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ProtAct-Us concept for injury mitigation, assessment, and benefits

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1. Executive Summary

This report shows a the general assessment approach (Chapter 2) and defines the necessary steps from statistical information (Chapter 3, provided by MHH) concerning physiological and cognitive injuries with long-term consequences (LTCs), and their assessment to the benefit determination of developed countermeasures. Several possible tests for the determination of cognitive injuries are listed in Chapter 4. This list is the basis for the work of WP2, where a scale like the AIS (Abbreviated Injury Scale) will be developed (UKA).

Physical injuries are subdivided for the four road user groups Pedestrians, VRUs (Motorcycles, Bicycles & New Micro-Mobility Concepts), Car Occupants and Passengers of Busses and Shuttles. For these groups, the accident statistics was analysed to identify the most common injuries with LTCs. For consistency reasons, the injuries are reported in Deliverable D1.2 together with the boundaries for the identified use case scenarios.

The described methods will be developed in WP3 to assess the injuries which are identified in Task 1.3. These methods are applied for the assessment of the concepts for each road user group which are developed in WP4. Based on that, the socio-economic benefit of the concepts can be determined.

The planned assessment methods for the road user groups are documented in this report. The following list summarizes which injuries or body regions will be investigated for each road user group.

- **Pedestrians (CIDAUT, UNISTRA, LAB/CEESAR)**
  Head and thorax injuries for adults and children, internal organs, lower extremities
- **Occupant Passenger Cars (RWTH, CIDAUT, VIF, LAB/CEESAR)**
  Head and thorax injuries for children

  Various injuries in all body regions for adults
- **VRUs (Motorcycles, Bicycles, New Mobility Devices) (UNISTRA, LAZER)**
  Children and adults, Head injuries (skull & facial fractures, brain injuries)
- **Occupants of Passenger Transport Systems (Bus, Shuttle) (VIF, ZF)**
  Various injuries in all body regions for adults

Additionally, injuries with LTCs which statistically appear in several road user groups are described in chapters 5 - 8 in this report. (VIF, CIDAUT, UNISTRA)

Further, different measurements to quantify the socio-economic impact of the countermeasures are documented in chapter 10. (HMU)

Keywords: Long-term consequences, Assessment methods for injuries, Socio-economic impact

2. General assessment approach

This report documents the main steps to mitigate and assess the injuries and further determine the socio-economic benefits. Therefore, countermeasures are developed for four road user groups and aim to prevent or reduce injuries with long-term consequences. This process is illustrated in Figure 2–1.

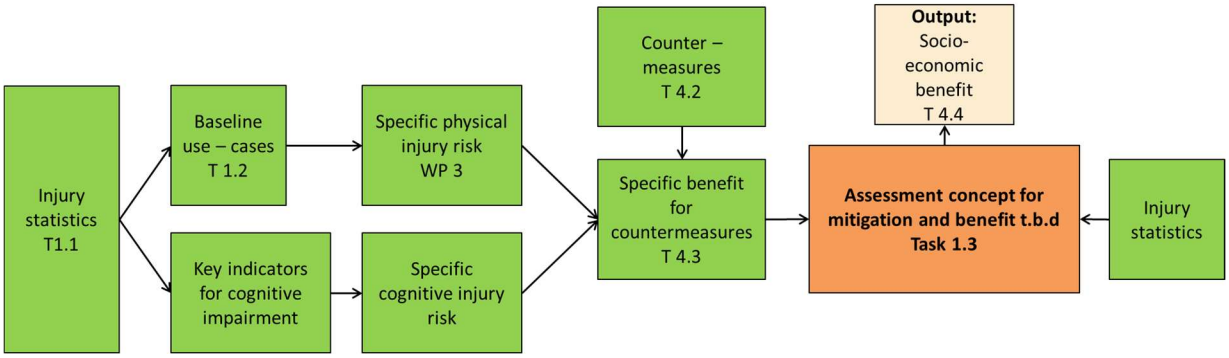


Figure 2–1: ProtAct-Us methodology to assess and mitigate physical and cognitive injuries with long-term consequences and determine the socio-economic benefit of countermeasures

- The first step is to identify the most common injuries which lead to long-term consequences for each of the four road user groups based on injury statistics. A brief summary and a link to the corresponding detailed report is given in chapter 3 of this report.
- The boundaries for the identified accidents are used to define the accident scenarios involving road users. They are further referred to as "use cases" and are described in detail in Deliverable D 1.2.
- For a selected number of physical injuries, assessment methods will be further developed in WP 3. An overview of the targeted developments is given in chapter 5 - 8 of this report.
- Countermeasures for the identified injuries in the respective use cases are developed in Task 4.2. First concepts and ideas are documented in this report in chapter 5 - 8. The application of the countermeasures should lead to a benefit (described by a reduced risk of injury and reduced risk for long-term consequences, including mental health).
- In parallel, the key indicators for cognitive impairment and specific cognitive injury risk are determined. This is explained in more detail in chapter 4.
- As detailed in chapter 4 long-term cognitive consequences (and effects on mental health) are often linked to post accident variables, such as delirium or traumatic memories and might be manageable by targeted mental health interventions.
- The reduced risk of injury is combined with currently available accident statistics and current socio-economic costs to assess the socio-economic benefits of the countermeasures developed. An overview of the methodology is given in chapter 10 of this report.

3. Accident Database

Next to the general analysis of crashes and their characteristics, which was conducted in the scope of task 1.2, the focus of this task lies on the identification of injury categories, which are relevant among accident victims, which suffer from long-term consequences. For this purpose the in-depth accident data from the Accident Database of the Hannover Medical School (MHH) was used (see "MHH Accident data analysis" in Deliverable 1.2 of this project).

This analysis was conducted using an injury category list, which had been established in the EU project EUROCOST. For the use in the ProtAct-US project, some sensible categories were added to represent some injury categories in more detail. Especially for the evaluation of costs related to injuries of road traffic accidents, this list is well suitable as it was set up to evaluate the burden of injury and can be translated from Abbreviated Injury Scale (AIS) or International Classification of Disease (ICD) codes.

A detailed analysis for persons with long-term consequences from the MHH-Database can be found for the different types of road users in the annex of Deliverable 1.2 of this project. Due to the data availability only persons that had at least one head or neck injury were taken into the analysis.

Initially a focus was set on persons with long-term consequences that had at least one head or neck injury. Subsequently, where necessary, further analysis was conducted with persons with all types of injuries. Further it has to be pointed out that the collection of information on long-term consequences was conducted via a follow-up interview via questionnaire. Thus the reported long-term consequences do not represent the actual incidences from certain injury patterns but are reliant on the amount of questionnaires that were responded. When comparing the number of injured persons to those that reported long-term consequences the frequency of occurrence of long-term consequences might be underestimated due to not answering the questionnaire.

4. Assessment approach for cognitive injuries

As detailed in D1.1, studies of cognitive impairment as an outcome, rather than a contributing factor, in road traffic crashes are very rare. We are therefore entering largely uncharted territory. But we can infer meaningful surveys and interventions from findings in less specific patient groups.

Survivors of critical illnesses, including those from road traffic accidents but not exclusively, often experience long-term neuropsychiatric complications such as cognitive impairment and depression. These outcomes are frequently linked to factors like intensive car unit (ICU) sedation, delirium, or traumatic memories, and they significantly impact quality of life. Early rehabilitation and patient education are recommended to mitigate these effects as indicated in cohorts of trauma patients [42]. A study on road traffic accident survivors found that psychiatric disorders, including depression, persisted in 26% of participants three years post-accident. These outcomes were not related to injury severity but were influenced by post-accident variables, highlighting the need for targeted mental health interventions [43]. Depression has also been identified as a predictor of worse outcomes in medical contexts, e.g. in knee surgery, suggesting its potential role in complicating recovery from traffic-related injuries. Addressing depression early may improve both short- and long-term outcomes [44].

Cognition is high level psychological concept, comprising a set of functions that work together, allowing humans to adapt to complex environments and act with purpose. Cognitive functions therefore refer to the mental processes that enable individuals to acquire, process, store, and apply information. They are essential for perception, learning, problem-solving, and decision-making. Their impairment on the other hand has imminent effects on everyday life. The key components of cognitive functions include attention, perception, memory, executive functions (such as planning, problem-solving, and cognitive flexibility), language, learning and problem-solving and decision making. Our aim is to define for WP2 a set of outcome measures relevant to "cognitive deficits" (i.e. attentional and memory deficits, slowed cognition, inability to multitask, increased distractibility and impaired executive function). As we seek to complement the well-established AIS (Abbreviated Injury Scale), which codes injury severity on an ordinal scale from 1 to 6, it will be desirable to develop one or a few items with an aggregated scaling from 1 to 6 in the same way as the AIS.

The theoretical demands of cognitive tests for our research question, are among the following:

- Available in most European languages or language free tests, prospectively available in languages outside Europe
- Easily to be applied and rated
- Robust against retests to allow for recurring observations to document progression or healing

There are a number of suitable tests, Table 4-1 details how the most widely used meet the above mentioned theoretical demands:

Table 4-1: Overview of potential cognitive tests suitable for ProtAct-US

Test Name / Test Domain	Languages Available	Suitability for Repeated Measurements
Mini-Mental State Examination (MMSE) / Brief screening interview assessing nine cognitive functions	Multiple languages, including English, Spanish, Danish, and Malay	Suitable for tracking cognitive changes over time, but cultural and language adaptations might be necessary outside Europe [8] [38]
Montreal Cognitive Assessment (MoCA) / Brief screening of seven cognitive functions	Available in over 50 languages	Suitable for repeated use with alternate forms to minimise practice effects [1] [7]
Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) / Cognitive screening and identification of cognitive decline (e.g. in dementia) in five cognitive domains	English, Chinese, Japanese, Italian, and other languages	Designed for repeated assessments; test-retest reliability is high [2][6]
Trail Making Test (TMT) / Usually sensitive test of two cognitive functions, i.e. visual attention and task switchug	Widely adapted, including English, Spanish, Czech, and Chinese	Suitable for repeated use; cultural adaptations like the Shape Trail Test might improve cross-cultural applicability [41][4]
Stroop Color-Word Test / Well establisged test of cognitive interference, a relatively demanding cognitive function	Available in many languages, including English, Hebrew, and Dutch	Suitable for repeated measurements; practice effects should be considered [30]
Wechsler Memory Scale (WMS) / Extensive test on different memory functions	Available in English, Spanish, and other languages	Suitable for repeated use, but practice effects and cultural adaptations must be accounted for [34][35]
Raven's Progressive Matrices / Nonverbal test of pattern recognition.	Available in multiple languages; designed to be culture-fair	Suitable for repeated use; minimal practice effects due to non-verbal nature [26][29]

However, the information from formal cognitive tests will have to be enhanced by inquiries about mental health, especially on quality of life, depressive symptoms and impairments of daily activities, such as professional work. Therefore, additional questionnaires will be added, most of them have been tested in preceding studies.

Table 4-2 : Additional tests to enhance assessment of cognitive impairments

Test Name / Test Domain	Languages Available	Suitability for Repeated Measurements
SF-12 Health Survey / General health questionnaire that consists of 12 questions which investigate the patient's state of health via 8 different dimensions	Available in over 40 languages, including English, Spanish, Italian, and Chinese	Suitable for repeated use; high test-retest reliability and sensitivity to changes in health status [28]
WHO-QOL (WHOQOL-BREF) / Quality of life assessment developed by the World Health Organization (WHO)	Available in multiple languages, including English, Spanish, and Arabic	Suitable for repeated use; validated for cross-cultural applicability and sensitive to quality-of-life changes [32]
CES-D (Center for Epidemiologic Studies Depression Scale) / S	Available in many languages, including English, Spanish, Chinese, and Tamil	Suitable for repeated use; validated for diverse populations, but some items may show cultural variability [5][14]
WHODAS 2.0 / The World Health Organization Disability Assessment Schedule (WHODAS) records health, functional ability and disability independently of the basic disease.	Translated into 47 languages, including English, Spanish, Hebrew, and Indonesian	Suitable for repeated use; high reliability and sensitivity to changes in disability status [11][36]

We are fully aware that this extensive battery is not suitable for general application but intend to propose an abbreviated test battery based on the statistical qualities identified in the prospective study in WP2. We furthermore intend to propose suitable sum scores to enhance the AIS.

Based on the literature the approach for intervention will be personalized and based on the questionnaire set. We expect that in most patients screening will indicate to the requirement of low level psychological counselling and cognitive training ([45], in trauma patients). In order to strengthen the patient's agency and autonomy educating patients about self-rehabilitation techniques, including gradual physical activity and mental exercises, can empower them to manage their recovery effectively ([42], broad critical care perspective). However, we will also take into account existing social support and engagement, because enhancing social support and addressing social impairments, such as isolation or financial insecurity, can mitigate depression and improve recovery outcomes ([46], post stroke depression).

Overall, our approach is to develop a concise battery of tests, which will then indicate the individual level of therapy or intervention indicated on a level from "no help needed" to "support for self-rehabilitation needed" up to "(multi-)professional rehabilitation needed".

5. Road user group: Pedestrians

The objective of this pedestrian assessment is to evaluate the risk and nature of head and chest injuries in pedestrians during vehicle collisions, with a focus on both mild and severe injuries that may result in long-term consequences. Injuries to these areas, especially the head and chest, have a high potential to affect vital functions, even when individual injuries might be of low severity (minor or moderate AIS levels -Abbreviated Injury Scale) e.g., because the impact conditions of the individual were uncritical.

The pedestrian MHH statistical data provides a small sample of 21 impact cases: 12 involving women, 9 involving men, and only 2 cases involving children aged 3 and 15. In all cases, the most severe injuries with long-term consequences affect the head, chest, and lower extremities. These cases will be analysed in the scenarios defined in deliverable 1.2, considering adults and children in crossing, longitudinal, and turning situations, for two types of vehicle geometry at two different speeds.

Considering this statistical data and the reviewed literature, head and chest injuries for adults and children will be studied by analysing the first and second impacts. The following methodology will be followed according to the type of injury

Analysis of Head Injuries using the DAMAGE Criterion as well as SUFEHM criteria:

The biomechanics of the brain are complex due to the unique mechanical properties of the organ (high bulk modulus and low shear modulus). The brain is suspended in cerebrospinal fluid within the skull, and injuries to it are difficult to detect. For this reason, it is proposed here to assess head injuries by using two different approaches, the first one is the use of a predictive finite element head model (SUFEHM) to assess skull and face injuries as well as brain injuries. The second approach is the use of the DAMAGE criterion (Diffuse Axonal Multi Axis General Evaluation) for the analysis.

Analysis of Internal Organ Injuries

Internal organ injuries in a pedestrian-vehicle collision can be severe and vary depending on the vehicle's speed, the impact position, and the vehicle's size. Injuries may include abdominal trauma affecting the liver, spleen, kidneys, or intestines, or thoracic trauma involving the heart, lungs, and major vessels (aorta, vena cava). These types of injuries will be analysed considering the strain distributions of the organs, based on the bibliographic values established by [40], [21]).

For this, the following methodology will be followed:

Analysis of HBM Model Capacity for Injury Prediction:

Advanced Human Body Models (HBM), will be employed to simulate human body responses to impacts across various anatomical regions.

The predictive ability of these models will be assessed for injury outcomes in each body region, incorporating both primary injuries from the initial vehicle impact and secondary injuries caused by subsequent ground contact or collisions with other objects.

Simulations will cover all phases of the impact, from the initial contact with the vehicle to the ground impact, allowing for a comprehensive analysis of injurydistribution and identifying the areas most prone to be injured

Experimental Validation and Risk Threshold Adjustment

The simulated head injury results will be cross-referenced with experimental data through partial head impactor tests in CIDAUT, which allow us to analyse different types of heads at various speeds and angles, where a new injury criterion (DAMAGE) will be introduced and the use of existing criteria from SUFEHM model could help in the analysis. This enables a comparison between the simulated results and real-world outcomes, providing robust validation of the model's injury prediction accuracy.

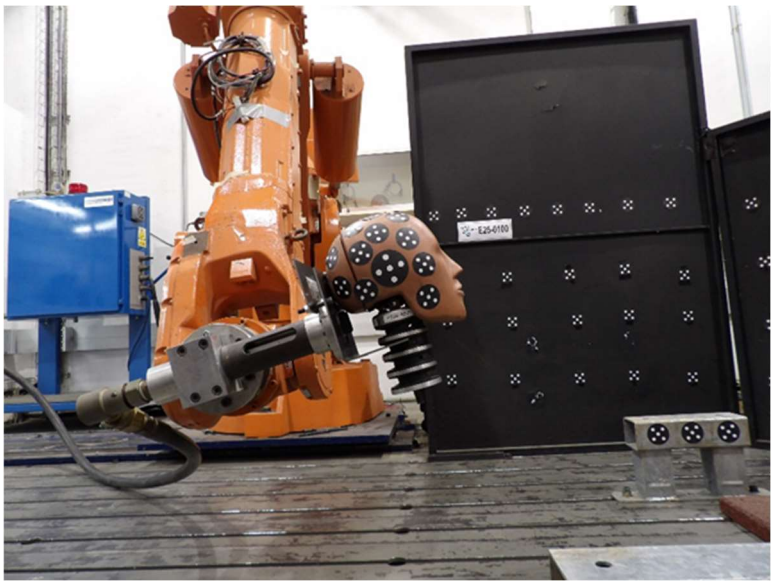


Figure 5–1: Physical head impactor

Expected Results:

- Identification of risk thresholds for mild and severe head and chest injuries that could cause long-term consequences.
- Development of risk curves specific to each scenario and type of injury
- Recommendations for prevention strategies and adjustments to road safety regulations to mitigate long-term damage to pedestrians after vehicle collisions.

Based on the most critical scenarios analysed, selected safety countermeasures will be proposed to mitigate the severity of the injuries with long-term consequences in pedestrian road users. Solutions should be focused for both the primary impact on the vehicle (vehicle structural modifications, or implementation of specific safety devices in the exterior of cars) as well as the secondary impact on the road surface (proposal of forgiving road infrastructure concepts, such as less aggressive kerb and sidewalk edging designs in the vicinity of pedestrian crossings).

Analysis of lower extremity (tibia) injury risk

According to the injury statistics, lower leg injuries are relatively often connected with long-term consequences and should therefore be considered in the assessment process and in countermeasures development. The approaches to develop an assessment method for tibia fractures are further described in chapter 9.3 in this report.

Possible countermeasures are either active systems to reduce the impact velocity and/or frontal design and protection measures at the vehicle.

LAB/CEESAR approach

The MHH data base shows injuries being present in all body regions that are present in pedestrians with long-term consequences:

- Brain injury and head bone fractures
- Pelvic bone fracture
- Bone fractures of lower extremities

LAB/CEESAR will use GHBMC (Global Human Body Models Consortium) models to assess these injuries. Vehicle models will be adapted to the most relevant load cases for these injuries with LTCs. Models of the most relevant occupant populations will be integrated into these vehicle models. Injuries predicted by GHBMC will be compared with the most relevant injuries for each load case. The deviation between them will be investigated. Further improvement, if necessary, may be made to GHBMC models and/or associated injury metrics, this in order to get more consistency between model predictions and accident features. Vehicle models may also need to be further adapted to better represent the load cases. Diversity effects such as age, size, sex and weight may also be considered in this investigation.

Based on the load case models validated above, LAB/CEESAR will perform simulations with different potential countermeasures and assess their mitigation effects in injuries with LTCs. These potential countermeasures will include, but not limited to, main vehicle front-end design parameters such as its geometry and stiffness repartition of its components.

Although important insight into injury conditions of pedestrians with long-term consequences was gained using MHH data, additional analyses w.r.t. vehicle shape, pedestrian properties and impact conditions are planned for WP 3 and WP4These further specifications have to be made as the first step in WP3 and WP4.

6. Road user group: Occupant Passenger Cars

Children

Since there is limited knowledge of physical long-term consequences for children injured in car crashes, children accident research combining finite element models' simulations and physical tests is proposed. According to the scenarios described in D1.2, lateral-oblique impacts will be taken into account. Far-side and near-side impacts will be analysed together including interaction between rear seats occupants. Two different child sizes (6 and 10-years-old), seated in different positions in the rear seat (struck and non-struck side) will be considered. The risk associated with the presence of larger children in the far-side seating location will be investigated.

Far-side occupant presence in the rear seat seems to be particu-larly important in side impact collisions. In the front seats the center console limits the lateral pelvis movement as well as the head. In general, in the rear seats there is not any component that restricts the lateral movement. The presence of multiple rear seat pediatric occupants may lead to an occupant-to-occupant interaction that may have implications for side impact protection (Charlton et al. 2007). Near-side child occupant was subjected to bilateral impacts, one side from the intruding structure and the other side from impact with the far-side child occupant. Thus, although the near-side child occupant was properly protected from the direct side impact, this occupant would suffer a potentially dangerous situation due to a second injury event. In addition, for far-side child occupant, injuries may increase when the adjacent occu-pant was seated due to occupant-to-occupant contact (Diez et al. 2024). From 2016, the presence of multi-ple rear seat occupants is considered in Euro NCAP program but it does not take into consideration the risk associated with the presence of larger children in the far-side seating location.

Far-side and near-side impacts will be analysed together including interaction between rear seat occupants. Two different child sizes (6 and 10-years-old), seated in different positions in the rear seats (struck and non-struck side) will be considered. The risk associated with the presence of larger children in the far-side seating location will be investigated.

Motor vehicle crashes are a common cause for head injuries (Viano et al. 2017), thus, focus will be placed on the head by the evaluation of the skull and brain injuries. On the other hand, potential injuries of internal thorax organs will be studied. Pediatric rib cage provides a less stiff shell for protecting the underlying soft tissue organs than does the adult rib cage (Ostermann et al. 2021). Childs' ribs tend to bend inwards rather than break when pressure is applied and the bony chest can withstand more deformation, so the force of an impact is transmitted widely through the body resulting in injuries to their soft tissue organs such as lungs or heart (Kaptein et al. 2011, Schoell et al. 2018, Minervini et al. 2020, Emigh et al. 2023). In addition, the analysis on MHH accident data highlighted that head and thorax were the most frequent injured body regions.

Additionally for the head injury assessment, it is proposed to assess head injuries by using both a predictive finite element head model (SUFEHM) to assess skull, face and brain injuries as well as the Diffuse Axonal Multi Axis General Evaluation (DAMAGE) brain injury criterion that was currently introduced for adults. DAMAGE criterion will be investigated in order to analyse the feasibility of adapting it to children.

Thresholds for injury assessment will be proposed based on literature and accident data review as well as virtual tests (with paediatric human body models). Physical tests study results based on a simplified vehicle environment that allows reproducing the lateral kinematics of the vehicle in the rear seats that will be further developed in WP3.

Possible countermeasures will be proposed to enhance children occupant protection under side impact conditions in vehicles rear seats. These potential countermeasures will be focused on avoiding interaction between the child occupants taking into account already validated solutions in front row far-side occupant protection such as central airbags. Countermeasures to reduce the interaction effects will be also proposed. The Exterior shell of the CRS plays a relevant role in mitigating or potentially causing child injuries. These structures could help to absorb more or less energy and thereby alter children kinematics and injury outcomes. In addition, adapted current restrains systems concepts will be considered.

Adults (LAB/CEESAR)

MHH data base shows a large range of injuries with LTCs relative to car occupants, implicating all body segments from the head to the foot. Following are some most outstanding injuries with LTCs of car occupants:

- Brain injury and facial bone fracture
- Rib and sternum fractures
- Clavicle and scapula fracture
- Organ injury in the thorax and the abdomen
- Pelvic bone fracture
- Bone fractures of upper and lower extremities

LAB/CEESAR will use GHBMC (Global Human Body Models Consortium) models to assess these injuries. Vehicle models will be adapted to the most relevant load cases for these LTCIs. Models of the most relevant occupant populations will be integrated into these vehicle models. Injuries predicted by GHBMC will be compared with the most relevant injuries for each load cases. The deviation between them will be investigated. Further improvement, if necessary, may be made to GHBMC models and/or associated injury metrics, this in order to get more consistency between model predictions and accident features. Vehicle models may also need to be further adapted to better represent the load cases. Diversity effects such as age, size, sex and weight may also be considered in this investigation.

Based on the load case models validated above, LAB/CESSAR will perform simulations with different potential countermeasures and assess their effects in LTCI mitigations. These potential countermeasures will include, but not limited to, optimization of main restraint devices such as belt load limitors, belt pretenstioners , airbags, seats.

Although important insight into injury conditions of car occupants with long-term consequences was gained using MHH data, additional analyses w.r.t. occupant properties, impact conditions, and seating position etc. are planned for WP 3 and WP4. At lease, one load case for frontal impact and another for lateral impact need to be defined based on statistic evidence.

These further specifications have to be made as the first step in WP3 and WP4.

Analysis of lower extremity (tibia) injury risk for adults

According to the injury statistics, lower leg injuries cause long-term consequences and should therefore be considered in the assessment process and in countermeasures development. The approaches to develop an assessment method for tibia fractures are further described in chapter 9.3 in this report.

Possible countermeasures are additional or adapted restraint concepts or structural adaptions in the affected area.

7. Road user group: Motorcycles, Bicycles, New Micro-Mobility riders

7.1 New Micro-Mobility riders

The analysis of MHH accident data has identified a limited number of cases involving e-scooter riders (only 45, of which four responded to the questionnaire on screening for long-term consequences and indicated to have long-term consequences). The primary injury regions include the head (75%) and the upper and lower extremities (25%), reinforcing the critical need for targeted injury assessment. To deepen our understanding of injury mechanisms and pave the way for potential safety countermeasures, multibody simulations are proposed. These simulations will extract body segment boundary conditions just before ground impact

As part of this study, 18 virtual accident scenarios (illustrated in Figure 7–1) will be simulated. The initial objective is to extract key kinematic parameters of the victim, including:

- **Head impact location** just before contact with the ground.
- **Head impact velocities** prior to ground contact.
- **Boundary conditions** for each body segment just before impact, ensuring a comprehensive biomechanical assessment of e-scooter falls.

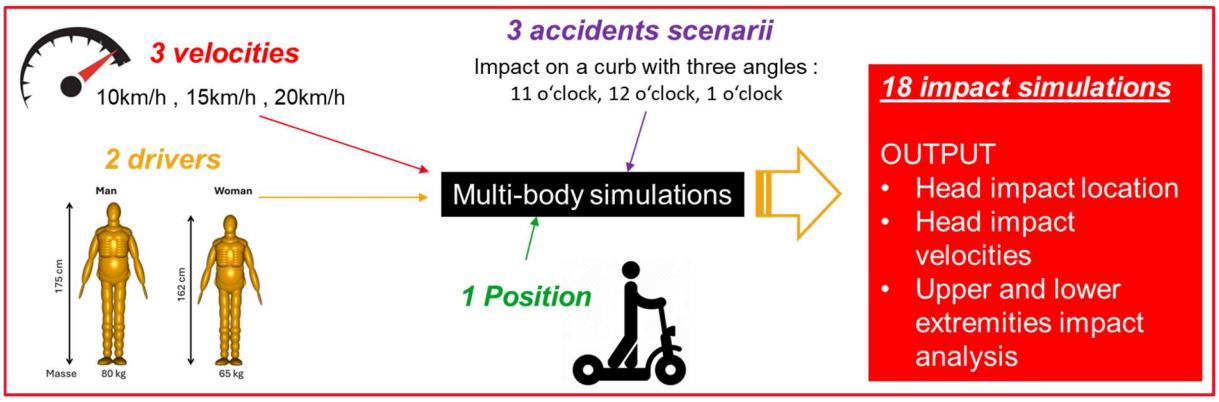


Figure 7–1: Baseline uses cases of e-scooter accident reconstructions that could conduce to injuries with LTC using multibody simulations

To conduct multibody simulations, we plan to utilise human multibody models from **Madymo**. These models are available in various sizes for both male and female riders, ensuring realistic representation of e-scooter users.

Additionally, an **e-scooter model** must be defined. Some models have already been developed at **UNISTRA** and will be enhanced if necessary. The **obstacle responsible for the accident** must also be precisely defined in terms of geometry. For example:

- **Curb**: Defined by its height and shape.
- **Road hole**: Defined by its diameter and shape.

Once the multibody simulations are completed, the next step will involve **head trauma simulations** using the **Strasbourg University Finite Element Head Model (SUFEHM)**. This model is capable of assessing skull, facial, and brain injuries.

To ensure accurate injury assessment, we will analyse multibody simulation results to:

- Understand **head kinematics** during an e-scooter accident.
- Identify **the most dangerous accident scenarios** for head injuries.

The evaluation of head injuries will be based on:

- **Skull fracture risk**
- **Brain injury risk**, including the likelihood of initial loss of consciousness
- **Facial bone fractures**

As a key countermeasure to reduce head injuries leading to long-term consequences (LTC), **helmet use** will be analysed. To evaluate its effectiveness, we will compare **head injury risks in identical impact conditions**, based on multibody simulation results, under three conditions:

- **Without a helmet**
- **With a reference helmet**
- **With an improved helmet design**

These comparisons will provide valuable insights into helmet performance and potential improvements to enhance protection for e-scooter riders. For the non-helmeted impact, the outputs of the multibody simulations can directly be used as input for the injury risk assessment by SUFEHM. However, the helmeted impacts will require an intermediate simulation taking into account the effect of helmet design. This intermediate simulation will be carried out using Lazer's LS-Dyna model. The reference helmet will be suggested by Lazer and its enhanced version will be developed by Lazer and based on the simulation results.

7.2 Children on PTW

Virtual Accident Simulations for Child Passengers on PTWs

Using the **MHH accident database**, an analysis of **180 powered two-wheeler (PTW) accident cases** was conducted, including **31 riders who reported long-term consequences (LTC)**. However, in only **one case involving a child passenger** on a PTW long term consequences were reported.

To address this lack of data, **virtual accident simulations** will be performed, specifically focusing on **sliding and imbalance-related impacts**. These simulations will use **multibody modelling** to study injury mechanisms involving a **6-year-old child (6YOC) as a PTW passenger**.

Simulation Setup

Human multibody models from Madymo will be used:

- A **50th percentile male** will represent the PTW driver.
- A **6YOC child model** will be used as the passenger.
- Both models will be sourced from **Madymo**.

Concerning PTW and Restraint System Models:

- A **multibody PTW model** must be defined.
- The **child restraint system (CRS)** to be used will also be specified.
- Some PTW models developed at **UNISTRA** may be enhanced if required.

Planned Virtual Accidents

A total of **12 virtual accidents** will be simulated, with the methodology outlined in Figure 7–2. As a first step, the simulations will extract key kinematic parameters related to the child passenger:

- **Child head impact location** just before ground impact.
- **Child head impact velocity** just before ground impact.
- **Boundary conditions for the child's upper and lower extremities** just before impact.

Head Trauma Simulations

Using these results, a second phase will involve **head trauma simulations** employing the **Strasbourg University Finite Element Head Model (SUFEHM)**. Since a 6YOC can be considered a **scaled-down adult in biomechanical terms**, this model will help assess:

- **Skull fracture risk**
- **Brain injury risk**
- **Facial bone fracture risk**

Potential Countermeasures

Findings from **WP3** could contribute to the development of safety measures, focusing on:

- **Child seat designs** for PTWs
- **Improved child restraint systems (CRS)**

These countermeasures aim to enhance child passenger protection and reduce **severe head and extremity injuries** in PTW accidents.

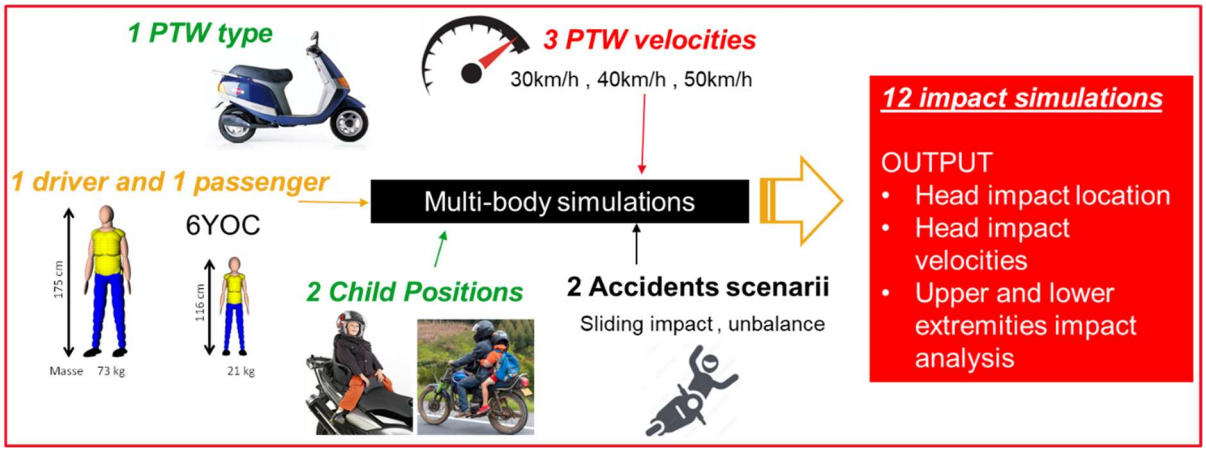


Figure 7–2: Baseline uses cases of children on PTW accident reconstructions that could conduce to injuries with LTC using multibody simulations

7.3 Cyclists

The MHH accident database includes a total of 805 cyclist accidents, among which 103 cyclists reported long-term consequences (LTC). The primary injured body regions for cases with LTC are as follows: **head** (40%), thorax (36%), upper extremities (48.5%), and lower extremities (56.3%).

To gain a deeper understanding of the impact characteristics of these body regions and to evaluate the risk of head injuries, **24 impact simulations** will be conducted. These simulations correspond to the **most frequently occurring scenarios** identified through the accident data analysis **involving LTC**, as illustrated in Figure 7–3.

For this purpose, **multibody simulations** will be utilised, employing Human multibody models from Madymo to represent both male and female cyclists. Additionally, a multibody model of a **bicycle** and the **frontal profile of a small car** will be used for accident reconstructions, either from existing models or newly developed ones.

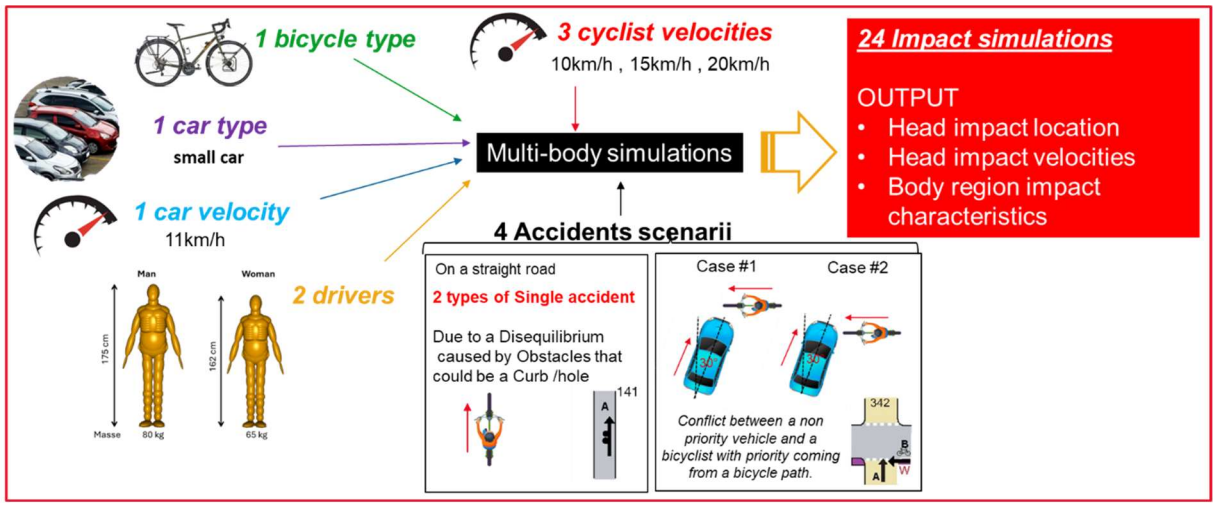


Figure 7–3: Baseline uses cases of cyclist's accidents that could conduce to injuries with LTC using multi-body simulations

Regarding the e-scooter road case, the proposed **countermeasure** for **cyclists** to reduce head injuries that could lead to long-term consequences (LTC) is **the use of helmets**. This

will be investigated and assessed by **comparing head injury risks under identical impact conditions** derived from multibody simulation analyses, both **with and without** the use of a standard helmet and an enhanced version. For non-helmeted impacts, the multibody simulation outputs can be directly utilised for injury risk assessment using SUFEHM. However, for helmeted impacts, an intermediate simulation is necessary to account for helmet design effects. This intermediate step will be conducted using Lazer's LS-Dyna model. Lazer will propose a reference helmet, while an improved version will be developed by Lazer based on the simulation results an illustration of the methodology proposed to evaluate the effectiveness of countermeasures aimed at reducing head injury risks for e-scooter riders and cyclists is presented in Figure 7–4.

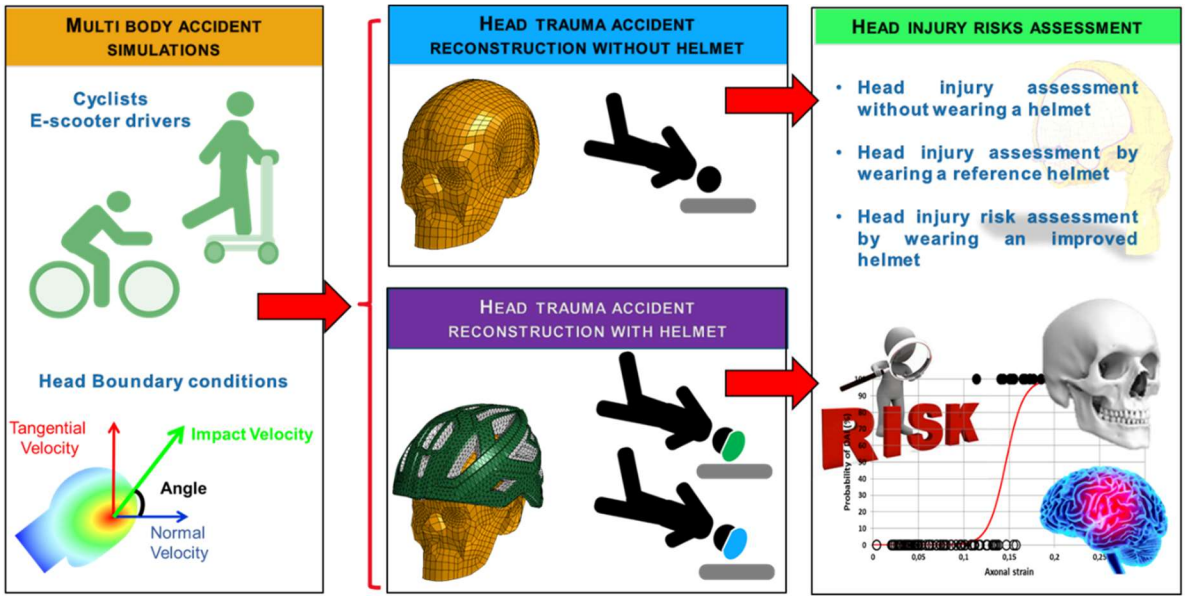


Figure 7–4: Methodology proposed to evaluate performance of countermeasures that will be developed for e-scooter drivers and cyclists in terms of decrease head injury risks.

8. Road user group: Occupants of Passenger Transportation Systems

8.1 Scenarios

For the road user group occupants of passenger transportation system three baseline use cases are defined based on the GIDAS database accident analysis and the MHH data base with reported long term consequences. The scenarios are braking, frontal collision and side collision. For braking, a deceleration of 7 m/s² and jerk of 30 m/s³ is proposed. The relative collision speed for the development of the methods and countermeasures is 30 kph. The effectiveness of the countermeasures will then also be investigated at 10 km/h and 50 km/h. The collision partners are mostly passenger cars. The proposed sizes of the passengers are 10 years old child (10YO), 5. percentile female (AF05) and 50. percentile male (AF50). The positions are sitting on side facing seats, on front facing seats or standing.

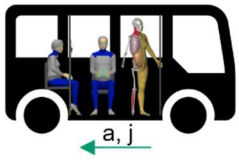
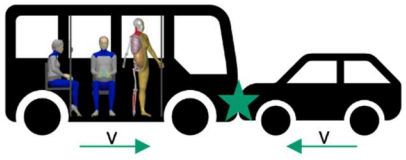
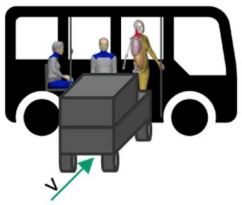
Use Case 1 Braking	Use Case 2 Frontal collision	Use Case 3 Side collision
		
a = 7 m/s² j = 30 m/s³	v_{rel} = 10 kph v_{rel} = 30 kph v_{rel} = 50 kph	v_{rel} = 10 kph v_{rel} = 30 kph v_{rel} = 50 kph

Figure 8–1: Baseline uses cases of Occupants of Passenger Transportation Systems

8.2 Workflow

The determination of the injury risk for bus and shuttle occupants is done in three steps

- **Determination of potentially unsafe parts inside the vehicle**

  Potentially unsafe spots are determined for sitting and standing passengers. While the boundaries for sitting passengers are quite well defined by the seats, the initial positions of standing passengers can vary widely. In [37] and [9] spots with higher (material) stiffness, underlying rigid structure or low radius are considered in the selection of spots to be further tested. These principles will be used to define the unsafe spots, which are then assessed in further simulations.

- **Kinematic boundary determination with Multibody simulations**

  The second step, after determining unsafe spots, is to calculate the impact velocity and the impact angle of the body parts which possibly get in contact with the identified spots. Therefore, Multibody simulations with passive models will be used and simulated with acceleration pulses known from literature.

- **Detailed simulation**

  In this simulation step, the actual injury risk is determined. Two options are possible for the simulation. First one is, to take the determined kinematic boundaries for the impacts in potentially unsafe spots and use them for FE impactor simulations. The impactors to be used depends on the identified injuries of the respective body regions.

The second option is, to identify the most critical unsafe spots and perform simulations with entire FE Human Body Models.

8.3 Required simulation models

Bus interior models

The public available interior models of busses from the EU funded project VIRTUAL will be used as a basis and will be enhanced by additional seat rows. They will be used to simulate the impact of seated passengers to the seats in front. Further that is necessary to simulate the kinematics of standing passengers in the aisle.

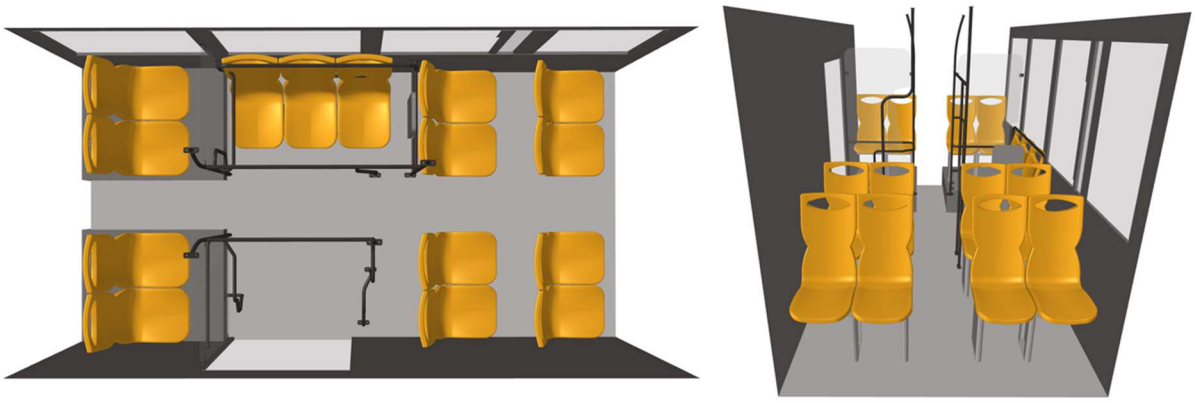


Figure 8–2 - Example interior based on model from project VIRTUAL

Multibody models for standing and sitting passengers

To simulate the accident events in the second step described above, we plan to use human body multibody models from Madymo. These models are available in different sizes, enabling us to simulate different passenger sizes, and will be used to calculate impact velocity and impact angles for different parts of the body upon various braking or crash pulses.

Multibody models are relatively fast, which is an advantage since several iterations might be needed to find an initial occupant position which results in a specific body part hitting the chosen, potentially unsafe, spots, in each case.

Seated and standing passengers will be simulated using passive models. This can be seen as a worst-case, especially for standing passengers, since any counteraction from the falling person cannot be simulated.

Impactors or HBM body parts

Existing FE impactor models from pedestrian assessment or HBM body parts of the according body regions will be used and will be applied with the determined kinematic boundaries.

Crash-pulse-estimator (ZF)

To investigate and further develop the proposed countermeasures for enhancing occupant safety, it is essential to estimate the **crash pulse**, which determines energy absorption and significantly influences occupant kinematics and injury severity. The crash pulse characterises the acceleration / deceleration profile of a vehicle during a collision.

In conventional vehicle safety analyses, crash pulses are typically derived from **Finite Element (FE) simulations**. However, these simulations require approximately 20 hours per

run, rendering them computationally expensive and impractical for assessing multiple countermeasure scenarios, including those to be analysed in WP4. To overcome this limitation, a crash pulse estimator based on a **hybrid surrogate model** is proposed to predict the crash pulse using key collision parameters such as impact velocity, collision angle, and point of impact [16] . This approach enables crash pulse estimation within seconds, significantly reducing computational effort compared to FE simulations.

The proposed estimator employs a machine learning model, specifically a **Multi-Layer Perceptron (MLP)**, to predict **the stiffness of the crumple zone**. This stiffness parameter is then applied to a **spring-damper-mass (SDM)** system, which models vehicle deformation during impact (see Figure 8–3 and Figure 8–4). To train the machine learning model, a dataset will be generated through FE crash simulations covering frontal and side collisions, as these scenarios were identified as the most relevant in D1.2. The simulations will be conducted using plausible FE models of bus, shuttle and a passenger car in LS-DYNA to ensure an accurate representation of vehicle structural behaviour under impact conditions.

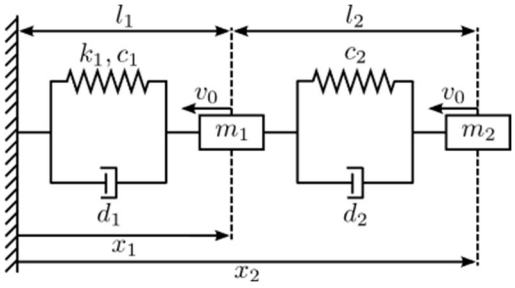


Figure 8–3:Spring-Damper-Mass (SDM) System for vehicle deformation modelling

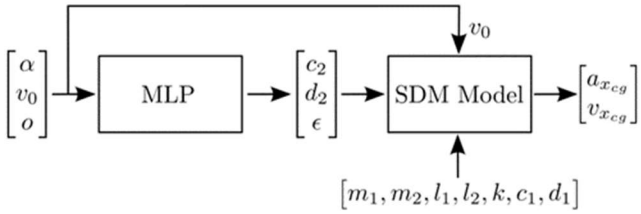


Figure 8–4: Hybrid Modelling Approach

8.4 Considered injuries

The statistical investigations gave 402 occupants injured in bus and shuttle accidents, while there were only 2 occupants with which had reported long-term consequences in a questionnaire. However, in most cases, there had been no follow-up regarding long-term consequences. Based on the injuries from the two cases with stated long-term consequences, plus on common injuries from the overall accident database, injuries which come into question are concussion, whiplash, fractures to ribs, sternum, pelvis, hip and femur. Other common injuries are open wounds and superficial injuries to head, face, thorax, and upper and lower extremities.

There will be no specific methods for injury evaluation developed for bus and shuttle passengers. Existing methods and methods developed in other parts of this project will be used. Thus, injuries which we aim to consider are head, thorax and extremity injuries. Open wounds and superficial injuries are outside of the scope of this project.

8.5 Possible countermeasures

The specific countermeasures will be selected on the basis of the injuries identified. This report gives some examples and general suggestions for countermeasures. These will be further defined in WP4. They will cover the standing occupant scenario, where e.g. bars or "catching structures" will be used.

[22] shows that vertical handrails are the second most common cause of injury after contact with the floor. Yet they are required to prevent passengers from falling. This leads to a focus on the design details of handrails, as suggested by [22] and shown in Figure 8–5.

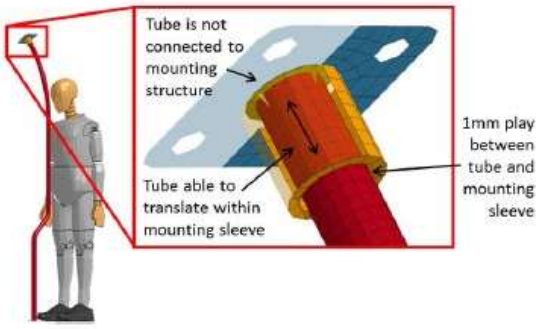


Figure 8–5: Alternative design of a floor to ceiling handrail [London Bus Safety]

Another possibility could be the mounting of narrow swing doors in the aisle, preventing passengers in groups falling along the aisle.

In addition, for seated passengers, belt/airbag concepts and handrails are of interest (side & forward seated passengers). Furthermore, the "soft covering" of rigid structures and the influence of sharp edges can be investigated and, if necessary, replaced by other designs and constructions. That applies to floor design as well as to the seat design (padding, surface roughness, backrest height, seat bar, seat bolster).

9. Development of assessment methods for the risk determination of injuries with long-term consequences

9.1 Head / face injuries

Head injuries, including brain injuries, facial trauma, and skull fractures, are among the most frequently observed injuries of persons with long-term consequences (LTCs) in road accidents. These injuries affect various road user groups, including pedestrians, cyclists, motorcyclists, and vehicle occupants, as identified in the MHH database analysis.

To develop effective countermeasures that reduce injury risks, it is essential to assess head and facial injuries occurring during accidents. This assessment will be carried out by extracting head boundary conditions just before impact—either with a car or the ground—using multibody simulations. These extracted conditions will then serve as input for head trauma reconstructions utilising the finite element (FE) head model available at UNISTRA. When facial injuries are involved, the model will be further enhanced as part of WP3.

In cases where full FE accident reconstructions or experimental tests are employed, the six-degree-of-freedom (6D) acceleration time history of the head impact against various structures (e.g., car, bus interior) will be calculated. This data will then be used to drive the Strasbourg University Finite Element Head Model (SUFEHM) to assess the risks of skull, facial, and brain injuries.

A summary of the proposed methodology for assessing head injury risks across the four road user groups is presented in Figure 9–1. This approach involves using a predictive finite element head model (SUFEHM) with an enhanced facial structure developed in WP3, capable of predicting bone fractures.

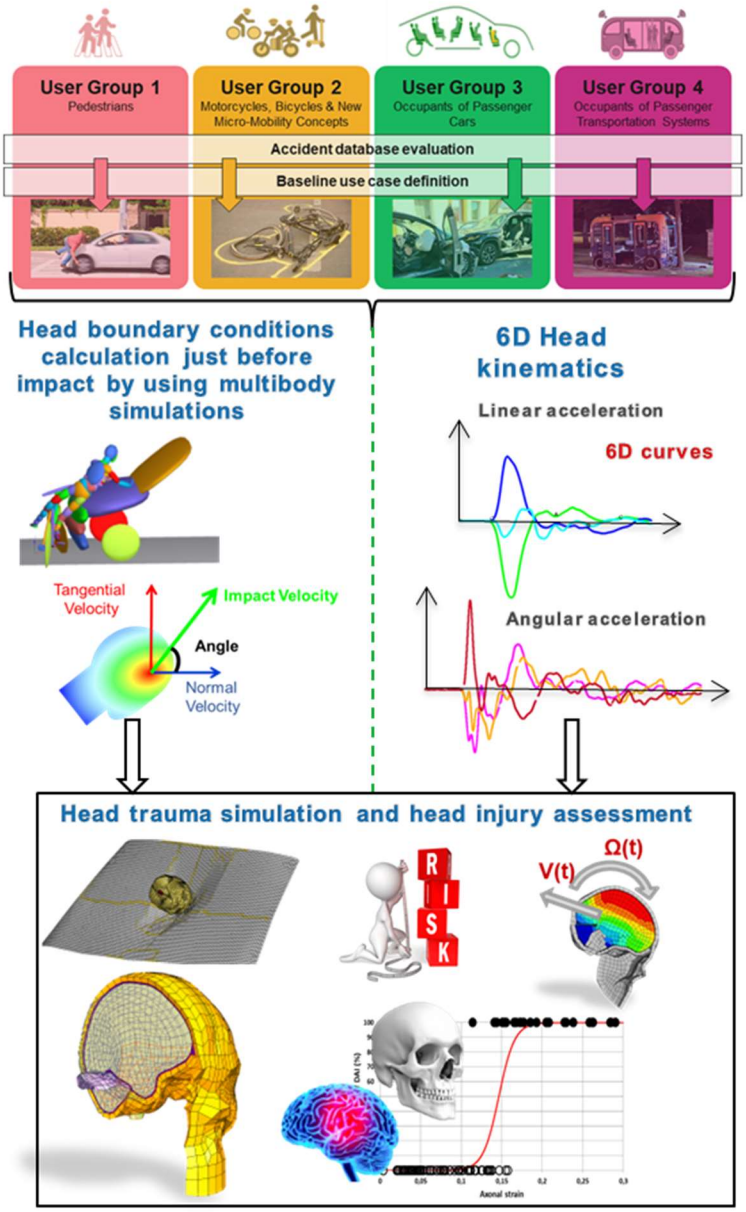


Figure 9–1: Methodology proposed to assess head injury risks in terms of skull fracture, face fracture and brain injuries, for the four road user groups.

An alternative approach for brain injuries assessment is based on the DAMAGE criterion, based on the maximum principal stress (MPS) of a male 50th percentile brain model (GHBMC).

For the calculation of this criterion, DAMAGE relies on the motion equations of a coupled second-order system with three degrees of freedom, which represent the brain's deformation caused by the rotational movement of the head, like the behaviour of the brain under impact, **Fehler! Verweisquelle konnte nicht gefunden werden.**.

9.2 Upper extremities

In the analysis of MHH accident data, 87 cases of road traffic accidents involving long-term consequences were provided. Focusing on upper extremities injuries, this analysis highlighted that the most frequent injuries to this part of the body were open or superficial wounds, mainly

MAIS 1 (38 cases), but that the most critical injuries (MAIS 2+) are related to fractures in the elbow/forearm (2 cases), upper arm (2 cases) and wrist (2 cases).

Based on the analysis of other statistics in the technical literature, according to Frampton et al. (2019), side impacts show a higher rate of upper extremity injuries than frontal or rollovers, and the shoulder is the most frequently injured region in side impacts (50%). Kelley et al. (2019) evaluated upper extremity injury patterns and contact sources in side impact crashes in terms of occupants (age, height, etc.) and crash variables (door intrusion, seat position, speed, etc.), concluding that the incidence of upper extremity injuries increases in side impact crashes, being the soft tissue the most common type of injuries (with the majority being AIS severity 1), while bone fractures account for the second highest rate (with the majority being AIS severity 2+).

Current protocols and regulations for side impact occupant safety (EuroNCAP, UNECE, FMVSS, IIHS) do not contemplate any injury criteria for the upper extremities, as they are carried out with anthropomorphic dummies with arms sectioned at the elbow and without any type of instrumentation (WorldSID 50% dummy). Consequently, in the standard protocols for side impact tests it is not possible to identify nor to evaluate injuries in upper extremities. In addition to this, the simplified arm configuration can affect to the optimal design of safety countermeasures for the side protection of the occupants (airbags), since their interaction with the upper extremity during the airbag deployment is different from what happens in a real accident.

For the injury assessment of upper extremities both virtual ATDs (Anthropometric Test Devices), HBMs(Human Body Model based), and physical tests will be carried out to provide necessary data. Focusing to the experimental testing assessment, CIDAUT will use a novel instrumented physical arm based on a 50-percentile dummy. The following instrumentation is available in this hardware:

- Six-channel load cell measuring Fx-Fy-Fz-Mx-My-Mz in Upper and Lower arm sections.
- Two-channel load cell measuring Mx-My and Rotary potentiometer measuring angles in Elbow and Wrist.

Figure 9–2: Instrumented arm for physical testing

The instrumented arm is compatible and implementable with different ATDs (Hybrid-III 50% dummy for frontal impact and WorldSID-50% dummy for side impact). This allows to use it for different applications considering the integration of the arm in a full anthropomorphic dummy in a sled test to reproduce a complete accident load case (road user group of car occupants).

For other road user groups (pedestrians, bicycles, e-scooters…) alternative experimental injury assessments could be feasible by sub-system component tests, by the definition of the appropriate loads and boundary conditions in the test set-up tooling. These conditions to apply to tests can be obtained from a virtual models of a selected accident scenario considering a full HBM or ATD.

In WP3 the assessment methods (both virtual and physical) and specific injury metrics for upper extremities will be developed. As references, the standards "ISO/TS 15827" and "TGW Side Airbag OoP" define the injury criteria based on the maximum bending moments and shear forces permissible on the upper extremity. In relation to the forearm, the recommended values were obtained from the biomechanical work by Pintar (1998) and Begeman (1999), while the reference values obtained for the humerus come from the works of Kirkish (1996). These values can be extrapolated to the complete Hybrid-III dummies family using a scalability methodology.

9.3 Lower extremities

Using advanced computational crash simulations that incorporate a range of influential parameters—including vehicle velocity, occupant seating position, seat inclination angle, and other relevant variables—we apply the resulting biomechanical forces to establish precise boundary conditions for a detailed finite element model of the human tibia. These simulations account for variations in crash scenarios, capturing the complexities of real-world vehicular accidents and their impact on lower extremity injuries.

The tibia model we employ intricately differentiates between cortical bone, characterized by its dense and rigid structure, and trabecular bone, known for its porous and spongy architecture. By incorporating the distinct mechanical properties of these bone tissues, the model achieves a high degree of anatomical and biomechanical fidelity, allowing for accurate simulation of bone behaviour under stress.

Subjecting the tibia model to various loading scenarios derived from the crash simulations, we induce fractures under different conditions that reflect the influence of the varied parameters. This approach enables us to generate a spectrum of fracture patterns that closely mimic those observed in clinical settings, considering how factors like impact velocity, seating posture, and seat angle affect fracture outcomes. Each fracture pattern is systematically analysed to evaluate its complexity, location, and the extent of structural disruption.

The primary objective of this analysis is to assess the potential impact of specific fracture configurations on the bone healing process. We hypothesise that certain fracture patterns, influenced by crash parameters such as collision speed and occupant positioning, may inherently possess a higher risk of progressing to non-union — a condition where the broken bone fails to heal properly. Factors contributing to non-union may include compromised vascular supply, mechanical instability at the fracture site, or extensive damage to both bone and surrounding soft tissues.

By identifying fracture patterns that are predisposed to non-union and understanding how different crash parameters influence these patterns, this research aims to enhance our understanding of the biomechanical and biological factors affecting bone healing. The insights gained could inform clinical decision-making, allowing for the implementation of targeted interventions — such as optimised surgical fixation strategies or the application of biologic

agents — to promote effective healing. Ultimately, this work seeks to reduce the incidence of complications associated with impaired bone regeneration and improve patient outcomes following traumatic injuries.

Parallel to the investigation concerning fracture patterns, a risk function is developed, to determine the probability for a tibia fracture in general by using the output of FE Human Body Model simulations. This risk function will be used to quantify the benefit of developed countermeasures. The definition of the risk function is based on a combination of PMHS test results and conducted simulations with a selected HBM, as conducted for ribs in [12].

10. Determination of the socio-economic benefit

This comprehensive impact assessment framework aims to quantify the effectiveness of ProtAct-Us prevention strategies in reducing the socioeconomic costs associated with road traffic crashes and provide policymakers and road safety stakeholders with accurate data to estimate the extent to which their actions mitigate long-term consequences from road incidents.

This evaluation goes beyond measuring direct safety benefits by assessing a wide range of impacts, including economic, social, and societal outcomes. It involves calculating healthcare cost savings from reduced injury severity and frequency, productivity gains from decreased work absenteeism, and the long-term economic benefits of preventing disability and loss of life. Additionally, it measures social benefits, such as improved quality of life, mental health outcomes, and enhanced public confidence in road safety. A crucial aspect of the evaluation is the analysis of societal equity, ensuring that safety benefits are equitably distributed across different population groups, particularly vulnerable users like pedestrians, cyclists, children, and the elderly. This involves assessing the reduction in injury disparities and increased accessibility and safety for these groups. Ultimately, the goal is to inform strategic decision-making, foster public support for safety initiatives, and enhance overall road safety outcomes.

Measurement of Impact

The impact assessment of ProtAct-US road traffic safety countermeasures will be categorised into five main areas: *Direct Safety Benefits, Indirect Safety Benefits, Economic Benefits, Social and Quality of Life Impacts, and Societal Impacts.* More precisely:

- *Direct Safety Benefits* will include injury risk reduction, which measures the decrease in the probability of sustaining injuries through Relative Risk Reduction (RRR) and Absolute Risk Reduction (ARR). It will also cover severity reduction, measured by improvements in the Abbreviated Injury Scale (AIS), Injury Severity Score (ISS), and decreases in serious injury rates.
- *Indirect Safety Benefits* focus on post-crash outcomes improvement, will be assessed by reductions in Disability-Adjusted Life Years (DALYs) and improved Return-to-Work Rates, reflecting better recovery and long-term health outcomes.
- *Economic Benefits* will be measured through healthcare cost savings, including direct medical expenses and long-term rehabilitation costs. Additionally, productivity gains will be assessed through reduced Value of Lost Productivity (VLP) and increased working life expectancy for those affected by crashes.
- *Social and Quality of Life* Impacts will involve enhancements in physical, mental, and social well-being, measured by Health-Related Quality of Life (HRQoL) scores and improvements in mental health conditions such as anxiety, depression, and PTSD.
- *Societal Impacts* will include improved safety and accessibility for vulnerable populations like children, the elderly, pedestrians, and cyclists. This is measured by reductions in injury disparities and increased safety for vulnerable road user groups.

Table 10-1: Benefits Metrics

Benefits	Metrics
1. Direct Safety Benefits	
Injury Risk Reduction *Decrease in the probability of sustaining injuries in road traffic crashes.*	Relative Risk Reduction (RRR): Percentage decrease in injury occurrence.
	Absolute Risk Reduction (ARR): Difference in injury rates before and after implementation.
Injury Severity Reduction *Reduction in the severity of injuries sustained during a crash.*	Abbreviated Injury Scale (AIS) reductions
	Reduction in Injury Severity Score (ISS) averages
	Decrease in Serious Injury Rates.
2. Indirect Safety Benefits	
Post-Crash Outcomes Improvement	Reduction in Disability-Adjusted Life Years (DALYs).
	Improved Return-to-Work Rates.
3. Economic Benefits	
Healthcare Cost Savings *Reduction in medical expenses associated with crash-related injuries.*	Direct medical cost savings (e.g., emergency services, hospitalization)
	Long-term rehabilitation and disability care cost reductions.
Productivity Gains *Economic benefits from reduced work absenteeism and productivity losses.*	Value of Lost Productivity (VLP) reductions
	Increased working life expectancy for injured individuals.
4. Social and Quality of Life Impacts	
Quality of Life Improvement *Enhanced physical, mental, and social well-being due to reduced injury severity.*	Health-Related Quality of Life (HRQoL) scores.
	Improved mental health and reduced psychological trauma (e.g. anxiety, depression, PTSD).
5. Societal Impacts	
Societal Equity and Accessibility: Improved safety for vulnerable populations (e.g., children, elderly, vulnerable road groups e.g. pedestrians, cyclists).	Reduction in injury disparities across vulnerable groups
	Increased safety and accessibility for vulnerable road user groups e.g. pedestrians and cyclists.

Data Sources and Analytical Tools

The impact evaluation of the ProtAct-US road traffic safety countermeasures relies on a comprehensive combination of data sources and advanced analytical tools to accurately estimate the financial and social gains. More specifically, we will employ the following data sources:

- *Injury Databases:* The MHH, the GIDAS and the Rehabilaid Project [27] injury databases (They provide detailed data on injury severity, and the circumstances surrounding each incident, allowing for accurate baseline and post-intervention comparisons. This data is crucial for calculating metrics like Relative Risk Reduction (RRR) and Absolute Risk Reduction (ARR).
- *National Health System and Hospital Databases:* These databases offer extensive information on medical expenses related to road traffic injuries, including emergency care, hospitalisation, surgery, rehabilitation, and long-term disability care. Examples include the DRGs in European hospitals. Diagnosis-Related Groups (DRGs) classify hospital cases into groups with similar clinical conditions and resource usage, enabling standardised cost analysis for injury treatment. This makes them highly valuable for assessing the direct medical costs and economic impacts of road traffic crashes. This data is used to calculate direct medical cost savings and long-term healthcare savings resulting from safety interventions. By matching patient records to corresponding DRG codes, the costs of emergency care, hospitalisation, surgeries, rehabilitation, and post-acute care will be accurately estimated. This includes costs for common crash-related injuries, such as fractures, traumatic brain injuries, and spinal cord injuries. Comparing these costs before and after implementing safety interventions allows for the assessment of healthcare cost savings. Furthermore, reduced injury severity, as reflected in DRG data, lead to faster shorter hospital days, faster recovery times and decreased work absenteeism. This information will be used to calculate productivity gains by estimating the Value of Lost Productivity (VLP) reductions and increased working life expectancy. DRGs will further enable comparative analysis across different regions, hospitals, and time periods. This will help in benchmarking the impact of road safety countermeasures on healthcare costs and injury outcomes. It will also allow for international comparisons, facilitating the evaluation of best practices in road safety.
- *Economic Records and Reports:* Economic reports from national statistical agencies and international organisations (e.g., the World Bank, OECD) will be used to obtain productivity data, employment rates, and macroeconomic indicators. These reports will provide data for calculating the Value of Lost Productivity (VLP) and estimating the economic impact of reduced work absenteeism and disability. Additionally, they will offer estimates of the Value of Statistical Life (VSL) and the economic costs of premature mortality, which are essential for cost-benefit analysis.
- *Social Impact Surveys:* Social and quality of life impacts will be evaluated including Health-Related Quality of Life (HRQoL) scores using standardised instruments such as the SF12 and the WHO Quality of Life (WHOQOL), WHODAS, Center for Epidemiologic Studies Depression Scale (CES-D), assessment tools.
- *Societal Data Sources:* Equity analysis will be performed using demographic data from census records to evaluate injury disparities and the accessibility of safety interventions for vulnerable road users.

Statistical Analysis Tools

- *Regression Analysis* will be used to establish causal relationships between safety interventions and changes in injury rates, severity, and economic costs.
    - *Time-Series Analysis* will be applied to observe trends and long-term impacts of safety measures on road traffic injuries by analyszing data collected over consistent intervals. This approach will help in identifying patterns, seasonal variations, and the causal effects of interventions on road safety outcomes. Hospital and Emergency Room Records will be used and Information on injury types, medical treatments, hospitalisation durations, and patient outcomes over time to run this analysis.

Expected Outcomes

This impact assessment framework will evaluate long-term sustainability by monitoring sustained safety improvements, such as consistent reductions in injury severity. It will also examine the scalability of effective safety interventions, supporting the replication and adaptation of successful policies in other regions. These insights will inform strategic policy development, legislative changes, and infrastructure investments to continuously improve road safety. The framework will further enhance decision-making by providing robust, data-driven evidence to policymakers, stakeholders, and road safety organizations. By demonstrating the socioeconomic benefits of safety measures, the framework will promote optimised resource allocation.

11. Conclusion

A workflow is presented in chapter 2 which leads from the injury statistics (covering injuries which lead to long-term consequences) to the assessment of cognitive and physical injuries to the determination of the socio-economic benefit for developed countermeasures for four road user groups.

Cognitive injuries

A list of possible cognitive tests is defined to determine cognitive impairments. The aim is, to develop a scale like the AIS for cognitive injuries in WP2. That will be applied to gain the data of future accidents with injuries causing LTCs. The enhanced data which will result from that will be available for upcoming projects.

Physical injuries

The determination of the risk for physical injuries in each of the road user groups is outlined and the underlying methods and ideas for enhancing the assessment methods are mentioned in this deliverable. The body regions and injuries were identified based on accident statistics covering long-term consequences. For the identified body regions and injuries, the mentioned methods will be used and/or enhanced in WP3 and further applied to the use-cases in WP4. They allow to determine the benefit (identified by the injury risk) of certain countermeasures for the specific use-cases in WP4. The next step to specify the influence of the countermeasures concerning LTCs on the entire society is the determination of the socio-economic benefit.

Socio-economic benefit

Several metrics are listed to determine the benefit of developed countermeasures. The listed data sources, metrics and possible tools are the basis for the work in WP2. There, further definition concerning common data sources and methods to transfer the output from one metric to the other need to be discussed. The method how to calculate the socio-economic benefit will then be applied in WP4.

12. Abbreviations

Term	Definition
AIS	Abbreviated Injury Scale (rating the injury severity of an individual injury between 1 (slight injury) and 6 (not survivable injury)
DEC	Websites, Patent Filings, Videos etc.
DEM	Demonstrator, Pilot, Prototype
GIDAS	German In-Depth Accident study
ISS	Injury Severity Score (combines injury severity levels in different body regions by calculating the AIS of the most severe injuries in three different body regions in order to take into account the risk resulting from multiple injuries compared to just one injury)
LTC	Long-term consequence
MHH	Hanover Medical School
ProtAct-Us	ProtAct-Us from long-term consequences of road crashes
PU	Public
R	Document, Report
RTC	Road Traffic Accident
SEN	Sensitive
WP	Work Package

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