PPE for the trunk region (jacket with/without airbag)

The required information, for each accident, to establish these risk curves are the following (please refer to the section 4.4 of the D1.1 of the PIONEERS project for their exact definitions):

- The accident scenario as defined in the PIONEERS-WP1
- The PTW type
- The collision angle
- The impact speed
- The output speed just after impact
- The PTW Principal direction of Force (PDOF)
- The opponent type:
  - car,
  - ground: curbstone; rails; roadside ditch; ditch overpass; embankment downward slope; object on road; road surface; sidewalk/bicycle lane; other paved road; sand, gravel; grass, lawn; field; shrubbery,

- narrow fixed objects: guardrail post; guidepost; traffic sign pole; traffic light pole; streetlight pole; wooden mast; metal or concrete mast; tree, snapped by collision; stable tree; crash barrier pillar; bridge balustrade,
- wide object: wire-mesh fence; wooden fence; fence, partially bricked; wall; earth wall; house wall; crash barrier; guardrail,
- others
- The opponent impact speed
- The opponent PDOF
- The rider impact speed (if available)
- The MAIS for each body segment as defined in the PIONEERS project: head/face, neck/cervical spine, thorax/thoracic spine, abdomen/lumbar spine, upper extremities, lower extremities, pelvis
- The presence or not of PPE for the trunk region: jacket, airbag jacket

Then, regarding the available data (sample of accidents, accuracy of the data ...) from WP1, risk curves could be established for the whole body or for body segments, for different scenarios, for different opponent type, etc.

The second step of the methodology is to take into account the benefits of the passive safety systems developed in the PIONEERS project. This part will be based on the data provided by the WP3, WP4 and WP5 of the PIONEERS project.

Indeed, in these WPs, it is expected to test and evaluate the protective level of new PPE's and on-board systems like lateral protection using new protocol tests. So the objective will be to take as inputs the results of these WP in order to calculate the new risk curves if the passive safety system was present. The main principle is to evaluate the new injury level obtained during the accident but with the system. Finally, all the injury level will be reconsidered to provide new risk curves.

The new injury level could be estimated by considering three approaches:

- A pessimistic approach which will consider the minimal level of protection offered by the passive safety systems
- An optimistic approach which will consider the maximal level of protection offered by the passive safety systems
- A mean approach which will consider the average level of protection offered by the passive safety systems

So, as needed inputs to perform this evaluation, WP3, WP4 and WP5 have to provide results of tests to assess the performance of the system or at least the levels of protection offered by the systems. These data-packs can concern, for example; level of energy, impact speed or directly injury level.

### 3.2.3 Integrated Systems

As described above, the integrated evaluation will include the benefits calculation of on-board system aiming to reduce impact speed like the PCB and the passive safety system (PPE and lateral protection). This work is based on the methodology already described in the literature by (Roth and Stoll, 2011) or (Lubbe, 2012). In summary, the method could be described as follows:

- Analysis of in-depth data to find the possible closing speed and delta v reduction with PCB with a given functionality

- Application of the resulting delta v reduction to the exposure (shifting the exposure to the left in Figure 10)
- Calculation of the injury reduction based on the derived risk curve
- Estimation of the reduction in severe accidents per year in national statistics

The three first steps have been already detailed in the previous section. Concerning the last one, the objective is to evaluate the benefits in terms on national statistics. To do this, the method will be based on the data already provided by the WP1 and which concerns the national data in terms of number of accidents, number of injuries, accident scenarios, etc. The idea is to report the benefits identified for example for a specific scenario to the sample of the same scenario identified in the national statistics.

As for the passive safety evaluation, different approaches could be considered here: a pessimistic one, an optimistic one and an average one by considering the minimum, respectively maximum or mean impact of the new systems on the accidents. The final objective is to provide assessment of minimal, maximal and mean benefits.

## 4 Summary

The present deliverable includes the full explanation of the procedure to be followed in order to perform the Impact Analysis of the safety measures that have been developed in the PIONEERS project.

As to the economical benefit analysis of these safety countermeasures, the literature review has shown the overall massive benefit of proposing safety measures for Powered Two-Wheelers. Different approaches to economical safety benefit analysis have been identified by means of a literature review. These include, the Valuation of a Statistical Life (VSL) method and the cost-of-illness method. However, the final methodology is based on the use of the SafetyCube DSS E<sub>3</sub> Calculator. The use of this calculator has been thoroughly explained in Section 2 of this document; detailing the required input and resulting output of using this tool.

Furthermore, in section 3, a safety benefit analysis methodology has also been elaborated. This methodology has been based in an extensive Literature Review adapted to the use case of the PIONEERS project. The methodology to be followed has been split in Pre-crash systems (referred to as Active Safety systems for consistency with the literature sources even if the technology is activated when the crash is considered unavoidable), passive Safety Systems and Merged/Integrated safety systems.

The output from the Safety and Economical Benefit Analysis calculation can be used by decision-makers in order to choose which countermeasures could be beneficial for the safety of Powered-Two-Wheelers. Moreover, the work will enable to quantify which countermeasures give a higher benefit both from a safety and economical point of view; allowing to prioritize these measures by impact.

This deliverable includes the necessary output (Economical and Safety Benefit Analysis Calculation Methodology) in order to be able to make these calculations further on in the PIONEERS project (Task 6.2) achieving the above-mentioned project conclusions.



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