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Thierry Serre, Claire Naude, Christophe Perrin, Adrien Canu, Sandra Breunig, Ricard Casalins, Thomas Lich, Maria de Odriozola, Simone Piantini, Giovanni Savino, et al.

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Publishable Executive Summary

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 implementation of the PIONEERS' main results will contribute to reducing PTW fatalities and injuries by defining test methods to develop protective systems and on-board systems to reduce impact severity.

In order to assess if this major conclusion of the PIONEERS project is being fulfilled and to quantify the benefit, an Impact Evaluation has been developed in this document.

This evaluation concerns both economical and safety benefits (in terms of avoided or mitigated accidents, reduction of morbidity and severity of injuries) of the following proposed PTW safety countermeasures that have been developed in PIONEERS:

- PreCrash Braking System
- Airbag jacket and the PTW-PPE communication system
- Motorcycle and scooter leg protector

Concerning the PCB, the evaluation was obtained via computer simulations of a set of 60 real-world in-depth crashes. The effects were assessed in terms of a reduction of the absolute and relative impact speed of the PTW. A parametric approach in which PCB intervention parameters were varied (field of view, range, deceleration, fade-in jerk, triggering strategy...) was adopted to compute the effects of the system for different conditions. Such approach led to the identification of three combinations of parameters to represent typical system effects assuming a pessimistic (low efficiency), average, and an optimistic approach (high efficiency). Depending on the set of parameters, benefits in terms of speed reduction can go until a median value of 15km/h. Then societal benefits have been calculated in terms of casualties' reduction or crashes using Injury Risk Function and the new relative impact speed distribution. Results show that global benefits for slight, serious or fatal injuries are included between -4% to -31%. Finally, economic benefits in terms of cost were evaluated using the SafetyCube software. Several configurations were considered like the implementation rate of PCB among all motorcycles in Europe, the cost to promote such systems, the horizon, etc. In a 5 years period, this cost will be balanced by savings from health and social expenses, and in a high rate of implementation (with the average evaluation) Europe could save, at least, 30 human lives in this period. With an optimistic configuration, the net value of the benefits could be reached between approximately 500k€ until more than 90 M€.

Concerning the Airbag jackets, the societal benefits calculation was first based on the establishment of Injury Risk Function for slight, serious and fatal injuries on the trunk without the airbag. In order to establish these IRF, four accident databases were considered and 382 accidents concerned a rider with at least one injury in trunk body region. Then, according to the work performed in others WP's of the Pioneers project, three hypotheses have been considered for the level of protection and the reduction of injuries. They considered that the airbag jacket provides a reduction of an AIS-1 for speed impact lower than 20km/h, respectively 30km/h and 40km/h. Results of the societal evaluation show that between 1,3% until 19% of injuries could be avoided in function of the configuration. From an economical point of view, with a high implementation rate (6%) in the next 5 years, a net value of more than 140M€ could be saved.

Concerning the Lateral Protectors, Injury Risk Function of the Lower Leg in lateral impact configuration were first established based on 81 accidents. Then, based on the findings from the lateral protection devices that have been developed in the PIONEERS project (in particular WP3), two hypotheses have been retained for the level of protection of such systems: one considered as a "low-speed" countermeasure (only effective until 15km/h) and one considered as "medium-speed" countermeasure (only effective between 15 to 30km/h). Global societal

and economic benefits have been observed but results have to be taken very cautiously. Indeed, the economic evaluation show that an amount of more than 5M€ for the net benefits could be saved with the best configuration. But it is important to remind that these systems are not still available in the market, so these evaluations have to be considered as a theoretical exercise.

In conclusion, this work allowed to evaluate safety and economic benefits of several protective systems: Pre-Crash Braking, airbag jackets, Lateral protectors. But because some of these systems are prototypes and not yet on the market, **all the evaluations have to be taken very carefully**. In particular, **results from societal and economical evaluations are sensible and have to be considered cautiously**. Beyond these specific evaluations, theoretical methodologies have been defined and could be applied on other systems.

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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 Purpose of the document

The main goal of this document is to describe the evaluation of the benefits that can be achieved by implementing the PIONEERS project results in terms of safety (avoided or mitigated accidents, reduction of morbidity and severity of injuries) and in terms of economic reduction of costs.

The evaluation was done regarding the PCB, the airbag, and the lateral protector.

2 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 in the deliverable 6.1, 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 reduction 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.

This evaluation concerns both economical and safety benefits (in terms of avoided or mitigated accidents, reduction of morbidity and severity of injuries) of the following proposed PTW safety countermeasures that have been developed in PIONEERS:

- Pre-Crash Braking System
- Airbag jacket and the PTW-PPE communication system
- Motorcycle and scooter leg protector

Safety benefits for each of these systems will be firstly described and then an economic benefit calculation will be given.

3 Safety Benefits

3.1 Pre-Crash Braking

3.1.1 Methodological Reminders

3.1.1.1 Methods to simulate the PCB

The evaluation of the effects of PCB was obtained via computer simulations of a set of real-world in-depth crashes selected from the InSAFE database and EDA database. Simulations were conducted by UNIFI and UGE with a common methodology and two specific in-house software tools capable of modelling the actual vehicle trajectories that led to a crash (see D1.1 and D6.1 for details on the databases and accident reconstruction methodology), as well as modelling the modified kinematics as the result of the intervention of a virtual PCB, assuming such system was fitted on the host PTW. The effects were assessed in terms of a reduction of the absolute and relative impact speed of the PTW. In some of the cases, the intervention of the PCB may even cause a full crash avoidance. This was not the primary aim of the system and was treated as a side effect that positively influences the benefit assessment of the PCB. Potential benefits for the cases in which a PCB intervention determined a collision avoidance in the simulations were analyzed as a separate group.

A set of cases was analyzed by both UNIFI and UGE so that similarities and differences of the results produced by the software tools could be highlighted (see Section 3.1.1.3).

The common methodology for a given crash case consisted in the following steps.

- 1) Reconstruction of the original crash kinematics based on the information available in the in-depth crash report and any prior crash reconstruction available. The trajectories of the vehicles involved in the crash were separately calculated and their kinematics identified on a detailed map from a few seconds (approx. 3 s) before the collision, while accommodating the possibility to observe the subsequent trajectories for a few seconds after the expected impact point. This information was then displayed on a map to allow for a check with available case reports. Concerning speed profiles, both PTW and opponent vehicle maneuvers were modelled as combinations of constant speed segments and constant acceleration segments.
- 2) The PTW was set as a reference in the scene and the opponent vehicle location and trajectory were defined with respect to the PTW position, paying special attention in setting the correct synchronization of the trajectories. Initial position and time of synchronization were set to obtain a point of impact between vehicles that matched the actual impact point according to the case reported information.
- 3) Once the crash event was reconstructed in the simulation tool, variant cases were generated to simulate the influence of the intervention of the PCB, which is meant to trigger at a given point in time producing a predefined modification in the deceleration profile of the host PTW.

A parametric approach in which PCB intervention parameters were varied in each variant case, within predefined ranges, was adopted to compute the effects of the system for different conditions. Such approach led to the identification of a pessimistic, a standard, and an optimistic condition with respect to the potential benefits of PCB. The parameters considered in the tests and their range are listed in Table 1.

Parameter	Level	Step
Field Of View	[10°, 70°]	15°
Range	[30 m, 90 m]	15 m
Deceleration	[-3 m/s ² , -7 m/s ²]	2 m/s ²
Fade-in-Jerk	[15 m/s ³ , 25 m/s ³]	-
Triggering strategy	[conservative, standard, progressive]	

Table 1. PCB Parameters variation

A detection cone representing the FOV (Field Of View) is added to the motorcycle to allow the calculation of the instant when the other vehicle is detected by embedded sensors. The range is the maximum distance at which the PCB can detect an opponent vehicle. Different deceleration applied by the PCB should be tested from -3 m/s² up to -7 m/s² incremented with a step of 2 m/s². The decelerations of -3 m/s² and -5 m/s² are the nominal values that were investigated in the field tests of Task 5.2. A deceleration of -7 m/s² goes one step beyond the current experimental investigation and is included in the analysis aiming to simulate the effects that PCB may achieve with new frontier intervention parameters, which are warranted future investigation and validation. Furthermore, three PCB triggering criteria were analysed: conservative (intervention closer to collision), standard, progressive (earlier in time and longer duration). The nominal “time to collision” (TTC) at which the PCB was triggered in the three settings are respectively 0.6 s, 0.8 s, 1.0 s. The triggering method is implemented with different approaches in the UNIFI and UGE simulations. For UGE simulations, PCB was deployed at the nominal values of TTC.

According to the UNIFI approach, PCB intervention is deployed as soon as the imminent impact becomes inevitable (“inevitable collision state”), assuming that both the rider and the driver of the opponent vehicle may operate their vehicles with longitudinal and lateral accelerations within predefined thresholds. When computing the possible maneuvers, the theory of the ellipsoid of friction is considered, so that the modulus of the vectorial combination of the longitudinal and lateral acceleration does not exceed the maximum adherence available in each reconstructed crash case. The fixed threshold values for the triggering were identified beforehand using an iterative, trial-and-error process, so that the median TTC at PCB triggering over the crash cases used in this study matched the nominal values of 0.6 s, 0.8 s, and 1.0 s respectively for the conservative, standard and progressive activation criteria. A summary of the threshold values used to compute the inevitable collision state are presented in **Error! Reference source not found.**

	Nominal (target) TTC at triggering (s)	PTW ICS thresh. longitudinal (m/s ²)	PTW ICS thresh. lateral (m/s ²)	Car ICS thresh. longitudinal (m/s ²)	Car ICS thresh. lateral (m/s ²)
Conservative	0.6	6.0	4.0	6.0	4.0
Standard	0.8	4.0	2.5	4.0	2.5
Progressive	1.0	3.0	2.0	1.0	1.0

Table 2. Threshold accelerations adopted for the definition of the three UNIFI triggering strategies, in longitudinal and lateral direction.

To identify the triggering instant during a crash simulation, at each time step the relative position and speed of both the PTW and the opponent vehicle are used as inputs to compute all the combinations of longitudinal and lateral actions that may be performed in the subsequent steps by the two vehicles. The vehicles are modelled by rectangles with fixed dimensions of 2x1 m and 4x2 m, respectively for the PTW and opponent vehicle. Any potential action is evaluated at the acceleration threshold, according to the values identified for the selected triggering strategy. If none of the combinations of maneuvers lead to collision avoidance, the vehicle state at the considered time step is labelled as “inevitable collision state” and the PCB triggering is issued.

This approach, defined in a previous study, is implemented via dedicated, pre-computed look up tables. The inputs for the look up table are the relative position and heading of the opponent vehicle, and the travelling speed of both vehicles. The output of the look up table is a Boolean value (avoidable vs. non-avoidable impact). The PTW in the initial time step is assumed to be travelling straight, as this was the condition in which the model used to simulate realistic emergency swerving of the PTW was validated.

Concerning the approach adopted by University Gustave Eiffel, each detailed accident case was reconstructed using an internal software (ANAC), which provides as output the trajectories and kinematic data over time (positions, speeds, accelerations) to the point of impact for both vehicles involved.

The kinematics reconstruction method used with ANAC, is based on final and impact positions, skid marks, angle of the impact, impact locations on the vehicles, involved persons accounts, victim's injuries, etc. It requires knowledge in kinematics and is based on the estimation of some parameters such as the energy spent in the vehicle deformation, the decrease in speed of the vehicle depending on the tyre marks on road, etc. Trajectories of vehicles involved are determined according to data collected on the scene of the accident: final positions, marks, estimated positions at impact point, and arrival directions of each vehicle. In general, it is necessary to go back in time and on the trajectory of each vehicle involved with the calculation of simple kinematics sequences (each sequence is associated to a simple kinematics model). The post-crash phase is modelled by a constant speed movement or by a uniformly accelerated movement. The analysis of the collision consists in applying simple mechanical laws: conservation of momentum (two axes) and conservation of energy (kinetic and deformation). The global objective is thus to balance these three simultaneous equations. The study of the pre-crash phase uses exactly the same principles of calculation than the post-crash ones. The final

objective of the reconstruction is to build a spatiotemporal description of the accident proceedings, consistent with the whole data. Its results provide a spatiotemporal description of the accident proceedings.

From both databases, accidents where the rider lost control before the crash occurred were simulated with ABS and retained if the crash still occurred, or discarded if it did not.

Once the crash scene is reconstructed, a parametric study is carried out to simulate the PCB effects, considering the parameters variation (Table 1).

With regards to triggering, the Univ. Eiffel initial computation was based on the 3 longitudinal strategies:

- “Standard” triggering: PCB intervention as soon as the impact becomes physically inevitable with a PTW longitudinal deceleration of -7 m/s^2
- “Progressive” triggering: PCB intervention when the collision becomes inevitable with a PTW longitudinal deceleration of -5 m/s^2
- “Conservative” triggering: PCB intervention when the collision becomes inevitable with a PTW longitudinal deceleration of -3 m/s^2

In order to have a more realistic PCB behaviour, also to get closer to the UNIFI method, Univ. Eiffel added to PCB simulation a constraint on times to collision with the realistic values of 0.6 s (Conservative), 0.8 s (Standard) and 1 s (Progressive).

Apart from the main method, Univ. Eiffel performed simulations including the presence of an obstacle hiding the view, a stopped vehicle, buildings or tree-lined shoulder of a curve. However, it should be noted that the values of time to collision used reduce the influence of the consideration of obstacles to visibility.

Certain rules have been applied for the simulation of the PCB:

- If the motorcyclist is already braking in the real accident at a time when the PCB has to be triggered because the collision is unavoidable, the PCB only triggers braking if its predicted deceleration value is higher than that of the motorcyclist at the time considered, otherwise the deceleration of the motorcyclist is applied, because the PCB cannot do worse than the motorcyclist.
- If the collision becomes unavoidable at a time when the opposing vehicle is no longer detectable by the PCB due to the trajectories of the vehicles, the PCB does not apply a brake.
- When the PCB is activated for the motorcyclist, the trajectory and speed development of the opposing car is maintained as in the real accident situation.
- Such three rules were also adopted in the UNIFI simulations.

The collision detection principle is applied at each moment as follows:

The vehicles are modelled by rectangles with known real dimensions (length, width) and positioned at each instant according to the new deceleration data for the PTW and according to the accident data for the car, with their orientation. A collision occurs when one of the four corners of the PTW penetrates the rectangle of the car.

The PCB simulation tool uses the kinematic data from the reconstruction to simulate the accident on a scale map and to verify the crash conditions through animation and graphics (Figure 1).

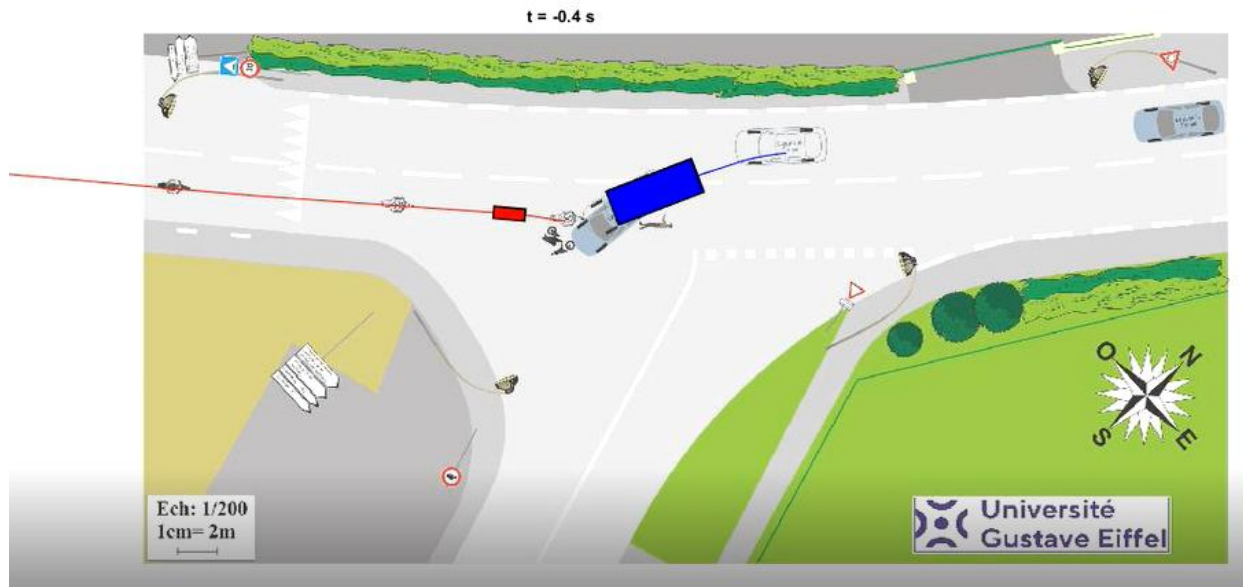


Figure 1. Animation of an accident simulation

Then the PCB is simulated with a few different combinations of parameters to check the results in terms of triggering, impact speed reduction and last time to brake, also with the help of graphics and animations (Figures 2 and 3).

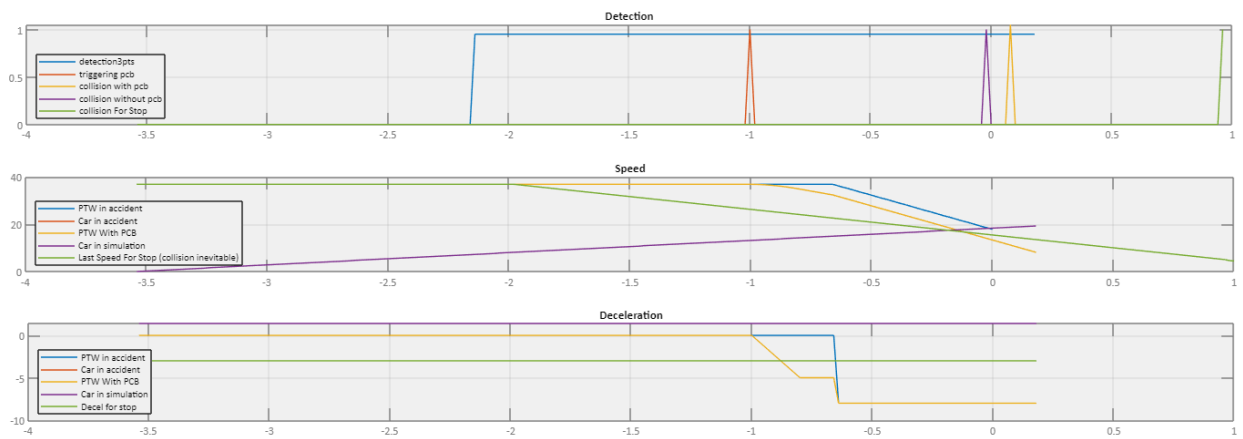


Figure 2. Graphs of a PCB simulation – Evolution of detection, speeds and deceleration versus time

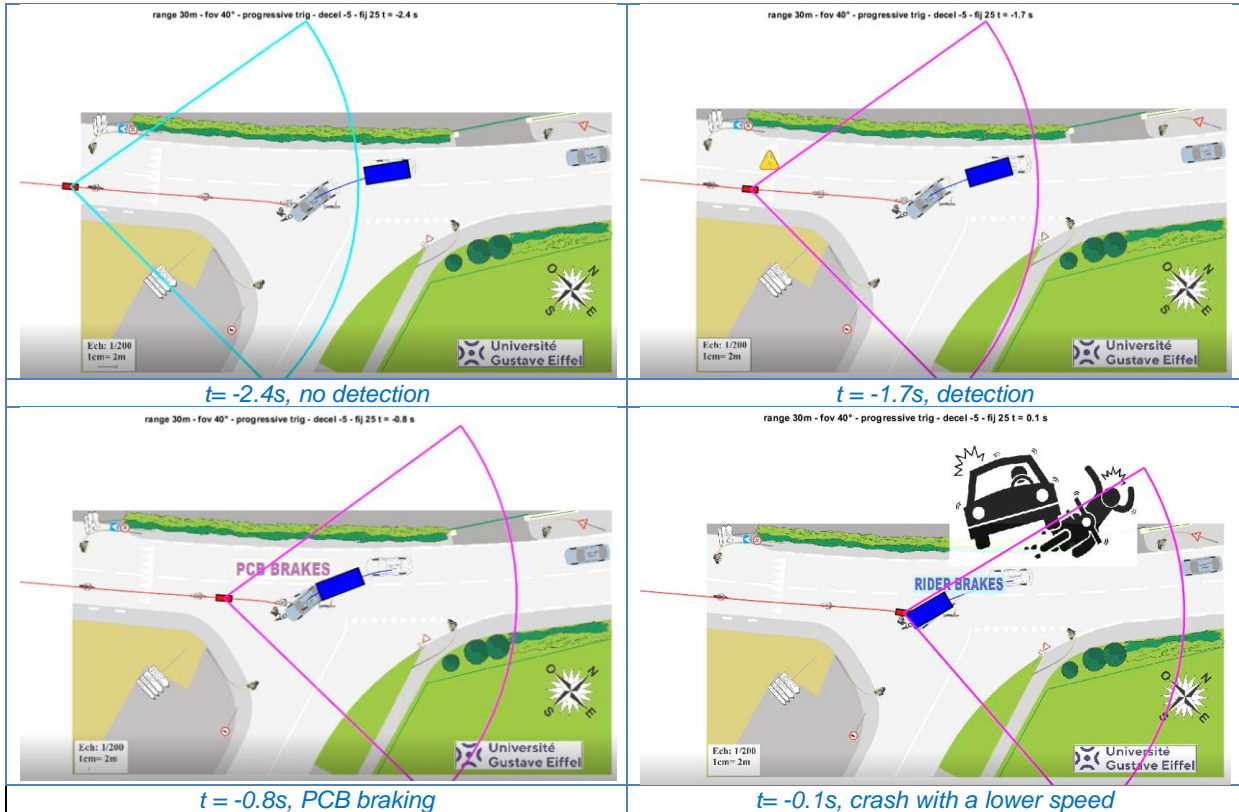


Figure 3. Images of a PCB simulation animation

Then the 450-parameter combinations of the PCB, both for UNIFI and UGE cases, were simulated to obtain the complete results given in a format that allows comparison of cases, such as the example presented at Figure 4.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	realImpactSpeed		decel -3	decel -3	decel -3	decel -3	decel -3	decel -5	decel -5	decel -5	decel -5	decel -5	decel -7	decel -7	decel -7	decel -7	decel -7
2	18.4	fov 10°	fov 25°	fov 40°	fov 55°	fov 70°	fov 10°	fov 25°	fov 40°	fov 55°	fov 70°	fov 10°	fov 25°	fov 40°	fov 55°	fov 70°	
3	fij 15 m/s³	range 30 m	0.0968	4.1	4.1	4.1	4.1	0.0968	5.9936	5.9936	5.9936	5.9936	0.0968	6.0296	6.0296	6.0296	6.0296
4	fij 15 m/s³	range 45 m	0.0968	4.1	4.1	4.1	4.1	0.0968	5.9936	5.9936	5.9936	5.9936	0.0968	6.0296	6.0296	6.0296	6.0296
5	fij 15 m/s³	range 60 m	0.0968	4.1	4.1	4.1	4.1	0.0968	5.9936	5.9936	5.9936	5.9936	0.0968	6.0296	6.0296	6.0296	6.0296
6	fij 15 m/s³	range 75 m	0.0968	4.1	4.1	4.1	4.1	0.0968	5.9936	5.9936	5.9936	5.9936	0.0968	6.0296	6.0296	6.0296	6.0296
7	fij 15 m/s³	range 90 m	0.0968	4.1	4.1	4.1	4.1	0.0968	5.9936	5.9936	5.9936	5.9936	0.0968	6.0296	6.0296	6.0296	6.0296
8	fij 25 m/s³	range 30 m	0.14	5.108	5.108	5.108	5.108	0.14	8.348	8.348	8.348	8.348	0.14	9.86	9.86	9.86	9.86
9	fij 25 m/s³	range 45 m	0.14	5.108	5.108	5.108	5.108	0.14	8.348	8.348	8.348	8.348	0.14	9.86	9.86	9.86	9.86
10	fij 25 m/s³	range 60 m	0.14	5.108	5.108	5.108	5.108	0.14	8.348	8.348	8.348	8.348	0.14	9.86	9.86	9.86	9.86
11	fij 25 m/s³	range 75 m	0.14	5.108	5.108	5.108	5.108	0.14	8.348	8.348	8.348	8.348	0.14	9.86	9.86	9.86	9.86
12	fij 25 m/s³	range 90 m	0.14	5.108	5.108	5.108	5.108	0.14	8.348	8.348	8.348	8.348	0.14	9.86	9.86	9.86	9.86

Figure 4. Format of Impact Speed Reduction results for one triggering strategy

3.1.1.2 Description of 60 cases

The methodology leans on a sample of 60 detailed real crashes, 30 from the in-depth InSAFE database and 30 from the in-depth EDA database (more information available in the deliverable “D1.1 Powered Two-Wheelers – Road Traffic Accident scenarios and common injuries”).

The complete materials consist of L1 and L3 vehicles against cars and others vehicles (OV) in crash scenarios AS1, AS2, AS3 and AS4 as defined in Deliverable 1.1 of Pioneers (Table 4).

Accident scenario	L1 vs		L3 vs		Single PTW crashes	
	Car	others	Car	Others	L1	L3
Use case 1 URBAN	AS1-U	AS2-U	AS3-U	AS4-U	AS5-U	AS6-U
Use case 2 RURAL	AS1-R	AS2-R	AS3-R	AS4-R	AS5-R	AS6-R

Table 3. Scenarios defined in T.1.1 of the Pioneers project

Accident cases where the other vehicle (OV) is coming from sides or rear of the PTW are excluded, it represents about 10% (Figure 5, source MAIDS [ACEM, 2009])

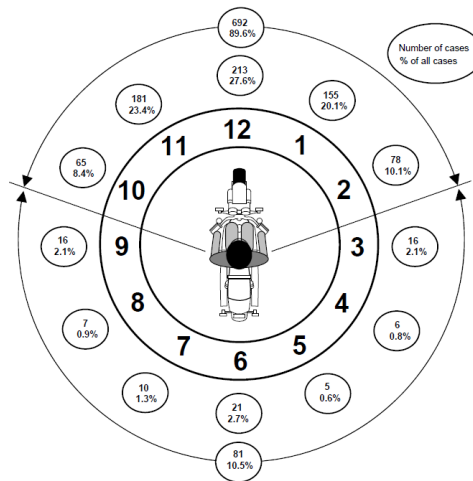


Figure 5. PTW line of sight to OV (Source MAIDS report [ACEM, 2009])

The vast majority of InSAFE crash cases occurred in urban areas, while for the EDA dataset half took place in rural areas.

Environment	InSAFE	EDA	Total
Rural	1 (3.3%)	15 (50.0%)	16 (26.7%)
Urban	29 (96.7%)	15 (50.0%)	44 (73.3%)
Total	30 (100.0%)	30 (100.0%)	60 (100.0%)

Table 4. Environment of 60 cases

Both datasets show a prevalence of PTW type L3 (motorcycle with an engine capacity $\geq 125 \text{ cm}^3$, without sidecar) accounting for an overall 77%.

PTW Category	InSAFE	EDA	Total
L1	5 (16.5%)	9 (30%)	14 (23%)
L3	25 (83.5%)	21 (70%)	46 (77%)
Total	30 (100.0%)	30 (100.0%)	60 (100.0%)

Table 5. PTW Category of 60 cases

In both InSAFE and EDA datasets, two-thirds of the selected crashes occurred at intersections with the majority at crossroads (four road legs). The main differences between the two datasets can be found for crashes that occurred on the straight road (33% in the InSAFE vs. 10% in EDA) and curves (no cases in the InSAFE dataset vs. 7% in EDA).

Spot Type	InSAFE	EDA	Total
Crossroads	12 (40.0%)	7 (23.3%)	19 (31.7%)
Straight Road	10 (33.3%)	3 (10.0%)	13 (21.7%)
Curve	0 (0.0%)	5 (16.7%)	5 (8.3%)
T-Junction	7 (23.3%)	7 (23.3%)	14 (23.3%)
Y-Junction	1 (3.3%)	6 (20.0%)	7 (11.7%)
Roundabout	0 (0.0%)	2 (6.7%)	2 (3.3%)
Total	30 (100.0%)	30 (100.0%)	60 (100.0%)

Table 6. Spot type of 60 cases

In order to quantify how much intensely the rider braked, the Braking Intensity (BI) was calculated for each case. The deceleration was normalized with respect to the maximum deceleration available with the hypothesized friction value ($9,81 \cdot \text{friction}$) and expressed in percentage:

$$BI = \frac{\text{Braking}}{\text{Max Braking}} \cdot 100$$

38% of the total riders experience a low braking intensity, often no braking at all, and in one third of the cases, the motorcyclist brakes hard (8 [26.7%] from InSAFE and 12 [40.0%] from EDA).

Braking Intensity	InSAFE	EDA	Total
< 25%	10 (33.3%)	13 (43.3%)	23 (38.3%)
25 - 50%	7 (23.3%)	1 (3.3%)	8 (13.3%)
50 - 75%	5 (16.7%)	4 (13.3%)	9 (15.0%)
> 75%	8 (26.7%)	12 (40.0%)	20 (33.3%)
Total	30 (100.0%)	30 (100.0%)	60 (100.0%)

Table 7. Braking intensity of 60 cases

More than half of the InSAFE cases are head-to-side collisions, while half of the EDA cases are head-on collisions. The second most common crash configuration is sideswipe.

Crash Configuration	InSAFE	EDA	Total
head-on	5 (16.7%)	15 (50.0%)	20 (33.3%)
head-to-rear	3 (10.0%)	2 (6.7%)	5 (8.3%)
head-to-side	17 (56.7%)	7 (23.3%)	24 (40.0%)
sideswipe	5 (16.7%)	6 (20.0%)	11 (18.3%)
Total	30 (100.0%)	30 (100.0%)	60 (100.0%)

Table 8. Crash Configuration of 60 cases (when two directions, first one concerns the PTW)

The cross distribution between spot type and crash configuration is presented in Table 8. The most common combination is the head-to-side intersection collision (13 cases). In both datasets, the PTW riders most often impact frontally the side of the other vehicle at crossroads (75% and 57%, respectively).

Among intersection cases, T-junction crashes account for 23% overall, with 36% of the cases occurred with head-on and head-to-side crash configurations, respectively. On the other hand, at Y-junction the most common crash configuration was the sideswipe.

The InSAFE dataset shows the highest crash number occurred on straight roads than the EDA dataset, with the majority of the PTW riders collided frontally the side of the other vehicle (5/10, 50%) due to frequent U-turn maneuvers from the other vehicle.

Spot Type / Crash Config.	InSAFE	EDA	Total
Crossroads	12	7	19 (31.7%)
head-on	1 (8.3%)	3 (42.9%)	4 (21.1%)
head-to-rear	1 (8.3%)	0 (0.0%)	1 (5.3%)
head-to-side	9 (75.0%)	4 (57.1%)	13 (68.4%)
sideswipe	1 (8.3%)	0 (0.0%)	1 (5.3%)
Straight Road	10	3	13 (21.7%)
head-on	3 (30.0%)	1 (33.3%)	4 (30.8%)
head-to-rear	1 (10.0%)	1 (33.3%)	2 (15.4%)
head-to-side	5 (50.0%)	0 (0.0%)	5 (38.5%)
sideswipe	1 (10.0%)	1 (33.3%)	2 (15.4%)
Curve	0	5	5 (8.3%)
head-on	0 (0.0%)	4 (80.0%)	4 (80.0%)
sideswipe	0 (0.0%)	1 (20.0%)	1 (20.0%)
T-Junction	7	7	14 (23.3%)
head-on	1 (14.3%)	4 (57.1%)	5 (35.7%)
head-to-rear	1 (14.3%)	0 (0.0%)	1 (7.1%)
head-to-side	3 (42.9%)	2 (28.6%)	5 (35.7%)
sideswipe	2 (28.6%)	1 (14.3%)	3 (21.4%)
Y-Junction	1	6	7 (11.7%)
head-on	0 (0.0%)	2 (33.3%)	2 (28.6%)
head-to-rear	0 (0.0%)	1 (16.7%)	1 (14.3%)
sideswipe	1 (100.0%)	3 (50.0%)	4 (57.1%)
Roundabout	0	2	2 (3.3%)
head-on	0 (0.0%)	1 (50.0%)	1 (50.0%)
head-to-side	0 (0.0%)	1 (50.0%)	1 (50.0%)
Total	30	30	60 (100.0%)

Table 9. Crossing of Spot Type and Crash Configuration for the 60 cases (when two directions, first one concerns the PTW)

3.1.1.3 Comparison of methods

A part of the accident cases was exchanged between UNIFI and Univ. Eiffel to be simulated by both the team, in order to compare the methods. Among the 30 cases from UNIFI InSafe database, 10 were transmitted to Univ. Eiffel and among the 30 cases from Univ. Eiffel EDA database, 10 were transmitted to UNIFI.

	Simulations performed by only one partner	Simulations performed by UNIFI & Univ. Eiffel	Total
Cases provided by UNIFI	20	10	30
Cases provided by Univ. Eiffel	20	10	30
Total	40	20	60

Table 10. Repartition of cases selected for the PCB evaluation

The results of the simulations for the 20 shared cases are presented in terms of speed reduction at impact in Figure 6 for one set of parameters (left and right graphs) and also depending on the trigger (middle graph). The simulations were performed with the possibility of avoiding the accident when the PCB allows the motorbike to stop before the impact point. In this case, the speed reduction is equal to the impact speed in the accident. The results are contrasted: for some accidents, the speed reductions are close between the UNIFI simulation and the Univ. Eiffel simulation, while for others the reduction is very different. In particular, some accidents are avoided with the UNIFI simulation whereas the collision does take place in the Univ. Eiffel simulation. For the selected set of parameters, the 20 UNIFI simulations give a median speed reduction value of 7.5 km/h (collision avoidance cases excluded from computation), while the 20 Univ. Eiffel simulations give 10.5 km/h. The last time to brake values in the simulations (Figure 7) explain these differences. For Univ. Eiffel, this value for the "standard" triggering is fixed at 0.8 s except for a few cases where it is zero, corresponding to a non-detection of the opponent vehicle, whereas it varies between 0.15 and 1.25 s for UNIFI, with a median value around 0.9 s.

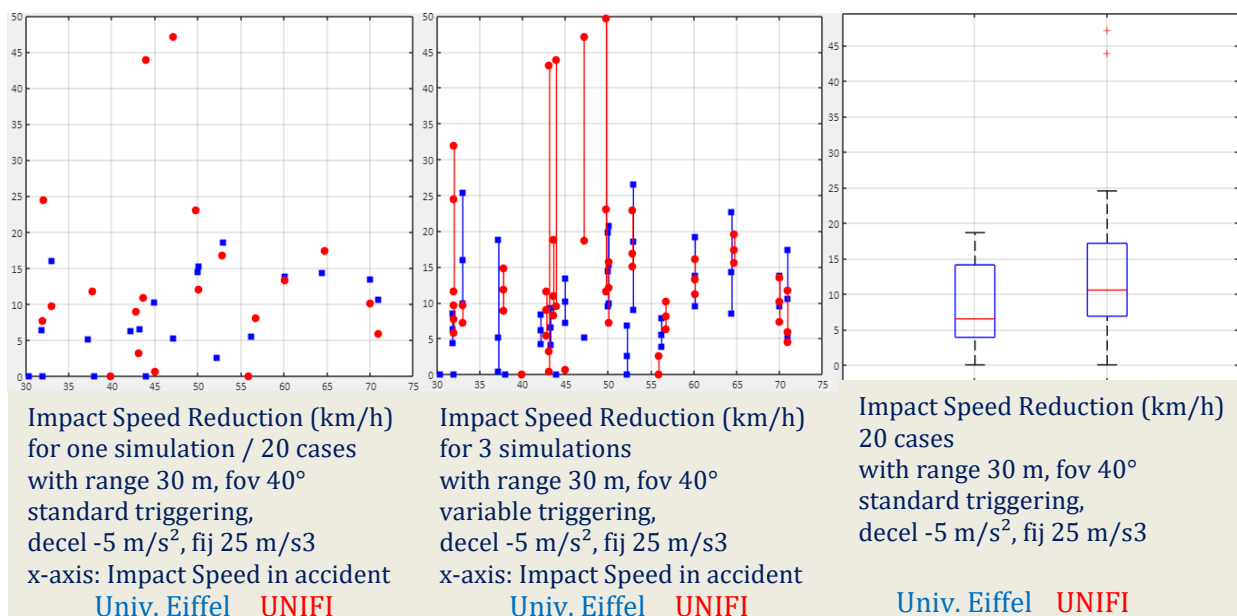


Figure 6. Comparison of Impact Speed Reduction with PCB for UNIFI and Univ. Eiffel simulations of the 20 shared cases

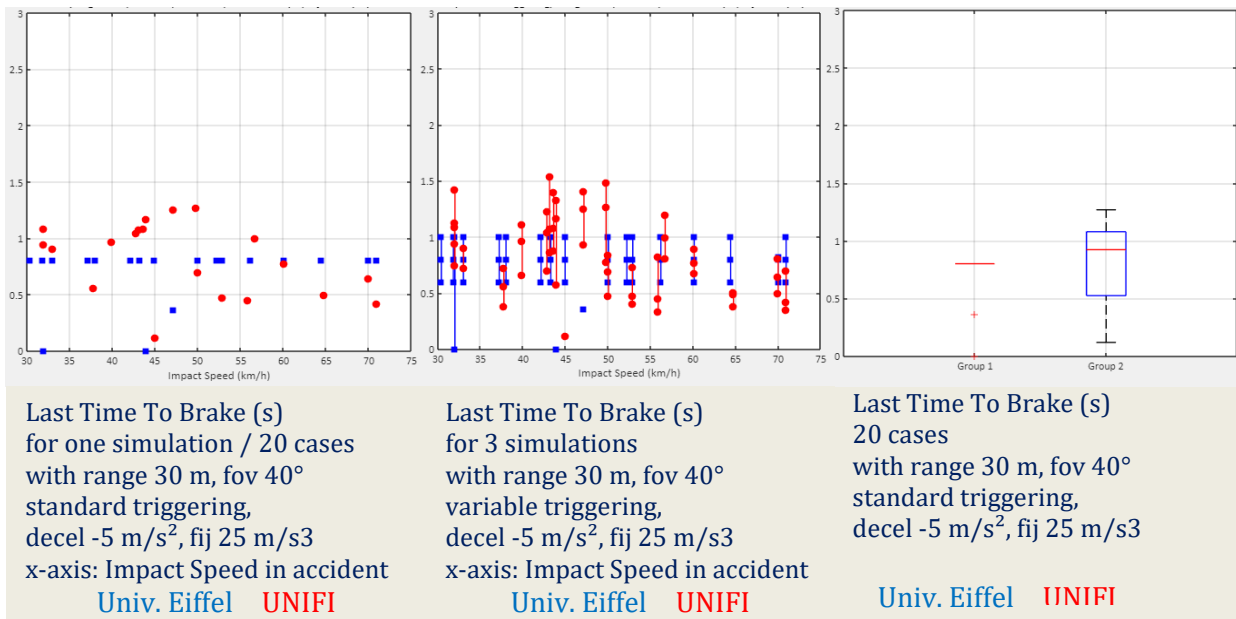


Figure 7. Comparison of Last Time To Brake with PCB for UNIFI and Univ. Eiffel simulations of the 20 shared cases

3.1.2 Results of simulation

3.1.2.1 Parametric study

The results of the PCB parametric study concern primarily the 60 accident cases, 30 EDA cases simulated by Univ. Eiffel and 30 InSafe cases simulated by UNIFI. They allow the study of the influence of the Field Of View, the triggering strategy, the deceleration applied by the PCB, and the Fade-In-Jerk. The influence of the range is studied thanks to the 40 cases simulated by Univ. Eiffel, including 30 EDA cases and 10 InSafe cases shared by UNIFI.

Figure 8 shows the influence of the Field Of View for an "average" set of parameters (see next paragraph). With a FOV of 10° (on either side of the longitudinal axis of the PTW, i.e. 20° of total aperture), detection is zero in at least half the cases. At 25° FOV, the median impact speed reduction is 4 km/h, at 40° it is 7.5 km/h. Beyond that, the speed reduction gain is small.

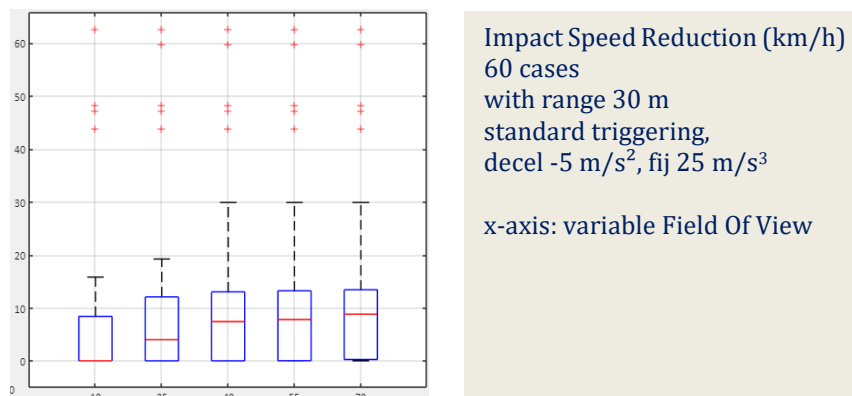


Figure 8. Influence of the Field Of View in PCB simulation for a set of average parameters

All other parameters being equal, the triggering strategy induces a median reduction in impact speed of 5km/h (conservative), 7.5 km/h (standard) and 12 km/h (progressive) (Figure 9).

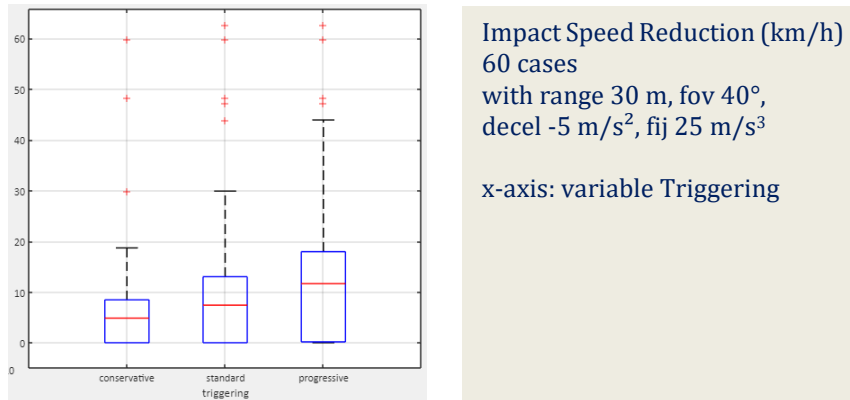


Figure 9. Influence of the Triggering in PCB simulation for a set of average parameters

If we now consider the PCB deceleration variation between -3, -5 and -7 m/s², in average condition for the other parameters, the median speed reduction induced is 2.5 km/h, 7.5 km/h and 9 km/h.

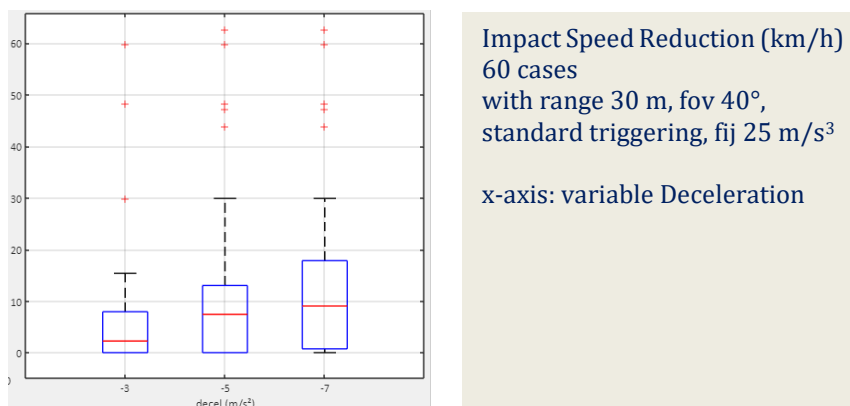


Figure 10. Influence of the Deceleration in PCB simulation for a set of average parameters

The influence of fade-in-jerk is quite small, with median speed reductions of 6 km/h for a fade-in-jerk of 15 m/s³ and 7 km/h for a fade-in-jerk of 25 m/s³.

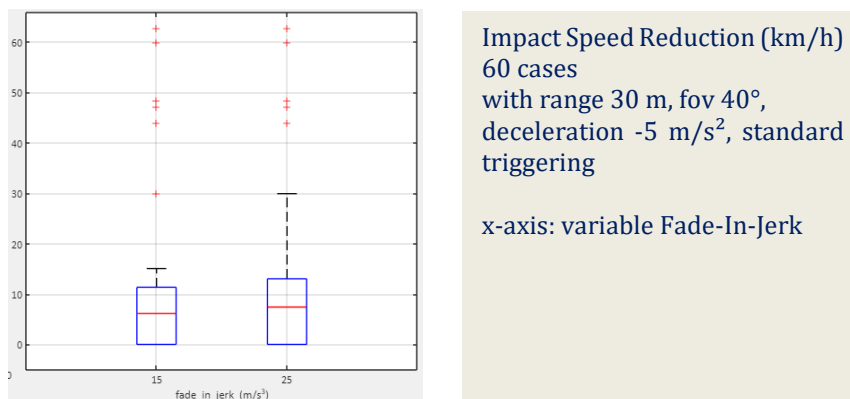


Figure 11. Influence of the Fade-In-Jerk in PCB simulation for a set of average parameters

For the 40 cases simulated by Univ. Eiffel, the influence of the range could be measured, first under average condition (Figure 12) and then under optimistic condition (Figure 13). In both cases, there is only a small difference between a range of 30 m and a range of 45 m and no difference beyond that. For the average condition, it is 0.2 km/h and it is due to only one case; for the optimistic condition, it is 0.4 km/h and it is due to three cases.

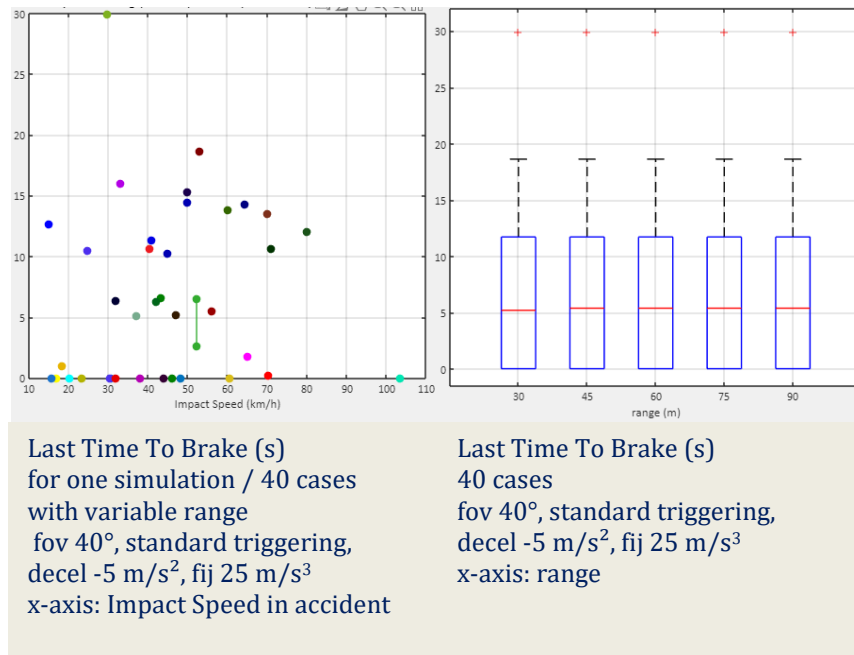


Figure 12. Influence of the range in PCB simulation for a set of average parameters

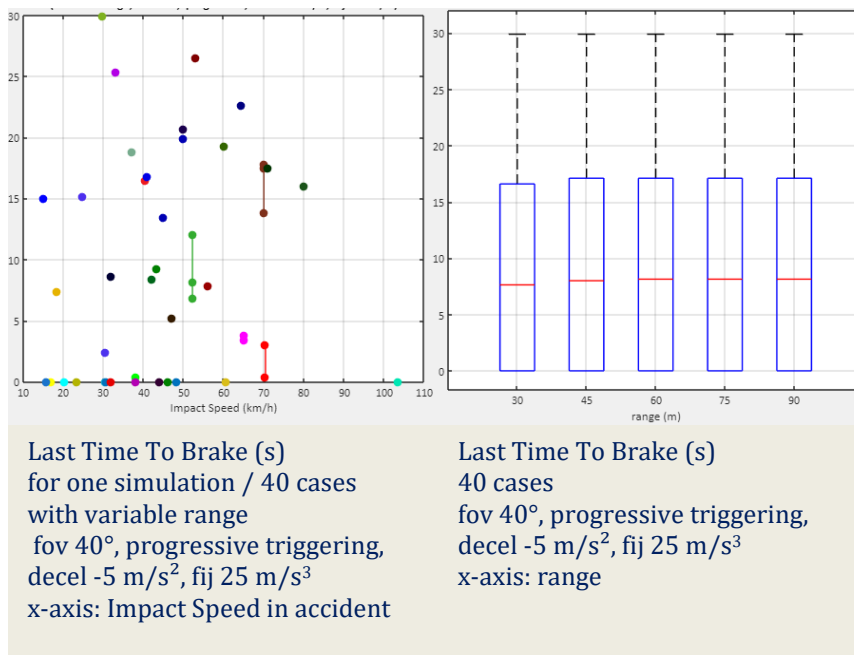


Figure 13. Influence of the range in PCB simulation for a set of optimistic parameters

3.1.2.2 Pessimistic / Average / Optimistic configurations

The large number of parameters considered in the analysis of PCB effects (field of view, range, deceleration, fade-in jerk, triggering, i.e. $5 \times 5 \times 3 \times 2 \times 3 = 450$ configurations) allows for a wide exploration of the different combinations of settings for the system. On the contrary, such variety makes it difficult to provide a clear overview of the expected benefits for the system.

For a synoptic analysis of the influence of PCB on the considered cases, among the 450 configurations, three combinations of parameters were selected to represent typical system effects assuming a pessimistic (low efficiency), average, and an optimistic approach (high efficiency).

Considering that long sensor ranges had limited influence on the system effectiveness (due to the last resort triggering approach, combined with the considered crash configurations), such parameter was set to 30 m for all the three configurations; field of view was set to 15° for the pessimistic configuration and 45° for both the average and the optimistic configurations. Considering that both field of view and range had limited influence on the system effectiveness, it was decided to keep a balance between simulation effort and sensor/system characteristics. A typical radar sensor has a range of about 60m and an aperture angle of $\pm 45^\circ$.

Depending on the motorbike, different applications for PCB implementation must be selected, especially to avoid false-positive triggers. Depending on the motorbike, different applications must be selected, especially to avoid false-positive triggers. This may lead to system dead times until a system reacts from detection, pre-processing to activation. In UNIFI simulations it has been considered a very short dead time (0.05 s).

The influence of the reduced system parameters is justified by the fact that only 7 cases out of a total of 30 common cases are accidents where both vehicles are driving in the same direction and do not need a large FOV for example. While in intersection situations the aperture angle usually has to be larger in order to detect opposing vehicles at high speeds, the sensor parameters were not used in these simulations beyond the standard.

Concerning the deceleration, the more conservative setting (3 m/s^2 as target deceleration) was selected for the pessimistic estimation. Considering the overall encouraging results of the field tests (Task 5.2), for the average and optimistic combination of parameters, a deceleration of 5 m/s^2 was chosen. With the same motivation, the fade-in jerk was set to 15 m/s^3 for the pessimistic configuration and 25 m/s^3 for both the average and optimistic configuration.

3.1.2.3 Pessimistic / Average / Optimistic results

Overall, considering all 60 simulated cases in the three pessimistic, average and optimistic configurations, median reductions in impact speeds of 0 km/h, 7.4 km/h and 11.6 km/h are obtained. (Figure 14, left). There are, however, 15 accident cases for which the PCB does not activate in any of the three configurations. Excluding these cases, the median speed reduction values become 2.8 km/h, 10.7 km/h and 15.1 km/h (Figure 14, right).

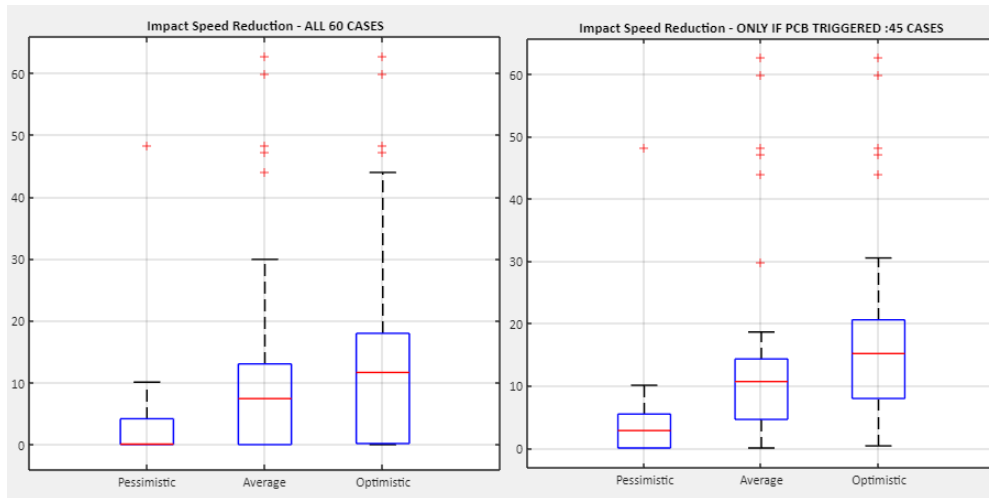


Figure 14. Impact speed reductions for the three main configurations considered for the influence of the PCB trigger

In more detail, Figure 15 shows the impact speeds in the 60 accidents in ascending order and the new speeds with the PCB in the three pessimistic, average and optimistic configurations. In 8 cases at least one of the 3 configurations allows an accident avoidance with a PTW speed reduced to 0 without impact. In 15 cases, the PCB was not triggered in any of the 3 configurations studied. This may be due to the PCB not detecting the opposing vehicle, or to the fact that the motorcyclist was already braking beyond the deceleration value set for the PCB (-3 or -5 m/s² depending on the configuration) at the moment when the PCB should have triggered.

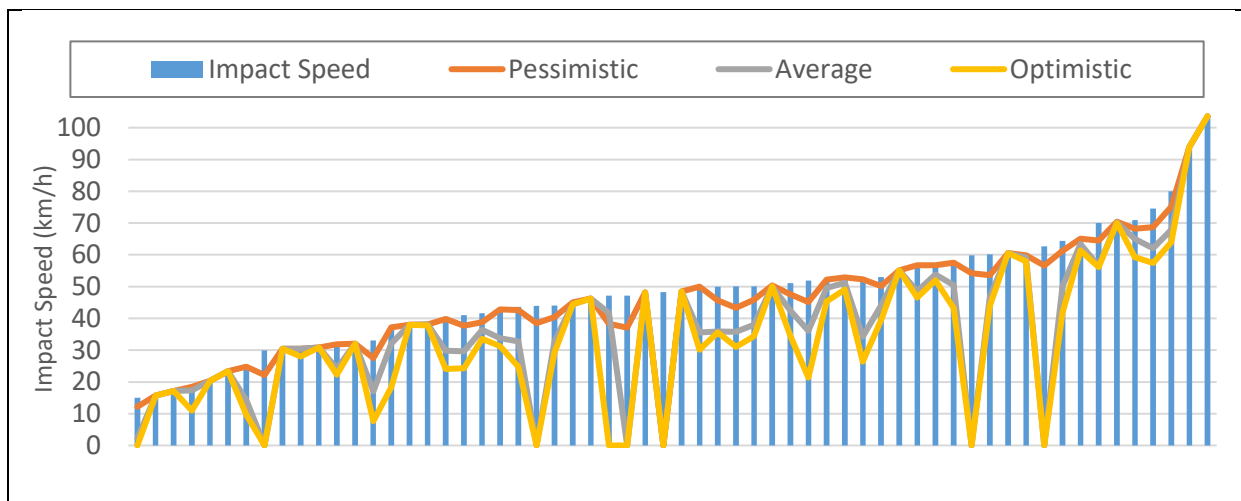


Figure 15. Impact speed without and with PCB in the three main configurations considered

3.1.3 Societal Benefits

3.1.3.1 Methodological Reminders

According to the D6.1 of the Pioneers project (see [D6.1]), the evaluation of the societal benefits of the PCB will be based on the work published by (Johan Strandroth, 2012) and entitled: “Head on collisions between passenger cars and heavy good vehicles (HGV): Injury risk function and benefits of Autonomous Emergency Braking (AEB)”

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).

The methodology is as follow (see Figure 16):

1. Data on accidents have to be gathered in order to establish risk functions. Risk functions were plotted as the proportion of injured in interval of change of velocity.
2. In depth data are analysed to find the possible closing speed and delta V reduction with PCB.
3. The delta V reduction is applied to the risk exposure.
4. Then the injury reduction was calculated based on the derived risk curve.
5. Finally, the decrement of severe accidents through national statistic is estimated.

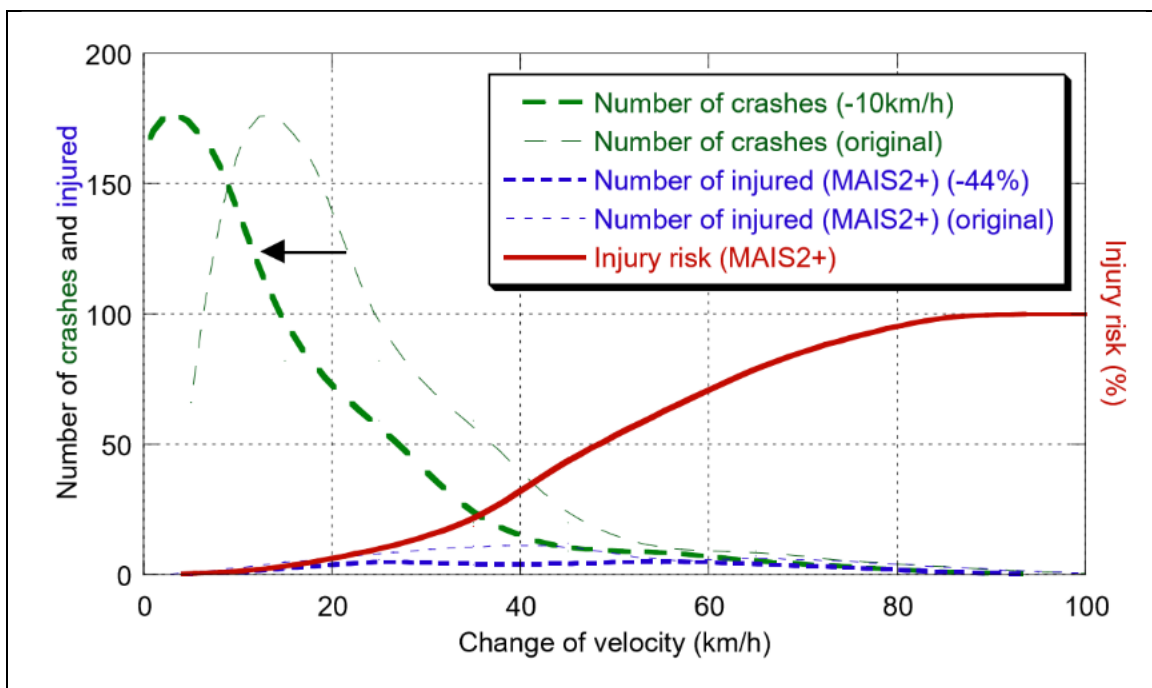


Figure 16. Reduction in injured occupant due to reduced delta V (Johan Strandroth, 2012)

3.1.3.2 Injury Risk Function

The first step of the evaluation concerns the establishment of an injury risk function. According to the literature review performed in the D6.1 of the Pioneers project, the establishment of the originally risk curves can be based on curves proposed by [Ding et al., 2019]. So the following curve will be used to evaluate the IRF for a motorcyclist (see Figure 17). The best fitting model in this 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 17).

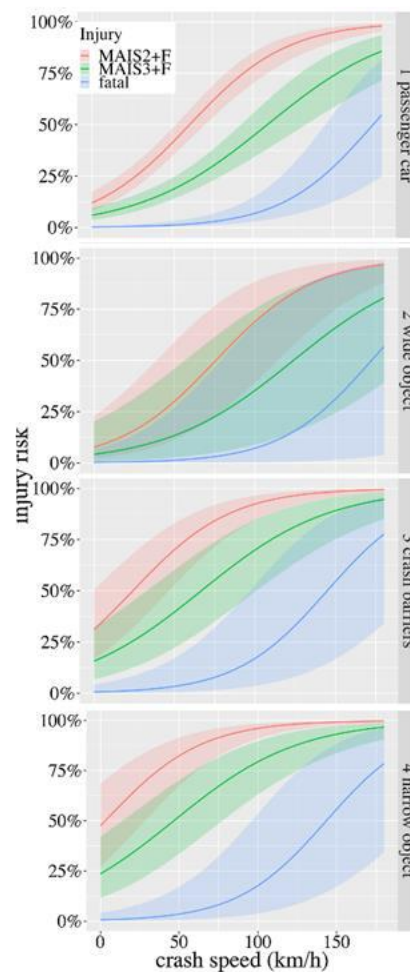


Figure 17. Injury risk curves for different crash opponents (Ding et al, 2019)

3.1.3.3 Relative Speed Distribution with/without PCB

The second step of the process aims to evaluate the reduction of speed with PCB. To do that, the work is based on the results provided by the 60 simulated cases in the three pessimistic, average and optimistic configurations.

Moreover, the effects of the PCB were assessed in terms of a reduction of the absolute and relative impact speed of the PTW. But in some of the cases, the intervention of the PCB may even cause a full crash avoidance. This was not the primary aim of the system and was treated

as a side effect that positively influences the benefit assessment of the PCB. So, potential benefits for the cases in which a PCB intervention determined a collision avoidance in the simulations were analyzed as a separate group and 2 modalities were considered:

- one with avoidance where accidents avoided are removed from the accident database. So, in this case, the number of accidents is reduced and the benefits are calculated with "only" 59 or 54 or 52 accidents.
- one without avoidance: in this configuration, in fact we consider for the avoided accident the impact speed of the lower configuration without avoidance (except for one case that we decided to suppress because it is avoided for any configuration - case ID 046).

As a recall, in 15 cases, the PCB was not triggered in any of the 3 configurations studied.

Based on this hypothesis, all the 60 accident cases were classified by relative impact speed and by injuries. Three kinds of injuries were considered:

- slight injuries which concern AIS 1 & 2
- serious injuries "AIS3+" which concern injuries AIS 3, 4 and 5 (but not fatal)
- fatal injuries

For each intervals of relative impact speed and type of injuries, the new number of accidents with PCB were calculated and classified. Results are presented in the following Figure 18.

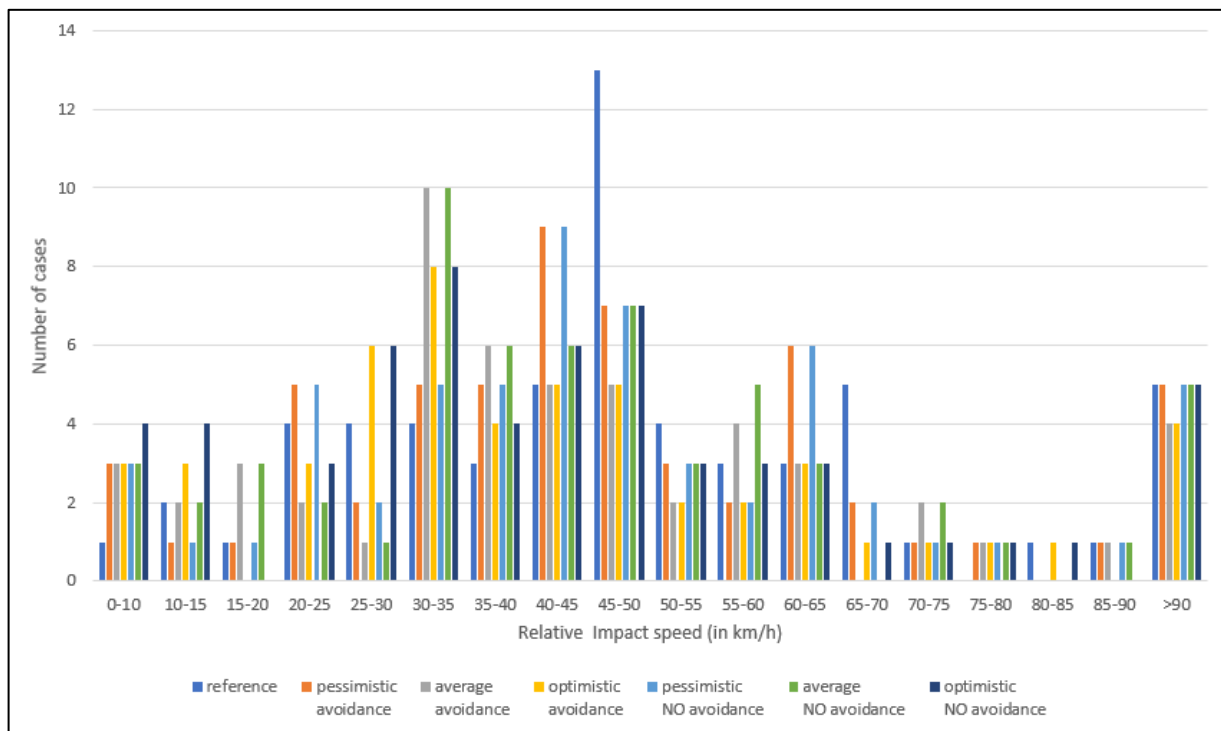


Figure 18. New distribution of the 60 accident cases with/without PCB with different type of PCB (optimistic/average/pessimistic, avoidance/no avoidance)

3.1.3.4 Injury Benefits

The final step of the evaluation concerns the calculation of the reduction injuries using the PCB. According to the figure 16 provided by [Strandroth et al., 2012], this work consists on multiplying the IRF by the distribution of number of accident cases in relation with the relative speed. The original and the new relative speed are considered to evaluate the difference between without PCB and with the PCB.

Results are presented in the three following figures respectively Figure 19 for slight injuries, 20 for serious injuries and 21 for fatal injuries.

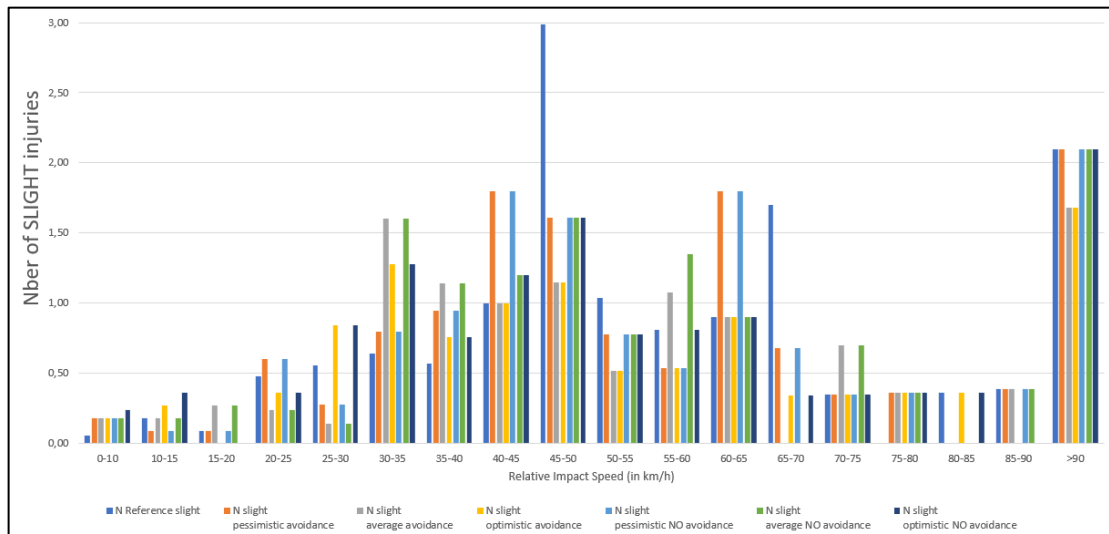


Figure 19. New distribution of slight injuries with/without PCB with different type of PCB (optimistic/average/pessimistic, avoidance/no avoidance)

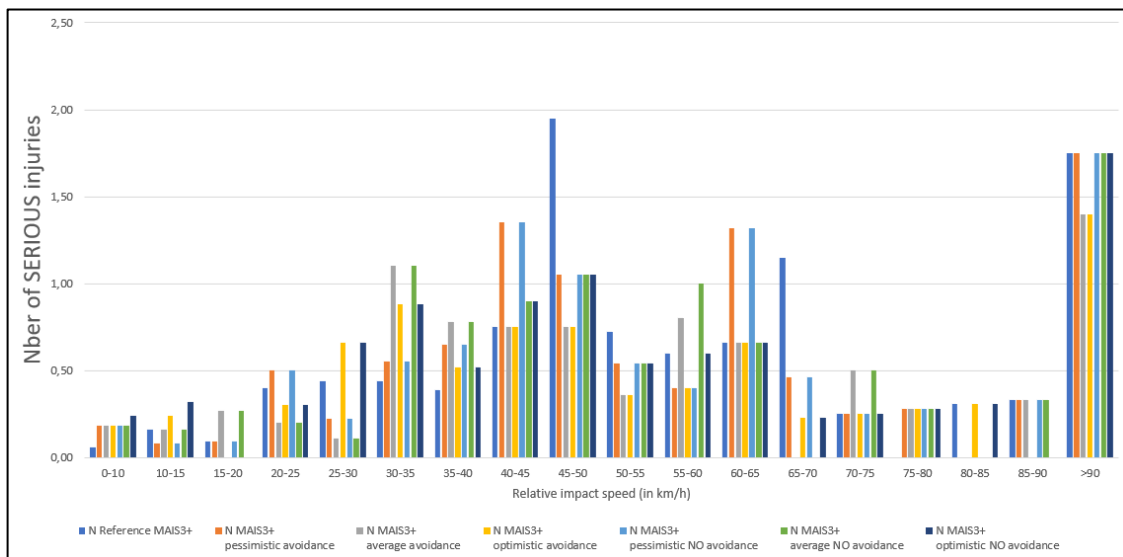


Figure 20. New distribution of serious injuries with/without PCB with different type of PCB (optimistic/average/pessimistic, avoidance/no avoidance)

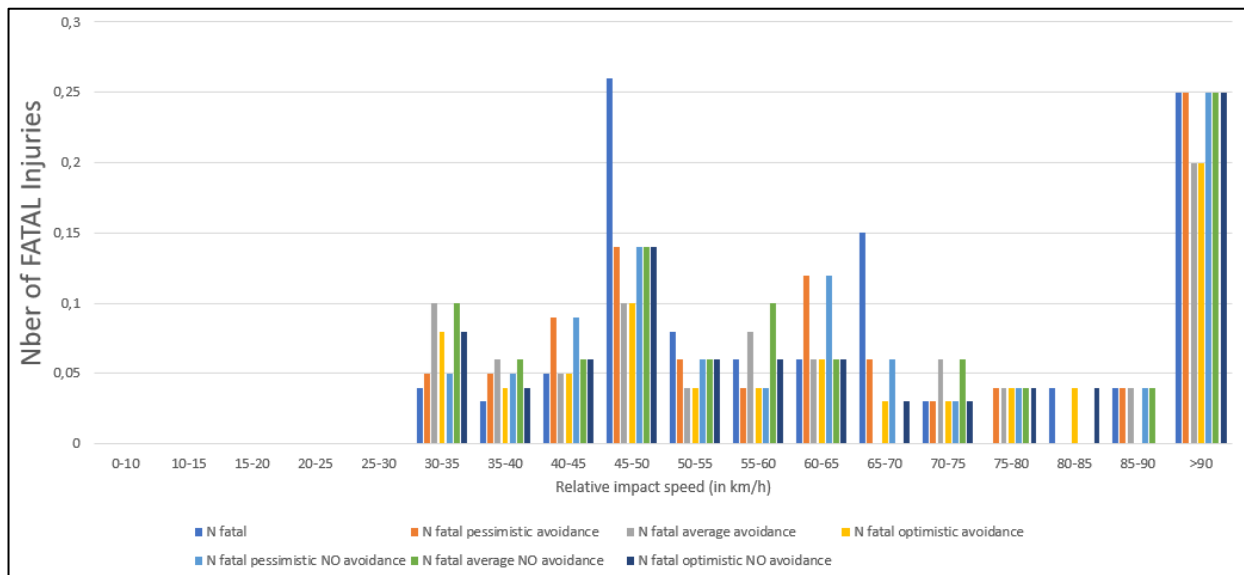


Figure 21. New distribution of fatal injuries with/without PCB with different type of PCB (optimistic/average/pessimistic, avoidance/no avoidance)

Finally, global benefits in terms of percentage of reduction of slight, serious and fatal injuries can be calculated. These global results are provided in the following Table 11 in function of the modality of the PCB (avoidance/no avoidance) and the version of the PCB (pessimistic/average/optimistic).

	N_{fatal} pessimistic	N_{MAIS3+} pessimistic	N_{slight} pessimistic	N_{fatal} average	N_{MAIS3+} average	N_{slight} average	N_{fatal} optimistic	N_{MAIS3+} optimistic	N_{slight} optimistic
avoidance	-11,01	-4,31	-5,77	-23,85	-17,42	-18,92	-31,19	-21,82	-23,42
NO avoidance	-11,01	-4,31	-5,77	-11,01	-6,12	-7,59	-18,35	-9,19	-11,04

Table 11. Societal benefits for the PCB (in %)

These percentages will be then used for the calculation of the cost benefits using the safety cube software (see part 4 of the deliverable).

But in order to extrapolate these benefits at a national or a European level, it is necessary to consider that the 60 accidents selected for the evaluation were mainly “Accident Scenario 3” as defined in the Deliverable 1.1 of the PIONEERS projects. Since this scenario represents about 35% of the accidents according to global database like CARE (see Deliverable 1.1), it will be considered that PCB will be efficiency on only 35% of accidents cases (see part 3).

3.2 Airbag jackets

3.2.1 Methodological Reminders

A similar methodology used for the evaluation of the PCB benefits has been also considered for the societal benefits of the airbag jackets.

The most important aspects are as follows:

- the establishments of the Injury Risk Function without airbag jacket;
- the determination of the hypothesis of the protection level provided by the airbag jacket in terms of injuries reduction;
- the calculation of the distribution of the injuries according to the rider speed of impact without airbag jacket;
- and finally, the new distribution of injuries with airbag jackets.

3.2.2 Injury Risk Function without airbag

In order to establish the Injury Risk Function, four accident databases already used in the WP1 of the PIONEERS project were considered to perform this work. These databases were the GIDAS from BAST, the EDA from the University Gustave Eiffel (UGE), the InSAFE from the University of Florence (UNIFI) and the database from the University of Munich (LMU).

According to the D1.1 of the PIONEERS project, accidents considered were KSI L1 and L3 cases in urban and rural environment (excluding motorways) with maximum 2 participating parties. All kind of injuries were considered (AIS1-6) but regarding the Body Regions, only the thorax and thoracal spine “Thorax/TS” (body region 3) and the abdomen and lumbar spine “Abdomen/LS” (body region 4) were considered (see D1.1 for the detailed definition of the body region). For each of these accidents, partners provided an estimation of the rider impact speed and not the PTW impact speed. The impact speed of the body region was first considered when it was available like for the cases reconstructed in task 2.1 of the PIONEERS project. If it is not available, the impact speed of the rider has been taken.

The global sample of the accident cases which have been considered for the evaluation is summarized in the following Table 12. These cases are the same as were considered in WP1. In all, more than 1300 accidents were considered but only 382 accidents concern a rider with at least one injury in the PIONEERS defined trunk body region and also contain the necessary variables for the development of an IRF. That is to say that only 29.1% of accident have to be considered for an extrapolate evaluation at a national or European level.

	BAST/GIDAS	1064
	UGE/EDA	48
	UNIFI/InSafe	58
	LMU	143
Total number of rider accidents:		1313
Total number of accidents with trunk injuries:		382

Table 12. Accidents considered for the societal benefits of the airbag jacket

The distribution of maximum injury severities for the trunk body region per each accident database is provided by Table 13.

	Univ. Eiffel- LMA/EDA	UNIFI/InSafe	BAST/GIDAS	LMU	Total
 AIS 1 	25	3	64	2	94
 AIS 2 	3	10	45	1	59
 AIS 3 	6	24	37	29	96
 AIS 4 	2	15	11	37	65
 AIS 5 	1	1	2	38	42
 AIS 6 			1	25	26
 Total 	37	53	160	132	382

Table 13. Injury severity distribution for the trunk body region per accident database

Then, it is possible to calculate the IRF for the trunk using these data as the cumulative frequency of the injuries in function of the rider impact speed. Three IRF were performed: one for the slight injuries (AIS 1 & 2), one for the serious injuries (AIS 3, 4 & 5) and a third one for the fatal injuries (AIS 6).

Results of these three IRF are presented in Figure 22.

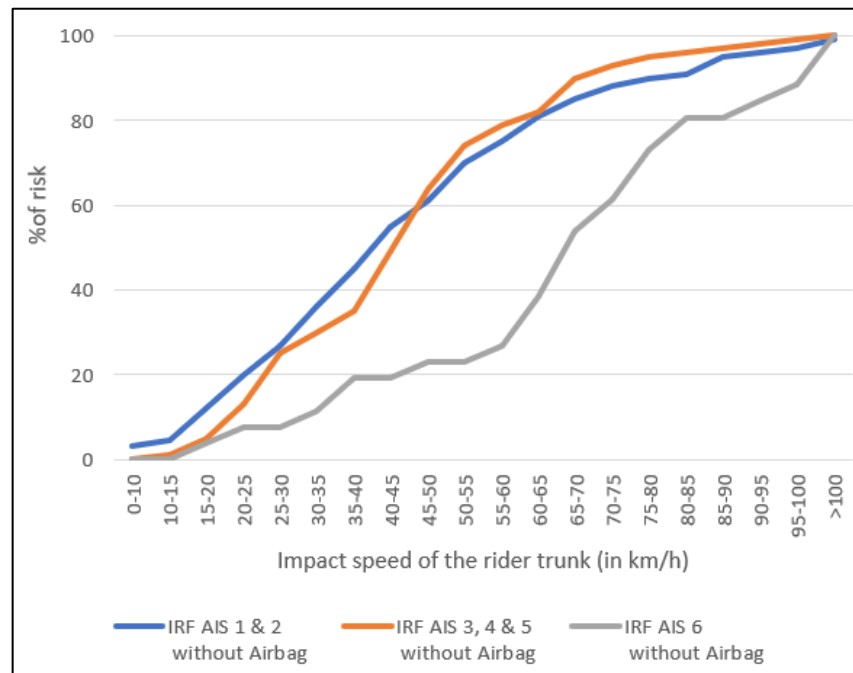


Figure 22. IRF for slight, serious and fatal injuries on the rider trunk without airbag

3.2.3 Airbag protection hypothesis

To estimate the economic benefit analysis provided by an Airbag-equipped jacket for motorcyclists, three different hypotheses have been defined and based on the findings of this kind of PPEs that have been developed during the PIONEERS project and whose initial prototypes were tested.

The hypotheses described below are not directly linked to the test conditions performed to the project prototypes.

Due to the fact that the machine designed to carry out the tests is the first version built exclusively to reproduce this type of test, and need to be reinforced in some points and if we add that some of the prototypes were not commercial products in their final version, can be confirmed that they are not representative tests for the rest of the products currently available in the market.

Within work package 3, the manufacturing process of the exclusive testing machine for personal protective equipment finished, and it allow to perform frontal impact tests to be carried out on this kind of PPEs equipped with airbag under different impact conditions.

During this task, the different levels of protection of these prototypes have been evaluated. Below, is shown the configuration of the test done in IDIADA's facilities (see **Error! Reference source not found.23**).

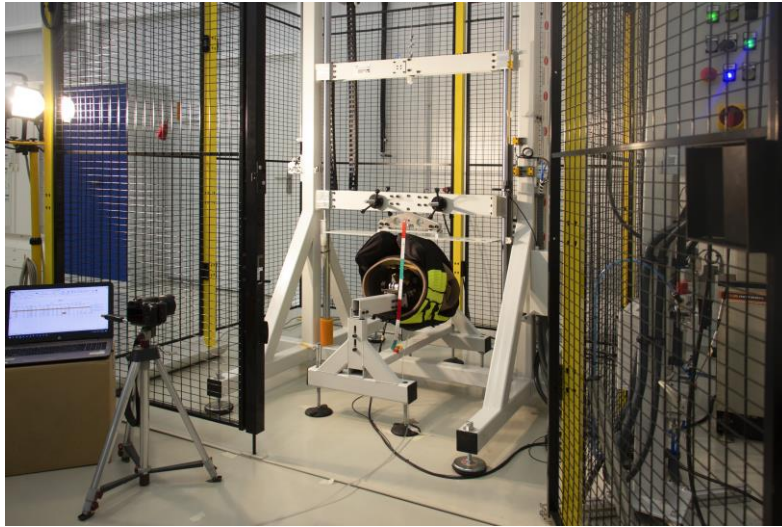


Figure 23. Test configuration for one of the airbag prototypes

An HIII 95th dummy was used to carry out the test. It was capable to simulate the torso of a human body in a frontal use case.

Under, are shown the test conditions selected for the physical tests in the laboratory, described in Table 14 for the flat striker and Table 15 for the cylindrical striker. The machine was able to demonstrate a good repeatability and reproducibility of the results.

Flat-striker-0-deg (physical test)				
Kg	speed (m/s)	height (m)	Potentiometer (mm)	Camera (mm)
25	3,2	0,6	38,04	48
25	3,2	0,6	37,69	48
25	3,2	0,6	37,33	49
25	3,2	0,6	37,69	49
25	3,2	0,6	37,33	48

Table 14. Flat striker 0 deg (physical test)

Cylindrical-striker-0-deg (physical test)				
Kg	speed (m/s)	height (m)	Potentiometer (mm)	Camera
25	3,24	0,6	37,69	42
25	3,23	0,6	38,04	55
25	3,24	0,6	38,05	55
25	3,21	0,6	38,05	53
25	3,22	0,6	38,04	55

Table 15. Cylindrical striker 0 deg (physical test)

The tested prototypes were able to support well to these conditions, although in some cases, depending on the level of development of the sample, the applied test condition could have been too severe.

The proposal for the optimized airbag jacket safety benefit hypothesis is based on three steps. Starting from the most optimistic ($v \leq 20$ km/h), an intermediate level ($v \leq 30$ km/h) and finally the pessimistic and more restrictive one ($v \leq 40$ km/h).

For the first step, considering the low speed, it could reduce the injuries caused by the impact by 1 point in AIS. It was proved under the physical test up to 11.50 km/h.

As for the intermediate level it should be able to completely avoid AIS1 injuries, but not be able to reduce or mitigate all other injuries as the system is optimized for lower speed and to reduce injuries caused from a front impact. For the highest range of speeds within this intermediate level up to 30 km/h, it has not been physically tested so we cannot guarantee its full effectiveness against an impact at these speeds.

The worst case, due to its high impact speed between 30 km/h and 40 km/h, the system is considered as not effective for these range since we cannot confirm its results.

Airbag equipped jackets seems effective at low speeds. The aim of this device is to completely prevent serious frontal impact injuries to the torso at lower speeds and only to reduce the severity of injuries at high speeds.

Here, triggering of the airbag jackets is not considered. This analysis considers a perfect trigger that will always cause the airbag to deploy in the case of a relevant accident. This is both functionally challenging and has implications for the ease of use and therefore market acceptance of the jackets. In Work Package 5, a novel interoperable connected triggering system was developed. See [deliverable D5.2](#) for more details.

3.2.4 Speed Distribution and injury benefits

Based on the data provided by the different partners (see Section 3.2.2), it has been possible to calculate the distribution of the estimated rider's trunk impact speed by type of injuries (slight, serious and fatal), shown in Figure 24.

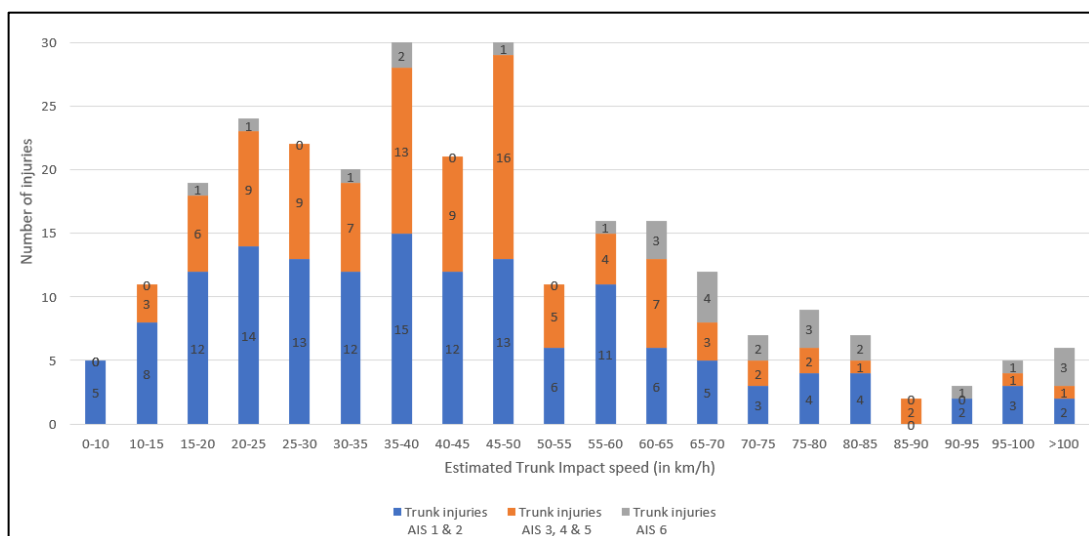


Figure 24. Estimated rider's trunk impact speed distribution in function of the severity of injuries (slight, serious and fatal injuries)

Then, according to the hypotheses considered in the previous part, it was possible to estimate the new AIS for each accident. As a recall, the three hypotheses considered were:

- Hyp. 1: the airbag jacket provides a reduction of an AIS-1 for speed impact lower than 20km/h
- Hyp. 2: the airbag jacket provides a reduction of an AIS-1 for speed impact lower than 30km/h
- Hyp. 3: the airbag jacket provides a reduction of an AIS-1 for speed impact lower than 40km/h

The following Table 16 provides the new AIS distribution for each of these hypotheses. And finally, it is possible to estimate the benefits in terms of percentage of injuries reduction for each hypothesis (see Table 16).

Hypothesis 1:

become	AIS1	AIS2	AIS3	AIS4&5	AIS6	TOTAL
AIS0	12					12
AIS1	82	13				95
AIS2		46	10			56
AIS3&4&5			86	107	2	195
AIS6					24	24
TOTAL	94	59	96	107	26	382

Hypothesis 2:

become	AIS1	AIS2	AIS3	AIS4&5	AIS6	TOTAL
AIS0	32					32
AIS1	62	20				82
AIS2		39	26			65
AIS3&4&5			70	107	2	179
AIS6					24	24
TOTAL	94	59	96	107	26	382

Hypothesis 3:

become	AIS1	AIS2	AIS3	AIS4&5	AIS6	TOTAL
AIS0	52					52
AIS1	42	27				69
AIS2		32	38			70
AIS3&4&5			58	107	5	170
AIS6					21	21
TOTAL	94	59	96	107	26	382

Global benefits:

	original	Hyp. 1: AIS -1 <20km/h	Benefits Hyp. 1 (%)	Hyp. 2: AIS -1 <30km/h	Benefits Hyp. 2 (%)	Hyp. 3: AIS -1 <40km/h	Benefits Hyp. 3 (%)
AIS 0	0	12		32		52	
AIS 1&2 slight injuries	153	151	-1,3	147	-3,9	139	-9,2
AIS3+ serious injuries	203	195	-3,9	179	-11,8	170	-16,3
AIS6 Fatal injuries	26	24	-7,7	24	-7,7	21	-19,2

Table 16. New injuries distribution with Airbag jacket and the corresponding benefits in function of the three different hypotheses

These percentages will be then used for the calculation of the cost benefits using the safety cube software (see part 4 of the deliverable).

Concerning the extrapolation of these benefits at a national or a European level, it is necessary to consider that all kinds of accidents scenarios were used for the evaluation. But on the 1313 accidents considered, only 382 have a trunk injury. So, it will be considered that Airbag Jackets will be efficiency on only 29.1% of accidents cases (see part 4).

3.3 Lateral Protector

3.3.1 Methodological Reminders

Exactly the same methodology used for the airbag jacket evaluation was considered for the evaluation of the lateral protector benefits. It consists on:

- the establishments of the Injury Risk Function without lateral protectors;
- the determination of the hypothesis of the protection level provided by the lateral protectors in terms of reduction of injuries;
- the calculation of the distribution of the injuries according to the lower leg rider speed of impact without lateral protector;
- and finally, the new distribution of injuries with lateral protectors.

3.3.2 Injury Risk Function without lateral protector

To establish the Injury Risk Function, three accident databases already used in the WP1 of the PIONEERS project were considered to perform this work. These databases were provided by BAST, University Gustave Eiffel (UGE) and the University of Florence (UNIFI).

According to the D1.1 of the PIONEERS project, accidents considered were KSI L1 and L3 cases in urban and rural environment (excluding motorways) with maximum 2 participating parties. All kind of injuries were taken into account (AIS1-6), while for the Body Region only the BR-6 “Lower leg” was considered (see D1.1 for the detailed definition of the body region). Because only lateral impact on the lower leg for the PTW have to be considered here, it has been decided to retain accidents with an impact angle between -70° to -110° and between 70° to 110° (see Figure 25).

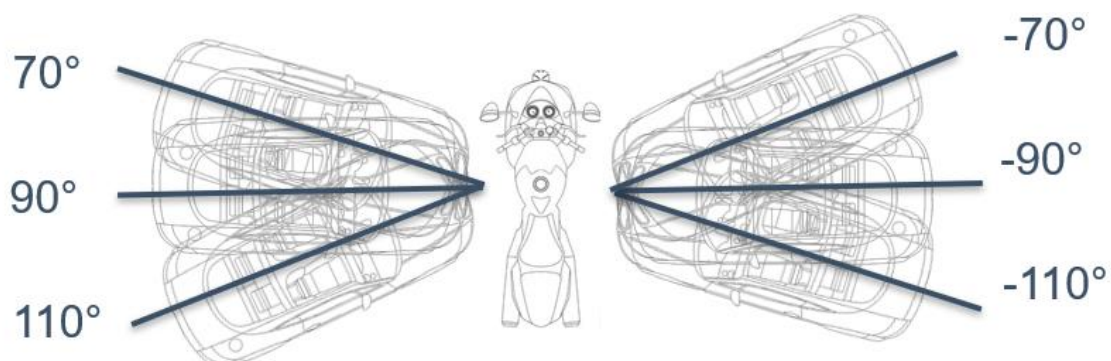


Figure 25. Impact angle configurations considered for the lateral protector evaluation

For each of these accidents, partners provided an estimation of the opponent vehicle impact speed.

The global sample of the accident cases which have been taken into account for the evaluation is summarised in Table 17 (cf. Section 2.2.2). In total, more than 1300 accidents were considered. After data cleaning (e.g. completeness of the dataset for needed variables), in only 81 accidents the rider suffered at least a lower leg injury, thereof 63 accidents with a slight injury (AIS 1 & 2) and 18 with a serious injury (AIS 3+). That is to say that only 7% of accident have to be considered for an extrapolate evaluation at a national or European level.

	Number of accidents	of Number of accidents with LL injury	Number of accidents with LL injury in a lateral impact
BAST/GIDAS	1064	517	79
UGE/EDA	48	15	1
UNIFI/InSafe	58	22	1
LMU (not considered)	143	-	-
Total	1313		81

Table 17. Accidents considered for the societal benefits of the lateral protectors

In all, the database contained 63 accidents with a slight injury (AIS 1 & 2) and 18 with a serious injury (AIS 3+).

Then, it is possible to calculate the IRF as the cumulative frequency curves for the lower leg in lateral impact using these data and the correlation between the opponent impact speed and the corresponding injuries. Two IRF were performed: one for the slight injuries (AIS 1 & 2) and one for serious injuries (AIS 3, 4 & 5) as no fatal injuries (AIS 6) exists in the accident databases. Results of these two IRF are presented in the following Figure 26.

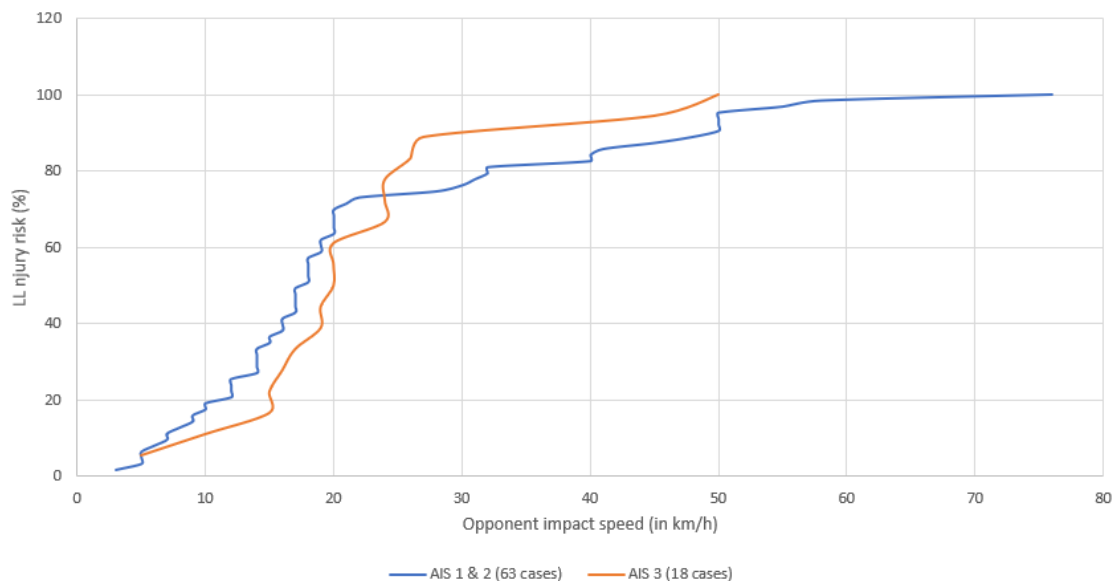


Figure 26. IRF for slight and serious for the lower leg in lateral impact configuration and without lateral protectors

3.3.3 Hypotheses for Lateral Protection

In order to estimate the Economic Benefit Analysis provided by on-board motorcycle lateral protectors, a series of hypotheses have been made. These hypotheses are based on the findings from the lateral protection devices that have been developed in the PIONEERS project and whose initial prototypes were tested in Task 3.5 of this project. However, these hypotheses are not directly linked to any of the two On-board safety systems that were tested in T3.5 (namely: Piaggio Safety Leg Cover and Ducati Lateral Airbags), as those were unique development tests that were conducted using non-optimized systems. Thus, they are not representative of the real effect that lateral protectors could have on the entire European motorcycle fleet. This fact is explained in further detail in the sub-sections found below.

3.3.3.1 Crash tests with on-board safety systems (Task 3.5)

As part of WP3, in task 3.3, a series of crash test protocols were developed in order to assess the effectiveness of the on-board safety systems (lateral protectors) that were developed by PIAGGIO and DUCATI in the framework of the PIONEERS Project.

The PIAGGIO system consists of a safety leg cover that was assembled on the PIAGGIO MP3 motorcycle. This countermeasure intended to reduce lower leg injury in side impact crash tests where the opponent vehicle hits the motorcycle at a speed of up to 15 km/h. On the other hand, the DUCATI system consists of two lateral airbags to be assembled on the DUCATI MULTISTRADA motorcycle with design conditions based on the opponent vehicle having an impact speed of up to 30 km/h. Further information on both of these systems may be found in Deliverable 5.2. However, images of both vehicles (with their corresponding lateral protectors) may be found below in Figure 27.

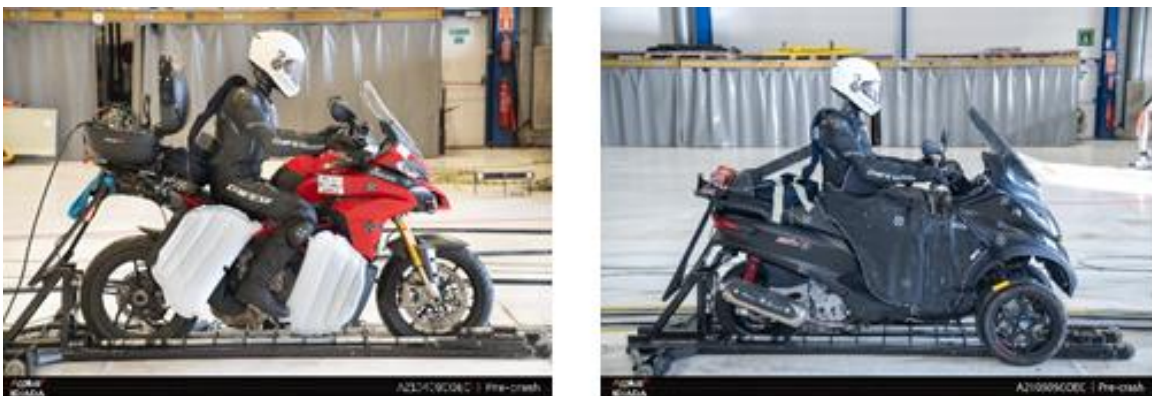


Figure 27. Pre-crash images of the DUCATI Multistrada with lateral airbags (left) and the PIAGGIO MP3 with safety leg cover (right)

Given the design conditions explained above, test protocols were defined in order to do a preliminary evaluation of the safety benefit potential of the PIAGGIO and DUCATI systems. In both cases, the tested motorcycle was impacted laterally by an AE-MDB barrier. The impact speed was of 30 km/h in the DUCATI tests and 15 km/h in the PIAGGIO tests. In both cases, the motorcycle was riding at a constant target speed of 30 km/h. Figure 28, found below shows a schematic of this test configuration.

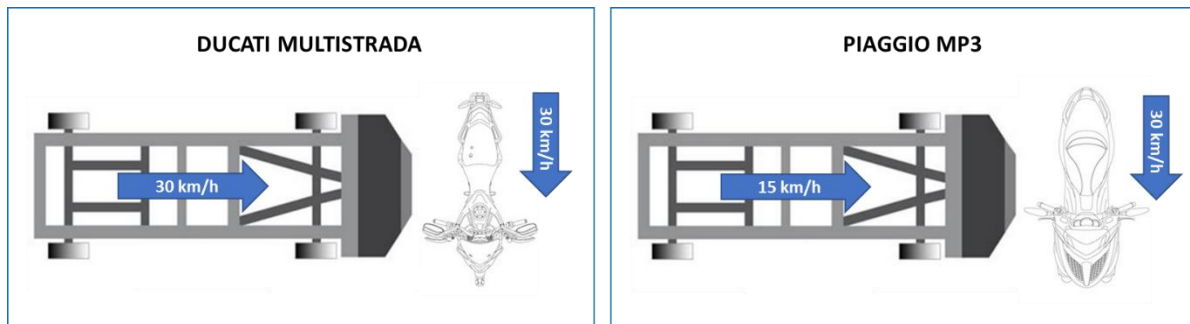


Figure 28. Images showing the two different layouts for the full-vehicle crash tests

In both cases, the motorcycle rider was either a full MATD (Motorcyclist Anthropometric Test Device) dummy or a modified version of the Hybrid III 50th percentile male with the abdomen and lower body of an MATD dummy. Further information on the test protocol definition is reported in Deliverable 3.1.

Regarding the test matrix, only two tests were done with each motorcycle. In each case, one test without the lateral protector was conducted, and a matching test was conducted using the corresponding lateral protector. The summarized test matrix can be seen in Table 18.

Test	Test number		Vehicle		Test date	Test type	Barrier		
	IDIADA	Customer	Brand	Set-up			Trolley	Def. element	Serial no.
1	A210409COEC	WP3.5_1	Ducati	W/ AIRBAG	28/1/2021	Side barrier AE-MDB	Lateral	Cellbond AE-MDB	208318
2	A210410COEC	WP3.5_2	Ducati	W/O AIRBAG	28/1/2021		Europe	Side impact	208429
3	A210415COEC	WP3.5_3	Piaggio	W/O safety leg cover	29/1/2021		1400 kg	barrier Part.no.	208317
4	A210505COEC	WP3.5_4	Piaggio	W/safety leg cover	2/2/2021		(+/-20 kg)	70AEMDB05L	208427

Table 18. Task 3.5 Crash Test Matrix

Given that only one test with lateral protector was done in each case (DUCATI and PIAGGIO), and that the systems were not optimized at the time of the test (they were only initial prototypes), it is impossible and unrealistic to directly use the data from these crash tests to estimate the Economic Benefits of implementing optimized-market ready lateral protectors in European motorcycles. Nevertheless, the in-depth analysis of crash test results that was conducted in D3.3 did show initial findings regarding the safety potential of these types of systems. For this reason, the overall safety potential of the PIAGGIO and DUCATI systems will be summarized below and used in section 3.3.2.2 to generate the hypotheses that would be applicable to ideal, optimized lateral protectors with design condition similarities to the systems that have been developed in the PIONEERS project.

In the case of the Ducati Lateral Airbags, in the crash tests, the airbags had a cushioning effect that showed clear potential to reduce the overall severity of the crash event. This could be seen by means of the reduced intrusion in the impactor deformable element (attached to a trolley representing the opponent vehicle) and the reduced free flight distance of the rider with regards to the motorcycle after the crash. However, this type of solution would only be effective at higher speeds, as the airbags would probably not deploy at low impact speeds.

On the other hand, in the case of the PIAGGIO test, although clear differences were not found between the test with and without the safety leg cover, it is believed that with an optimized glue (to make sure that the protective foam pads stay in place during the impact), foam density and size, this system could significantly prevent and mitigate lower extremity injuries when the crash is at very low speeds. At higher speeds, the foam blocks would detach making the system no longer effective.

3.3.3.2 Retained Hypotheses

Analysing the results explained in the previous sub-section, it is easy to deduce that different hypotheses have to be made depending on whether the lateral protector is designed for low speed effectiveness (such as the PIAGGIO safety leg cover) or for mid-to-high speed effectiveness (such as the DUCATI Lateral Airbags).

With this idea in mind, a series of hypotheses were made, where for each MAIS level found in lateral impact accident statistics data with lower leg injury, a new MAIS level was estimated considering the potential safety benefit of the lateral protector in the given speed and considering its baseline characteristics.

In this way, lower-speed countermeasures are assumed to be aimed at entirely avoiding lower leg injuries when the impact is at a very low speed and only reducing the injury severity level at the optimal design speed. On the contrary, medium-speed countermeasures would always aim at reducing the injury severity over full injury avoidance.

A summary of the overall Hypotheses that have been used for the calculation of the Economic Benefits linked to the Lateral Protectors may be found in the following page in Table 19.

PIONEERS T6.2 Optimized Lateral Protector Lower Leg Safety Benefit Hypotheses Proposal				
Speed (km/h)	Old IMAIS	New Optimistic IMAIS	Reasoning/Comments	
			Overall Comment on Type of countermeasure	
v < 5	1	0	At such a low speed, an optimized low-speed countermeasure should be able to entirely avoid "old" AIS1 and AIS2 injuries and reduce the severities of all other injuries	
	2	0		
	3	1		
	0	0		
5 ≤ v < 10	1	0	At a "medium" low speed, an optimized low-speed countermeasure should be able to reduce the severities of all injury levels by 1 point	
	2	1		
	3	2		
10 ≤ v < 15	1	0	At a "higher" low speed, this countermeasure should be able to entirely avoid AIS1 injuries but will not be able to reduce or mitigate all other injuries as the system is optimized for a lower speed (max. 15 km/h) and to reduce lower severity injuries	
	2	2		
	3	3		
v ≥ 15	1	1	The system is <u>not</u> effective in this speed range	
	2	2		
	3	3		
Low-speed countermeasure <small>(only effective from 0-15 km/h)</small>	Overall Comment on Type of countermeasure Assumption: The low-speed lateral protector countermeasure (such as the PIAGGIO one) is designed for optimal performance up to 10 km/h. The aim of the system is to entirely avoid lower extremity injuries at lower speeds and to only reduce injury severity at optimal speeds			
	v < 15	1	1	It is assumed that the airbags will not deploy in an impact at this speed The system is <u>not</u> effective in this speed range
		2	2	
		3	3	
		0	0	
	15 ≤ v < 20	1	1	At a "lower" high-speed range, the countermeasure should be able to reduce the severities of all injury levels by 1 point
		2	2	
		3	2	
	20 ≤ v < 25	1	1	In this speed range, although the AIS1 injuries cannot be avoided (as the leg is impacted fully by an opponent vehicle at a relatively high speed), the severity of the AIS2 and 3 is reduced due to the cushioning effect of the Airbag
		2	1	
		3	2	
	25 ≤ v < 30	1	1	At the highest speed, the system is not capable of avoiding AIS1 injuries as it does not cover the lower leg at all and the tibia is still impacted by the opponent vehicle at high speed. The system can only aim at reducing the severity of the highest AIS
2		2		
3		2		
v ≥ 30	1	1	The system is <u>not</u> effective in this speed range	
	2	2		
	3	3		
Medium-speed countermeasure <small>(only effective from 1.5-30 km/h)</small>	Overall Comment on Type of countermeasure Assumption: The Medium-speed lateral protector countermeasure (such as the DUCATI one) is designed for optimal performance up to 30 km/h. The system works by providing a cushioning effect to reduce the crash severity but does not provide direct coverage of the leg from an opposing vehicle. Therefore, it is aimed at reduction in injury severity over avoidance of injury.			
	v < 15	1	1	It is assumed that the airbags will not deploy in an impact at this speed The system is <u>not</u> effective in this speed range
		2	2	
		3	3	
		0	0	
	15 ≤ v < 20	1	1	At a "lower" high-speed range, the countermeasure should be able to reduce the severities of all injury levels by 1 point
		2	2	
		3	2	
	20 ≤ v < 25	1	1	In this speed range, although the AIS1 injuries cannot be avoided (as the leg is impacted fully by an opponent vehicle at a relatively high speed), the severity of the AIS2 and 3 is reduced due to the cushioning effect of the Airbag
		2	1	
		3	2	
	25 ≤ v < 30	1	1	At the highest speed, the system is not capable of avoiding AIS1 injuries as it does not cover the lower leg at all and the tibia is still impacted by the opponent vehicle at high speed. The system can only aim at reducing the severity of the highest AIS
2		2		
3		2		
v ≥ 30	1	1	The system is <u>not</u> effective in this speed range	
	2	2		
	3	3		

Table 19. T6.2 Optimized Lateral Protector Lower Leg Safety Benefit Hypotheses Proposal

3.3.4 Speed Distribution and injury benefits

Based on the data provided by the different partners, it has been possible to calculate the distribution of the opponent speed impact on the lower leg of the rider by type of injuries (slight and serious). The following Figure 29 provides these distribution.

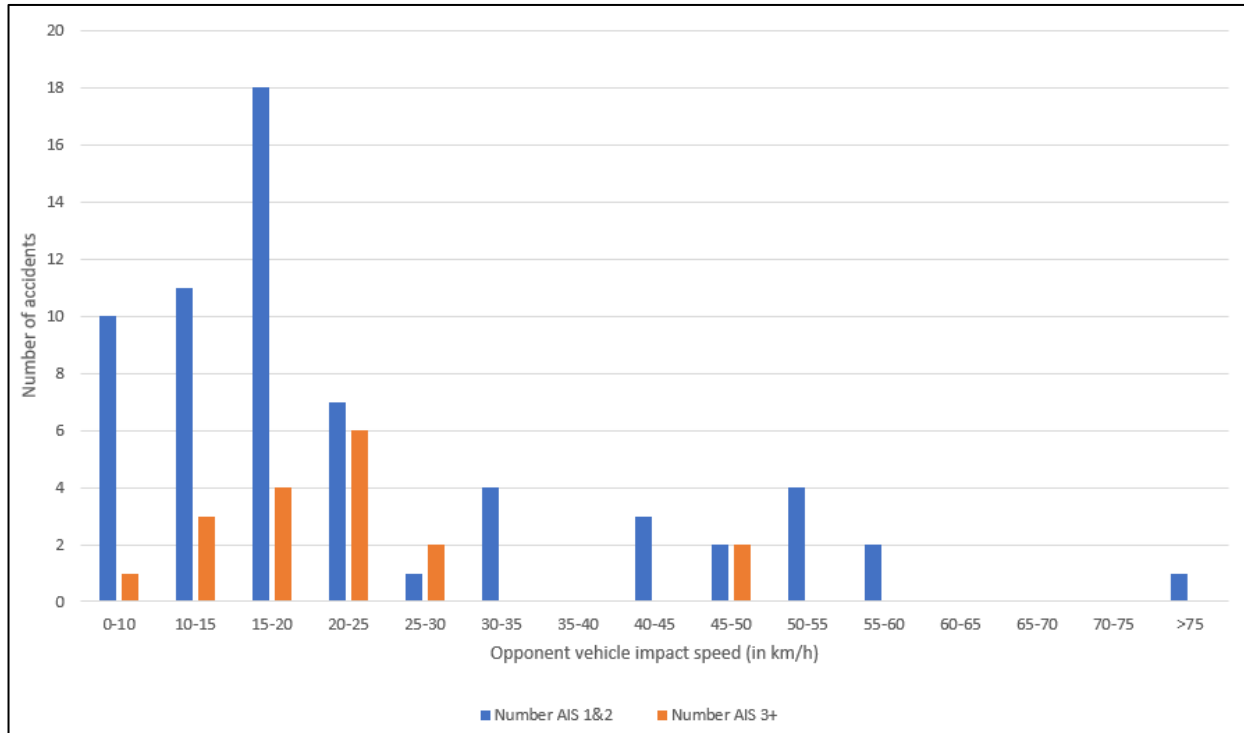


Figure 29. Distribution of the opponent vehicle speed impact in function of the severity of injuries (slight and serious injuries)

Then, according to the hypotheses considered in the previous part (low-speed one and Medium-speed one), it was possible to estimate the new AIS for each accident. The following Tables 20 provide the new AIS distribution for each of these hypotheses and the global benefits considered for the economical evaluation (see Part 4).

Low Speed countermeasure benefits:

become	AIS1	AIS2	AIS3	TOTAL
AIS0	15			15
AIS1	23	3		26
AIS2		22	1	23
AIS3			17	17
TOTAL	38	25	18	81

Medium Speed countermeasure benefits:

become	AIS1	AIS2	AIS3	TOTAL
AIS0	14			14
AIS1	24	8		32
AIS2		17	14	31
AIS3			4	4
TOTAL	38	25	18	81

Global benefits:

	Original MAIS Body region LowerLeg (6)	Low-Speed Countermeasur e (<15km/h)	Low-Speed Countermeasur e Benefits	Medium-Speed Countermeasur e (<30km/h)	Medium-Speed Countermeasur e Benefits
Cases AIS 0	0	15		14	
Cases AIS 1 & 2 (slight injuries)	63	49	-22,2	63	0
Cases AIS 3+ (serious injuries)	18	17	-5,6	4	-77,8

Table 20. New injuries distribution with lateral protectors and the corresponding benefits in function of the two different hypotheses

Concerning the extrapolation of these benefits at a national or a European level, it is necessary to consider that all kinds of accidents scenarios were used for the evaluation. But on the all accidents considered, only 81 have a Lower Leg injury in lateral configuration. So, it will be considered that Lateral Protectors will be efficiency on only 7% of accidents cases (see part 4).

4 Economic Benefits

The objective of Economic Benefits is to evaluate how new PPE system and new methods can contribute to significant health care cost savings. Benefits could concern the cost of medical treatment, the length of hospital stay, the necessity for special medical treatments, the probability of long-term disability, etc.

As explained in detail in deliverable 6.1 Impact Evaluation Methodology (see [D6.1]), the methodology that will be used to evaluate the economic benefits is based on the outcome of the SafetyCube project (<https://www.safetycube-project.eu>).

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.

The SafetyCube DSS includes an Economic Efficiency Analysis calculator known as SafetyCube DSS E3 calculator. The E3 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. The calculator integrates updated information of crash-costs in the European countries, allowing to express all costs and benefits of a measure in monetary values and conducting cost benefit analysis.

This calculator for Economic Efficiency Evaluation of road safety counter measures allows to combine information about the effectiveness of a measure (i.e. the percentage of crashes or casualties prevented) with the costs of this measure.

A table chart showing the SafetyCube input and outputs may be found below in Figure 30:

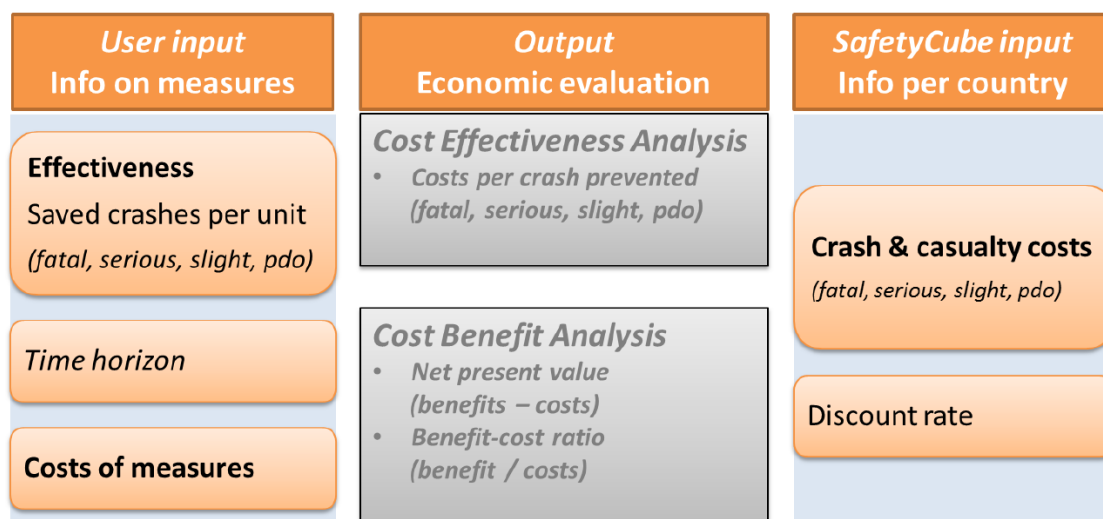


Figure 30. Table of SafetyCube DSS E3 calculator input and outputs

The first decisions taken have been about how to define the setup of these calculations. The inputs used to execute these calculations are:

- Measure to apply: Is about which measures will be analyzed. According to the work done, the measures are Pre-Crash Braking, Airbag-equipped jackets and on-board motorcycle Lateral Protectors.
- Country: The calculation tool provides output as European Union (as a whole) or can provide outputs to specific countries. As a European project we will calculate benefits in terms of total European Union, but we could calculate some data for specific countries during some dissemination activity.
- Horizon (period of analysis): The horizon included in the study is 5 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.
- Reduction in terms of casualties or crashes: There are two available options: Reduction in casualties or Reductions in crashes. According to Deliverable 6.1, measures included in this project are considered to have passive safety objectives as they are triggered once the collision is known to be unavoidable, therefore, studied measures in this analysis will be evaluated against the reduction of casualties
- Costs: In calculations it has been considered two types of costs: Awareness campaign and some promotion of buying the measures. These two types of costs will be compared with savings because of the use of these measures. The analysis is planned with the Public Administration perspective: Calculations includes savings and costs of the same actor, so the analysis is consistent.
- Number of units implemented: The measures analyzed are not yet available in the market, so a couple of scenarios of implementation have defined for each measure.
- Safety: It is necessary to include the improvement of safety performance. The selected methodology defines the safety improvement through the % of reduction of fatalities, the % of reduction of serious injuries and the % of reduction of slight injuries for each measure. Of course, the number of fatalities, serious injuries and slight injuries where the measure can work is also needed.

The outputs of these calculations are:

- Costs of the measure: Total cost of implanting measures. It depends on the number of units and the costs of adopting measures.
- Total benefits: The savings generated by usage of better protective solutions. These savings are mainly by savings in health and social costs because of the reduction of injuries due to the use of solutions developed by PIONEERS Project.
- Benefit-cost ratio (benefits/costs): Ratio obtained from benefits vs costs.
- Net effect (benefits – costs): Resulting total amount of money.
- Break-even costs: Unit cost to reach the break-even.

On the following pages the results of these calculations will be shown of each measure.

4.1 Pre-Crash Braking (PCB)

According to analysis of PCB explained in section 3.1 (Safety Benefits of Pre-Crash Braking), two modalities have been analysed:

- **With avoidance:** In this modality, avoided accidents have been removed from the accident database. Therefore, the accidents where crash is avoided are not considered in the benefits.
- **Without avoidance:** In this modality, Project has considered the avoided accidents, for the avoided accidents impact speed for lower configuration has been considered.

With avoidance analysis:

The % of reduction of fatalities, serious injuries and slight injuries are shown below:

PCB Benefits (AVOIDANCE) (% of reduction)	Pessimistic evaluation	Average evaluation	Optimistic evaluation
Fatalities	-11,01%	- 23,85%	- 31,19%
Serious injuries	-4,31%	- 17,42%	- 21,82%
Slight injuries	-5,77%	- 18,92%	- 23,42%

Table 21. PCB Benefits (AVOIDANCE)

Without avoidance analysis:

The % of reduction of fatalities, serious injuries and slight injuries are shown below:

PCB Benefits (NOT AVOIDANCE) (% of reduction)	Pessimistic evaluation	Average evaluation	Optimistic evaluation
Fatalities	-11,01%	- 11,01%	- 18,35%
Serious injuries	-4,31%	- 6,12%	- 9,19%
Slight injuries	-5,77%	- 7,59%	- 11,04%

Table 22. PCB Benefits (NOT AVOIDANCE)

This % of reduction has been identified by analysing 60 accidents with two participants involved (car and motorcycle). The methodology is fully explained in section 2.1.

Step 1: Estimate the number of accidents where motorcycle and car have been involved.

According to CARE dataset used for analysis in Deliverable D1.1 Powered Two-Wheelers - Road Traffic Accident scenarios and common injuries (submitted EC), the total number of these accidents with fatalities or seriously injured casualties in Europe during 2013-2017 were 203.980. So, we estimate an average of 40.796 accidents by year.

Considering that total fatalities in EC in 2015 were 3.952, considering that accidents where car and motorcycle involved are 35,2% and considering usual proportions between slight and serious injuries, the estimated composition of European accidents where car and motorcycle are involved are 1.393 fatalities, 12.984 serious injuries and 19.475 slight injuries.

Step 2: Estimate the implementation rate of PCB among all motorcycles in Europe.

It is not possible to know the rate of implementation of this device in following years, therefore, we must work in 2 scenarios. First scenario with low implementation rate of PCB's (1% of total motorcycles in Europe) and a second scenario with higher implementation rate (2% of total motorcycles in Europe).

Considering that Europe have 24.000.000 of motorcycles (ACEM 02/04/2020), we can estimate that scenario of low implementation rate of PCB includes 240.000 motorcycles equipped with PCB and scenario of higher implementation rate of PCB includes 480.000 motorcycles equipped with PCB.

Step 3: Estimate the costs.

It has been considered two types of costs, the cost of an awareness campaign to increase the rate of implement PCB's on European motorcycles and the cost of promotion the bought of this type of safety device.

Regarding the awareness campaign, we estimate a hypothetical cost to whole European Union. If the objective is to have a higher implementation rate it is needed a higher awareness campaign. Therefore, scenarios have considered an awareness campaign with a 10.000.000€ cost to reach 1% of implementation rate and 20.000.000€ cost one to reach 2% of implementation rate.

The scenarios also consider some costs to promote this implementation. Project has considered that administrations could afford, just as an example, the promotion of 150€ of each PCB installed in each motorcycle in European Union.

The results:

Considering that we have 2 scenarios of reduction of injuries and we have 2 scenarios in terms of implementation rate. We have 6 scenarios for each modality:

With avoidance analysis:

PCB Scenarios. Avoidance	Low rate of implem. & pessimistic	Low rate of implem. & average	Low rate of implem. & optimistic	High rate of implem. & pessimistic	High rate of implem. & average	High rate of implem. & optimistic
Measure to apply:	Pre-Crash braking	Pre-Crash braking	Pre-Crash braking	Pre-Crash braking	Pre-Crash braking	Pre-Crash braking
Country:	EU (Whole)	EU (Whole)	EU (Whole)	EU (Whole)	EU (Whole)	EU (Whole)
Period of analysis:	5 years	5 years	5 years	5 years	5 years	5 years
Awareness campaign:	10.000.000€	10.000.000€	10.000.000€	20.000.000€	20.000.000€	20.000.000€
Costs (Promotion)	150€	150€	150€	150€	150€	150€
Number of units implem.	240.000	240.000	240.000	480.000	480.000	480.000
Fatalities with PCB	14	14	14	28	28	28
Serious inj's. with PCB	130	130	130	260	260	260
Slight inj's. with PCB	195	195	195	390	390	390
Fatalities reduction (%)	-11,01%	- 23,85%	- 31,19%	-11,01%	- 23,85%	- 31,19%
Serious inj's. reduction (%)	-4,31%	- 17,42%	- 21,82%	-4,31%	-17,42%	- 21,82%
Slight inj's. reduction (%)	-5,77%	- 18,92%	- 23,42%	-5,77%	- 18,92%	- 23,42%
Cost	46.000.000 €	46.000.000 €	46.000.000 €	92.000.000 €	92.000.000 €	92.000.000 €
Total Benefits	25.482.050 €	71.573.489 €	91.515.142 €	50.951.959 €	143.119.621 €	182.994.626 €
Net Value	-20.517.950 €	25.573.489 €	45.515.142 €	-41.048.041 €	51.119.621 €	90.994.626 €
Benefit-Cost ratio	0,55%	1,56%	1,99%	0,55%	1,56%	1,99%
Promotion Break even	65 €	257 €	340 €	64 €	256 €	340 €

Table 23. PCB Economic Benefits (AVOIDANCE)

Without avoidance analysis:

PCB Scenarios.Not Avoidance	Low rate of implem. & pessimistic	Low rate of implem. & average	Low rate of implem. & optimistic	High rate of implem. & pessimistic	High rate of implem. & average	High rate of implem. & optimistic
Measure to apply:	Pre-Crash braking	Pre-Crash braking	Pre-Crash braking	Pre-Crash braking	Pre-Crash braking	Pre-Crash braking
Country:	EU (Whole)	EU (Whole)	EU (Whole)	EU (Whole)	EU (Whole)	EU (Whole)
Period of analysis:	5 years	5 years	5 years	5 years	5 years	5 years
Awareness campaign:	10.000.000€	10.000.000€	10.000.000€	20.000.000€	20.000.000€	20.000.000€
Costs (Promotion)	150€	150€	150€	150€	150€	150€
Number of units implem.	240.000	240.000	240.000	480.000	480.000	480.000
Fatalities with PCB	14	14	14	28	28	28
Serious inj's. with PCB	130	130	130	260	260	260
Slight inj's. with PCB	195	195	195	390	390	390
Fatalities reduction (%)	-11,01%	- 11,01%	- 18,35%	-11,01%	- 11,01%	- 18,35%
Serious inj's. reduction (%)	-4,31%	- 6,12%	- 9,19%	-4,31%	- 6,12%	- 9,19%
Slight inj's. reduction (%)	-5,77%	- 7,59%	- 11,04%	-5,77%	- 7,59%	- 11,04%
Cost	46.000.000 €	46.000.000 €	46.000.000 €	92.000.000 €	92.000.000 €	92.000.000 €
Total Benefits	25.482.050 €	29.243.168 €	46.492.410 €	50.951.959 €	58.473.963 €	92.964.319 €
Net Value	-20.517.950 €	-16.756.832 €	492.410 €	-41.048.041 €	-33.526.037 €	964.319 €
Benefit-Cost ratio	0,55%	0,64%	1,01%	0,55%	0,64%	1,01%
Promotion Break even	65 €	80 €	152 €	64 €	80 €	152 €

Table 24. PCB Economic Benefits (NOT AVOIDANCE)

Conclusions:

The average evaluation is the most probable, therefore it seems reasonable that European countries promote PCB (with an awareness campaign and promoting at least 100€ the buying of these devices). In a 5 years period, this cost will be balanced by savings from health and social expenses, and the most important: in a high rate of implementation (with the average evaluation) Europe can save, at least, 30 human lives in this period (using modality Avoidance)

In case of higher rate of implementation, the number of lives saved will be higher. For example, with a theoretical 15% of PCB implementation rate, in 5 years period almost 250 lives will be saved in Europe (using modality Avoidance)

It is also necessary to emphasize that this scenario considers only the benefits in one type of accident: Accidents with two participants (Motorcycles vs. passenger car), that means 35.2% of total PTW accidents.

4.2 Airbag jackets

According to analysis of Airbag explained in section 3.2 (Safety Benefits of Airbag), the % of reduction of fatalities, serious injuries and slight injuries are shown below:

AIRBAG Benefits (% of reduction)	Scenario 1	Scenario 2	Scenario 3
Fatalities	- 7,7%	- 7,7%	- 19,2%
Serious injuries	- 3,9%	- 11,8%	- 16,3%
Slight injuries	- 1,3%	- 3,9%	- 9,2%

Table 25. AIRBAG Benefits

This % of reduction has been identified by analysing accidents with trunk injuries (29,1% of total). These scenarios are supported with 3 hypotheses:

Scenario 1: AIS -1 for rider impact Speed < 20 km/h

Scenario 2: AIS -1 for rider impact Speed < 30 km/h

Scenario 3: AIS -1 for rider impact Speed < 40 km/h

Step 1: Estimate the number of accidents with trunk injuries.

According to CARE dataset used for analysis in Deliverable D1.1 Powered Two-Wheelers - Road Traffic Accident scenarios and common injuries (submitted EC). The total number of this accidents with fatalities or seriously injured casualties in Europe during 2013-2017 are 203.980. So, we estimate an average of 40.796 accidents by year, but if we consider only accidents with trunk injuries, the number of accidents to account are 11.872.

Considering that total fatalities in EC in 2015 were 3.952, considering that accidents with trunk injuries are 29.1% and considering usual proportions between slight and serious injuries, the estimated composition of European accidents where car and motorcycle are involved are 1.150 fatalities, 10.722 serious injuries and 16.082 slight injuries.

Step 2: Estimate the implementation rate of Airbag jackets among all motorcycles in Europe.

It is not possible to know the rate of implementation of this device in following years, therefore, Project has worked in 2 scenarios. First, with a scenario with low implementation rate of Airbag jackets (3% of total riders in Europe) and secondly, with a scenario with higher implementation rate (6% of total riders in Europe).

Considering that Europe have 24.000.000 of motorcycles (ACEM 02/04/2020) and considering 1.2 riders for each motorcycle, we can estimate that scenario with low implementation rate includes 861.641 riders equipped with airbag jackets and scenario of higher implementation rate includes 1.723.281 riders equipped with airbag jackets.

Step 3: Estimate the costs.

It has been considered two types of costs, the cost of an awareness campaign to increase the rate of implement PCB's on European motorcycles and the cost of promotion the bought of this type of safety device.

Regarding the awareness campaign, we estimate a hypothetical cost to whole European Union. If the objective is to have a higher implementation rate it is needed a higher awareness campaign. Therefore, first scenarios have considered an awareness campaign with a 10.000.000€ cost to reach 3% of implementation rate and 20.000.000€ cost to reach 6% of implementation rate.

The scenarios also consider some costs to promote this implementation. PIONEERS Project has considered that administrations could afford, just as an example, the promotion of 80€ of each Airbag bought by each rider in European Union.

The results:

Considering that we have 3 scenarios of reduction of injuries and we have 2 scenarios in terms of implementation rate. We have 6 scenarios:

Airbag Scenarios	Low implement. rate & Scenario 1	Low implement. rate & Scenario 2	Low implement. rate & Scenario 3	High implement. rate & Scenario 1	High implement rate & Scenario 2	High implement rate & Scenario 3
Measure to apply:	Airbag	Airbag	Airbag	Airbag	Airbag	Airbag
Country:	EU (whole)	EU (whole)	EU (whole)	EU (whole)	EU (whole)	EU (whole)
Period of analysis:	5 years	5 years	5 years	5 years	5 years	5 years
Awareness campaign:	10.000.000€	10.000.000€	10.000.000€	20.000.000€	20.000.000€	20.000.000€
Costs (Promotion)	80€	80€	80€	80€	80€	80€
Number of units implem.	861.641	861.641	861.641	1.723.281	1.723.281	1.723.281
Fatalities with Airbag	35	35	35	69	69	69
Serious inj's. with Airbag	322	322	322	643	643	643
Slight inj's. with Airbag	482	482	482	965	965	965
Fatalities reduction (%)	- 7,70%	- 7,70%	-19,20%	- 7,70%	- 7,70%	-19,20%
Serious inj. reduction (%)	- 3,90%	-11,80%	-16,30%	- 3,90%	-11,80%	-16,30%
Slight inj. reduction (%)	- 1,30%	- 3,90%	- 9,20%	- 1,30%	- 3,90%	- 9,20%
Cost (€)	78.931.245 €	78.931.245 €	78.931.245 €	157.862.490 €	157.862.490 €	157.862.490 €
Total Benefits	46.469.832 €	83.847.384 €	149.314.960 €	92.928.679 €	167.661.533 €	298.584.011 €
Net Value	-32.461.413 €	4.916.139 €	70.383.716 €	-64.933.811 €	9.799.043 €	140.721.521 €
Benefit-Cost ratio	0,59%	1,06%	1,89%	0,59%	1,06%	1,89%
Promotion Break even	42,3 €	85,7 €	161,7 €	42,3 €	85,7 €	161,7 €

Table 26. AIRBAG Economic Benefits

Conclusions:

Considering the scenario 2 (the most realistic one), it seems reasonable that European countries promote Airbag jackets (with an awareness campaign and promoting 80€ the buying of this PPE). In a 5 years period, this cost will be balanced by savings from health and social expenses, and the most important: in a high rate of implementation (with the average evaluation) Europe can save, at least, 26 human lives in this period.

In case of higher rate of implementation, the number of lives saved will be higher. For example, with a theoretical 25% of AIRBAG implementation among riders, in a 5 years period around 110 lives will be saved in Europe.

It is also necessary to emphasize that this scenario considers only the benefits in one type of accident: accidents with trunk injuries in riders, that means 29.1% of total PTW accidents and considering the benefits in case of rider impact speed < 30 km/h. Probably at higher speeds there may be other benefits not studied by the Project.

4.3 Lateral Protector

According to analysis of Lateral protectors explained in section 3.3 (Safety Benefits of Lateral Protector), the % of reduction of fatalities, serious injuries and slight injuries are shown below:

Lateral Protector Benefits (% of reduction)	Reinforced Leg Cover (Low speed measure)	Lateral Airbag (High speed measure)
Fatalities	Not available	Not available
Serious injuries	- 5,6%	- 77,8%
Slight injuries	- 22,2%	- 0,0%

Table 27. Lateral Protector Benefits

PIONEERS project has analysed the benefits of two different solutions. On the one hand, Project has developed a solution to mitigate consequences of lateral impacts in low speed (effective in cases of speed <15 km/h), a Reinforced Leg Cover, on the other hand PIONEERS has developed a solution to mitigate lateral impacts in higher speed (effective in speed between 15 km/h and 30 km/h), Lateral Airbags.

These solutions are aimed to reduce the injuries in lower legs (Body region 6) in lateral impacts in cases where opponent vehicle speed is not 0 km/h. According to Project analysis this situation happens in the 7% of accidents. (PIONEERS Project has checked 1.170 accidents and only 81 accomplished that requirements)

Step 1: Estimate the number of accidents with injuries in lower legs in lateral impacts.

According to CARE dataset used for analysis in Deliverable D1.1 Powered Two-Wheelers - Road Traffic Accident scenarios and common injuries (submitted EC). The total number of this accidents with fatalities or seriously injured casualties in Europe during 2013-2017 are 71.881. So, we estimate an average of 14.376 accidents by year.

Considering that total fatalities in EC in 2015 were 3.952, considering that accidents with injuries in lower leg and lateral impact are 7% and considering usual proportions between slight and serious injuries, the estimated composition of European accidents to account are 277 fatalities, 2.579 serious injuries and 3.869 slight injuries.

Step 2: Estimate the implementation rate of lateral protectors among all motorcycles in Europe.

It is not possible to know the rate of implementation of this device in following years, therefore, PIONEERS Project has worked in 2 scenarios. First scenario with low implementation rate of lateral protectors (3% of total motorcycles in Europe) and a second scenario with higher implementation rate (6% of total motorcycles in Europe).

Considering that Europe have 24.000.000 of motorcycles (ACEM 02/04/2020), we can estimate that scenario of low implementation rate includes 720.000 motorcycles equipped with lateral protection and scenario with higher implementation rate of lateral protector includes 1.440.000 motorcycles equipped with these types of devices.

Step 3: Estimate the costs.

It has been considered two types of costs, the cost of an awareness campaign to increase the rate of implement PCB's on European motorcycles and the cost of promotion the bought of this type of safety device.

Regarding the awareness campaign, we estimate a hypothetical cost to whole European Union. If the objective is to have a higher implementation rate it is needed a higher awareness campaign. Therefore, first scenarios have considered an awareness campaign with a 10.000.000€ cost to reach 3% of implementation rate and 20.000.000€ cost to reach 6% of implementation rate.

The scenarios also consider some costs to promote this implementation, we consider that administrations could afford. PIONEERS Project has assumed that no promotion is needed in case of reinforced leg cover because this device probably will not be much more expensive than current leg covers. However, in terms of lateral airbags probably some promotion could be necessary, just as an example, Project did the hypothesis of 100€ in case of lateral airbag installed in motorcycles in European Union. It is important to consider that these systems are not still available in the market, this is just an exercise to show theoretically the benefits of the implementation of these measures.

The results:

Considering that we have 2 scenarios of reduction of injuries and we have 2 scenarios in terms of implementation rate. We have 4 scenarios:

Lateral Protectors Scenarios	Low implem. rate & low speed solution	High implem. rate & low speed solution	Low implem. rate & high speed solution	High implem. rate & high speed solution
Measure to apply:	Reinf. Leg Cover	Reinf. Leg Cover	Lateral Airbag	Lateral Airbag
Country:	EU (Whole)	EU (Whole)	EU (Whole)	EU (Whole)
Period of analysis:	5 years	5 years	5 years	5 years
Awareness campaign:	10.000.000€	20.000.000€	10.000.000€	20.000.000€
Costs (Promotion)	0€	0€	100€	100€
Number of units implemented:	720.000	720.000	1.440.000	1.440.000
Fatalities with solution implem.	8	17	8	17
Serious inj's. with solution implem.	77	154	77	154
Slight inj's. with solution implem.	116	232	116	232
Fatalities reduction (%)	N/A	N/A	N/A	N/A
Serious injuries reduction (%)	- 5,6%	- 5,6%	- 77,8%	- 77,8%
Slight injuries reduction (%)	- 22,2%	- 22,2%	0%	0%
Cost	10.000.000 €	20.000.000 €	82.000.000 €	164.000.000 €
Benefits	9.352.819 €	18.784.502 €	84.803.280 €	169.496.995 €
Net Value	-647.181 €	-1.215.498 €	2.803.280 €	5.496.995 €
Benefit-Cost ratio	0,94%	0,94%	1,03%	1,03%
Promotion Break even	N/A	N/A	103.9	103.9

Table 28. Lateral Protector Economic Benefits

Conclusions:

These elements are not still available in the market, this is just a theoretical exercise to show the benefit that the implementation of these measures would mean for society. It is no reasonable to recommend anything yet.

5 Summary

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 has been developed in this document.

This evaluation concerns both economical and safety benefits (in terms of avoided or mitigated accidents, reduction of morbidity and severity of injuries) of the proposed PTW safety countermeasures that have been developed in PIONEERS.

The evaluation was done on three main system:

- PreCrash Braking System
- Airbag jacket and the PTW-PPE communication system
- Motorcycle and scooter leg protector

Because some of these systems are prototypes and not yet on the market, **all the evaluations have to be taken very carefully**. In particular, **results from societal and economical evaluations are sensible and have to be considered cautiously**.

Concerning the PCB, the evaluation was obtained via computer simulations of a set of 60 real-world in-depth crashes selected from the InSafe database provided by UNIFI and EDA database provided by University of Eiffel. Simulations were conducted with a common methodology. The effects were assessed in terms of a reduction of the absolute and relative impact speed of the PTW. A parametric approach in which PCB intervention parameters were varied was adopted to compute the effects of the system for different conditions. The large number of parameters considered in the analysis of PCB effects (field of view, range, deceleration, fade-in jerk, triggering, i.e. $5 \times 5 \times 3 \times 2 \times 3 = 450$ configurations) allows for a wide exploration of the different combinations of settings for the system. But on the contrary, such variety makes it difficult to provide a clear overview of the expected benefits for the system. Nevertheless, such approach led to the identification of three combinations of parameters to represent typical system effects assuming a pessimistic (low efficiency), average, and an optimistic approach (high efficiency).

Depending on the set of parameters, benefits in terms of speed reduction can go until a median value of 15 km/h. Then societal benefits have been calculated in terms of casualties' reduction or crashes using Injury Risk Function and the new relative impact speed distribution. Results show that global benefits for slight, serious or fatal injuries are included between -4% to -31%. Finally, economic benefits in terms of cost were evaluated using the SafetyCube software. Several configurations were considered like the implementation rate of PCB among all motorcycles in Europe, the cost to promote such systems, the horizon, etc. In a 5 years period, this cost will be balanced by savings from health and social expenses, and in a high rate of implementation (with the average evaluation) Europe could save, at least, 30 human lives in this period. With an optimistic configuration, the net value of the benefits could be reached between approximately 500k€ until more than 90M€.

Concerning the Airbag jackets, the societal benefits calculation was based on the establishment of Injury Risk Function for slight, serious and fatal injuries on the trunk without the airbag. In order to establish these IRF, four accident databases were considered: the GIDAS from BAST, the EDA from the University Gustave Eiffel (UGE), the InSAFE from the University of Florence (UNIFI) and the database from the University of Munich (LMU). In all, more than 1300 accidents were considered but only 382 accidents concerned a rider with at least one injury in the PIONEERS defined trunk body region and also contained the necessary variables for the development of an IRF. Then, according to the work performed in others WP's of the Pioneers project, three hypotheses have been considered for the level of protection and the reduction of injuries. They considered that the airbag jacket provides a reduction of an AIS-1 for speed impact lower than 20 km/h, respectively 30km/h and 40km/h. Results of the societal evaluation show that between 1.3% until 19% of injuries could be avoided in function of the configuration. From an economical point of view, with a high implementation rate (6%) in the next 5 years, a net value of more than 140M€ could be saved.

Concerning the Lateral Protectors, exactly the same methodology used for the airbag jacket evaluation was considered. Injury Risk Function of the Lower Leg in lateral impact configuration were first established based on accident databases provided by BAST, University Gustave Eiffel (UGE) and the University of Florence (UNIFI). More than 1300 accidents were considered but only 81 accidents concerned at least a lower leg injury in lateral impact configuration. Then, based on the findings from the lateral protection devices that have been developed in the PIONEERS project (in particular WP3), two hypotheses have been retained for the level of protection of such systems: one considered as a "low-speed" countermeasure (only effective until 15 km/h) and one considered as "medium-speed" countermeasure (only effective between 15 to 30 km/h). Global societal and economic benefits have been observed but results have to be taken very cautiously. Indeed, the economic evaluation show that an amount of more than 5M€ for the net benefits could be saved with the best configuration. But it is important to remind that these systems are not still available in the market, so these evaluations have to be considered as a theoretical exercise.

In conclusion, this work allowed to evaluate safety and economic benefits of several protective systems: Pre-Crash Braking, airbag jackets, Lateral protectors. Beyond these specific evaluations, theoretical methodologies have been defined and applied. They show their

adaptabilities, relevance and effectiveness to calculate benefits. They could be used to evaluate other systems developed in the PIONEERS project like helmets, pelvis protection, boots, etc.

6 References

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