Extrapolation of performance assessment of safety solutions and countermeasures over time and at EU level

Deliverable D6.2 – WP6 – PU

Extrapolation of performance assessment of safety solutions and countermeasures over time and at EU level

Work package 6, Deliverable D6.2

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Table of Contents

About V4SAFETY

An accepted, reliable method for comparing safety measures for CCAM is needed to set policies for road safety in the coming decades and push for Vision Zero.
The V4SAFETY method covers the safety of all road users, from vulnerable road users to vehicle occupants. It emphasises those measures that involve at least one motorised vehicle.

V4SAFETY provides a prospective safety assessment framework that can handle a large variety of safety measures, ranging from in-vehicle safety technology, new vehicle types, and infrastructure solutions to regulations that influence road user behaviour. It includes methods to project the results in future scenarios and over EU regions - for use by policy makers, authorities and consumer organizations.

To help users understand the differences between studies and the influence of underlying data, assumptions and models, the method provides tools to characterise the influence of the contributing factors and their uncertainties. The resulting transparent, consistent simulation-based safety assessments will in the future lead to conclusions that are much more comparable and reliable.

The V4SAFETY consortium, led by TNO, consists of the following international partners: BMW, BASt, Chalmers, Fraunhofer IVI, IDIADA, IKA, LAB France, SWOV, THI, TME, UNIFI, VIF, VCC, ZF, ERTICO, W2Economics. The project was executed in the period 2022-2025.

Terms and definitions

Baseline
A set of data without the technology under study, to be compared when performing prospective assessments of a technology's performance.

Case
A case is equivalent to a concrete scenario.

Concrete scenario
A concrete scenario is a scenario depicted with explicit parameter values describing physical attributes. It is always anchored in the real world.

Epoch
A segment of time that can be anchored at some event (e.g., a critical event) or randomly selected in collected data. It has typically a duration of seconds, though there is no duration limit.

Exposure
The occurrence of any factor or event, limited in time and space, that has the potential of generating an crash by bringing road users close to each other in time or space or by requiring a road user to take action to avoid leaving the roadway.

Extrapolation of Data over Space (abbr. Data Extrapolation)
Any technique aimed at inferring the state of target data (e.g., network length, annual distances travelled) in a region, based on the state of a set of data (which may include the target data) from a subset area of this region or from another region (or subset area).

Extrapolation of Measure's Performance over Space (abbreviation: Performance extrapolation)
Any technique aimed at inferring the performance of a target measure in a region, based on data and/or performances of a set of measures (which may include the target measure) originating from a subset area of this region or from another region (or subset area). Linear extrapolations (also known as "scaling-up" techniques), often using simplified hypotheses, are a subset of these techniques.

Pre-crash phase
The time phase prior to the crash which ends with the contact between participants and/or objects involved in the crash.

Predictive safety assessment framework
(Or simply: framework) is a structured process for the use of simulation models and tools to predict the safety performance of a road safety solution.

Primary data
Data that originate directly from real-world observations and may have been modified when parsed through quality and plausibility checks.

Projection of a Measure's Performance over Time (abbr. Performance Projection)
Any technique aimed at inferring the future performance of a target measure based on past data and/or past performances of a set of measures (which may include the target measure). Data Projection (e.g., building timelines for penetration/installation rates of measures in the fleet) might be required to feed the Performance Projection process.

Projection of Data over Time (abbr. Data Projection)
Any technique aimed at inferring the future state of target data (e.g., building timelines for fleet size, fleet characteristics, or penetration/installation rates of measures in the fleet) from past states of a set of data (which may include the target data)

Prospective assessment
A predictive assessment of the future performance of given safety solutions before their deployment.

Safety performance
The quantified capability of a road safety solution to achieve an improvement in road traffic safety in terms of fewer crashes and fewer or less serious injuries.

Safety solution
A measure intended to increase road safety, whether implemented as an in-vehicle technology, infrastructure measure, policy, or regulation.

Scenario
A sequence of scenes, defined in terms of time and space, for a simulation. A scene is a snapshot that encompasses the mobile and immobile elements of the traffic, infrastructure, and environment (for example, weather and lighting conditions), as well as all actors and observers, and the relations between them.

Secondary data
Data that are derived from primary data by manipulation, modification, aggregation, subsampling, or model building.

Simulation model
A computational model which allows the virtual evaluation of the technology, process, or behaviour it represents. A simulation model can also contain other simulation models.

Technology
The collection of techniques, processes, and systems capable of temporarily or permanently directing, restricting, or controlling traffic participants; the expected safety benefit will be predicted in the prospective assessment.

Test
The use of quantitative measures to evaluate a technology under a set of specified conditions, with reference to values that represent an acceptable outcome.

Test case
A test case is a test scenario (a simplified concrete scenario) that also includes a description of the output (e.g., delta-V or TTC) to be assessed and any criteria for a successful execution of the simulation.

Test scenario
A test scenario is typically a simpler version of a concrete scenario, created for the purpose of assessing a technology under a set of specified conditions.

Treatment
The specific safety solution applied during a prospective assessment. Treatment simulations provide data on the performance of the safety solution under assessment for comparison with baseline data.

Vulnerable Road Users (VRUs)
Pedestrians, cyclists, and powered two-wheelers (including e-scooters and mobility scooters) as well as people with disabilities, the elderly, and children.

Abbreviations

2D	Two-dimensional
ADAS	Advanced Driver-Assistance System
AEB	Autonomous Emergency Braking
AEBP	AEB for Pedestrian
AIS	Abbreviated Injury Scale
ASAM	Association for Standardization of Automation and Measuring Systems
B2V	Bicycle-to-Vehicle communication
BSI	Blind spot intervention
CADaS	Common Accident Dataset (of the CARE database)
CARE	Community database on Accidents on the Roads in Europe
CBA	Cost-Benefit Analysis
CI	Confidence Interval
CINEA	European Climate, Infrastructure and Environment Executive Agency
COVID	Coronavirus disease
ESRA	E-Survey of Road users' Attitudes
EU	European Union
Euro NCAP	European New Car Assessment Programme
FCW	Forward Collision Warning
FOV	Field Of View
GDV	German Insurance Association
GSR	General Safety Regulation
GIDAS	German In-Depth Accident Study
ICE	Internal Combustion Engine
IRF	Injury Risk Function
IRTAD	International Road Traffic and Accident Database
ITS	Intelligent Transport Systems (in terms of communication and technology systems)
KSI	Killed or Seriously Injured
PCM	Pre-Crash Matrix
SUMO	Simulation of Urban MObility
TASC	Traffic Accident Scenario Community
TRL	Transport Research Laboratory
TTC	Time To Collision
V4SAFETY	Vehicles and VRU Virtual eValuation of Road Safety
V&V	Validation & Verification
VDA	German Association of Automotive Industry
VOIESUR	Véhicule Occupant Infrastructure Etudes de la Sécurité des Usagers de la Route
VRU	Vulnerable Road User

Executive summary

This document describes the application of the V4SAFETY Prospective Safety Assessment Framework and serves three primary purposes. The first purpose is to extend the validation of the V4SAFETY Framework (Deliverable D2.2; Fahrenkrog et al., 2025) beyond the work showcased in Deliverable D6.1 (Menzel et al., 2025) by applying projection in time,extrapolation over space, and cost-benefit analysis (CBA) to prospective road safety use cases. The second purpose is to provide examples of these to potential users and demonstrate the use of the framework. Finally, the lessons learned from the application of the framework need to be provided to the developers of the framework.

The demonstrated use cases are illustrative applications of the V4SAFETY framework and are in general not intended to inform decision-making. The assessments presented in this document are idealised, so are the models used.

Extrapolation over regions requires two essential elements: firstly, a dataset collected for a sampling country or region – the simulation baseline is built on this database; and secondly, a target dataset or statistics that represent the target regions. This document presents three examples: one example from sampling region to target country and two examples from sampling country to the entire European Union (EU) as a target region. The latter used a machine learning approach to overcome the lack of completeness in the target data, where different coding systems coexist and reporting policies differ from country to country even amongst those sharing a common coding system. A clustering method was used to identify best proxies amongst countries with lack of information and offer substitute information that takes country specifics into account, even though biases – also discussed in this document – still exist.
Extrapolation to the EU could be conducted using the Community database on Accidents on the Roads in Europe (CARE) database, to which all EU member states report their police recorded crashes. However, not all member states follow the Common Accident Data Scheme (CADaS), resulting in lack of detailedness of the aggregated data. Consequently, scaling to the European level may increase uncertainty of the results if data selection cannot be carried out to the extent required by the research question.

Projection over time requires a good knowledge of the past, the present and plausible future trends that have an influence on the use case under study. Unprecedented events might also be superimposed on trends, provided the projection model assumptions are not invalidated. Two examples are presented here. The first addresses the introduction of e-bikes into the traffic system in Germany and the future challenges posed to in-vehicle systems aimed at avoiding collisions between cyclists and right-turning vehicles. The second addresses car to jay-crossing pedestrians crashes in France and gives insights on the effects of the progressive introduction of in-vehicle collision prevention systems, regulations (e.g., new speed limits), transport modal shift and population ageing on the outcomes of these conflicts.
The results of the projection are highly dependent on the accuracy, completeness, and granularity of the available data sources. While comprehensive information is available on some characteristics such as fleet size and age, other characteristics may be only partially or in aggregated from available data. Such heterogeneity can increase uncertainty of projections resulting in over- or underestimation of the future impact of safety measures.

Cost-Benefit Analysis (CBA) is a decision support method for evaluating, comparing and prioritising different investment options based on their consequences over a time horizon. In the context of V4SAFETY, such investment options may lead to decisions whether or not to introduce certain road safety measures. Road safety measures are socio-economically advantageous if the benefits, in terms of reduced crash costs, outweigh the costs of implementing them – both costs and benefits are assessed in (discounted) monetary units. The results of two CBA are presented in this report: the first assesses an Autonomous Emergency Braking (AEB) in-vehicle device aimed at preventing intersection collisions in Germany, the second an AEB for Pedestrian in France. The main challenge for the first CBA was to handle a simplified assessment with a “100% penetration rate of the fleet” hypothesis, not including an investment period duration. The main challenge for the second one, that was based on a full projection in time, was about the validity of the data and models used for the projection itself.

The V4SAFETY Framework demonstrated broad applicability across diverse safety assessment use cases, offering structured guidance and useful tools such as a CBA assessment tool and Verification & Validation (V&V) support materials. While the framework enables more transparent and comparable assessments, it cannot fully eliminate challenges stemming from limited data availability or modelling constraints.

1. Introduction

This deliverable (D6.2) demonstrates the application of projection in time, extrapolation over space and cost-benefit analysis, as described in Fahrenkrog (2024, 2025). This is done through example studies with a variety of use cases.

The Background section explains the relevance of this report for the project “Vehicles and VRU Virtual eValuation of Road Safety”, abbreviated as V4SAFETY. The Motivation section (1.2) describes the main drivers for projection, extrapolation and cost-benefit analysis. The Scope section (1.3) describes what is covered and not covered by the report. Finally, the Objectives of the report are formulated; they are sub-objectives of the V4SAFETY project.

1.1. Background

The V4SAFETY project is based on the need for an accepted and reliable method to assess the benefit of introducing safety measures at an early stage, typically before they are introduced in the market. These kinds of methods are called ‘prospective’, ‘a priori’ or ‘ex ante’ because their conclusions are drawn from logic (deductive reasoning). These methods differ from ‘retrospective’, ‘a posteriori’ or ‘ex post’ methods, which draw conclusions from observations (inductive reasoning); for example, a retrospective evaluation of collected real-world data. The project objectives can be found in European Climate, Infrastructure and Environment Executive Agency (CINEA) 2023 (page 36).

Though prospective assessments might also be done on small sample sizes based on prototypic real-world installations (e.g., data from specific regions, limited number of scenarios, limited number of cases per scenario), the generalisation of those results might be questioned:

- Do the collected data cover all relevant variances that can occur in real-world situations?
- Virtual simulations are an effective method to ensure the coverage of variations and their dependencies, since simulation runs with up to hundreds of thousands of parameter combinations can be conducted faster than real time. But are the results reliable?
- What does a study result mean for the same scenario category in 5 years?
- What does a study result mean for another EU country?
- What would be the cost-benefit balance in 5 years?

The V4SAFETY framework comprises five themes, each divided into distinct topics, to address the various aspects necessary for prospective safety assessment through virtual simulation:

- The General Framework Overview: Definitions, User & Stakeholder, Examples and Formulate Conclusions
- Prepare Assessment: Define Evaluation Scope, Select Baseline Approach, Prepare Data, Select Models
- Execute Simulation: Configure Simulation and Manage Simulation
- Analyse Assessment: Evaluate Safety Performance, Analyse Cost / Benefit, and Project the Results.
- Perform Cross-Assessment: Conduct Validation & Verification and Document Assessment.

1.2. Motivation

To ensure the generalisability and validation of the framework, it is important to assess it across a wide range of use cases. These use cases must encompass diverse evaluation scopes, including different scenarios or conflict types, safety measures, models, simulation tools, and metrics. Furthermore, they should address most of the framework's themes in order to support a comprehensive validation of the entire framework.
The assessments presented in this report focus on extending the scope of the assessments such as presented in Deliverable D6.1 (Menzel, 2025) – be it over time or over space / regions. This is done through specific approaches, often necessitating a wider array of data and methods.

1.3. Scope

The scope of the use cases that are presented in this report covers the themes and topics of the V4SAFETY Safety Assessment Framework outlined in red in Figure 1.1, namely 'Analyse Cost / Benefit' and 'Project the results'. The four grey topics at the second row are not relevant for the execution of an assessment, since it covers general aspects of the framework.

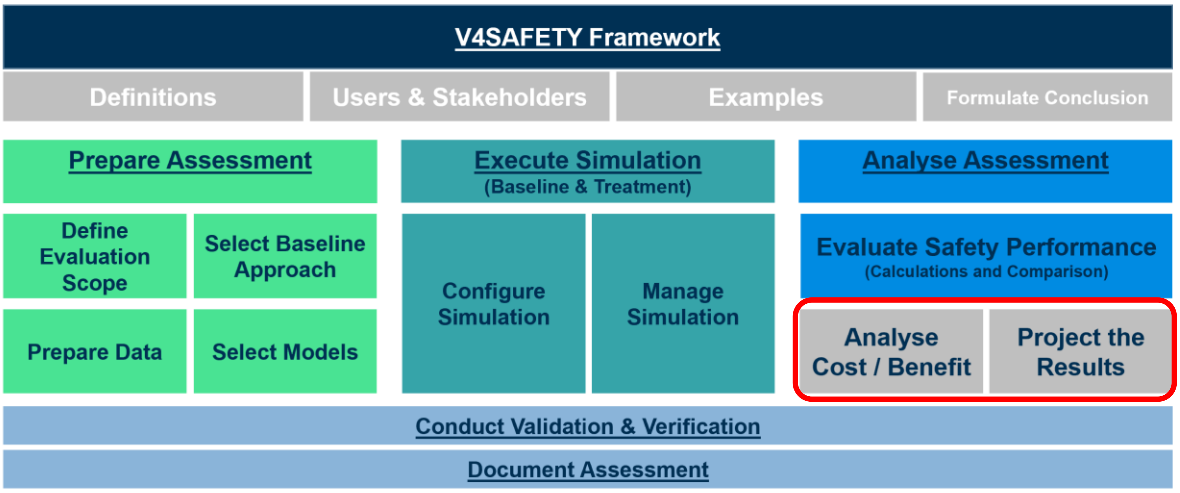


Figure 1.1. Covered themes and topics of the V4SAFETY Safety Assessment Framework. The scope of this report is shown in a red outline.

More precisely, the following processes will be illustrated in this document:

- Projection in time
- Extrapolation over space / regions
- Cost-Benefit Analysis

1.4. Objectives

The objectives of this report are:

- To validate the Framework by applying it on use cases that include projection in time and extrapolation over space / regions based on formulated assessment metrics.
- To create assessment reports following the instructions of D2.2 (Fahrenkrog et al., 2024). The reports exemplify the documentation of prospective safety assessment results for these types of use cases.
- To provide examples of Cost-Benefit Analyses built both on simplified and full-size projection in time use cases.
- To provide readers with hands-on experiences from the use cases applying the Framework.

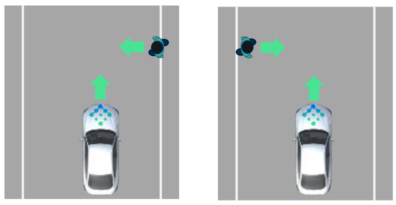
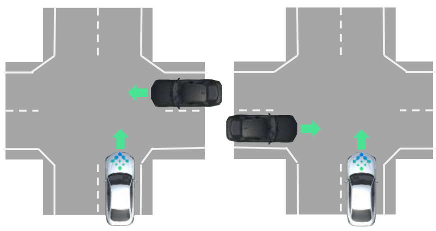
Throughout the application of the use cases and writing this report, feedback was provided to the development team of the framework.

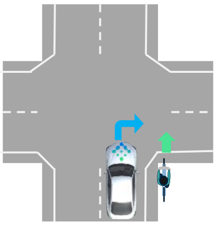
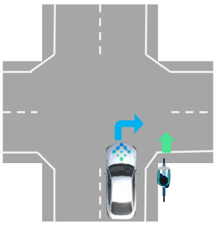
2. Use cases

2.1. Overview

This section provides an overview of the use cases addressed in this document. It includes a summary table containing information on the safety measures, the countries or regions represented in the assessment and the type of analysis presented (Table 2.1).

Table 2.1 Use case overview

Section	Author	Safety measure	Conflict scenario description	Visualisation of conflict scenario
2.2.1, 2.3.1, 2.4.1, A.1.1, A.2.3	LAB	In-car (AEB)	Extrapolation in space from France to EU level, projection in time and Cost-Benefit Analysis for France. Driving along the road with a Pedestrian crossing the road from right or left side. The driver is driving along the road and does not recognise the intention of the pedestrian to cross the road (orthogonal to the road but also other angles are considered).	
2.3.3, 2.4.2, A.2.2	TME	In-car (AEB)	Extrapolation in space of the State of Saxony to Germany level and Cost-Benefit Analysis. Two passenger cars are crossing the intersection straight at the same time. Both drivers don't see or recognise the upcoming collision.	

2.3.2, A.2.4	VCC	In-car (AEB)	Extrapolation in space from Germany to EU level. Right turn with cyclist crossing the right arm of intersection: The passenger car performs a right turn, and the cyclist is crossing the right arm of the intersection coming from same direction as passenger car.	
2.2.2, A.1.2	THI	In-car (AEB, BSI)	Projection in time from Germany, with increased penetration of e-bikes. Right turn with cyclist crossing the right arm of intersection: The passenger car performs a right turn, and the cyclist is crossing the right arm of the intersection coming from same direction as passenger car.	

2.2. Use case summaries for projection in time

Projection in time is a methodological approach aimed at estimating outcomes beyond the temporal scope covered by the available baseline. It relies on the systematic analysis of existing datasets to generate informed predictions for future periods that have not been directly monitored or measured, for instance when the collected data pertains to a different reference timeframe. In the context of V4SAFETY treatment simulations, the direct applicability of findings (e.g., crash avoidance rate, crash mitigation rate, etc.) to a different point in time requires careful consideration of multiple factors. Typical influencing elements include the evolution of fleet size and fleet composition, changes in driver demographics, modal shifts, and variations in market penetration and usage rates of safety measures. In addition, external influences such as regulatory changes, technological upgrades of the safety measures, or behavioural adaptations by drivers over time may impact the reliability of projected outcomes.

To ensure robust projections over time, these temporal dynamics must be systematically incorporated into the analysis. This may involve the application of an iterative process (Figure 2.1) stepping through increments of time, for example, year by year, updating parameters such as crash risk, injury risk, and the performance of the safety measures, while integrating relevant contextual changes.

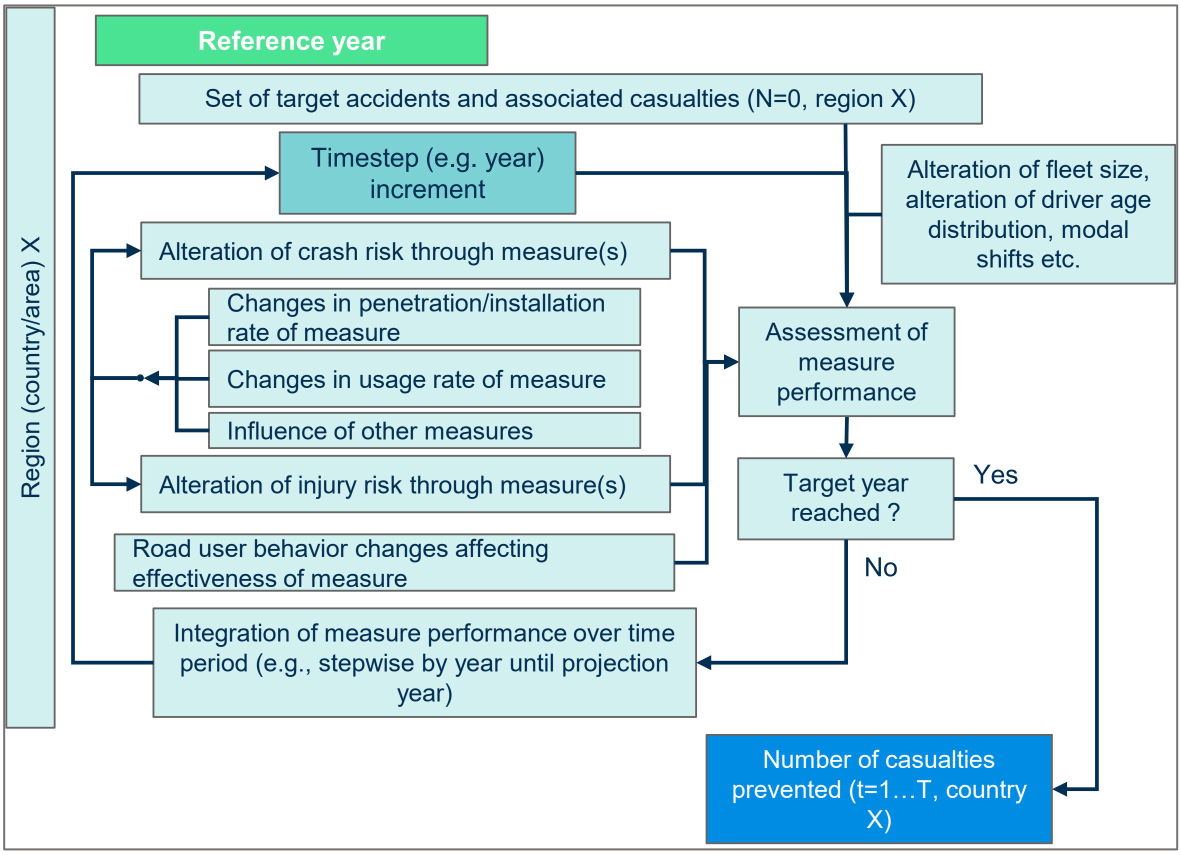


Figure 2.1 Workflow for time projection of results (from Fahrenkrog et al., 2025)

The theoretical framework and methodological constraints for projection in time, along with more detailed explanations of its necessity and application, are explained in the V4SAFETY D2.2, section 6.2 (Fahrenkrog et al., 2025). The approach described in D2.2 provides the basis for practical demonstrations in the context of V4SAFETY Use Cases (see LAB and THI use cases, 2.3.1 and 2.3.2 respectively). These demonstrations project simulation results into future years, enabling the assessment of how effective outcomes evolve over time. The results illustrate changes in safety performance indicators and provide a basis for strategic decision-making regarding the deployment and scaling of safety measures.

2.2.1. Projection in time of the Safety Performance in France of an in-vehicle Autonomous Emergency Braking for Pedestrians in Car vs. Jay-Crossing Pedestrians scenarios

The EU's long-term goal is to move as close as possible to zero fatalities in road transport by 2050 ("Vision Zero") (CINEA, 2022). A large portion of current fatalities in the EU are pedestrians, accounting for 18% in 2022, which is still very high, despite significant progress since 2012 (-31% at EU level) and even 2019 (-20% at EU level) [All numbers from CARE, 2023]. In France, the number of pedestrian fatalities has all but flatlined between 2010 and 2019 and decreased by 10% between 2019 and 2023. In 2023, 474 pedestrians were killed on French roads. 282 (60%) of them were killed when crossing the street, of which nearly half (134, 48%) when jay-crossing away from protected crossings or intersections (ONISR 2023).

The research question to be answered by this study was formulated as follows:

> *"What reduction of the injury burden – expressed in terms of avoided injuries (fatal, serious or slight) – can be expected in year 2050 in France considering the market penetration of a specific Automated Emergency Braking for Pedestrians (AEBP) in car going straight vs jay-crossing pedestrians?"*

The V4SAFETY framework was employed to prospectively assess the evolution over time of the performance of an AEB for Pedestrians (AEBP) system in reducing the injury burden in collisions with jay-crossing pedestrians in France. The following effects were assessed as the most influential:

- Market Penetration of the AEBP measure
- Population Ageing
- Fleet renewal
- Trends (e.g., numbers and age classes of injured, accident numbers) from the reference year (2011) to present

Potential effects such as modal shifts to e-scooters or electrified vehicles were investigated and seen as not influential. Lowered, not law-enforced speed limits in cities were not included either for the same reason. Lastly, the effects of the 2020 pandemic and other international events were not included, as it was hypothesized that they would have no lasting effects on kilometers travelled but a temporary low in new registrations.

The main results to be retained from our simulations are as follows:

- No or almost no effect can be seen until present as uptake is slow and there is already a positive trend from other measures
- The full effect will be reached between years 2035 and 2050, when even older vehicles are equipped with AEBP
- AEBP will help compensate for the growth of the senior population, starting 2025+ with more unresponsive senior drivers on the roads and more senior pedestrians crossing the streets.

A more detailed description of the use cases including the study limitations can be found in Appendix A1.1.

2.2.2. Projection in time of the Safety Performance in Germany of an in-vehicle Autonomous Emergency Braking and a Blind Spot Intervention in Right-Turning Cars vs. Same Direction Cyclists scenarios

Bicycles—especially e-bikes—are changing urban mobility, potentially increasing the risk with higher speed when a car turns right while a cyclist is riding straight ahead along the same road. The autonomous emergency braking (AEB) system, which is now widely used in cars, was initially developed for frontal conflicts (e.g. rear-end collisions, jay-walking pedestrians) where forward-looking sensors can detect hazards directly in front of the vehicle. In further development, also crossing scenarios were considered in AEB.
This study investigates whether such systems can also reduce collisions in right-turn situations, even though the approach angles and positions of cyclists are outside the original design scope of AEB. As the use of e-bikes is expected to increase, a prospective safety assessment was carried out, focusing on future traffic conditions with higher e-bike penetration, using the V4SAFETY framework and a sample of baseline scenarios generated using stochastic traffic simulation. Given the geometric challenges, Blind Spot Intervention (BSI) was also evaluated, utilising a backward facing sensor in the vehicle. The primary assumption is that future traffic will differ mainly in terms of a higher proportion of e-bikes, which will change the composition of bicycle traffic and possibly also the detection, timing, and risk profiles of these systems.

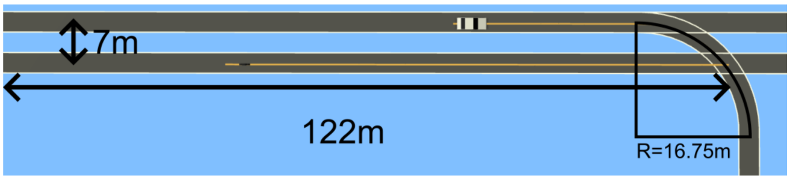


Figure 2.2 Intersection geometry used for the analysis: a car turning right while a bicycle (conventional or e-bike) proceeds straight in the same direction. The coordinate system and layout depicted here define the spatial configuration for all simulated scenarios and analyses. Visualization done with esmini.

The following research questions are addressed:

- *AEB: What percentage of crashes can be avoided in the scenario "car turning right, cyclist going straight in the same direction" at the intersection geometry shown in Figure 2.2 with traffic flow parameters originating from a specific intersection in the city of Ingolstadt, if a specific forward-looking AEB system with 100° sensor field of view is implemented in all cars in Germany (100% penetration rate), considering a projected increase in absolute share of e-bikes to 50% by 2036?*
- *BSI: What percentage of crashes can be avoided in the scenario "car turning right, cyclist going straight in the same direction" at the intersection geometry shown in Figure 2.2 with traffic flow parameters originating from a specific intersection in the city of Ingolstadt, if a BSI system with a backward looking camera (180° sensor field of view) is implemented with varying range of view in all cars in Germany (100% penetration rate), considering a projected increase in absolute share of e-bikes to 50% by 2036?*

The present study is conducted in an urban environment at a generic right-angle, single-lane intersection controlled by traffic lights, representing characteristics commonly found in Germany. The data used for calibration of traffic flow parameters for the study is originating from a specific intersection in the city of Ingolstadt, as described in the Annex. The parameters of the road geometry are provided in Figure 2.2.

The C2 baseline approach was chosen because it enables the generation of a representative sample of crash scenarios via stochastic microscopic traffic simulation, allowing systematic variation of key parameters such as the projected e-bike share. A total of 1579 baseline scenarios were generated.
For the AEB treatment simulations, the baseline scenarios were exported into Association for Standardization of Automation and Measuring Systems (ASAM) OpenSCENARIO format and transferred to partner VCC, where the treatment simulation was performed by applying the AEB system described in A.2.4 to these scenarios.
For the BSI treatment simulations, the baseline was provided to LAB as Matlab structures containing the EGO and bicycle trajectories as lists of (X,Y) planar coordinates. It was used without alteration, using a constant 10 ms timestep for computing speeds and acceleration.

In total, 4 of 1579 collisions of the baseline scenarios were avoided by the AEB system, corresponding to a decrease of 0.25%. The 95% confidence interval (CI) is estimated to [0.00%, 1.38%]. An extended analysis of the results provided in the Annex reveals that the majority of cases (77.9%) were not geometrically detectable by the AEB due to the scenario's lateral nature. The avoidance rates for the three field of view ranges of the BSI system tested were: 5 m range: 0.55%, 10 m range: 31%, 30 m range: 89%.
A more detailed description of the use cases including the study limitations can be found in Appendix 0.

2.3. Use case summaries for extrapolation in space

Extrapolation in space serves as an analytical method to estimate outcomes that extend beyond the available spatial range in which the simulation data has been collected. The technique involves utilizing existing information to infer insights about areas that have not been directly measured or observed.
In the context of V4SAFETY treatment simulations, the direct applicability of findings (e.g. crash avoidance rate, crash mitigation rate) of one geographical area in which data for baseline generation was collected to another geographical area may be limited due to a multitude of factors. Typical factors include cultural attitudes, traffic regulations, infrastructure design standards, demography or environmental conditions. In addition, differences and inconsistencies in data reporting practices across regions can lead to biases and unreliable conclusions, making it crucial to account for these differences when interpreting simulation results. These factors must be carefully considered to ensure that findings are applicable and meaningful across diverse contexts. The theoretical approach and constraints for this extrapolation over space and more detailed explanations for its necessity are explained in the V4SAFETY Deliverable D2.2 (Fahrenkrog et al., 2025). The approach described in D2.2 lays the groundwork for a practical demonstration in the context of V4SAFETY use cases and are be presented in the following sections of this report. The extrapolation examples include an extrapolation of simulation results to the EU level (see LAB (2.3.1) and VCC Use Case (2.3.2) to an EU-country level (see TME use case (2.3.3)). The change in effectiveness outcomes between the treatment simulations and the extrapolated outcomes will be discussed for each case.

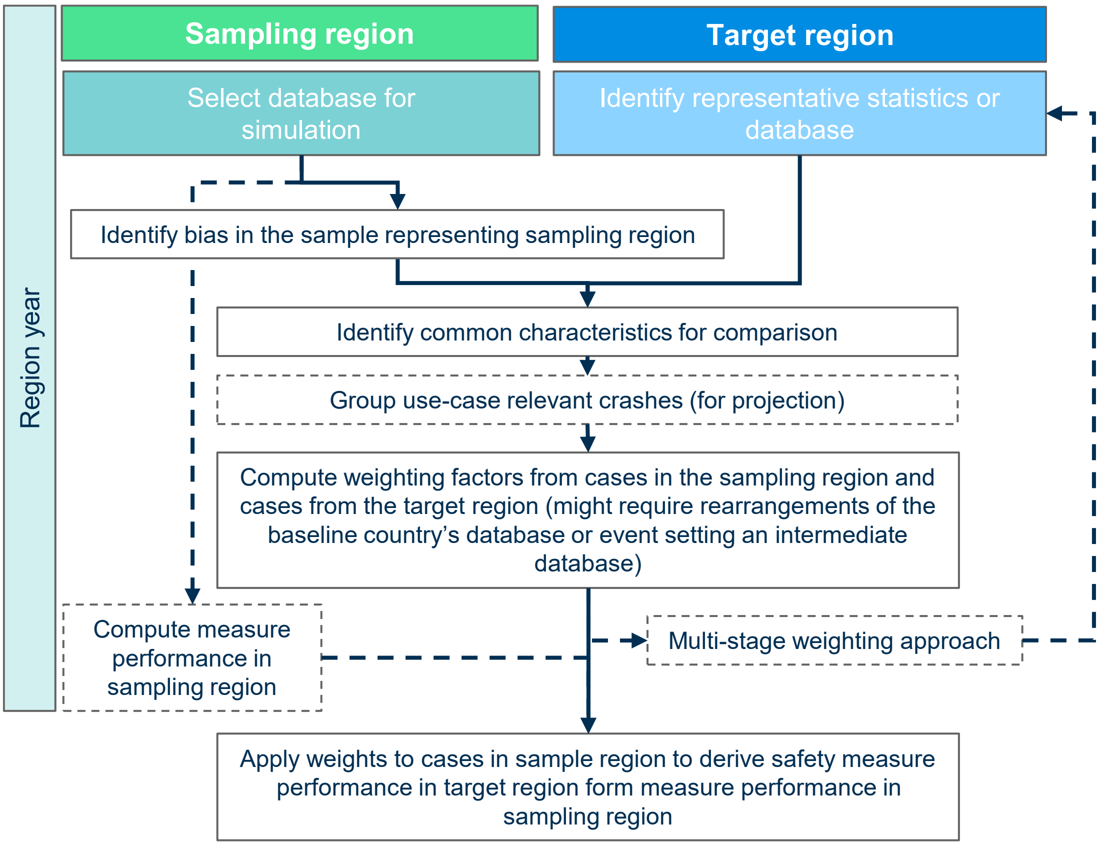


Figure 2.3 Workflow for extrapolation of results in space

In addition to the summaries of extrapolation studies, a more detailed presentation of the calculated weights and rationale of the weighting for each use case is provided in Appendix A. The demonstration of the following three extrapolation examples also provides hands-on-experience in the application of the framework presented in section 3.1.2.

2.3.1. Extrapolation to the EU of the Safety Performance in France of an in-vehicle Autonomous Emergency Braking for Pedestrians in Car vs. Jay-Crossing Pedestrians scenarios

The study investigates the performance of an Autonomous Emergency Braking for Pedestrians (AEBP) system to answer the following question:

> *What is the reduction of the injury burden in a 'car going straight, jay-crossing pedestrian' scenario if all cars in the 2019 EU are equipped with AEBP, measured in number of casualties and patients inside and outside the hospital?*

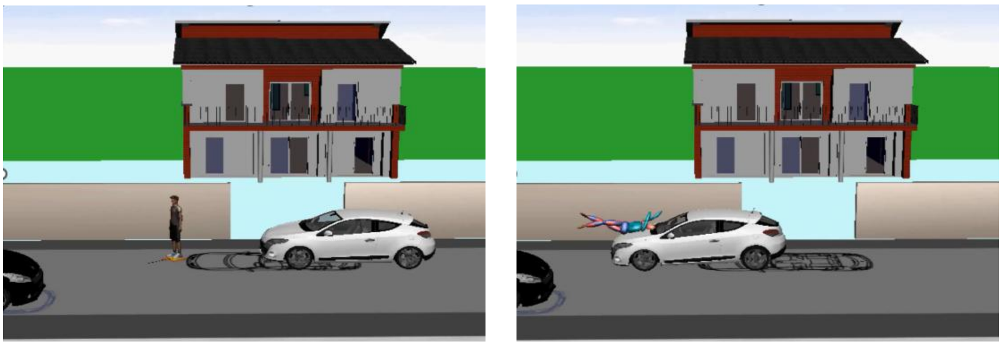


Figure 2.4 Visualization of the analyzed scenario.

A selected sample of 150 cases from the Véhicule Occupant Infrastructure Etudes de la Sécurité des Usagers de la Route (VOIESUR) accident database representing the French crash scene (Amoros et al., 2015) was used to build the baseline. Injury Risk Functions (IRF) built on a population of car-front vs pedestrian crashes extracted from that same database (Cuny et al., 2018) were used to assess injury outcomes. An alternative version of the original VOIESUR weights (Amoros et al., 2015) was computed to make this sample representative for the population of police recorded crashes in France (BAAC 2025). Additional weights were computed from the European CARE database (Manuti, 2018) to make the French data sample representative for the EU.

Metrics to answer the research questions were: the reduction of the number of killed, in- and out-patients.

The AEBP leads to a reduction in the injury burden in both France and Europe. The injury burden reduction rates for France and the EU are of the same magnitude. Generally speaking, France and EU results seem to be statistically different, although overlapping CI95% do not allow to have clear-cut conclusions in some cases.

Table 2.2 Results of the AEBP treatment simulation in France and extrapolated to the EU.

	Treatment AEBP in France	Treatment AEBP in the EU
Reduction (%) of the number of killed - Highway	0% [0%, 1%]	0% [0%, 1%]
Reduction (%) of the number of Severely Injured - Highway	0% [0%, 1%]	0% [0%, 1%]
Reduction (%) of the number of Slightly Injured - Highway	0% [0%, 1%]	0% [0%, 1%]
Reduction (%) of the number of killed - Rural	29% [33%, 24%]	22% [26%, 18%]
Reduction (%) of the number of Severely Injured - Rural	35% [28%, 43%]	26% [21%, 32%]

	Treatment AEBP in France	Treatment AEBP in the EU
Reduction (%) of the number of Slightly Injured - Rural	32% [25%, 38%]	56% [44%, 68%]
Reduction (%) of the number of killed - Urban	94% [88%, 100%]	73% [69%, 77%]
Reduction (%) of the number of Severely Injured - Urban	68% [60%, 76%]	43% [37%, 50%]
Reduction (%) of the number of Slightly Injured - Urban	41% [37%, 48%]	51% [43%, 59%]

A more detailed description of the us case along with the study's limitations can be found in section A.2.3.

2.3.2. Extrapolation of the Safety performance assessment of AEB, FCW, and B2V communication in ‘car-turning right – cyclist going straight in same direction’ scenarios

The study investigates the effectiveness of an Autonomous Emergency Braking (AEB) system to answer the following question:

What is the percentage of avoided and mitigated crashes in a ‘car turning right, cyclist straight in same direction’ scenario Figure 2.5 if AEB is implemented to all cars in Germany and the EU ?

Figure 2.5 Visualisation of the analyzed scenario. The car is tuning right, while the bicycle is going straight. The bicycle can be either on the road or on a separated bicycle lane.

German In-Depth Accident Study (GIDAS) data (Otte, Krettek, Brunner & Zwipp, 2008) was used to identify the characteristics of the relevant real-world crashes. The selected scenario comprised 210 cases. Weights were computed to make the GIDAS data sample representative for the population of police recorded crashes in Germany (Hautzinger, Pfeiffer & Schmidt, 2004). Additional weights were computed from the European CARE database (Manuti, 2018) to make the GIDAS data sample representative for the EU.
One thousand synthetic baseline test scenarios were generated from the joint distributions of relevant characteristics of the weighted GIDAS data sample. Metrics to answer the research questions were the percentage of avoided and mitigated crashes.

Baseline Simulation
Of the 1000 synthetic test scenarios, the car and bicycle did not collide in seven of the test scenarios. In these cases, the driver model of the car could not follow properly the generated trajectories and arrived earlier at the theoretical collision point. Therefore, the baseline comprises 993 test scenarios.

Treatment Simulations
The AEB lead to a reduction in the crash rate in both Germany and the EU (Table 2.3). The EU has a higher crash avoidance rate than Germany, namely 7.2% versus 4.9%. However, the rate of crashes with reduced impact speed is comparable between the EU and Germany (8.2%). In general, the crash avoidance and mitigation rates for EU and Germany are in the same magnitude, but statistically different for an alpha value of $p < 0.05$.

Table 2.3 Results of the treatment simulations covering different combinations of in-vehicle safety measures.

	Baseline	Treatment AEB in Germany	Treatment AEB in the EU
Number runs	993	993	993
Crash avoidance rate	-	4.9% [3.6%, 6.4%]	7.2% [5.6%, 8.9%]
Crash mitigation rate	-	8.2% [6.6%, 10.1%]	8.2% [6.5%, 10.0%]

A more detailed description of the use cases including the study limitations can be found in Appendix A.2.4.

2.3.3. Extrapolation of the Safety performance assessment of an AEB in Car-to-Car Straight Crossing Path Situations.

The safety performance of an AEB in Car-to-Car Straight Crossing Path situations, was analysed as reported under Deliverable D6.1 (Menzel et al., 2025). The data used in the analysis is the Traffic Accident Scenario Community (TASC) database (https://www.vufo.de/en/scenarios/), with crashes collected between 2018 and 2023. This database contains police reported crashes from the state of Saxony in Germany and allows extrapolation to a country level for Germany.

In order to perform the extrapolation in space, the baseline and treatment results of driver's injuries were weighted and extrapolated focussing on the research question:

> *What is the percentage of injury reduction in drivers in Germany involved in Car-to-Car Straight crossing path conflict situations, when the vehicle who is the main causer of the crash is equipped with an AEB system and how is this percentage influenced by the region in which the AEB system is introduced? The injury reduction is to be expressed for the following injury levels (combined fatal/severe injuries, Slight injuries) and measured based on the probability of injury reduction.*

Analogous to the GIDAS weighting approach (Hautzinger, Pfeiffer & Schmidt, 2004), weights were computed to ensure a representativeness between the TASC data sample and the police-recorded crashes in Saxony. In a next step, the data set was then made representative for the German crash collective and extrapolated to Germany.

The baseline simulation consisted of 668 TASC-cases. In the treatment simulation 38.6% of crashes could be prevented. Applying the weighting and extrapolation factors, this corresponds to a crash avoidance rate of 40.2% in Saxony and 36.3% in Germany (see Table 2.4).

Table 2.4 Results of the TME treatment simulations for Saxony and extrapolated results for Germany

	Baseline Simulation	Treatment Simulation	Treatment AEB in Saxony	Treatment AEB in Germany
Number runs	668	668	668	668
Severely injured/killed drivers	24	16	689	15,256

Slightly injured drivers	204	137	5,762	123,164
Crash avoidance rate	-	38.6% [32.8%, 43.3%]	40.2% [32.8%, 43.3%]	37.9% [32.7%, 43.2%]

A more detailed description of the use cases including the study limitations can be found in Appendix A2.2.

2.4. Cost-Benefit Analyses (CBA)

CBA is a method that considers the potential benefits and costs of the introduction of a safety measure to prioritize different options and evaluate a decision from the societal perspective. All costs and benefits are expressed in terms of money as much as possible. The costs reflect the value of all resources needed to implement a road safety measure, including the development, manufacturing/ implementation, and service costs. The benefits consist of the avoided societal costs of prevented road crashes and injuries, such as medical costs, loss of productivity, human costs (intangible costs of loss of life and quality of life), property damage and administrative costs. The calculation of the benefits considers the crash risk, the injury probability in a crash, and the vehicle fleet as well as the effectiveness of a safety measure to calculate the number of prevented or mitigated crashes. Key results of a CBA are the benefit-cost ratio and the net present value (benefits minus costs), which indicate the extent to which the measure is favorable from the perspective of societal benefits and costs.

CBA is strongly connected with time projection, as measures become beneficial over time if they are effective during a certain period of time (e.g. 30 years in case of infrastructure). CBA is then best performed as post-processing of a full projection in time analysis, when the outputs of the assessments are in terms of reduction of the injury burden split by categories of injury (fatal, severe, slight).

A practical CBA-tool has been developed within V4SAFETY, which can be used to conduct a CBA of road safety measures, particularly vehicle safety systems and infrastructure improvements. The tool is based on the CBA-methodology as described in Deliverable D2.2 (Fahrenkrog et al., 2025). Several inputs are required to run the CBA tool, such as the costs of road safety measures, their effectiveness and the penetration rate of measures. The outputs of the tool are an overview of the total costs and benefits including breakdowns of these costs and benefits.

The CBA-tool allows to conduct a sensitivity analysis by inserting upper and lower values of the costs and safety impacts, in addition to a best estimate, to reflect uncertainty in the input data. For example, the costs of introducing a safety system in a vehicle may depend on the vehicle type and vehicle manufacturer. A range of costs is typically found in such cases and the upper and lower values of this range can be used in the CBA-tool to reflect this variability. The mean costs may be used as the best estimate, although the analyst should judge which estimate can be regarded as 'best', taking into account the reliability of the data sources for example. Concerning the safety impact (prevented number of casualties), confidence intervals may be available. In that case, the boundaries of the interval may be used as upper and lower values in the CBA. See Wijnen (2025) for more details on the CBA-tool.

The next two sub-section present CBAs of use cases that were conducted using the CBA-tool.

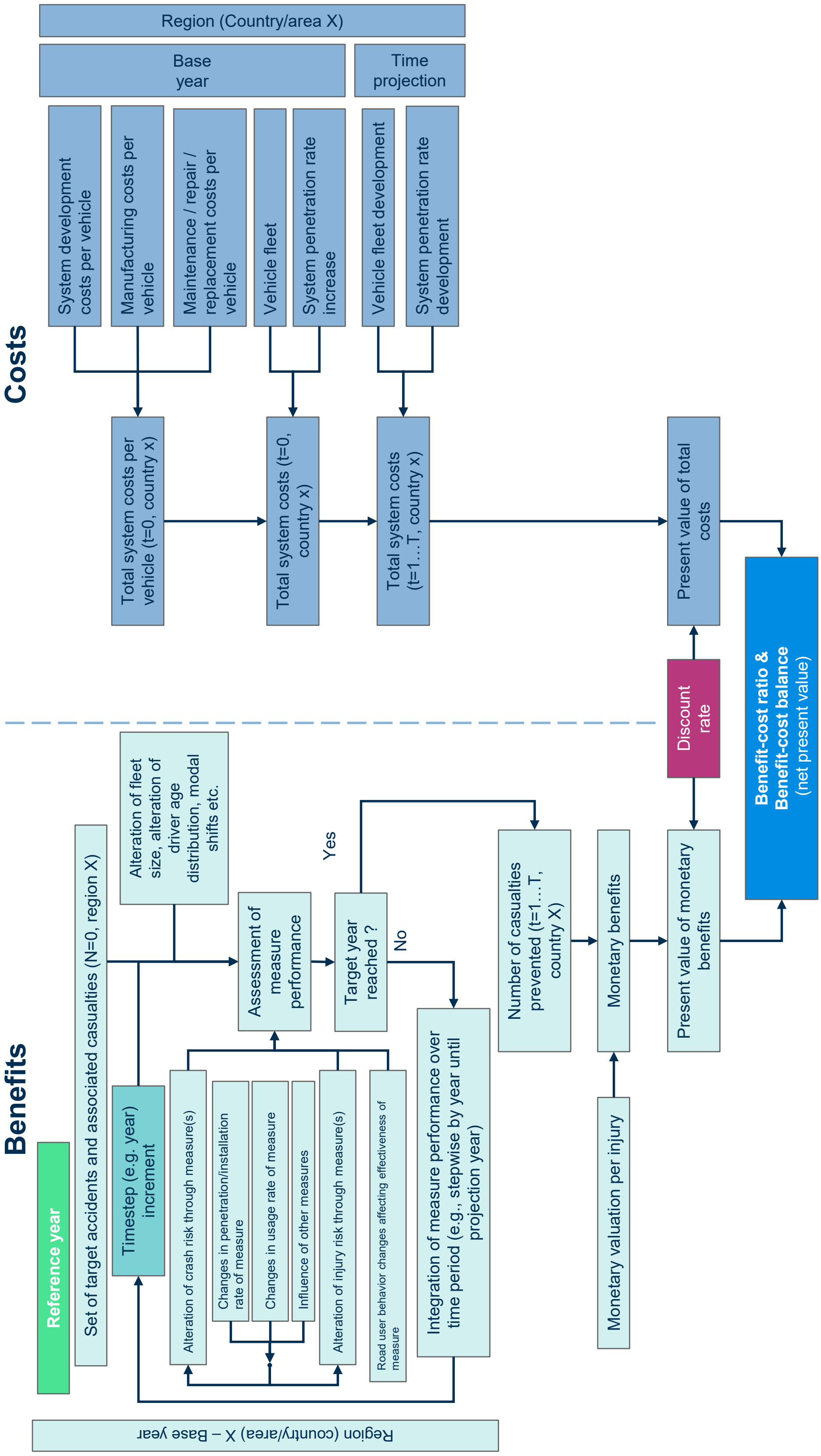


Figure 2.6 Workflow for Cost-benefit analysis

2.4.1. CBA of the Safety performance assessment of an AEB in Car-to-Car Straight Crossing Path Situations.

In order to perform the CBA, information needs to be identified as well as a research question. Among the information that is necessary for conducting CBA are: cost associated to the safety measure, the investment period, the annual increase of vehicle numbers equipped with the measure and the annual safety. Below, the research question as well as each CBA necessary information are explained, including the assumptions taken:

> *What is the specific socio-economic benefit of implementing an AEB in cars for car-to-car crashes with straight crossing paths, leading to a personal damage, in Germany until 2036 considering 2018 as reference year? The benefits shall be presented by different types of reduction (medical costs, production loss, human costs, property damage, administrative and other costs), considering only drivers are the only occupants evaluated in the crash.*

Safety measure costs

In order to provide an input to the CBA tool developed in the project (Wijnen, 2025) a best estimate, as well as a lower and upper estimate, if available, are needed for the safety measure. The costs are split between development costs, annual manufacturing costs and annual maintenance costs. The safety measure under scope is an AEB in Car-to-Car situations. The cost of an AEB Car-to-Car technology includes that of components that can be shared with other safety measures such as AEB-Pedestrians/Cyclist, Intelligent Speed Assist or Lane Keeping systems. For those systems, there would be components such as sensors, brackets, covers and wires that would be needed in any case. For that reason, and using as source the reports performed by TRL for the European Commission (European Commission, 2017 and European Commission, 2018), it is proposed to consider the system development cost of the specific safety measure, in this case AEB-Car-to-Car and one fourth of the overall manufacturing and development cost that could be used for the four safety measures mentioned. The costs provided in the report are based on 2012 figures wherefore inflation from 2012 up to 2023 needs to be considered. The reason for this year, is that the CBA tool considers prices for the benefit aspects based on 2023.
Since this case deals with Germany, the inflation values are based on the German Federal Statistical Office (Statistisches Bundesamt, 2025). The values are provided as cost estimate in euro per vehicle equipped for the given year (subject to inflation). Estimated development and fixed production costs are included and spread equally across vehicles. Since there is no further information on the cost split, it is estimated that within the CBA-tool the costs cover the sum of development, manufacturing and maintenance costs. Table 2.5 shows the lower, best and upper estimate of measure costs.

Table 2.5 Lower, best and upper estimate of safety measure costs for the TME use case (€/vehicle equipped for the given year). Including development and fixed production costs.

Year		Cost (lower estimate)	Cost (best estimate)	Cost (upper estimate)
2012		82	96	109
2025		97	114	130

Investment period

This value represents the number of years that the new vehicles with the safety measure are introduced in the market. The year from which the AEB is introduced (2024) to the year it achieves 100% penetration (2050), resulting in an overall investment period of 27 years.

Annual increase of vehicles with measure

The investment period starts in 2024 when all newly registered vehicles must be equipped with an AEB Car-to-Car system (EU 2019/2144). The value of new registration of vehicles has been researched and figures have been taken from the German Association of Automotive Industry, VDA (Verband der Automobilindustrie, 2024). Table 2.6 shows the number of newly registered cars in Germany in 2024 as well as in 2023 on which basis, an annual number of newly registered cars in the German car fleet was estimated. Since newly introduced cars since 2024 must be equipped with an AEB, the number of newly introduced cars corresponds to the annual increase of vehicles with the safety measure (AEB).

Table 2.6 Estimate for new passenger car registrations for the TME use case

	2023	2024	Estimate for CBA
New Passenger car registrations	2,844,609	2,817,331	2,800,000

Annual safety effect

The annual safety effect needs a reference year for the CBA. Usually, this is the year before the measure is implemented. However, if the required data are not available for that year, another year or period may be choses and assumed to be representative for the situation before the measure is implemented. The original dataset used (TASC), contains crashes for the years 2018 to 2022 and was used for the TME use case reported under D6.1 (Menzel et al, 2025). The overall figures of reduced casualties were reported for the identified crashes in those years. In order to define a reference annual safety effect, two alternatives could be used:

- Use an average for the data available from the 5 years
- Identify a „representative year“

Figure 2.7 hows the distribution of slight crashes (light green) and Killed or Seriously Injured (KSI) crashes (darker green) in the baseline simulation. The TASC dataset aims to capture all KSI crashes per year reported by the police in the region of Saxony, and as many slight injury crashes as possible. In 2019, the coding scheme was extended, leading to a decrease of the number of crashes involving slightly injured person. This made 2019 a non-representative year. Additionally, 2020 and 2022 are years where travel behaviour was strongly influenced by Covid, wherefore it is proposed to use the figures from 2018.

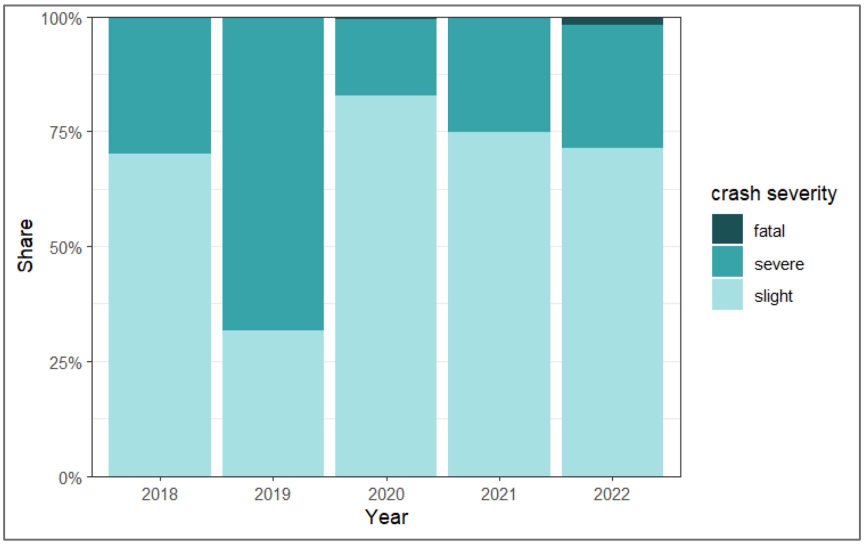


Figure 2.7 Share of crash severity within baseline simulation of TME use case

The values used for 2018, can be seen in Table 2.7, showing both baseline, treatment and the casualty reduction, for Germany.

Table 2.7 Estimated reduced casualties, for the reference year 2018

	Baseline	Treatment	Reduced casualties (Germany)
KSI	6,724	4,654	2,070
Slight Injuries	53,526	33,944	19,582

The casualty reduction shown in Table 2.8 would occur when it can be assured that at least one vehicle involved in a crash is equipped with an AEB. For the demonstration of applying CBA in this use case, it will be assumed that this can only be achieved when the whole German car fleet is equipped with an AEB.

Table 2.9 shows the number of preventable casualties assuming a full implementation of AEB in the vehicle fleet. In order to calculate the actual annual safety effect, it is necessary to estimate the reduced casualties for years in which full implementation has not been reached. As an approximation, it is assumed that the reduction correlates with the penetration rate of AEB in the German car fleet. To estimate the uptake of the AEB penetration rate in the future, the following five assumptions have been made:

- Each year 2.8 million new cars are added to the German car fleet
- Cars do not remain longer than 30 years in the German car fleet
- The age distribution (as a consequence of the survival rate of individual cars) of vehicles in the German car fleet of 2022 (Kraftfahrt-Bundesamt, 2022) remains constant over the years
- All passenger cars registered in or after 2024 are equipped with an AEB
- The penetration rate of AEB in 2024 is 13.7 % (extrapolated from reported equipment rates in Germany for the year 2019 and 2021 (Gruschwitz, et al., 2022; Gruschwitz, Hölscher, van Nek, Busch, & Woopen, 2023).

Based on these assumptions, for each future year 2.8 million cars are added to the German vehicle fleet and their survival over the years can be estimated using the survival rate of vehicles shown in Figure 2.8.

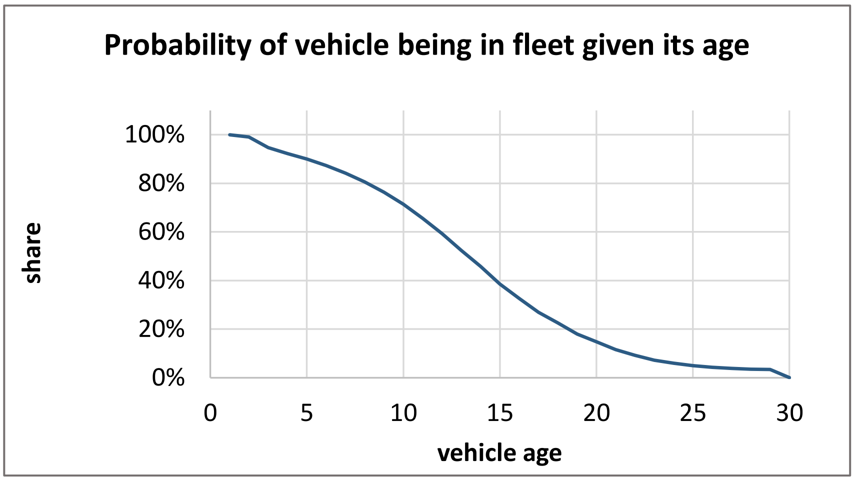


Figure 2.8 Survival rate of cars over the years (Kraftfahrt-Bundesamt, 2022)

If all vehicles added to the German vehicle fleet from start of 2024 are equipped with an AEB the penetration rate can be estimated by the share of all vehicles added to the fleet after 2023 within the vehicle fleet.

Table 2.8 shows the resulting penetration rates considered for each year in Germany, from the start of investment time, until a full fleet penetration is expected.

Table 2.8 Uptake of AEB penetration rate in German car fleet until 2050

Year	AEB penetration rate	Year	AEB penetration rate
2024	13%	2038	85%
2025	14%	2039	88%
2026	21%	2040	90%
2027	28%	2041	92%
2028	35%	2042	94%
2029	41%	2043	95%
2030	47%	2044	96%
2031	53%	2045	97%
2032	59%	2046	98%
2033	64%	2047	98%
2034	69%	2048	99%
2035	74%	2049	99%
2036	78%	2050	99%
2037	82%		

An additional aspect to be highlighted is that for the severity estimation within the treatment simulation, IRFs are used that predict whether the driver was either severely/fatally injured or slightly injured. Consequently, annual safety effects can only be calculated for these two groups without a further distinction between killed and seriously injured. In order to estimate the actual values for killed and seriously injured separately, the share of killed and seriously injured drivers is estimated from casualty distributions in similar crashes in Germany (crashes at crossings). However, the most detailed information in the German statistics only provides the distribution of crash severities amongst crossing accidents involving cars (Statistische Ämter des Bundes und der Länder, 2025). Thereby, crossing crashes between 2022 and 2024 involving cars and at least personal injuries of involved parties are split into: 0.5% fatal crashes, 13.2% severe crashes and 85.3% slight crashes. To further specify the distribution of drivers' casualties within those crashes, the crash database of Fraunhofer IVI was used. The best match of crash severity distributions between Federal states and Germany was found using the crash data from the Federal States of Saxony, Brandenburg and Hessen. Table 2.9 shows the distribution of the used values.

Table 2.9 Distribution of casualties of car drivers

Fatally injured	Seriously injured	Slightly injured
0.3%	10.2%	89.6%

CBA results

Based on the input mentioned above, the CBA results for this use case are reported in Table 2.10.

Table 2.10 Estimated Socio-Economic return by 2050

Net present value (in million Euro)	20,331

2.4.2. CBA of the Safety Performance in France of an in-vehicle Autonomous Emergency Braking for Pedestrians in Car vs. Jay-Crossing Pedestrians scenarios

A CBA was performed as a post-processing of the projection in time results of the performance of an in-vehicle Autonomous Emergency Braking system for Pedestrians. The initial research question envisioned could be stated in the following way:

> *What is the Benefit/Cost ratio of an in-vehicle Autonomous Emergency Braking system for Pedestrians used in car vs jay-crossing conflict situations over the 2015-2050 timespan?*

The rationale for choosing this period of time was that it is a period in which AEB went from a 0% penetration rate to an estimated 100% penetration rates in the French passenger car fleet. However, in its current version, the V4SAFETY CBA tool only allows for entering a constant value of the annual absolute increase of equipped entities (locations, vehicles). It was therefore decided to limit the analysis to the 2024-2050 time period – this allows using the average number of registered vehicles as proxy for the annual increase of equipped vehicles.

The hypotheses used for the valuation of the measure's benefits over time (period 2011-2050) are listed in section 2.2.1. The effects of the coronavirus disease (COVID) pandemic in years 2020-2021 was not taken into account, as the post COVID trends have returned unaltered to the norm after a few years of "recovery".

Safety measure costs

In order to provide an input to the CBA tool developed in the project, a best, a lower and an upper estimate can be used. The costs are split between development costs, annual manufacturing costs and annual maintenance costs. The safety measure under study is an AEB Pedestrians and costs for this measure are available from the EU General Safety Regulation (GSR) report on cost-effectiveness, performed by Transport Research Laboratory (TRL) (European Commission, 2018).

The provided costs are based on 2012 figures and had to be updated considering inflation from 2012 up to 2025. The inflation values come from the French National Institute of Statistics (INSEE 2025). The values are provided as cost estimate in € per vehicle equipped for the given year (subject to inflation). Estimated development and fixed production costs are included and spread equally across vehicles. The input costs to the CBA-tool covers development, manufacturing and maintenance costs. In this use case, not all categories were available and only one of these types of costs needed to be entered. Table 2.11 shows the lower, best and upper estimate of measure costs.

Table 2.11 Lower, best and upper estimate of safety measure costs for the AEB Pedestrian

Year	Cost (lower estimate)	Cost (best estimate)	Cost (upper estimate)
2012	54	43	65
2023	64	51	77

Investment period

This value represents the number of years during which all new types of vehicles are introduced in the market with the safety measure. The timing from which the effect is considered to take place is 2022 so the investment period is 29 years.

Annual increase of vehicles with measure

Since the investment period starts in 2022, when all new types of vehicles must be equipped with an AEB system (EU 2019/2144), it is considered that all new vehicles need to be equipped with an AEB. The annual number of new registrations of passenger car was recovered from the Ministry for Sustainable Development (Bilan annuel des Transports, 2023). Table 2.12 shows the proposed value of the number of vehicles.

Table 2.12 New passenger cars registrations in France

	2023	2024	Estimate for CBA
New Passenger car registrations	1,817 Mo	1,755 Mo	1,800 Mo

Using the results listed in appendix A1.1, and applying the V4SAFETY CBA Tool, the following results were obtained (Table 2.13):

Table 2.13 Socio-economic return for AEB Pedestrians

Socio-economic return	Lower Cost	Best-Estimate Cost	Upper Cost
Net present value	**M€ 6 356**	**M€ 5 907**	**M€ 5 458**
Benefit-cost ratio	4,6	3,7	3,1

These results mean that regardless of cost-hypothesis, this measure will be socially beneficial, with a benefit cost ratio well above 1. The reader's attention is however drawn to the fact that it is only over a long period of investment time that these results are obtained. Calculations done over a shorter period of time, especially over the first years of slow measure uptake would certainly have shown less positive results. The full positive impact of making the measure mandatory on all vehicles surfaces after a period of more than 25 years. This highlights the importance of carrying out full projections in time, over long periods, even though the hypotheses used in activity may be more fragile than short term projections or projections made under over-simplified conditions.

3. Hands-on experience with framework

3.1. Project the results

For the discussion of hands-on experience, we will distinguish between two different types of assessments for the topic “Project the results” between two different types of assessments:

- Projecting measure performances over time: this type of assessment is used when the research question involves evaluating the performance of measures over a long duration of time, with simulation only possible for a given reference period (e.g., a given year). Targeted here are the factors that may over time influence the effectiveness of the measure (e.g., installation, acceptance or market penetration rates, introduction of other measures), its usage and also the context in which it operates (e.g., alterations of fleet size, ageing of population, transport modal shifts, disruptive regulatory interventions).
- Extrapolating measure performance over space (or regions): this type of assessment is used when the research question involves evaluating the performance of measures over a target region (or country) when baselines fitted for simulation can only be obtained from a sampled subset thereof. It often involves the use of weighting techniques but also circumventing biased information or missing data in either the sampling or the target regions.

Theoretically, these two types of assessments can be combined in one use case. However, this would require access to precise data on trends influencing crash characteristics for the target region, specifically the EU. As this data is generally speaking neither accessible nor existent (to the authors’ knowledge), such a use case was not considered.

3.1.1. Projection in time

The projection in time procedure involves a range of methodological considerations. The quality and availability of longitudinal data (time series) are essential to ensure reliable projections. In many cases, only a limited number of historical datasets provide consistent temporal coverage of the key parameters needed for the assessment, such as crash frequencies, fleet composition and its evolution over time, usage rates of safety solutions (e.g., the ability to activate/deactivate a vehicle’s Advanced Driver-Assistance System (ADAS) features, such as Lane Keeping Assist), and penetration rates of safety measures (e.g., the proportion of vehicles equipped with a specific technology).

The absence of alternative or complementary data sources reduces the flexibility for model calibration and validation, making the projection highly dependent on the accuracy, completeness, and granularity of the available inputs.

Another limitation arises from the varying degrees of detail in historical data across years. While some datasets include comprehensive information on fleet size, exposure, and behavioural metrics, other datasets provide only aggregated or partially coded variables. This heterogeneity can lead to uncertainty in the temporal modelling process. As a result, projections may over- or underestimate the future impact of safety measures if these variations are not adequately addressed.

When working with historical datasets, it is essential to establish a data validation and harmonization process. Historical data should be checked for completeness, consistency, and accuracy before being used as inputs for projections. In cases where significant gaps or inconsistencies are detected, supplementary external datasets, such as fleet registration statistics, population data, or road safety reports, can be used to cross-validate trends and fill critical information gaps. Maintaining data that documents data sources, assumptions, and any corrections applied ensures greater transparency and reproducibility in the Projection process. Different strategies can be applied to manage these temporal data inconsistencies:

- **Restricting historic data to periods with high-quality and detailed data.** This approach enhances reliability but reduces the temporal scope, potentially overlooking relevant long-term trends.
- **Simplifying the set of input variables.** By reducing the number of factors incorporated into the projection, the temporal model becomes more robust to data gaps. However, this simplification reduces the ability to represent the full complexity of future traffic and safety dynamics.
- **Applying statistical estimation or imputation methods** to fill gaps in historical data, provided the proportion of missing data is within acceptable limits and the data are missing at random. For datasets with significant missingness or non-random gaps, imputation should be used cautiously, as it can propagate bias and increase uncertainty.

The framework does not prescribe a fixed method for handling temporal data inconsistencies. It is the analyst's responsibility to identify an appropriate approach, or a combination of approaches, that best fits the data quality and the objectives of the projection. Often, the most practical solution is a hybrid strategy: simplifying certain variables to reduce uncertainty while applying controlled imputation techniques to others, accepting that some temporal dynamics may not be fully captured. Selecting the best strategy also depends on the projection model being used. Iterative, year-by-year projections (as recommended in the framework) require a consistent and continuous data series to ensure accurate incremental updates of key parameters such as crash risk, injury risk, and measure penetration rates. Coarser, multi-year projection steps can reduce sensitivity to missing data but at the expense of temporal precision.

Finally, the projection is only meaningful if the input data adequately represents the "evolving dynamics" of the target population. For example, significant modal shifts, technological updates, or behavioural adaptations occurring between the base year and the target year must be captured in the model. If these dynamics are poorly represented in the input data, the reliability of the projected safety outcomes will be limited, highlighting the critical importance of robust, high-quality temporal datasets for projection exercises.

3.1.2. Extrapolation over space

The extrapolation from national data to EU level (section 2.3) poses several challenges. First, there is only one database, namely CARE, that contains police reported crashes reported in EU member states in a common data schema. Thus, there are no alternatives for input data selection (see Glasmacher et al., 2025). However, access to CARE is limited to a small number of organizations per member state. Therefore, the validation of a data query is limited to only those organizations who have these rights. This leads to several iterative query definition loops involving use case owners and CARE access-right owners.

Despite CADaS, specific variables are sparsely or not coded at all, as they might be not available in all national datasets. This is because not all EU member states follow CADaS protocol. To circumnavigate this issue, the structure of the CARE database allows a provision of various levels of detail, e.g., by usage of aggregated values. As a consequence, for some countries more details are available than for others.

There are different approaches to address these inequalities.

- To select only countries with detailed information on relevant variables. This approach bears the risk of inducing bias by neglecting crash data from counties with unknown figures. Especially, when the set of variables for which details are required is high, it is likely that only a few countries are left to represent the EU.

- To reduce the number of variables for which details are required. This may improve the representation of the EU by enlarging the number of countries with relevant information available. However, filtering for desired scenarios becomes more unspecific and increases the risk, that the weighting process will not reflect the specifics of the evaluation scope anymore.
- To impute missing data using external data or the CARE data itself. Imputation is only meaningful and recommended when the proportion of missing data is below a certain threshold. Recommendations for thresholds have changed over time with the development of imputation methods. However, utmost caution has to be taken when the missing data rate is above 50% and data is not missing at random (e.g. McNeish (2017)).

The framework cannot provide specific guidelines how to handle data coding inequalities as present in the CARE database. Thus, it is up to the analyst to select one or more approaches from the list above. Most often it is suitable to combine approaches to find the best compromise: to drop some desired filtering variables that make the weighting process more unspecific while conducting imputation on another set of variables—and accepting that some countries that may not contribute much to the overall variance are not considered at all.

To identify the best compromise also depends on the methods that are chosen for extrapolation to EU level. Post-stratification weighting, which means a comparison of variable-defined strata (cells) derived from the sample and the target population, usually requires the availability of all values from the selected stratification variables. Another approach of weighting involves the generation of a decision tree to merge strata based on shape of the derived tree (Flannagan et al., 2013). The resulting stratum structure may then allow aggregated values for specific variables.

One of the common post-stratification weighting issues is the generation of one or more empty strata. The risk increases with small sample sizes. For example, the CARE data query for the use cases in section 2.3.2 resulted in zero car-to-cyclist crashes with fatal outcome on motorways in Germany, while the number for the EU was non-zero. As a result, a weight cannot be computed to make the data from Germany representative for the EU.

This highlights, that extrapolation over space is only meaningful if the sample represents (the majority of) the variance of the target population. In the example above the missing cell generated a zero weight for only one case in the target population, which was deemed neglectable. On the other hand, the scenarios from the German Pre-Crash Matrix (PCM) database may not include specific characteristics present in other EU countries. Therefore, the selection of variables and their values for weighting is crucial.

Another weighting issue could be found in the use case presented in section A.2.2 concerning the occurrence and characteristics of use cases in the sample database (TASC). The TME extrapolation involves a two-step weighting process: in the first step, a weighting from the sample region towards the Saxony region; and in a second step, an extrapolation towards Germany. It was found that the occurrence of the use case within the sample database showed a general decline between the years 2018-2022. This could be approached by using a weighting method by year. The weighting approach involves the use of strata by crash types and severity. sample of use cases for each year is weighted separately (by stratum). Thereby, the sample of use cases for each year is weighted separately (by stratum). However, it could be found that within the sample especially crash severities are distributed differently over the years compared to the stratum. Consequently, severe crashes are especially overrepresented in the final extrapolation results and also lead to a higher crash avoidance rate in the sample region compared to the simulation results in the sample of use cases.

3.2. Cost-Benefit Analysis

The CBA process, as well as the required information to apply the V4SAFETY Framework is described under section 6.3 of Deliverable D2.2 (Fahrenkrog et al., 2025). While a lot of attention related to the required data availability may be put, at the beginning of a study, to perform the safety effectiveness assessment of a safety measure, the user of the framework may be confronted at a late stage with the need for additional data to conduct the CBA. In some cases, this may be solved when assumptions to cover for missing information are well documented and justified. In other cases, users may find the need to redo a study. This may be solved, if from the beginning, a dedicated research question to address the needs of a CBA study is stated.

Within the hands-on experience with the use cases reported under section 2.4, even if research questions where not drafted at the beginning of the assessment, the studies were still conducted as the necessary information to conduct a CBA was available. However, there were other use cases, where it was not possible to execute the CBA due to availability of data or due to the lack of the information in the required format by CBA. One practical example is related to the injury information, which for CBA needs to be defined as per “Slight”, “Serious” or “Fatal” injury, while it is common that safety assessment studies evaluate injuries using the Abbreviated Injury Scale (AIS) classification. This aspect is further elaborated under section 4. It is a pre-condition that information at the right injury level is available for the user. Assumptions for splitting groups such as KSI, into “Killed” and “Serious Injured” should be properly justified and documented.

Beyond the above-mentioned example, the users of the framework that intend to perform a CBA, need to use the CBA tool, which is the practical implementation of the elements described under section 6.3 of Deliverable D2.2. Dealing with actual input to the tool, may be challenging as it is needed to clearly understand the meaning of each required input and most importantly, such information needs to be mapped to available information to conduct the CBA. Some examples where definition of such information was challenging was related to terms such as “investment period”, “time horizon safety effect” and “annual increase number of vehicles with measure”. However, these terms are covered within section 6.3 of Deliverable D2.2 and the guidelines for the tool (Wijnen, 2025) which helps the user of the CBA-tool to interpret the variables correctly.

Practically, other feedback provided by members performing CBA has been around the definition of the time horizon, “projection in time analysis” and the definition of injury levels:

- Projection in time: Usually, CBA builds on projection in time analysis. If such analysis is not available or cannot be performed, CBA can be conducted with simplified assumptions. An example of such a research question can be “What would happen if 100% of the vehicle fleet would be instantly equipped with a given measure?” This requires as a first step to replace “instantly” with a realistic timespan, representing the minimal duration of the investment in the measure.
- Injury levels: To estimate the numbers of casualties across different severity levels requires the knowledge of a dose-response relationship. This relationship is often expressed in form of an IRF. If such an IRF is not purpose-built for the specific assessment, but taken from literature, it needs to be ensured that the constraints imposed in the definition of the IRF meet the constraints of the assessment. For example, if the IRF was designed on a dataset including only adults, the IRF cannot be applied to children, even if the assessment dataset includes them. It should be verified that the IRF was not modelled on a biased dataset. Additionally, the CBA tool uses the injury severity levels ‘fatal’, serious’ and ‘slight’, which are usually coded by

the police and not by medical experts. Different definitions of these levels in the sample data and the IRF may induce a systematic error.

3.3. Documentation

In Deliverable D2.2, Fahrenkrog et al. (2025) proposed a documentation scheme that serves two key purposes: first, to present results in a form that supports stakeholder decision-making, and second, to transparently explain how these results were produced, including underlying assumptions, limitations, and critical methodological decisions.

The documentation of extrapolation activities and CBA is particularly important for two reasons. On the one hand, extrapolation and CBA form the final steps of the V4SAFETY framework and produce the results that stakeholders ultimately use for decision-making. These outcomes therefore need to be documented in an appropriate, transparent and accessible way. On the other hand, proper interpretation of these results requires a clear understanding of the methods applied. As outlined in the previous sections, these methods often face challenges such as limited data availability, data quality issues, or methodological constraints. Assumptions made to address such limitations must be explicitly documented to ensure the results can be correctly understood and assessed.

To support this, the V4SAFETY framework proposes a tiered documentation approach at three levels: 3, 30, and 300 pages (corresponding to roughly 1,500, 15,000, and 150,000 words). The 3-page version functions as an extended executive summary (as shown in Chapter 2), the 30-page version provides sufficient detail to evaluate validity and relevance, and the 300-page version contains all necessary details for replication. The 3/30/300 model serves as a guideline rather than a strict requirement, with the most comprehensive documents often used internally (Fahrenkrog et al. 2024).

For the 3-page document, a high-level overview should be provided, including a concise description of the methods used for extrapolation, projection, and CBA, together with the key results and a brief conclusion to support interpretation.
In the 30-page document, substantially more detail is required. Following the recommendations of Fahrenkrog et al. (2024), the documentation should systematically address methods, results, and conclusions. For extrapolation, this includes specifying data sources, describing projection methods, and outlining linkage variables and mapping functions for spatial projections. If projections are integrated into scenario sampling, the alignment of sample distributions with target distributions should be reported. For temporal projections, assumptions, rationales, references, and expected changes to the baseline over time must be clearly documented.
Results should be presented in sufficient detail, followed by a discussion of their implications for the assessment scope, with explicit attention to assumptions and limitations affecting generalisability and validity.
For CBA, the documentation should cover the necessary information and assumptions taken, the basis of cost calculations, and justification for each assumption, supported by relevant graphical representations. Again, results should be presented transparently, with the discussion highlighting implications, methodological choices, and assumptions to ensure decision-makers are equipped with the context needed for informed decisions.

4. Discussion and conclusion

In this section, various choices and alternatives for the use cases will be discussed. Then, limitations for the approach are given and conclusions are drawn.

A common aspect to the three topics addressed in the deliverable of projection in time, extrapolation over space and cost-benefit analysis, is the limitation on the data that may be used for any study, e.g. time series of accident data, penetration rates of safety measures in the vehicle fleet. These data limitations could be related to the data quality, to the quantity, to the access, to the data or to its potential bias. A common data series scheme in Europe would allow for higher accuracy of studies as well as for more representative results. Even it some of the studies may be limited in its projection in time, to different time horizons or in its extrapolation over space to smaller regions, such as at country level, a common data scheme would allow to select the relevant data for each study. This is particularly relevant for crash data, where at European level, information exists only at aggregated level, and the datasets available require specific methods to be scaled up. When dealing with time-series data, this becomes especially critical, as the availability is usually restricted to specific regions or periods of time. Therefore, it would be of great importance for stakeholders dealing with studies on projection in time, extrapolation over space and cost-benefit analysis to have access to such data at European level.

4.1. Projection in time

Projection in time assessments require an intimate knowledge of an array of current and past trends and the effects thereof on the use cases under study. This requires availability and access to a variety of data sources regarding traffic, regulation, technology and of crash or near-crash related events. Available data may be limited, biased and may not be accessible at all.

It is essential to understand how the various selected influencing factors develop over time. This may be mostly at a similar speed, but not necessarily. This distinguishes time projection from "what if" type of assessments. Typically, many assessments are found in the literature where the baseline does not develop over time when it should and only the treatment penetration rates are updated. Both baseline and treatment should develop over time.

A thorough knowledge of factors affecting the use case under study is necessary. As an example, very similar looking use cases involving car vs pedestrians may be influenced by the ageing of the drivers' population or not, by the introduction of electrified vehicles in the fleet or not.
Taking into account too wide an array of factors, with interactions between them little known, will only blur assessment results and even lead to misleading conclusions.

Limitations
The key limitation is low availability of data and models., In addition, the lack of knowledge of factor effects and especially of the interaction between factors effects will be a strong limitation to this kind of analysis.

Conclusion
It is by nature difficult to validate results that are supposed to describe a situation that will possibly occur in a remote future. The only possibility left to the analyst is to make the most plausible hypotheses possible and to base them on reliable data. Projected assessments over time are

always done based on the best knowledge of the moment – pending no unprecedented unforeseen event occurs between the reference year and the target year.

4.2. Extrapolation over space

The methods for conducting extrapolation in space are similar or even identical to methods for weighting a biased sample. The objective is to make a sample representative for a specific target region. Thus, one can for example consider the German police-reported crashes as a biased sample of the EU police-reported crashes. Ideally, target region data is collected through a common data scheme. This is not true for the European CARE database. Only 22 of the 27 members states use the CADaS protocol, for reporting their national data into CARE. Despite efforts to harmonise the data as much as possible after data collection using various schemes, many variables have missing values form specific countries.

Thus, the main challenge lies in finding the best compromise between building a weighting scheme using variables available for every member state but only describing high-level characteristics (risk of underfitting); or using variables available only for a limited set of member states and utilizing machine learning methods to impute missing information but addressing the specific evaluation question (risk of overfitting).
The V4SAFETY framework cannot make more detailed guidelines, as weighting methods have to be adapted to either the sampling or the target data limitations, on a case-by-case basis.

Limitations
One common limitation is that the sample data originates from only one EU member state. In general, if the sample covers the total variance present in the EU, this would be not an issue. As the EU is composed of many nations with varying levels of infrastructure, traffic density, weather conditions, vehicle safety equipment, and driver behaviour, all of which influence crash occurrence, variance coverage is unlikely.
Another limitation is the CARE database. As explained in section 3.1.2, this data is generated from post-processing of national police-recorded data into a common data schema. As the national data differ from each other, aggregated data contains a substantial amount of missing and unknown values. To date, there is no EU-level alternative to CARE (see Sander et al., 2024), meaning that one has to rely on the coded data and cannot verify results against another data source. Possibly, such a verification might be performed for some countries which provide open-source data (e.g., BAAC 2025).

Conclusion
The applied method for extrapolation of the simulation results from one EU member state to the entire EU is easy to apply and transparent: the weights are computed by direct comparison of the sum of crashes in one stratum of the member state versus the EU. Thus, strata that contain extreme weights are easily identifiable. Further, a sensitivity study can be conducted without high efforts to investigate the capping of weights. Additionally, the crash contribution of each member state on the strata can be assessed, guiding the allowance of uncertainty in, e.g., imputation. For example, in the VCC use case (section 2.3.2) the clustering of EU member states resulted in Estonia being a cluster on its own. This means, that no substitute country could be found for the imputation of shares between slight and seriously injured. However, Estonia’s contribution to the total number of crashes in the EU is very small. Therefore, a sensitivity analysis showed that the selection of shares from different countries hardly affects the overall weights. A more serious issue had to be circumvented in the LAB use case (section 2.3.1), when no country of the “Southern Europe” cluster (Italy, Portugal, Croatia, Greece, Cyprus) provided any detailed information on

crash involving jay-crossing pedestrians. The best proxy (Bulgaria) had to be found in another cluster.

The TME use case, in contrast, revealed that an extrapolation in space may also need a closer look on possible trends within the sample even if the sample represents only a short period of 5 years. Within the weighting process, weights are calculated for use cases according to their assignment to a stratum (defined by crash type and severity). However, during the 5-year period crash severities are differently distributed by years between the use cases in the sample and its assigned stratum in the TASC-data. Consequently, severe crashes are particularly overrepresented after weighting the use cases to the sample region which impairs the validity of the extrapolation results.

4.3. Cost-benefit analysis

Based on the dataset used for the TME use case reported under Deliverable D6.1 (Menzel et al., 2025), it was suggested to apply CBA for this use case, in addition to the extrapolation over space. No feasibility study was applied, assuming that with the extrapolation over space, enough information would be available. However, any CBA study requires detailed additional information, as it is covered under section 2.4.2. The lesson learned is that the availability of all necessary data has to be ensured before conducting a CBA study, and the necessary assumptions have to be documented, as it is possible that the information available is not supplied in the same format as it is required by the CBA tool.
One practical example is the assumption that if enough data for extrapolation over space is available, CBA may be executed. For CBA, time information is crucial and obtaining it requires specific data, thorough analyses and justifications.
As was the case with the TME analysis presented in the present document, many analyses found in the literature follow a “What would happen if the entirety (or a known proportion) of the fleet would be equipped with a given measure?” pattern. What follows is generally the application of this proportion of equipment to the present state of the fleet – which means that the actual research question answered is “What would happen if the entirety (or a known proportion) of the fleet would be **instantly** equipped with a given measure?”
To perform any meaningful CBA over this kind of results, the first task to perform is to calculate a realistic time horizon, at which the fleet could plausibly be equipped at the rate mentioned in the research question. And once this is done, the second task consists of building a realistic penetration rate of the measure, over time. CBA studies are closely connected with time, as measures generally become beneficial over time. This is the reason why full-size time projections, that account both for the evolution of baselines and of measure intrinsic effectiveness in a synchronised way are the best inputs to CBA.
Another lesson learnt is that CBA are best performed when the outputs of the performance assessments are in terms of injury burden, split in categories such as fatally, severely and slightly injured. The reason is that social costs for those injury categories are often available, when estimating costs for categories such as “fatally or severely injured” or even costs for crashes would hardly make sense.

Limitations

Several limitations have been identified in the use cases explained under section 2.4 and they are mainly related to the availability of required input to perform CBA and the assumptions that are taken. The limitations are explained by topic.

Safety measure cost

Cost data for in-vehicle safety measures are often hard to come by, as they are considered as sensitive by manufacturers or suppliers and are therefore not made public.
For the CBA of the AEB use cases presented in this report, cost estimates were taken from a detailed study published by the European Commission (European Commission, 2018). Costs were estimated at between €97 to €130 per car (2023 prices). However, other sources indicate that the cost depend on the type of car and varies across car producers, up to about €1300 per car (Masson, 2016; Thatcham Research, 2016). If AEB is installed in the current fleet (retrofit), the costs are estimated to be even much higher: more than €2000 (Bützer et al. 2022). This illustrates the importance of a critical assessment of the costs of vehicle safety system when a detailed CBA is conducted, taking into account the specific type of car among others and using data and expert judgements from the vehicle industry. For CBAs of generic vehicle safety systems, it illustrates the need for sensitivity analysis, by using upper and lower values (as included in the V4SAFETY CBA tool).

Investment period
The investment period is defined from the moment where the safety measure is introduced to a point in time as defined in the research question. For that period, the "annual increase of number of vehicles" (tool terminology) needs to be specified in the CBA tool. In the use case reported under section 2.4.2, it was decided to set the end of the time horizon as the time at which the whole fleet would be equipped with the safety measure, not only the newly introduced vehicles. This approach requires the consideration of realistic timelines for the penetration rates of in-vehicle measures. This information may be country specific. It gets complex when having to define the penetration of measures which are not market dependent but either law enforcement related, or up to local implementation by local authorities, such as infrastructure measures.

Annual increase of vehicles equipped with measure
This information is highly related to the previous one and to the assumptions taken for the definition of penetration rates. Within use case 2.4.2 it is assumed that in order to achieve the full annual safety effect of the system, a 100% penetration rate of the safety measure in the fleet would be required. However, this assumption may be considered as a very conservative approach since the probability of a vehicle involved in a crash, to be equipped with AEB, can be described based in the probability of selecting two random vehicles of a fleet, as described below:

If p is considered the probability that a randomly chosen vehicle in the fleet is equipped with AEB, then the probabilities of vehicle combinations being equipped with an AEB can be calculated as follows:

- Both vehicles equipped with AEB à p p=p2.
- Both vehicles not equipped with AEB à (1−p)·(1−p)=(1−p)2
- First vehicle equipped with AEB, second vehicle not equipped à p·(1−p)
- First vehicle not equipped with AEB, second vehicle not equipped à (1−p)·p

This would have an effect on the casualty reductions achieved, as in this case, it could be assumed that similar casualty reductions as reported in the use case with 100% penetration rate, could also be achieved with lower penetration rates values.

Annual safety effect
The tool used to execute the CBA uses the information on reduced casualties split by severity level, by killed, seriously injured or slightly injured, as input. Such information is needed by the CBA tool since also the costs associated to each type of injury are different. However, the differentiation

of injuries needs to be matched to the available data and correctly defined in the original research question. Otherwise, analysing grouped killed and serious injuries, which are usually referred to as KSI, requires an estimation or assumption to split both casualty numbers

In practice, deriving detailed severity distributions often depends on the use of IRFs. These functions estimate the likelihood of various injury outcomes based on parameters such as impact speed and collision type. However, IRFs cannot be indiscriminately applied across datasets or regions. Their validity is contingent upon alignment between the data used to develop the IRF and the data underpinning the specific use case. Without this alignment, the outputs of the IRF may be biased or misleading.

Therefore, prior to implementation, IRFs must undergo a verification process to assess their goodness of fit. This involves comparing the predicted distribution of injury severities with observed data from the target region and time period. If discrepancies are identified, appropriate weighting adjustments must be applied to ensure that the IRF reflects the characteristics of the use case accurately. Failure to conduct this verification introduces significant uncertainty into the analysis and undermines the reliability of the CBA results.

Conclusion

The validity of a CBA study will rely heavily on the input data used. In contrast to safety assessment studies, in CBA additional data is needed. Overall, the Validation & Verification process described under Deliverable D2.2 (Fahrenkrog 2025) is applicable. This is because the additional data needed does not affect the actual safety performance of the safety measure, but it does affect the CBA. This should cover not only the data sources used but also the assumptions taken and its limitations, as it has been done under use case 2.4.2. In this use case, the assumptions taken for the AEB penetration rate have been documented and the limitations covered under the subsection of section 4.3.
As is often the case, validity heavily rests with the realism and plausibility of the data used.

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Appendix A: Detailed Use Cases

Note that the responsibility for the detailed use cases rests solely with the authors of the respective reports, and not with all contributors to the deliverable.

A.1 Time Projections

In this appendix A.1, two time projection cases are presented in detail.

A.1.1 Projection in time of the Safety Performance in France of an in-vehicle Autonomous Emergency Braking for Pedestrians in Car vs. Jay-Crossing Pedestrians scenarios

Author: Henri Chajmowicz
Date: 2025-09-25

Objectives

The EU's long-term goal is to move as close as possible to zero fatalities in road transport by 2050 ("Vision Zero") (CINEA, 2022). A large portion of current fatalities in the EU are pedestrians, accounting for 18% in 2022, which is still very high, despite significant progress since 2012 (-31% at EU level) and even 2019 (-20% at EU level) [All numbers from CARE, 2023]. In France, the number of pedestrian fatalities has all but flatlined between 2010 and 2019 and decreased by 10% between 2019 and 2023. In 2023, 474 pedestrians were killed on French roads. 282 (60%) of them were killed when crossing the street, of which nearly half (134, 48%) when jay-crossing away from protected crossings or intersections (BAAC 2025).

In this study, the V4SAFETY framework was employed to prospectively assess the evolution over time of the performance of an AEB for Pedestrians (AEBP) system in reducing the injury burden in collisions with jay-crossing pedestrians in France. Influences of effects such as population ageing, higher proportions of electrified vehicles, increased market penetration of the AEBP, just to name a few, can be anticipated. The present study aims at showing to what extent these influences should be taken into account and to qualitatively assess effects on AEBP performance whenever this is possible. A baseline representing the French accident scene – using available historic data and lesson learned from recent events - was used at each timestep of this projection over time

The research question answered by this study can be formulated as follows:

> *"What reduction of the injury burden – expressed in terms of avoided injuries (fatal, serious or slight) – can be expected in year 2050 in France considering the market penetration of a specific Automated Emergency Braking for Pedestrians (AEBP) in car going straight vs jay-crossing pedestrians?"*

Methods and Data

Select Baseline Approach

To address the research question, an A-type baseline approach was adopted whenever possible, depending on the effects taken into account at each timestep. This was possible because the use case under study is a use case of limited dynamic collision parameter variability. Therefore, the initial test cases were kept reweighted over time to generate a new baseline (see D2.2). When this was not possible, e.g., a one given timestep a major traffic rules change had occurred, a B-type approach was used, meaning that both the weights and the cases had to be altered.

Subsection “Select Data”, hereafter describes the effects that were taken into account in this study with regard to the workflow described in Figure 2.1.

Select Data
Our assessment is based on the outcomes of the VOIESUR project, that gathered comprehensive data on mainland France road crashes from year 2011. The official annual accident statistics (BAAC) were used to compute weightings, so as to make the VOIESUR database representative of the whole of the French mainland accident situation for reference year 2011.

It is of the utmost importance, when projecting over time, to know the current trends regarding the use case under study. These trends will be the ones followed by the projection, until the simulation has to encompass the effects of either known / modelled disruptive events– in that case, trends will be altered – or unprecedented disruptive events – in that last case specific methods have to be used (see deliverable D4.2, Glasmacher et al., 2025).

Figure A1.1 shows the trends in numbers of injured pedestrians (in-patients are hospitalized for more than 24 hours, out-patients are hospitalized for less than 24h or not at all), pertaining to the use case under study (BAAC 2025), from the year the reference data was collected (2011) to the last known value. A slow downwards trend can be seen, for all categories of injuries. This is not connected to any uptake of AEBP, as the latter is quite recent.

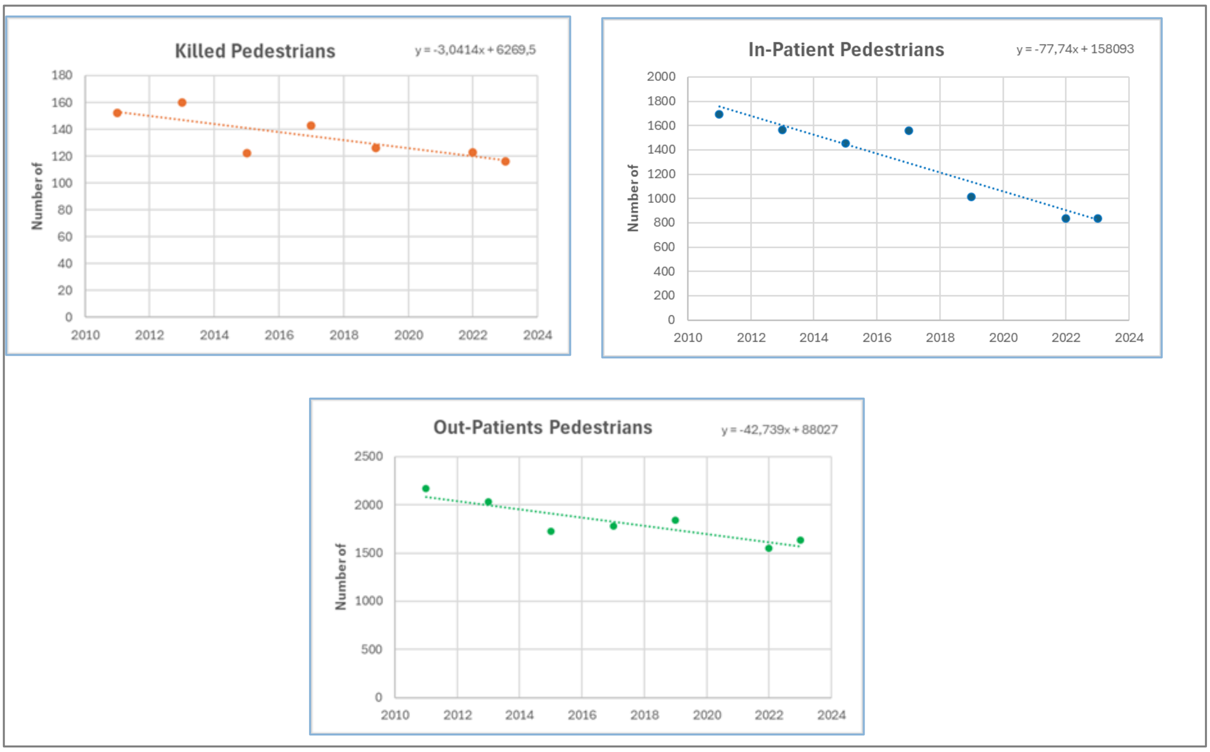

Figure A1.1 Trends in injured pedestrians (2011-2023)

Table A1.1 showcases the distribution of injured pedestrians according to age class as well as the distribution of age classes in the general population for a representative recent year (2019).

Table A1.1: Distribution of pedestrian victims and age-class-related exposure

Pedestrians Crossing

Age Class/Severity	Killed	%Killed	In-Patients	%In-Patients	Out-Patients	%Out-Patients	%Population
[0;10]	1	0,79%	87	8,56%	249	13,54%	12,95%
]10;20]	5	3,97%	173	17,03%	474	25,77%	12,33%
]20;30]	6	4,76%	68	6,69%	227	12,34%	11,26%
]30;40]	10	7,94%	61	6,00%	165	8,97%	12,35%
]40;50]	7	5,56%	63	6,20%	143	7,78%	12,98%
]50;60]	12	9,52%	122	12,01%	169	9,19%	12,98%
]60;70]	11	8,73%	129	12,70%	152	8,27%	11,77%
]70;80]	22	17,46%	158	15,55%	147	7,99%	7,53%
]80;90]	43	34,13%	137	13,48%	97	5,27%	4,85%
[90;Inf[	9	7,14%	18	1,77%	16	0,87%	1,00%

This table highlights the fact that age classes [70;80] and [80;90] are the most at risk as far as fatal or serious injuries are concerned and that are over-represented amongst pedestrian victims as compared to their prevalence in the population. For instance, age-class [80;90] represents 34.1% of the fatal pedestrian victims, 13.5% of the pedestrian in-patients and only 4.85% of the general population. This has to be kept in mind when projecting since it is probable that the size of those age classes is to undergo significant changes in the near future. This distribution has to be mirrored in the various baselines generated over time.

Table A1.2: Distribution of causer passenger car drivers and age-class-related exposure

PC Drivers

Age Class/Severity	Causers	% Causers	%Population
[0;10]	0	0,00%	12,95%
]10;20]	151	5,31%	12,33%
]20;30]	561	19,73%	11,26%
]30;40]	454	15,97%	12,35%
]40;50]	473	16,64%	12,98%
]50;60]	405	14,25%	12,98%
]60;70]	328	11,54%	11,77%
]70;80]	263	9,25%	7,53%
]80;90]	181	6,37%	4,85%
[90;Inf[	27	0,95%	1,00%

Table A1.2 highlights the distribution of passenger car drivers who cause the accident (“causers”) in the use case under study for 2019. Age class [20;30] comes here under scrutiny as it over-represented, as well as, in a lesser proportion, age classes [70;80] and [80;90]. Again, this distribution of causers’ age has to be mirrored in the various baselines used.

Table A1.3 highlights the fact that involved passenger cars are old vehicles, nearly half of them over 10 years old. This is a long-standing trend covering before and after the reference year data used in this study. The consequence is that only when even the oldest vehicles in the fleet are equipped with the measure under study, we will see massive effects of its penetration occur. The use case proportions seen in Table A1.3 reflect the proportions in the full French fleet, which is split in almost equal parts between vehicles under 5 years, between 5 and 10 years and over 10 years.

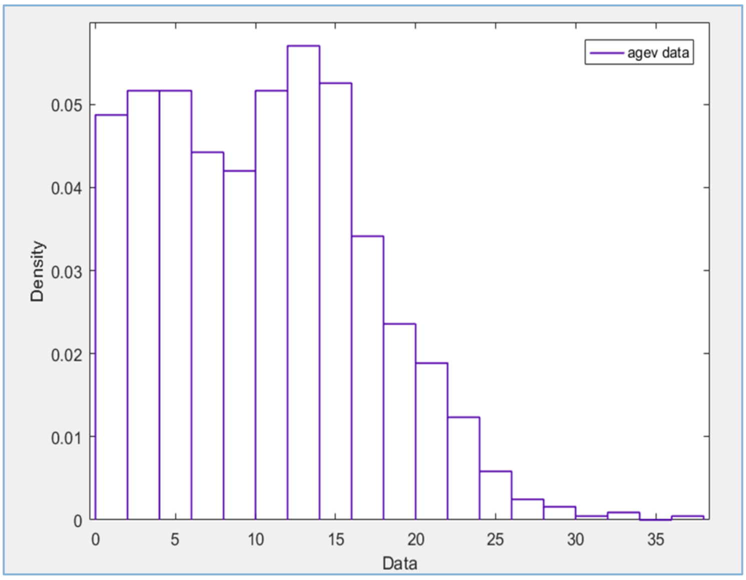

Figure A1.2: Distribution of causers' vehicle's age for the use case under study, for year 2022 (BAAC 2025)

Table A1.3: Aggregated distribution of causers' vehicle's age for the use case under study for year 2022 (BAAC 2025) and distribution of vehicle's age in the general fleet (ACEA, 2023)

	Numbers	% Use case	% General Fleet
Less 5 years	677	30,40%	27%
5-10 years	499	22,41%	23%
10-15 years	603	47,19%	50%
15-20 years	309		
20-25 years	113		
Over 25 years	26		

One of the most important effects considered in the present study is the uptake of the AEBP in the fleet. The uptake rate of AEBP in France had to be extrapolated from German data as no local data is publicly available. For a variety of reasons, especially incentives towards buying smaller cars during the 2008-2009 financial crisis, the bulk of the French passenger car fleet is composed by small versatile city cars (B segment) while the German passenger car fleet is centred on compact cars (C segment). This is illustrated by Figure A1.3 and resulted e.g., in the slow uptake of ESP in France prior to becoming mandatory (Figure A1.4).

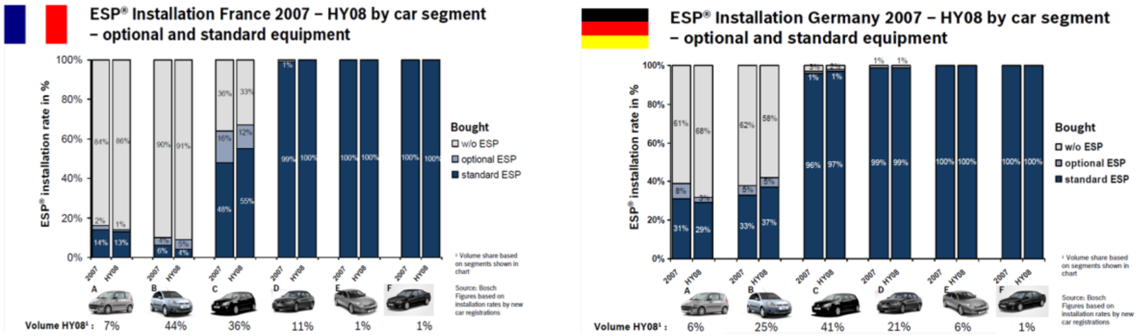

Figure A1.3: Segmentation of Car Fleet - France & Germany

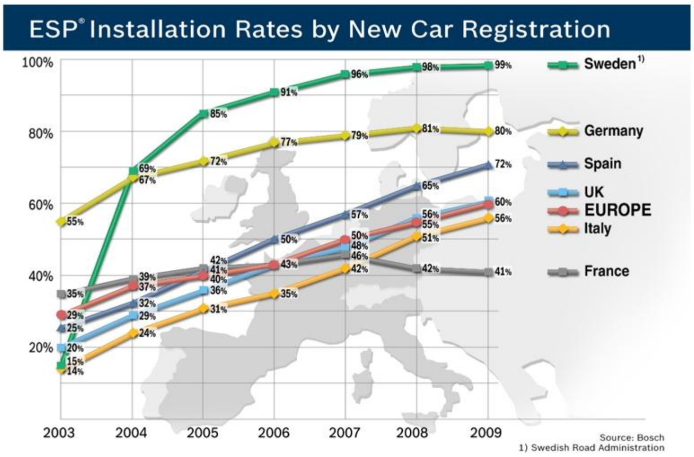

Figure A1.4: "Free market" uptake of ESP in EU countries (2003–2009) (from Busch et al., 2008; additional data provided by Robert Bosch GmbH and Swedish Road Administration).

The timeline for the AEBP uptake in the French new registrations fleet was derived from assumptions in (Reiter 2015) and is given by Figure A1.5:

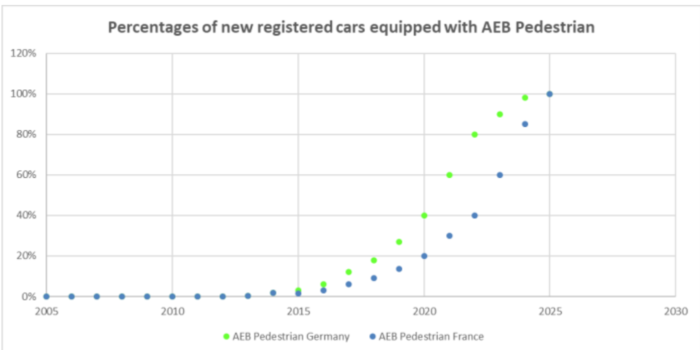

Figure A1.5 Percentage of new registered cars equipped with AEB Pedestrian (extrapolated from Reiter 2015)

The additional objects necessary to derive timelines of the measure's penetration in the whole of the fleet are:

- A projected timeline for new registrations. Based on (Bilan Annuel des Transports, 2023), a constant flow of 1.8Mo new registrations was assumed from 2024 on.
- A projected timeline for fleet size. Based on (Bilan Annuel des Transports, 2023), a constant yearly increase of 300000 vehicles was assumed from 2024 on.
- A fleet survival curve giving the probability for a passenger car to still be in use, given its age. This was taken from (André et al, 2019), see Figure A1.6, for generation 2009-2016.

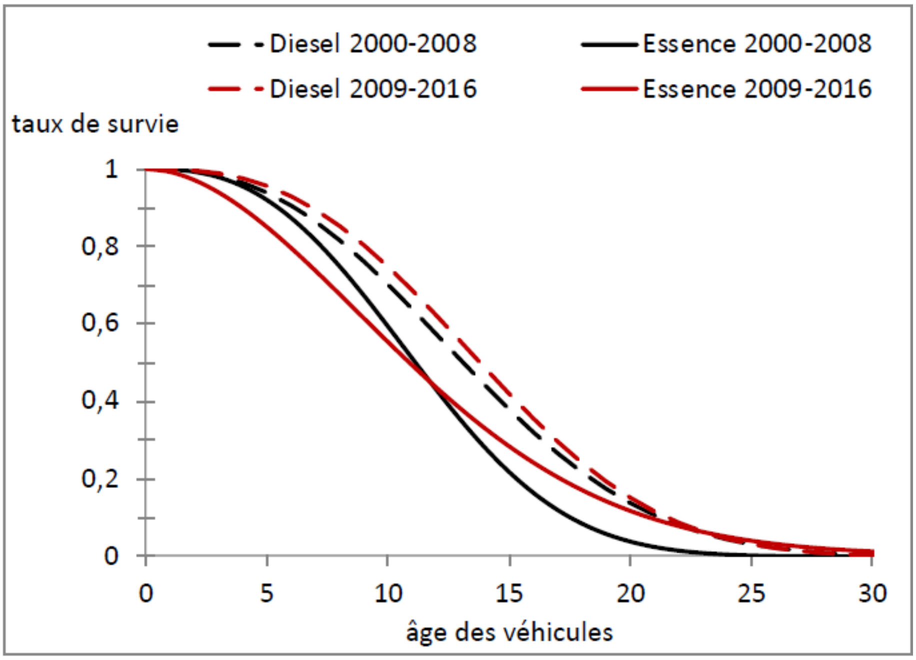

Figure A1.6: Survival Probability of Passenger Cars in the French fleet, given their age & propulsion type (Andre et al., 2019)

The ageing of the French population is forecasted by the European Union (Eurostat Population Projection, 2023). The share of the aged 60+ should reach more than one third of the population in 2050 (see Figure A1.7) as compared to one quarter in 2025.

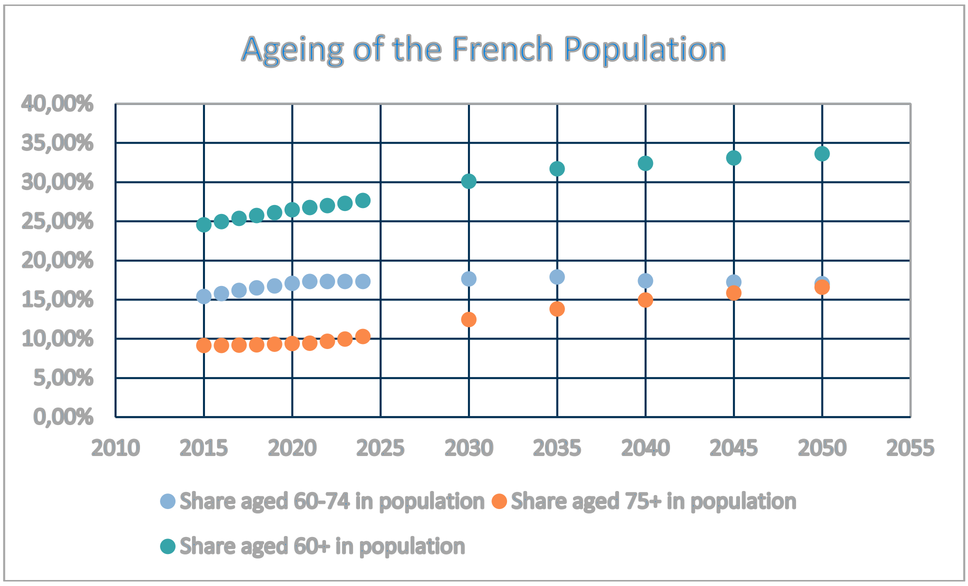

Figure A1.7: Share of Seniors in the French Population (Eurostat Population Projection, 2023)

It can be anticipated that this evolution will be reflected both in the numbers of causing passenger car drivers and also in the numbers of elderly pedestrian victims, thus breaking the trends seen in Figure A1.7, from 2025 on.

One of the effects that could have been influential on the present assessment was the introduction of electrified vehicles in the fleet. As these vehicles are very silent as compared to ICE-powered vehicles, negative effects in interactions with pedestrians could have been anticipated. A comparison was run from 2013 (year of the first crash involving an electrified vehicle and a pedestrian in France) to 2022 with the aim of checking the prevalence of the crash configuration under study amongst ICE and electrified vehicles. The result is shown in Table A1.4

Table A1.4: ICE vs EV Injury Accident Configurations of Pedestrian crashes (BAAC, 2025)

Proportions of Injury Accidents involving Passenger Cars (PC) and Pedestrians 2013-2022 by ...			
... PC Pre-Crash Manœuvre	**PC ICE Diesel (%)**	**PC ICE Petrol (%)**	**Full EV (%)**
Going Straight	56,34%	59,92%	45,08%
Driving Backwards	6,57%	4,47%	8,89%
Driving Wrong Way	0,14%	0,15%	0,32%
Merging into Traffic	1,63%	1,95%	1,27%
Turning Left	10,16%	9,98%	23,81%
Turning Right	4,66%	4,86%	4,13%
Moving into/out of Parking Slot	2,02%	1,78%	5,40%

The main differences do not concern the crash configuration under study (included in the “PC going straight” category), but rather crash configurations where the passenger car is turning left at an intersection (attention of the driver is mainly on oncoming traffic, crossing pedestrian doesn’t hear the electric engine starting off) and backing / parking crashes where pedestrians again are not aware of the electric engine starting off. The influence of the introduction of EV in the fleet was therefore neglected in the present assessment.

The pandemic dramatically reduced the distances travelled by the French passenger car fleet and stopped the growth of its size, as can be seen from Figure A1.8.

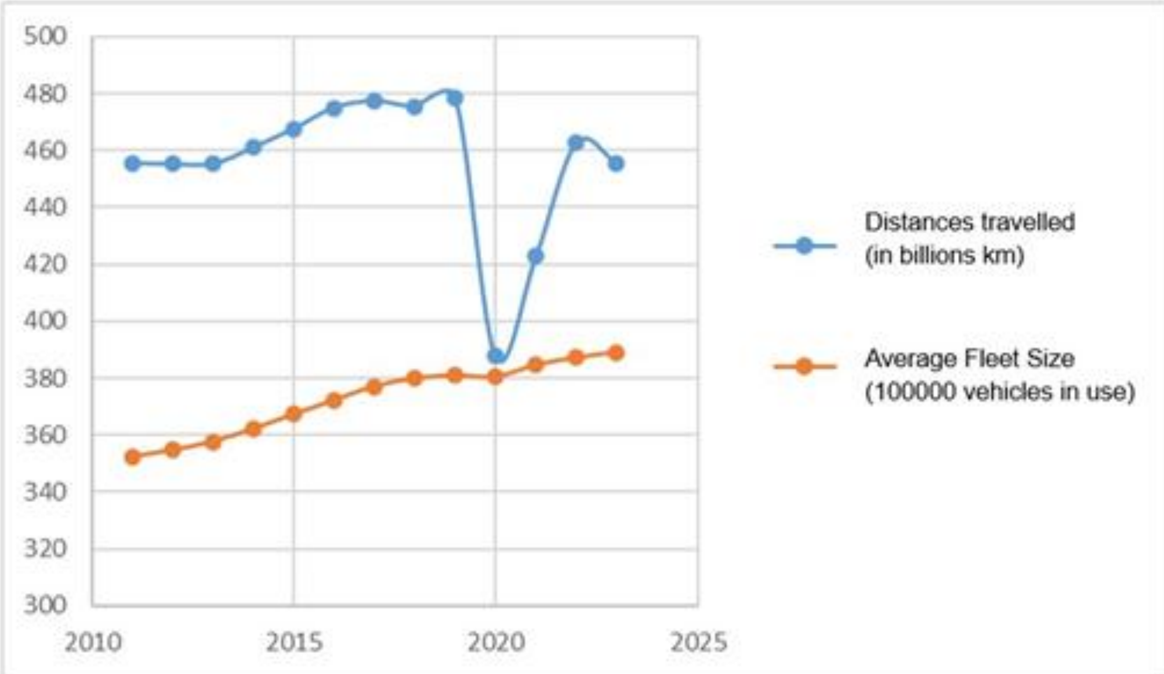

Figure A1.8: Effects of the pandemic on the French Passenger Car fleet (Etat annuel des transports, 2023)

The latter has resumed since, distances travelled however did not come back to their pre-pandemic levels. In lack of 2024 data, the hypothesis was made that both indicators (fleet growth, distances traveled) would soon return to their pre-pandemic levels and that we could neglect the effects in our projection. This is one of the most audacious hypotheses of this study.

As reported in deliverable D6.1 (Menzel et al., 2025), the introduction of lowered speed limits in cities without any stronger law enforcement had only limited effects on the crash configuration under study and were therefore neglected in the present study. Modal shifts to e-scooters were also shown to have a limited influence in reducing pedestrian travels (Deliverable D2.2, Fahrenkrog et al., 2025) The influence of modal shifts (e.g., from walking to using an e-scooter) is limited for our pedestrian use cases as this shift mostly removes lengthy multimodal trips in territories with scarce access to individual or public transport. Additionally, the investigated survey results were found to be hardly transferable from one country to another, indeed from one place to another in the same region or one time period to another in the same place.

In conclusion, the following effects were included in the projection:

- Observed trends in (BAAC 2025) from the reference year (2011) to present
- Market Penetration of the AEBP over time
- Population ageing

Methods

The following items need be explained in some details.

- **Market Penetration of the AEBP over time**
  Combining the timeline of new registrations (from Bilan Annuel des Transports 2023) and the survival curves from Figure A1.4, one can get the distribution of vehicle age at any given year

of projection. From this, an average penetration rate of the measure at any given year of projection can be derived, using Figure A1.4. This value was used whenever the exact age of the vehicle in our sample was unknown (less than 10 cases). For vehicles of known age, it was hypothesized that this age would be kept over the years of projection – meaning that year of registration was sufficient to know the probability of the vehicle being equipped.

- **Trends from reference year to present**
  Weights were applied at accident level to be representative of the trends seen Figure A1.6. They were supplemented by weights at victim level to keep representative of Table A1.1. This was mostly true for non-fatal injuries, as the reference sample didn't need re-weighting from that regard. No lasting effect of the pandemic or other international events was taken into account.
- **Population ageing**
  From 2025 on, it could be anticipated that accidents involving 60+ pedestrians and 60+ drivers would become more frequent, thus stopping and reverting the trends seen until present, as this population would significantly grow (see Figure A1.7). The hypothesis adopted was that pedestrian victims and causing drivers would follow the trends seen in senior population. This resulted in increased weights for accidents with unresponsive senior drivers and increased weights at victim level – seniors being more apt to sustain severe or fatal injuries at lower impact speeds.

Models

The AEBP model, the sensors and the activation logic are described in Deliverable D6.1 (Menzel et al., 2025) to which the reader is referred.

Results

Benefits of the introduction of the AEBP and, most of all, of the decision to make it compulsory on all new types of vehicles (2022) then on all vehicles can be summarized in Figure A1.9.

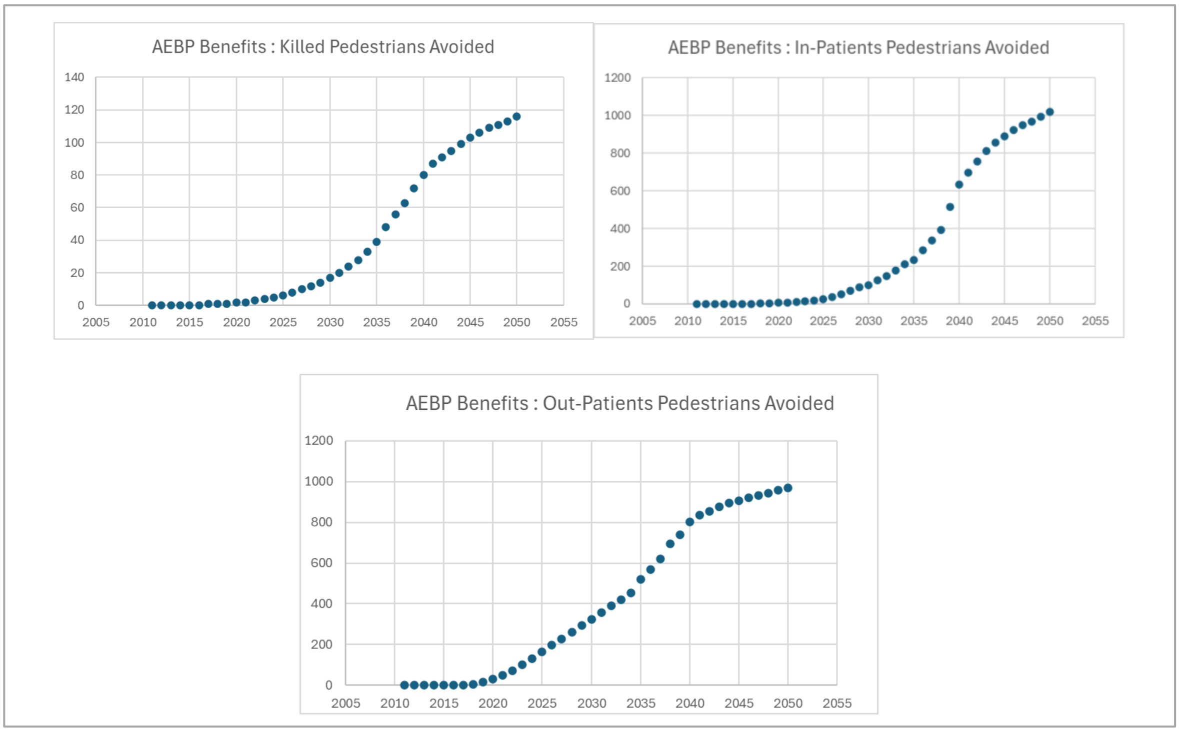

Figure A1.9: Benefits of the introduction of AEBP

Results can also be visualized in a tabular form (Table A.1.5):

Table A.1.5 Projected Road Safety Performance of AEBP in Car vs Jay-Crossing Pedestrians in France

Annual number of prevented casualties			
Year	**Fatal**	**Serious**	**Slight**
0			
1	3	10	73
2	4	14	102
3	5	20	133
4	6	26	165
5	8	38	197
6	10	53	229
7	12	72	261
8	14	88	293
9	17	101	325
10	20	124	357
11	24	147	390
12	28	176	422
13	33	211	454
14	39	234	521
15	48	286	567
16	56	339	622
17	63	391	693
18	72	516	738
19	80	634	802
20	87	696	835
21	91	754	854
22	95	813	877
23	99	855	893
24	103	888	905
25	106	921	919
26	109	947	933
27	111	967	941
28	113	992	956
29	116	1019	967

The main results to be retained from our simulations are as follows:

- No or almost no effect can be seen until present as uptake is slow and there is already a positive trend from other measures
- The full effect will be reached between years 2035 and 2050, when even older vehicles are equipped with AEBP
- AEBP will help compensate for the growth of the senior population, starting 2025+ with more unresponsive senior drivers on the roads and more senior pedestrians crossing the streets.
- It is also noteworthy that the full effect of making the measure mandatory over all new vehicles only shows more than 25 years later, on account of the slow renewal rate of the French passenger car fleet. This highlights the importance of carrying out full projections in time – assessment with simplified hypotheses such as “the fleet gets instantly equipped” can be misleading.

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A.1.2 Projection in time of the Safety Performance of an in-vehicle Autonomous Emergency Braking and a Blind Spot Intervention in Right-Turning Cars vs. Same Direction Cyclists scenarios

Author: Florian Denk
Date: 2025-08-28

Objectives, Research question(s)

The increasing popularity of bicycles as a sustainable mode of transportation, including the rise in the use of e-bikes, has significantly altered urban mobility patterns. As more cyclists share the roads with motor vehicles, traffic safety has become a crucial focus for urban planners, regulators, and automotive manufacturers. One particular scenario that poses considerable risk is when a car turns right while a bicycle is proceeding straight in the same direction.
Autonomous Emergency Braking systems (AEB) have been implemented in many cars and have become a standard safety feature. AEB systems were originally designed for longitudinal collision scenarios, such as jaywalking pedestrians or rear-end collisions, where the forward-looking sensors can effectively detect and respond to objects in the vehicle's path. Later, also crossing scenarios where considered, using a forward-looking sensor set.
It is valuable to investigate whether these existing systems may also have an effect in right-turn situations, even though they were not designed for this scenario. Because e-bike riders typically travel at higher average speeds than users of conventional bicycles (Schleinitz et al. 2017), the projected growth in e-bike usage is likely to alter the geometric constellation of right-turning conflicts which may in turn make the application of current AEB systems to right-turn conflicts particularly challenging. We therefore explicitly consider increased e-bike usage—and the associated higher cyclist speeds—as a key factor in our analysis. Consequently, our prospective safety assessment of automatic emergency braking (AEB) effectiveness in future traffic scenarios focuses on a representative sample that reflects higher e-bike penetration and speed distributions. Since right-turning is a scenario in which the geometric constellation of cyclists relative to cars may diverge substantially from the longitudinal configuration for which AEB was designed, Blind Spot Intervention (BSI) is studied as an alternative safety measure.
In this study, the V4SAFETY framework is employed to prospectively assess the effectiveness of AEB systems in reducing collisions within future traffic scenarios in the right-turn situation with anticipated rise in e-bike usage. The primary assumption is that future traffic will mainly differ from current conditions by a higher proportion of e-bikes, altering the mix of bicycle types present.

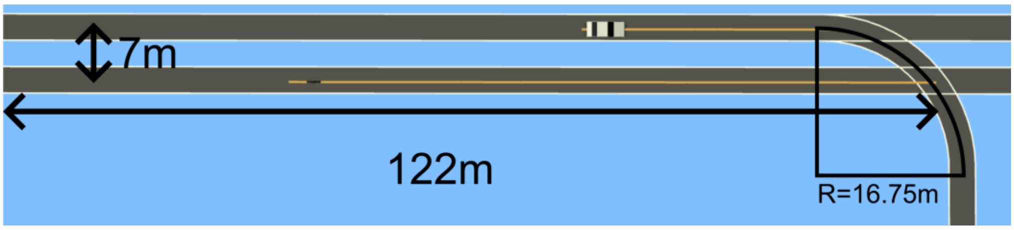

Figure A1.10 Intersection geometry used for the analysis: a car turning right while a bicycle (conventional or e-bike) proceeds straight in the same direction. The coordinate system and layout depicted here define the spatial configuration for all simulated scenarios and analyses. *Visualization done with esmini.*

The present study is conducted in an urban environment at a generic right-angle intersection controlled by traffic lights, as is commonly found in Germany. The intersection geometry, as depicted in Figure A1.10, is implemented in ASAM OpenDRIVE format. The parameters of the road

geometry are provided in Figure A1.10. The data used for calibration of traffic flow parameters for the study is originating from the city of Ingolstadt, as described subsequently.
For the purposes of the current study, the following conditions are assumed: Lorries and heavy trucks are not considered as dynamic objects on the road. Furthermore, it is assumed that cyclists do not commit any right-of-way violations (e.g., running a red light), nor do they react to a potentially conflicting situation by changing their speed or direction. In addition, cases in which cyclists travel in the wrong direction ("wrong-way riders") are not taken into account in the study. The study also focuses only on situations involving single cyclists, as this is the situation that was investigated in the experimental test described in (Denk et al. 2025) which yields the empirical basis for the car driver perception model. Consequently, the study does also not consider the "safety in numbers" effect, i.e. the potential positive influence of an increased presence of cyclists or other VRUs in traffic on safety.
The crash causation situation investigated here is that right-turning drivers occasionally overlook a cyclist rider and mistakenly fail to give them right of way. Both drivers traveling straight ahead and turning right are taken into account.

Within the V4SAFETY framework methodology, the following research questions are addressed:

Research Questions

- AEB: What percentage of crashes can be avoided in the scenario "car turning right, cyclist going straight in the same direction" at the intersection geometry shown in Figure A1.10 with traffic flow parameters originating from a specific intersection in the city of Ingolstadt, if a specific forward-looking AEB system with 100° sensor field of view is implemented in all cars in Germany (100% penetration rate), considering a projected increase in absolute share of e-bikes to 50% by 2036?
- BSI: What percentage of crashes can be avoided in the scenario "car turning right, cyclist going straight in the same direction" at the intersection geometry shown in Figure A1.10 with traffic flow parameters originating from a specific intersection in the city of Ingolstadt, if a BSI system with a backward looking camera (180° sensor field of view) is implemented with varying range of view in all cars in Germany (100% penetration rate), considering a projected increase in absolute share of e-bikes to 50% by 2036?

The projection that 100% penetration rate of safety systems such as AEB/BSI will happen in 2036 is based on ("Marktdurchdringung von Fahrzeugsicherheitssystemen 2021"). The projection that the absolute share of e-bikes will be 50% in 2036 is based on data from Statista Market Insights ("Fahrräder - Weltweit" 2024). Both events, the penetration rate of the safety systems AEB/BSI and the projection of the baseline in time are thus synchronized.

Methods and Data

Select Baseline Approach

To address the research question about AEB effectiveness in the future with increased e-bike usage, this study takes a simulation-based approach which requires scenario data that can represent projected future conditions (2036 e-bike share). While existing crash databases provide valuable insights into historical crash patterns, they have limitations for this prospective assessment: they primarily contain data from current traffic conditions with lower e-bike penetration compared to the projected penetration of 50% in 2036. The C2 baseline approach was selected for this assessment because it enables the generation of a representative sample of crash scenarios through stochastic microscopic traffic simulation, allowing for systematic variation of key parameters such as e-bike share and corresponding cyclist speeds. This methodology is particularly valuable for investigating how the effectiveness of AEB safety measures may change as the e-bike share increases.
Stochastic microscopic traffic simulation is a suitable option for analysing future traffic changes, as

it models individual vehicles, cyclists, and other road users as separate entities, capturing micro-level interactions and dynamics. Its high flexibility allows for the adjustment of traffic parameters, which is useful for realistically modelling the projected increase in e-bike usage. Furthermore, stochastic elements can be incorporated to account for variability in human behaviour, vehicle dynamics, and environmental conditions. The C2 methodology employed combines Baseline Approach C (simulation of cases with modification), case generation process 2 (stochastic variation), and in-simulation instantiation (I) to generate a representative sample of relevant traffic scenarios, including those that may not yet exist in sufficient numbers in current crash databases.

Select Data

The data used to parametrize the models used for stochastic traffic simulation in order to generate baseline scenarios is mainly originating from the following sources:
(Denk et al. 2025): Behavior-related crash causation model of car drivers

- (Schleinitz et al. 2017): Distribution of cyclist speeds
- (Brunner et al. 2022): Cyclist traffic flow parameters
- https://github.com/TUM-VT/sumo_ingolstadt: Car traffic flow parameters
- (Green, 2000): Reaction times for car drivers
- (Petzoldt et al. 2017): Gap acceptance data for right-turning car drivers
- (Tang et al. 2016): Data on car queue discharge dynamics at intersections
- (Lee 1976): Data on parameters of longitudinal control behavior of car drivers

The usage of the data in the models is described in detail in the section on model selection.

Treatment Simulation

AEB

In this study, the export of trajectories was used to transfer baseline data from THI to the treatment simulations conducted by VCC. This approach enabled seamless integration of THI's baseline scenario generation with VCC's simulation toolchain within the V4SAFETY framework. The process begins with THI generating baseline data through stochastic traffic simulation (C2 approach). This data forms the foundation for subsequent AEB treatment scenario simulations conducted by VCC. To ensure compatibility and efficient data transfer, the baseline scenarios are exported as ASAM OpenSCENARIO files. These files are specifically structured to include only the relevant collision objects from each simulated scenario. Before the scenarios are delivered to VCC, each ASAM OpenSCENARIO file was checked in a validation step: the scenarios were executed in esmini to confirm that a collision occurs as intended. This ensures that only valid crash scenarios are included in the dataset for subsequent AEB effectiveness analysis.
An exemplary visualization of a scenario is given in Figure A1.11.

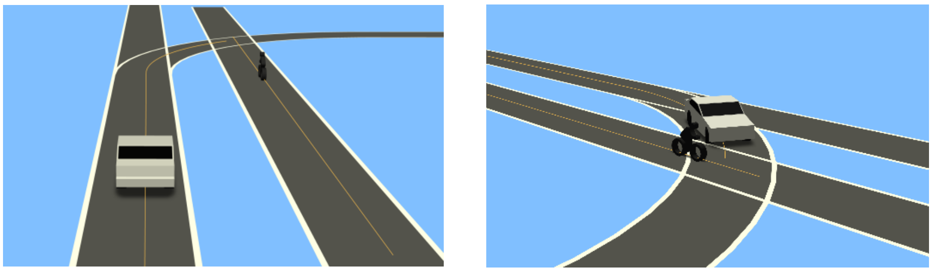

Figure A1.11 Exemplary scenario runs in esmini: the two screenshots show visualizations of the right-turn scenario with a car and a cyclist at the intersection. These screenshots demonstrate the spatial configuration and dynamic interaction as simulated in the present study

BSI

The THI baseline was provided to LAB as Matlab structures containing the EGO and bicycle trajectories as lists of (X,Y) planar coordinates. It was used without alteration, using a constant 10 ms timestep for computing speeds and acceleration

Select Models

Valid, representative scenarios in prospective safety assessment require explicit models of road-user behaviour across the full causal chain, from normal operations to rare, safety-critical events. As argued in the V4SAFETY guidelines on road-user behaviour models in Deliverable D3.1, behaviour models are essential to ensure that baseline scenarios are realistic, causally plausible, and suitable for prospective safety assessment. Below, an overview of the employed models is given. For an in-depth description of the models please refer to (Denk, 2026).

Traffic Demand Cyclists

The speed for a simulated cyclist is determined through a two-step Monte Carlo simulation process. First, the type of bicycle is randomly assigned. Each simulated cyclist is assigned to either being an e-bike or a conventional bicycle. The probability that a cyclist rides an e-bike is 50 percent, reflecting the projected future share of e-bikes in traffic introduced in the research questions. Conversely, there is also a 50 percent probability that the cyclist rides a conventional bicycle. Second, a speed is sampled from a distribution corresponding to the sampled bicycle type. The parameters are derived from *The German Naturalistic Cycling Study* (Schleinitz et al. 2017). The speed of each cyclist is then determined by sampling from a truncated normal distribution, with the parameters depending on the type of bicycle assigned. The truncated normal distribution is used in order to avoid sampling cyclist speed above / beyond the maximum / minimum observed value in empirical data to avoid speeds that are not grounded in evidence. For e-bike riders, the mean speed is 5.3 meters per second, with a standard deviation of 1.5 meters per second. The sampled speed is restricted to fall between 3.1 and go beyond 9.0 meters per second. For conventional bicycle riders, the mean speed is 4.5 meters per second, with a standard deviation of 1.0 meter per second, and the speed is truncated to the range between 3.0 and 7.0 meters per second. This approach ensures that the simulated cyclist speeds realistically reflect the differences between e-bike and conventional bicycle users, based on empirical data in (Schleinitz et al. 2017).
The crossing time of cyclists at the conflict point is modelled using an exponential distribution with the traffic volume per hour as rate parameter trafficFlowBike. The initial position of cyclists is determined such that cyclists arrive at the conflict point at the sampled crossing time given their sampled speed.

Car Driver Behavior Related Crash Causation Model

To generate valid simulation results for the AEB effectiveness assessment, particular emphasis was placed on the development of experimentally validated behaviour-related crash causation models, specifically for drivers' perception during right turns. This model is crucial because evidence (Kolrep-Rometsch et al. 2013) shows that the perception process during right turns can be occasionally error-prone, contributing significantly to crash causation in such scenarios.
Key aspects of the perception process of right-turning drivers include the frequency and timing of glances into specific areas of interest (e.g., shoulder glances, right-side view mirror, rearview mirror). The development of the model used is grounded in experimental data on the perception of cyclists by car drivers in right-turn scenarios collected from a realistic test-track experiment conducted. In this experiment, drivers demonstrated appropriate situational awareness under realistic cognitive demands. Thus, the model is supported by recent and relevant empirical

findings, providing a strong foundation for its validity. The design, as well as the initial empirical findings from the experiment, are published in (Denk et al. 2023, 2025).

Based on this empirical data on the frequency and timing of glances into specific areas of interest of human drivers in right-turning manoeuvre, a database of perception events is generated using the EQUGAT algorithm presented in (Denk et al. 2025). The EQUGAT algorithm basically generates a representative sample of virtual cyclists for each observed car driver trajectory in the experiment and determines the perception of the virtual cyclists based on a field of vision analysis of the gaze state at each point in time. Based on this perception event data, a time-to-event model using Kaplan-Meier estimation for the detection of cyclists in right-turn scenarios was developed. The time-to-event model predicts the probability that a cyclist sampled in online traffic simulation has not been detected until a certain point in time. Using this probabilistic model, the perception of cyclists by right-turning car drivers was sampled in online traffic simulation.

Car Driver - Initial Conditions, Everyday Driving and Critical Event Response Models

The initial conditions for vehicles include their position, speed, and intended route (straight going or right-turning). Traffic lights create queues of car drivers, which are modelled using mathematical tools from queueing theory. The intersection is modelled as a so-called M/M/1 queueing system (Kendall's notation), which essentially means that arrivals and departures follow exponential distributions and there is one effective lane ("server"). The saturation level rho (between 0 and 1) of the intersection determines the workload of the intersection. The queue length distribution follows a geometric distribution with parameter p = 1-rho, which means that longer queues are more likely at higher values of rho. For vehicles already in a queue, departure times are derived from naturalistic data of queue discharge patterns (Tang et al. 2016). Vehicles that are not in the queue are modeled as approaching according to exponential arrival times at the traffic light stop line. In the queue, cars are initially spaced 1 m apart and begin with zero speed, while approaching cars start with speeds up to 50 km/h, depending on how soon they reach the end of the queue at the intersection. The traffic volumes for straight going cars is referred to with trafficFlowCarStraight and for right-turning cars with trafficFlowCarRightTurn.

The car dynamics model describes how drivers accelerate, decelerate, and respond to traffic conditions at signalized intersections. It is implemented as a state-based model, meaning that the driver's current situation determines their "state" and, in turn, the method used to calculate the driver's desired acceleration or deceleration. Because drivers do not react instantly, a latency is incorporated through a first-order low pass filter that reflects human responses to reach a desired acceleration. The everyday traffic model represents normal, expected behaviour. Therefore, the reaction times in this mode is sampled from a gamma distribution with a mean of about 0.7 seconds and a standard deviation of 0.1 seconds, consistent with empirical studies on expected reaction times (Green, 2000).

Straight-going cars are assigned a target speed of 50 km/h, while right-turning cars adjust speed as they approach the curve. Based on experimental data, right-turning drivers show differences both in their minimum curve speeds (ranging from about 2.6 m/s to 8.6 m/s) and in how quickly they brake to reach them. This is modelled with an exponential decay process, characterized by a time constant (between 1.2 to 5.3 seconds) that varies between drivers. A right turning driver is modelled to brake such that the desired curve speed is reached roughly 10 m before entering the curve.

Several additional driving states are included. When waiting in a queue, acceleration is set to zero until the traffic light turns green. When yielding to cyclists, drivers act according to a gap-acceptance model based on experimental data available in (Petzoldt et al. 2017). If a car is faster than the vehicle in front, a controller maintains a safe time-to-collision of around 8 seconds according to evidence provided in (Lee 1976). When slower than the preceding vehicle, the car accelerates smoothly to the desired speed set to 50 km/h. Finally, cars accelerating in a queue are

modelled based on empirically measured discharge dynamics, ensuring that vehicles cross the stop line at times observed in naturalistic data (Tang et al. 2016).
If the detection of a cyclist that is in conflict with the car driver occurs too late to mitigate a collision, a critical event response model is triggered. In this case, drivers are assumed to attempt emergency braking. According to (Green, 2000), reaction times in such unexpected events have a mean of about 1.35 seconds and a standard deviation of 0.6 seconds, sampled from a gamma distribution grounded in empirical evidence on unexpected reaction times. Maximum braking deceleration is drawn from a normal distribution with a mean of 7.0 m/s², but values are capped at 10.0 m/s² to reflect realistic limits.

AEB Model
The same model as described in A.2.4 is used. Please refer to this section for the details of the AEB model employed in this use case.

BSI Model and Methods

Mechanics: Vehicle model (in-simulation)
The vehicle model for the passenger car is a simple trajectory-follower. The geometry is taken from the P.E.A.R.S specifications (see Deliverable D6.1, section 8.1.2). The bicycle model is also a trajectory-follower, the geometry being again taken from the P.E.A.R.S specifications for the cyclist shape (see Deliverable D6.1, section 8.1.3).

Technology: *BSI (in-simulation model)*
The safety measure is a time to collision (TTC) based conceptual Blind Spot Intervention (BSI) system. The perception of the system is a backward-looking camera.

Dependent on the calculated TTC value (threshold for activation: 1 s) and an identification delay of 0.2 s (the bicycle has to remain in the field of view of any of the camera for that duration to be identified), the system overrides the driver commands and decelerates the vehicle with a maximal deceleration of 0.9 G reached over 0.3 s and a jerk of 24.25 m/s³ after a delay of 0.05 s. The TTC is calculated at each timestep according to the formula given in the P.E.A.R.S specifications (see Deliverable D6.1, section 8.1.4.2) regardless of whether the bicycle is detected / identified or not.

The sensor is a backward-looking camera, located on vehicle longitudinal axis, at 1.3m from the vehicle’s front. Its field of view has a 180° angle of view. Tested ranges were: 5m, 10m and 30m.

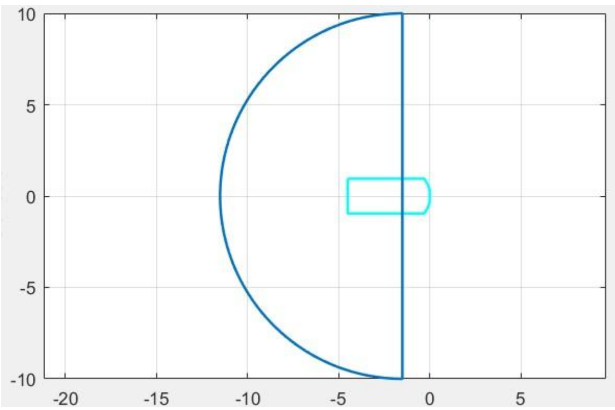

Figure A1.11 Vehicle shape (light-blue) and 10m range camera's field of view (dark blue)

Technology: Sensors (in-simulation model)
The sensor is represented through its semi-circular field of view (FOV) in two-dimensions (2D) defined by its range and opening angle. Its position relative to the vehicle is defined by (x, y) coordinates in the local vehicle coordinate system and a tilt angle around the vertical axis. At each time step, the FOV is calculated considering static objects and traffic participant positions and bounding boxes. A traffic participant is considered detected if 100% of its bounding box area is inside the FOV. The sensors are idealised, which means that no false positives or true negatives are considered.

Road
For these simulations, the road model is a 2D-plane. No model of the road marking nor of any infrastructure feature such as traffic signs was used due to the nature of the treatment.

Parameter Sets
The parameters for the aforementioned traffic parameters were estimated for the generic right-angled Goethe-Schiller intersection in Ingolstadt based on the calibrated Simulation of Urban MObility (SUMO) network provided at https://github.com/TUM-VT/sumo_ingolstadt. For this purpose, the SUMO simulation was performed and traffic flow values were measured per hour of day. Three classes of traffic intensities were defined (HIGH, MED, LOW). Data on the volume of cyclists per hour is estimated from high quality empirical observations on e-scooter usage in Ingolstadt provided in (Brunner 2022). The following number of simulations was performed per parameter set in order to generate the baseline scenarios:

Table A1.6 Parameters for three traffic intensities.

set	trafficFlowCarRightTurn [cars/hour]	trafficFlowCarStraight [cars/hour]	trafficFlowBike [cyclists/hour]	rho	Number of Simulations
HIGH	110	250	35	0.4	8 750 000
MED	50	120	25	0.2	2 500 000
LOW	12	29	10	0.05	3 750 000

Implementation Details
A custom simulation framework developed in the Julia programming language was used to generate the baseline scenarios. The framework implements roads based on ASAM OpenDRIVE files, traffic flow, and driver behaviour based on the previously presented modelling approaches and it records outcomes such as collisions. Simulation data is stored in a high-performance Redis database, ensuring fast handling of large volumes of runs. For analysis, the data is exported to the R statistical software. Export to ASAM OpenSCENARIO format was used to transfer the baseline scenarios to VCC for the treatment simulation.

Results

AEB (including extended analysis of geometric constellation)
The results of the prospective safety assessment using the V4SAFETY framework are shown in Figure A1.12. In total, four of 1579 collisions of the baseline scenarios were avoided by the AEB system, corresponding to a decrease of 0.25%. The 95% CI is estimated to [0.00%, 1.38%].

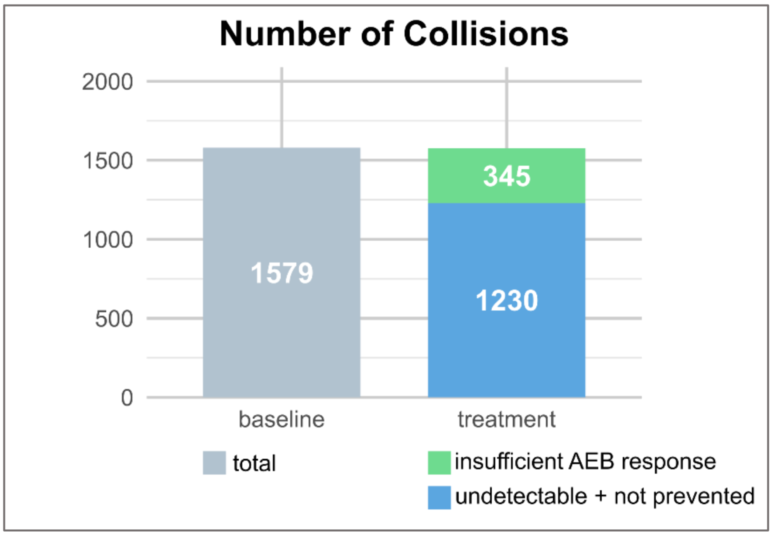

Figure A1.12 Number of collisions in the simulated 'car turning right, cyclist straight in same direction' scenario under future conditions (increased e-bike share), comparing the baseline (no AEB) and the treatment (AEB implemented). A total of 4 collisions were avoided by the AEB system. However, in a large number of baseline scenarios the cyclist was not detectable by the sensor setup

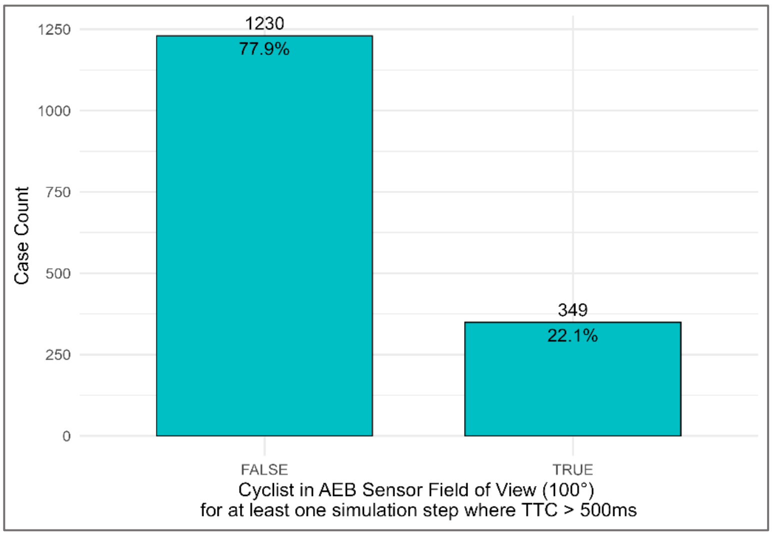

Figure A1.13 Boxplot showing the number and percentage of baseline scenarios in which the cyclist is in the AEB sensor field of view (100°) for at least one simulation step with time-to-collision (TTC) greater than 500 ms. This analysis provides insight into the proportion of simulated cases where the AEB system has the potential to detect and intervene, highlighting the relevance of the baseline data for evaluating AEB effectiveness

To understand the context of the results and validate the relevance of the baseline scenarios for AEB assessment, a detailed analysis of cyclist presence in the AEB sensor field of view was conducted. This analysis is crucial for interpreting the effectiveness results, as AEB systems can only intervene when cyclists are detected within the sensor coverage area.

As shown in Figure A1.13, analysis of the baseline dataset reveals that out of 1579 total collision scenarios, 22.1% involve cyclists who enter the AEB sensor field of view at least once, i.e. for at least one simulation step, with sufficient time-to-collision (TTC > 500 ms) for potential intervention. The cyclist should have been detected in these cases given the idealized sensor model in the AEB system, which only takes into account whether the cyclist is geometrically within the field of view. The remaining 77.9% of scenarios correspond to cases where cyclists never enter the sensor field of view under these conditions, rendering them inherently unsuitable for intervention by the considered AEB system.

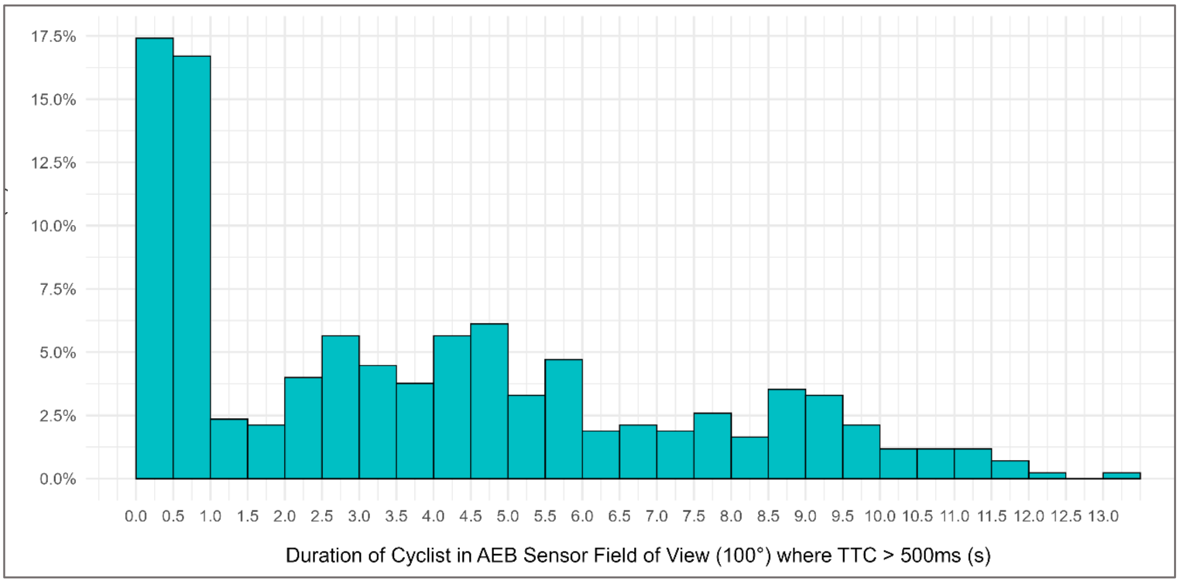

Figure A1.14 Histogram showing the number baseline scenarios in which the cyclist is in the AEB sensor field of view (100°) for at least one simulation step with time-to-collision (TTC) greater than 500 ms.

An in-depth analysis of the geometrical configuration of the 349 baseline scenarios in which the cyclist was in the field of view at least once where TTC>500ms is given in Figure A1.14. This figure shows that in around 65% of the cases, the cyclist was in the sensor field of view for at least 1 second.

When analyzing only the subset of scenarios where cyclists are within the AEB sensor field of view, the effectiveness increases from 0.25% to 1.15%. This demonstrates that the AEB system can provide benefits when the geometric position of the cyclists relative to the car allows for the detection of the cyclist. The aforementioned analysis shows that the baseline data contains relevant scenarios for AEB assessment, while also highlighting the importance of scenario selection in safety system evaluation.

The separation of detectable and non-detectable scenarios is crucial for understanding the true performance characteristics of the AEB system. The 77.9% of non-detectable scenarios represent cases where the forward-looking AEB system is fundamentally incapable of intervention due to the geometric constellation of the collision scenario, rather than a failure of the system itself. This distinction is essential for proper interpretation of the results and should be considered when evaluating the overall safety impact of AEB systems in right-turn scenarios.

The overall effectiveness of 0.25% collision reduction, while modest, must be interpreted within the context of the baseline scenario characteristics and the specific forward-looking AEB system configuration under evaluation.

However, it is important to emphasize that generating this baseline data remains highly relevant. Including these scenarios in the baseline is essential to ensure that the effectiveness results within the subgroup—where the treatment system can actually have an effect—are properly weighted relative to the overall population of collision scenarios. This approach is analogous to practices in the medical domain, where it is crucial to understand not only the efficacy of a treatment among those who can benefit, but also the proportion of the total population for whom the treatment is applicable.
Summarizing the results with respect to the research question ***AEB***, the effectiveness of the specific AEB system is 0.25% with a 95% CI of [0.00%, 1.38%].

BSI
The avoidance rates for the three field of view ranges tested were:

Table A1.7 Avoidance rates for the three field of view ranges.

	Baseline Simulation	5m range simulation	10m range simulation	30m range simulation
Crash avoidance rate	-	0.55%	31%	89%

This hypothesis underlying these results is that all the passenger cars are equipped with the tested BSI system.

Summarizing the results with respect to the research question ***BSI***, the effectiveness of the specific BSI system varies with the used range of view of the backward looking camera with a maximum effectiveness of 89% mitigated collisions at a range of view of 30m.

Limitations and Methodological Considerations
Several limitations must be acknowledged when interpreting these results.

- The stochastic traffic simulation approach, while providing comprehensive scenario sampling, relies on validated models of human behaviour with their own limitations. The driver perception model for right turns, while experimentally validated, represents a specific subset of driver behaviours and may not capture the full spectrum of real-world variability.
- Furthermore, the resulting baseline scenario data was not compared to real world crash statistics in order to prove the representativeness of the generated scenarios. The model parameterization partly relies on historical datasets that may not reflect current traffic conditions. Moreover, parameter values are also likely to evolve by 2036, introducing additional uncertainty. Because the 2036 traffic state cannot be holistically observed today, comprehensive re-calibration and validation are constrained.
- The AEB system under consideration had a sensor suite optimized to detect conflicting objects in the forward direction of travel, such as jaywalking pedestrians. This design characteristic has significant implications for the right-turn scenario under investigation, where cyclists may approach from lateral positions relative to the turning vehicle. The forward-looking sensor configuration inherently limits the system's ability to detect cyclists approaching from the side or rear, which is a common occurrence in right-turn scenarios, as analysed above. However, given the widespread deployment of AEB systems in modern vehicles, understanding their potential effectiveness in scenarios beyond their original design intent is valuable for comprehensive safety assessment.

The assessment of the BSI safety system was aimed at showing that there are already measures that are better fitted to deal with the crash configuration under study. The data on the BSI effectiveness shows that BSI effectiveness is substantially higher compared to the specific AEB system used in this study for field of view ranges greater than 10m. The specific AEB used in the first research question of this study is definitely not the best choice from a road safety point of view, even though the crash configuration under study poses specific challenges.

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A.2 Extrapolation over Space

In this appendix A.1, three cases of extrapolation in space are presented in detail.

A.2.1 Common Characteristics

Assessments described in sections A.2.3 and A.2.4 both make use of a clustering of EU countries. section A.2.1 describes how it was built, and which were the data sources used.

The clustering method used is the Agglomerative Hierarchical Clustering (AHC) method. Agglomerative clustering, often referred to as a "bottom-up" approach, begins with each data point as an individual cluster. At each step, the algorithm merges the two most similar clusters based on a chosen distance metric and a linkage criterion (see Murtagh & Contreras, 2012, for a complete overview). The Euclidean distance and Ward's criterion (Ward, 1963) were used in our case. The process continues until all data points are combined into a single cluster or a stopping criterion is met. Agglomerative methods are more commonly used due to their simplicity and computational efficiency for small to medium-sized datasets (Mojena, 1977) which corresponds to our case.

Use was made of the following clustering variables:

- % Car occupants killed by bus / coach *(Source: DGMOVE 2024)*
- % Car occupants killed by cars *(DGMOVE 2024)*
- % Car occupants killed by High Ground Vehicles *(DGMOVE 2024)*
- % Car occupants killed / no other involved *(DGMOVE 2024)*
- % Powered Two Wheelers occupants killed by cars *(DGMOVE 2024)*
- % Powered Two Wheelers occupants killed / no other involved by cars *(DGMOVE 2024)*
- % Cyclists killed by cars *(DGMOVE 2024)*
- % Cyclists killed / no other involved by cars *(DGMOVE 2024)*
- % Pedestrians killed by cars *(DGMOVE 2024)*
- Killed by 100000 population *(WHO 2023)*
- % Killed on Rural Roads (*Eurostat 2025)*
- % Killed on Urban Roads (*Eurostat 2025)*
- % Car drivers wearing seatbelts (*ESRA2 2022)*

The final number of clusters was decided upon by balancing two criteria: keeping the number of clusters to a minimum and ensuring that the share of the within-class variance in the global variance was well below that of the between-class variance. This was achieved with an 8 clusters distribution (within-class variance share: 40%) illustrated by A2.1.

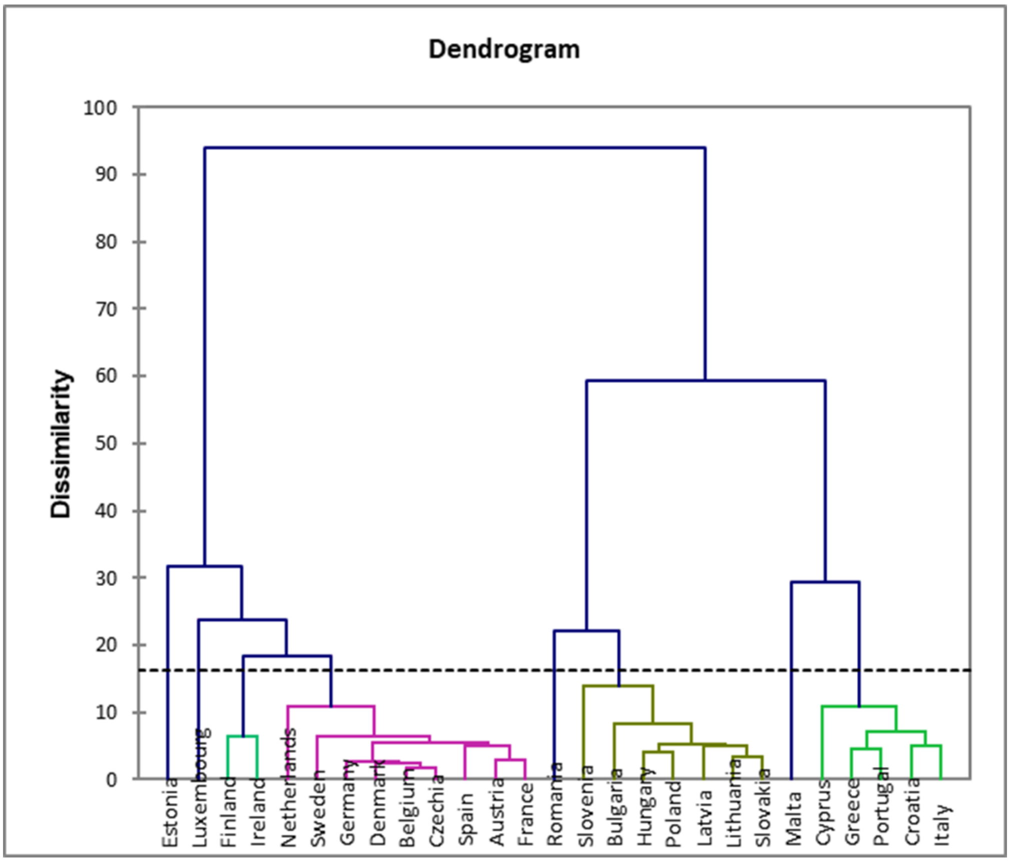

Figure A2.1 Clustering of EU 27 countries

Clusters are made of the following countries:

- Cluster #1: Estonia
- Cluster #2: Luxemburg
- Cluster #3: Finland, Ireland
- Cluster #4: The Netherlands, Sweden, Germany, Denmark, Belgium, Czechia, Spain, Austria, France [This cluster will be referred to as the North-Western Cluster in this document]
- Cluster #5: Romania
- Cluster #6: Slovenia, Bulgaria, Hungary, Poland, Latvia, Lithuania, Slovakia [This cluster will be referred to as the Eastern Cluster in this document]
- Cluster #7: Malta
- Cluster #8: Greece, Portugal, Italy, Croatia, Cyprus

Applications of this clustering include:

- Finding the best proxy if CARE data missing for a given country (e.g., Italy for Croatia, Austria for France if no recent data on injured)
- Finding a representative for a whole cluster

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A.2.2 Extrapolation to Germany of the Safety performance assessment of an AEB in Car-to-Car Straight Crossing Path situations

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Date: 2025-08-28

Background

The use case focusses on the potential safety benefit of an AEB within car-to-car straight crossing situations. As basis for the treatment simulations, scenarios from the TASC dataset between 2018-2022 are used, which are collected in the German region of Saxony. Relevant scenarios in the database that match the use case were selected via the classified conflicting situation, which follows the classification scheme of the German Insurance Accident Research (Unfalltypen-Katalog - GDV, 2016). As a result, 668 matching scenarios could be extracted from the database.

For demonstration purposes, an AEB model developed in V4SAFETY has been used within the treatment simulation using a TME in-house simulation framework. The implementation of the AEB prevented 258 crashes (38.6%). Injury risk functions were used to estimate the severity outcomes for drivers in the remaining crashes of the treatment simulation (see Table A2.1). A detailed description of the safety performance assessment can be found in the V4SAFETY Deliverable D6.1 (Menzel et al. 2025).

Table A2.1 Crash avoidance and injury severities in the baseline and treatment simulation

	Baseline Simulation	Treatment Simulation
Number runs	668	668
Severely injured/killed drivers	24	16
Slightly injured drivers	204	137
Crash avoidance rate	-	38.6% [32.8%, 43.3%]

Extrapolation method

The aim of the extrapolation in space is to estimate the crash avoidance rate in Germany based on the above-mentioned treatment simulation results. Following the V4SAFETY framework on extrapolation over space, the used sample of scenario data was inspected for a possible bias. The TASC database is known to have a bias leading to an overrepresentation of KSI crashes in the

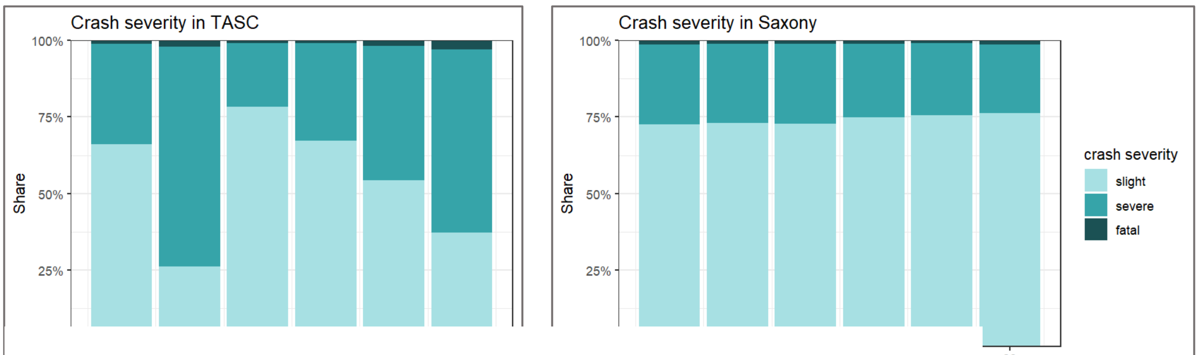

Figure A2.2 Distribution of crash severities in sample database (TASC) and sample region (Saxony) collective compared to the distribution of crash severities in the sample of police-recorded crashes in Saxony (see Figure A2.2). Therefore, weights were calculated in a first step to make the sample representative for the Saxon crash statistics. The stratums to calculate weights are defined by crash year, type, location, and severity. Categories for crash type, location and severity are similarly defined in the TASC database, Saxony, and Germany, wherefore a clear correspondence can be established between the crashes on the different spatial levels.

33 different combinations can be found in the sample data for which weights have been calculated according to their share in the sample data and in the Saxon crash statistics (Statistisches Landesamt Freistaat Sachsen, 2025). Not all weighting factors shall be presented, but the average weights by crash year and crash severity are listed for demonstration purposes in Table A2.2. The average weighting factors clearly show higher weights for slight injuries to overcome the bias in the sample data. Analogously, weights can be calculated for an application on a German level (see Statistisches Bundesamt, 2025).

Table A2.2 Average weights by crash year and severity

Crash year	Crash severity	Average weighting factor
2018	Serious	0.789
	Slight	1.200
2019	Serious	0.721.
	Slight	0.896
2020	Fatal	1.780
	Serious	0.813
	Slight	1.210
2021	Serious	0.747
	Slight	1.270
2022	Fatal	1.380
	Serious	0.782
	Slight	1.260

Results

Applying the different weights to the treatment simulations allows to estimate the corresponding number of prevented crashes in Saxony and in Germany, respectively. The results of all treatment simulations are summarised in Table A2.3. Assuming all cars would be equipped with the AEB, 40.2% of corresponding use case crashes could be prevented in Saxony and 37.9% in Germany. The slightly lower avoidance rate in Germany may be due to a slightly higher avoidance rate of the AEB in severe crashes and the fact that Saxony has a higher share of KSI crashes compared to Germany. Note that the provided confidence intervals cover just the uncertainty due to the sample size.

Table A2.3 Saxony extrapolated crash avoidance rates for Germany

	Treatment AEB in Saxony	Treatment AEB in Germany
Severely injured/killed drivers	689	15,256
Slightly injured drivers	5,762	123,164
Crash avoidance rate	40.2% [32.8%, 43.3%]	37.9% [32.7%, 43.2%]

Discussion

The extrapolation over space is based on strata defined by crash year, type, location, and severity. The use case mainly includes crossing and turning crashes as crash type. However, the road user type is not considered and would further reduce the number of cases per stratum. A closer look at these crash types in the Saxon crash statistics corresponding to the used scenario sample (2018-2022) exemplarily reveals that the use case (involving two cars) and crashes of the strata (involving all road users) show different developments in frequency and severity over time. Taking the year 2018 as reference year, crashes with only 2 cars and crossing/turning crashes as crash type have a stronger decline in numbers than all crashes of the stratum in Saxony (Statistisches Landesamt Freistaat Sachsen, 2025). Furthermore, the crash severity is generally lower than the crash of the used stratum for extrapolation (see Figure A2.3).

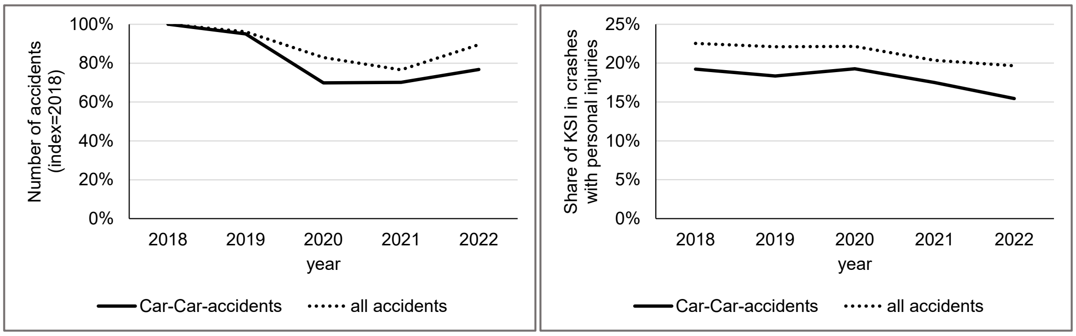

Figure A2.3 Differences in the development of crash numbers and crash severity between crossing/turning crashes involving only cars (use case - solid line) and crossing/turning crashes of all road users (stratum – dotted line) in Saxony

In consequence, it is expected that the extrapolation results in an overestimation of the number of crashes and a higher share of fatal and severe crashes in Saxony as well as in Germany.

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A.2.3 Extrapolation to the EU of the Safety Performance in France of an in-vehicle Autonomous Emergency Braking for Pedestrians in Car vs. Jay-Crossing Pedestrians scenarios

Author: Henri Chajmowicz
Date: 2025-08-19

A large proportion of current fatalities in the EU are pedestrians, accounting for 18% in 2022, which is still very high, despite significant progress since 2012 (-31% at EU level) [All numbers from CARE, 2023]. In France, the number of pedestrian fatalities has all but flatlined between 2010 and 2019 and decreased by 10% between 2019 and 2023. In 2023, 474 pedestrians were killed on French roads (BAAC 2025).

The performance of a Pedestrian Autonomous Emergency Braking (AEBP) in a passenger car vs. jay-crossing pedestrian scenario was investigated for 100% implementation rate in France and the entirety of the EU. A selected sample of 150 cases from the VOIESUR accident database representing the French crash scene (Amoros et al., 2015) was used to build the baseline. Injury Risk Functions (IRF) built on a population of car-front vs pedestrian crashes extracted from that same database (Cuny et al., 2018) were used to assess injury outcomes. An alternative version of the original VOIESUR weights (Amoros et al., 2015) was computed to make this sample representative for the population of police recorded crashes in France (BAAC 2025). Additional weights were computed from the European CARE database (CADAS, 2023) to make the French data sample representative for the EU.

Metrics to answer the research questions were the reduction of the number of killed, in- and out-patients.

The AEBP lead to a reduction in the injury burden in both France and Europe. The injury burden reduction rates for France and the EU are of the same magnitude. Generally speaking, France and EU results seem to be statistically different, although overlapping CI95% do not allow to have clear-cut conclusions in some cases.

Background and evaluation scope

Pedestrians represent 22% of the EU (CARE, 2023). In France 2023, 474 pedestrians were killed on French roads of which 282 (60%) were killed when crossing the street, and nearly half (134, 48%) when jay-crossing away from protected crossings or intersections (BAAC 2025). It is no wonder then that this crash configuration has drawn interest from the industry and authorities alike.

The investigated scenario (Figure A2.4) considers a car travelling straight outside of intersection and a jay-crossing pedestrian. The scenario selection is based on the VOIESUR classification of conflict types (types 803 & 804).

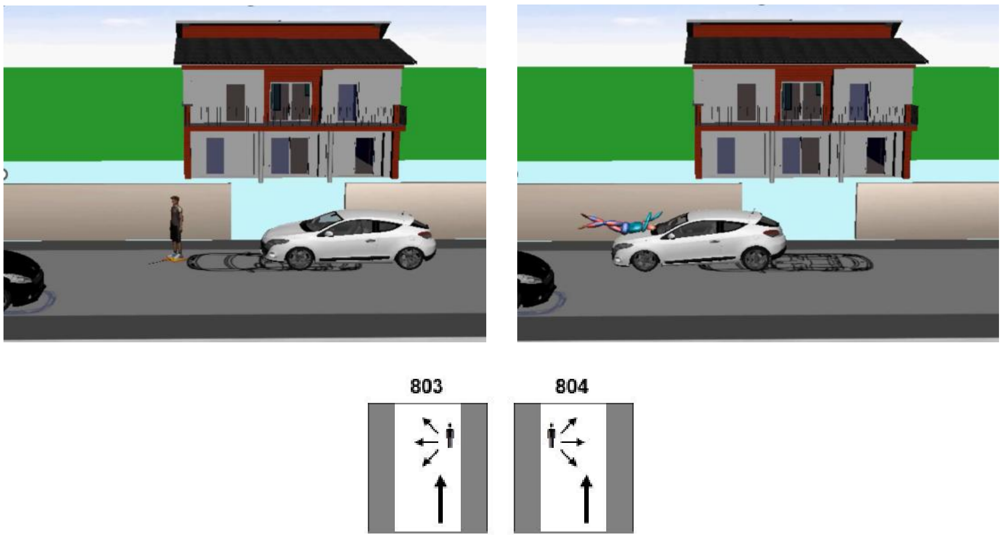

Figure A2.4 Visualizations of the analysed scenario

The considered regions are France and EU 27. The point in time of the evaluation is year 2019, the reference year for decade 2020-2030, assuming that 100% of the passenger cars were equipped with a pedestrian AEB. The performance metric is the reduction of the injury burden. The study answers the following research question:
What are the percentages of reduction of the injury burden in a 'car travelling straight, pedestrian jay-crossing out of any intersection' scenario if a pedestrian AEB is implemented to all cars in France and in the entirety of the EU 27?

Method

Data

The French VOIESUR database (collected in 2011) was used and filtered for fully coded and reconstructed crashes pertaining to the relevant crash configurations (VOIESUR variable GMANPR, set to values 803 and 804). Accidents and victims in the VOIESUR database are weighted in order to make the database representative (amongst other characteristics) of the distribution of victims by types of roads for year 2011, as reported by police forces (Amoros et al. 2015). Additional weights were computed to make the data sample representative for the specific configuration under study. The resulting sample comprised 150 cases in VOIESUR. Visual obstructions and light conditions were considered, the latter in a simplified way (as described in D6.1, section 6.7).

The CARE database is the only data source that provides crash statistics in a standardized and harmonized format (CADAS, 2023) covering all EU member states. However, not every member state provides the level of detail required by the Common Accident Data Set (CADaS) data structure, leading to a substantial amount of missing data. To be more use case specific, the three following situations were found:

- Category #1: countries reporting the full span of the necessary filtering variables (precise configuration of the car-pedestrian crash, road type, injury type)
- Category #2: A subset of category #1 countries reporting only the killed at 30 days and no information on the injured beyond 'Unknown Injury Type'
- Category #3: Countries mixing all configurations of car vs pedestrian crashes into one single black box

Use was made of the category #1 countries as “reference countries” to impute missing data on the category #2 and #3 countries. Reference countries were chosen with regard to their proximity to categories #2 and #3, as defined in section A.2.1.

The CARE database was filtered for the year 2019 and car travelling straight vs jay-crossing pedestrians crash scenarios. The scenario under study was identified by the CARE variable A-8 (“Accidents with Pedestrians”) selecting value: *Pedestrian crossing street – no turning of vehicle – outside a junction*

Per member state, seven variables were extracted:

- R-13 Accident at junction as ‘Label’,
- R-X Area as ‘Location’,
- Fatally Injured (at 30 days) as ‘Fatal’,
- Seriously Injured (at 30 days) as ‘Serious‘,
- Slightly Injured as ‘Slightly‘,
- Injured (injury severity not known) as ‘UknSeverity‘,
- Injury Type Not Known as ‘UknInjured‘.

An example of category #1 country is given by Austria:

Table A2.4 Austria CARE data regarding car vs pedestrian conflicts

Étiquettes de lignes	Summe von Fatally Injured (at 30 days)	Summe von Seriously Injured (at 30 days)	Summe von Slightly Injured
Austria	**250**	**2663**	**16744**
Motorway	**22**	**261**	**2399**
Not applicable	22	258	2393
Pedestrian accident - other	0	1	4
Pedestrian crossing street - no turning of vehicle - outside a junction	0	1	2
Pedestrian walking along the road	0	1	0
Rural	**196**	**1358**	**6179**
Not applicable	187	1320	6092
Pedestrian accident - other	0	7	20
Pedestrian crossing street - no turning of vehicle - at a junction	0	0	1
Pedestrian crossing street - no turning of vehicle - outside a junction	5	16	23
Pedestrian walking along the road	4	11	30
Pedestrians on pavement or bicycle lane	0	4	13
Urban	**32**	**1044**	**8166**
Not applicable	13	730	7000
Pedestrian accident - other	4	92	366
Pedestrian crossing street - no turning of vehicle - at a junction	0	0	3
Pedestrian crossing street - no turning of vehicle - outside a junction	11	180	579
Pedestrian walking along the road	2	18	118
Pedestrians crossing - turning of vehicle turning left (right)	0	0	2
Pedestrians crossing - turning of vehicle turning right (left)	0	0	2
Pedestrians on pavement or bicycle lane	2	24	96

An example of category #2 country is given by Poland:

Table A2.5 Poland CARE data regarding car vs pedestrian conflicts

Étiquettes de lignes	Summe von Fatally Injured (at 30 days)	Summe von Seriously Injured (at 30 days)	Summe von Slightly Injured
Poland	**1904**	**6137**	**14051**
Motorway	**55**	**126**	**381**
Not applicable	51	120	380
Pedestrian accident - other	3	5	1
Pedestrian accident - unknown	0	1	0
Pedestrian stationery in the road	1	0	0
Rural	**1208**	**2518**	**5241**
Not applicable	994	2377	5084
Pedestrian accident - other	136	110	121
Pedestrian accident - unknown	13	10	8
Pedestrian stationery in the road	33	9	10
Pedestrian walking along the road	32	12	18
Urban	**641**	**3493**	**8429**
Not applicable	346	2145	6339
Pedestrian accident - other	262	1306	2046
Pedestrian accident - unknown	1	16	26
Pedestrian stationery in the road	27	13	10
Pedestrian walking along the road	5	13	8

An example of category #3 country is given by France:

Table A2.6 France CARE regarding car vs pedestrian conflicts

Étiquettes de lignes	Summe von Fatally Injured (at 30 days)	Summe von Seriously Injured (at 30 days)	Summe von Slightly Injured
France	**1928**	**0**	**0**
Motorway	**183**	**0**	**0**
Not applicable	155	0	0
Pedestrian accident - other	3	0	0
Pedestrian accident - unknown	5	0	0
Pedestrian crossing street - no turning of vehicle - outside a junction	12	0	0
Pedestrian walking along the road	3	0	0
Pedestrian walking along the road or stationary in the road	1	0	0
Pedestrians on pavement or bicycle lane	4	0	0
Rural	**1298**	**0**	**0**
Not applicable	1230	0	0
Pedestrian accident - other	0	0	0
Pedestrian accident - unknown	7	0	0
Pedestrian crossing street - no turning of vehicle - outside a junction	18	0	0
Pedestrian walking along the road	15	0	0
Pedestrian walking along the road or stationary in the road	12	0	0
Pedestrians crossing - turning of vehicle turning left (right)	1	0	0
Pedestrians crossing - turning of vehicle turning right (left)	0	0	0
Pedestrians on pavement or bicycle lane	15	0	0
Urban	**447**	**0**	**0**
Not applicable	290	0	0
Pedestrian accident - other	3	0	0
Pedestrian accident - unknown	7	0	0
Pedestrian crossing street - no turning of vehicle - outside a junction	102	0	0
Pedestrian walking along the road	8	0	0
Pedestrian walking along the road or stationary in the road	11	0	0
Pedestrians crossing - turning of vehicle turning left (right)	3	0	0
Pedestrians crossing - turning of vehicle turning right (left)	1	0	0
Pedestrians on pavement or bicycle lane	22	0	0

For category #1 countries, the full table of victim types by road types can be recovered for both the crash configuration of interest and all crashes configurations of car vs pedestrian, for categories #2 countries, only the latter. Victim types by road type values in the crash configuration of interest for the category #2 countries were computed by imputing the ratios “configuration of interest / all configurations” from the “nearest” (see section A2.1) category #1 country as exemplified in Figure A2.5.

Sweden
Germany

2019	K	SI	SLI
Highway	1	1	1
Rural	4	10	25
Urban	6	49	192

Imputed Accident Category of Interest

2019	K	SI	SLI
Highway	1	2	4
Rural	7	25	129
Urban	9	69	409

CARE All Accident Categories

Germany

2019	K	SI	SLI
Highway	9	11	24
Rural	34	111	126
Urban	99	2374	5654

CARE Accident Category of Interest

2019	K	SI	SLI
Highway	15	32	80
Rural	59	283	641
Urban	145	3339	12073

CARE All Accident Categories

Figure A2.5 Germany to Sweden example imputation process

Category #3 countries were imputed by using relevant ratios between killed and injured from the nearest category #1 or imputed category #2 country.

Finally, the following imputations were made:

- Sweden, The Netherlands: from Germany
- Belgium, Czechia: from Denmark
- France: from Spain (Highways) and Austria
- Italy, Portugal, Croatia, Greece, Cyprus, Romania, Slovenia: from Bulgaria
- and all outliers (except Malta that was excluded as no nearest) taken into account as category #1 countries. The entirety of the "Southern" cluster had to be imputed from Bulgaria as no category #1 country was found amongst this cluster.

The summarized statistics for the specified scenario for the EU 27 member states are shown in Table A2.7. These can be then compared to the statistics for France (Table A2.8).

Table A2.7 Summarized statistics for the EU member states for the specified scenario

Europe

2019	K	SI	SLI
Highway	65	32	70
Rural	157	318	526
Urban	605	6447	19627

Europe %

2019	K	SI	SLI
Highway	0,23%	0,12%	0,25%
Rural	0,56%	1,14%	1,89%
Urban	2,17%	23,15%	70,48%

Table A2.8 Summarized statistics for France for the specified scenario

France Baseline

2011	K	IP	OP
Highway	8	6	9
Rural	31	63	44
Urban	114	1471	2327

France Baseline %

2011	K	SI	SLI
Highway	0,20%	0,15%	0,22%
Rural	0,76%	1,55%	1,08%
Urban	2,80%	36,12%	57,13%

Table A2.9 Weights to make France representative for the EU 27 member states

Europe % / France %

2019	K	SI	SLI
Highway	1,19	0,79	1,13
Rural	0,74	0,74	1,75
Urban	0,78	0,64	1,23

From the comparison of the relative percentages of the stratum defined by crash location and crash severity, the weights to make France representative for the EU 27 member states were calculated (Table A2.9).

Baseline Approach

Same as D6.1, section 6.7

Models

Same as D6.1, section 6.7

Results

Extrapolated results for Europe 27 were obtained by applying the weights from Table A2.10 to the percentage reduction of victim types by road types obtained by applying the treatment.

Table A2.10 Extrapolation from France to EU 27 7

	Treatment AEBP in France	Treatment AEBP in the EU
Reduction (%) of the number of killed - Highway	0% [0%, 1%]	0% [0%, 1%]
Reduction (%) of the number of Severely Injured - Highway	0% [0%, 1%]	0% [0%, 1%]
Reduction (%) of the number of Slightly Injured - Highway	0% [0%, 1%]	0% [0%, 1%]
Reduction (%) of the number of killed - Rural	29% [33%, 24%]	22% [26%, 18%]
Reduction (%) of the number of Severely Injured - Rural	35% [28%, 43%]	26% [21%, 32%]
Reduction (%) of the number of Slightly Injured - Rural	32% [25%, 38%]	56% [44%, 68%]

	Treatment AEBP in France	Treatment AEBP in the EU
Reduction (%) of the number of killed - Urban	94% [88%, 100%]	73% [69%, 77%]
Reduction (%) of the number of Severely Injured - Urban	68% [60%, 76%]	43% [37%, 50%]
Reduction (%) of the number of Slightly Injured - Urban	41% [37%, 48%]	51% [43%, 59%]

Discussion and conclusion

The generation of the weights is straight-forward but the reliability of the weighted results is limited by several assumptions:

- The share of slightly and seriously injured crashes is reflected by the similarity of countries in the variables used for clustering them (section A.2.1).
- It was assumed that factors influencing crash severity (e.g., distribution of car speeds, distribution of victims' age) was the same in the sampling country (France) and the target countries.
- A 100% fleet equipment by the measure was hypothesised for the entirety of EU 27. This might take a very long time or not happen at all, pending on future economic conditions.
- A more realistic assessment would have consisted in assuming 100% fitment of the fleet in France and using timing-consistent fitment rates over the whole of EU 27. From Figure A2.6, one can assume that not all EU 27 countries' fleets will be fitted at the same pace.

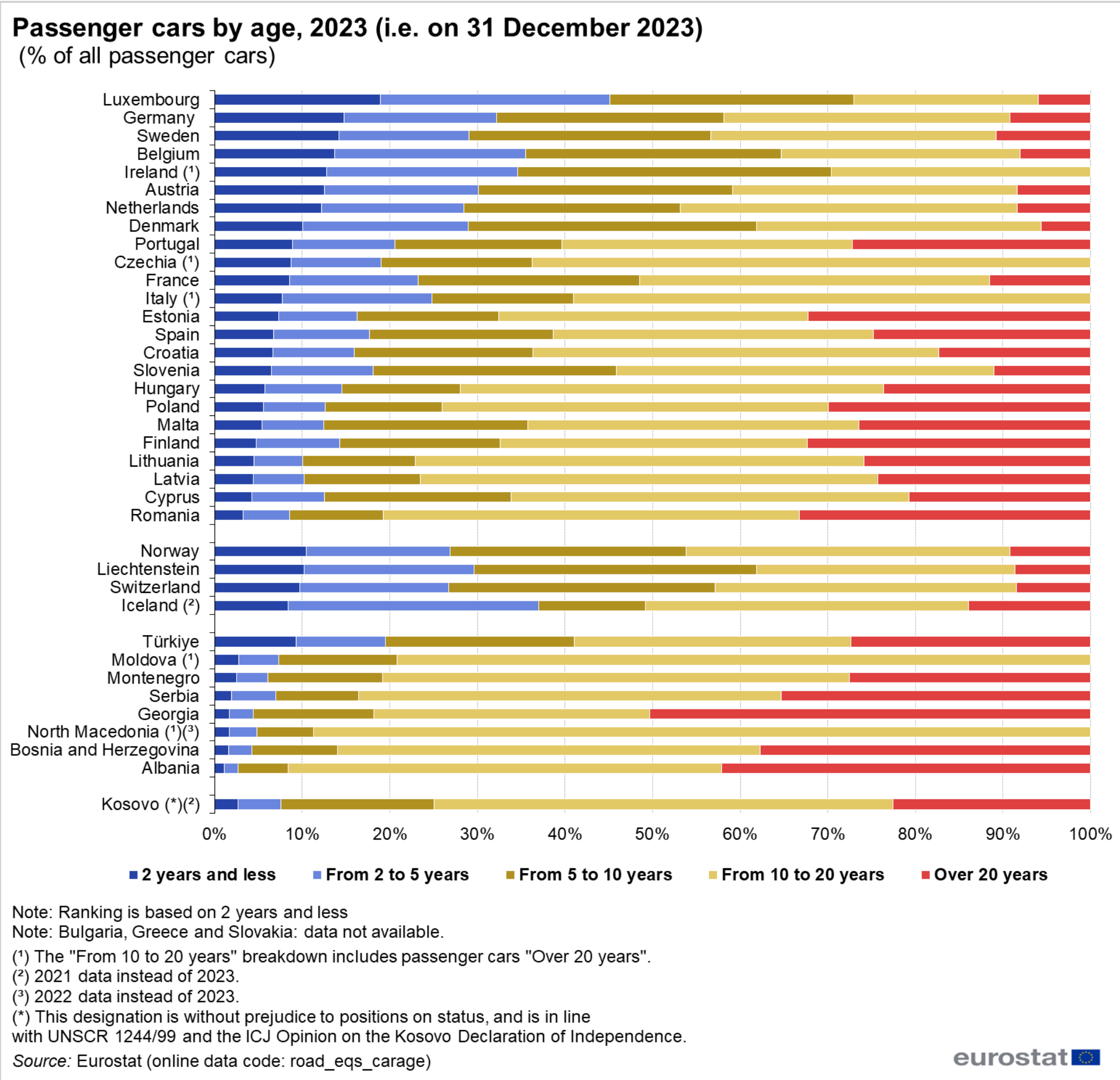

Figure A2.6 EU fleets by age (Source EuroStat 2025)

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A.2.4 Safety performance assessment of AEB in 'car-turning right – cyclist going straight in same direction' scenarios for Germany and the EU

Author: Ulrich Sander
Date: 2025-07-05

Over the last decade the number of cyclist fatalities is nearly unchanged in the EU. Close to one fifth of all fatalities happen at intersections. For one common crash scenario between a passenger car and a cycle, when the car is turning right and the cycle is going straight with initial same direction, a Cyclist Autonomous Emergency Braking (AEB) is investigated for 100% implementation rate in Germany and the entire EU.
A total of 210 cases form the German In-Depth Accident Study (GIDAS) were used to generate 1,000 representative crashes of the scenario by parametric multivariate modelling using a C2P baseline generation approach. The driver model was not able to follow the trajectories in 986 generated test scenarios.
The AEB lead to a reduction in the crash rate in both Germany and the EU. The EU has a higher crash avoidance rate than Germany, namely 7.2% versus 4.9%. Further, the rate of crashes with reduced impact speed is similar between the EU and Germany (8.2%). In general, the crash avoidance and mitigation rates for EU and Germany are in the same magnitude, but statistically different for an alpha value of $p < 0.05$.
The results show a limited effect of AEB as the cyclist is often out of the field of view of the vehicle sensor prior to the crash.

Background and evaluation scope

Ten percent of all road fatalities in the EU are cyclists (ERSO[1], 2023). While the number of fatalities other traffic participant types have decreased since 2010, the fatality numbers for cyclists were nearly unchanged. While nine percent of all fatalities occur at junctions, cyclist fatalities at junctions cover 17%. In about half of the fatal cyclist crashes, a passenger car is the collision opponent (ERSO, 2022). Thus, there is a high interest from government, industry and academia to reduce the occurrence of car-to-cycle crashes.

This study summarises the investigations on the effectiveness of an Autonomous Emergency Braking (AEB) system and additionally a Forward Collision Warning (FCW) and a Bicycle-to-Vehicle (B2V) communication installed in passenger cars to prevent collisions with cyclists and mitigate injuries. The investigated scenario represents a car turning right at an intersection and a cyclist, initially going in the same direction, continuing straight (Figure A2.7). The scenario selection is based on the German Insurance Association (GDV, 2016) classification of conflict types.

[1] ERSO: European Road Safety Observatory

Figure A2.7 Visualisation of the analysed scenario: Car and cycle are initially going in the same direction, then the car is turning right, while the cyclist intends to go straight. The cyclist can be either on the road or on a separated cycle path

The considered regions are Germany and the entire EU. The point in time of the evaluation is the present, assuming that 100% of the passenger cars were equipped with the safety measures. The key performance indicators are the rate of crash avoidance and the rate of crash mitigation by lowering the impact speeds.
In conclusion, the study answers the following evaluation question:

> *What is the percentage of avoided and mitigated crashes in a ‘car turning right, cyclist going straight in same direction’ scenario if a cyclist AEB is implemented to all cars in Germany and in the entire EU?*

Method

Data

The German In-Depth Accident Study (GIDAS) data (Otte, Krettek, Brunner & Zwipp, 2003) were filtered for the years 2013 to 2023 (2013-2022 Dresden data and 2013-2016 Hannover data) to balance between a representation of most recent real-world crashes and a sufficient number of crashes for analysis. Weights were computed to make the GIDAS data sample representative for the population of police recorded crashes in Germany. Fully coded and reconstructed crashes involving a passenger car and a cycle in the initial conflict were selected. One-hundred-eleven cases were excluded as there was no collision between them, however, the cyclist got injured during an avoidance manoeuvre. The GIDAS variable ‘UTYP’ was filtered for the values (232, 241, and 342) to select the relevant GDV conflict scenarios (GDV, 2016). The resulting sample comprised 222 cases in GIDAS. Visual obstruction was not considered as only for two GIDAS cases permanent visual obstruction was coded.

The CARE database (Manuti, 2018) is the only data source that provides crash statistics in a standardized and harmonized format covering all EU member states. However, not every member state can provide the level of detail that is provided by the Common Accident Data Set (CADaS) data structure, leading to a substantial amount of missing data.
There are different approaches to handle missing data: Firstly, to only consider complete rows for relevant columns that describe the scenario sufficiently. Secondly, to reduce the selection of columns to achieve complete rows. Third, keep all relevant columns and rows and impute missing data.
The first approach might be acceptable, if the selection of rows does not lead to a bias of the analysis results. However, we identified that only a few member states would represent the EU for the ‘car is turning right, cyclist straight in same direction’ scenario. The second approach will reduce the characteristics that describe the scenario and therefore may not lead to a meaningful

weighting. The third approach is only possible if additional data is available to support the imputation. Therefore, we selected a combination of all approaches.
The CARE database was filtered for the year 2023 and car-to-cyclist crashes in a turning or crossing scenario.
The CARE variable A-12 has a value 'At least two vehicles – turning – same road – same direction – turning right (left)' that describes the specified scenario very well. However, this value is not used in the encoding of the German national crash records in CARE. Instead, Germany decodes all turning and crossing scenarios in the following four values:

- At least two vehicles – crossing or turning – others,
- At least two vehicles – turning – same road – same direction – others,
- At least two vehicles – turning – same road – same direction – rear-end collision,
- At least two vehicles – turning – same road – opposite direction – not specified.

Therefore, all instances were selected that represented a turning or crossing scenario.
This selection corresponds to car-to-cyclist crashes in GIDAS with an accident type (UTYP) of the value 2xx and 3xx according the GDV classification (GDV, 2016).

Per member state, seven variables were extracted:

- R-13 Accident at junction as 'Label',
- R-X Area as 'Location',
- Fatally Injured (at 30 days) as 'Fatal',
- Seriously Injured (at 30 days) as 'Serious',
- Slightly Injured as 'Slightly',
- Injured (injury severity not known) as 'UknSeverity',
- Injury Type Not Known as 'UknInjured'.

An example of the extracted data for Austria is shown in Table A2.11.
For all members states the Label values 'Not at junction' were excluded to further narrow down to the investigated scenario.

Table A2.11 The seven extracted data columns for Austria. The Label value "Not at junction" was excluded for all member states

Country	Labels	Location	Fatal	Serious	Slight	UknSeverity	UknInjured
Austria	At-grade - crossroad	Motorway	0	0	1	0	0
Austria	At-grade - crossroad	Rural	3	27	38	0	0
Austria	At-grade - crossroad	Urban	1	97	573	0	0
Austria	At-grade - multiple junction	Urban	0	4	10	0	0
Austria	At-grade - roundabout	Rural	0	5	9	0	0
Austria	At-grade - roundabout	Urban	0	23	90	0	0
Austria	At-grade - T or staggered junction	Motorway	0	2	4	0	0
Austria	At-grade - T or staggered junction	Rural	1	30	56	0	0
Austria	At-grade - T or staggered junction	Urban	1	125	593	0	0
Austria	Not at junction	Rural	2	64	135	0	0
Austria	Not at junction	Urban	2	187	1055	0	0

With the aggregation of the remaining Label values, the total of 'Fatal', 'Serious', 'Slight', and 'UknSeverity' were computed (Table A2.12).

Table A2.12 Aggregated 'Label' values for Austria

Country	Labels	Location	Fatal	Serious	Slight	UknSeverity	% Serious	% Slight
Austria	Junction	Motorway	0	2	5		0.286	0.714
	Junction	Rural	4	62	103		0.376	0.624
	Junction	Urban	2	249	1266		0.164	0.836

The '% Serious' and '% Slight' columns were introduced, as several countries had only 'UknSeverity' available (see example of France (see Table A2.13)

Table A2.13 The seven extracted columns for France. The Label value ''Not at junction" was excluded for all member states

Country	Labels	Location	Fatal	Serious	Slight	UknSeverity	UknInjured
France	At level crossing	Urban	0	0	0	1	0
France	At-grade - crossroad	Rural	3	0	0	39	0
France	At-grade - crossroad	Urban	3	0	0	456	1
France	At-grade - multiple junction	Rural	0	0	0	2	0
France	At-grade - multiple junction	Urban	0	0	0	25	1
France	At-grade - roundabout	Motorway	0	0	0	1	0
France	At-grade - roundabout	Rural	2	0	0	57	0
France	At-grade - roundabout	Urban	7	0	0	320	1
France	At-grade - T or staggered junction	Rural	7	0	0	73	0
France	At-grade - T or staggered junction	Urban	7	0	0	525	3
France	Not at junction	Motorway	1	0	0	0	0
France	Not at junction	Rural	35	0	0	240	0
France	Not at junction	Urban	13	0	0	1002	1
France	Other	Rural	0	0	0	12	0
France	Other	Urban	0	0	0	152	1

The split of 'UknSeverity' into 'Serious' and 'Slight' was conducted by using the percent shares from the most similar member state (see Table A2.14).

Table A2.14 Aggregated 'Label values for France. The missing values for 'Serious' and 'Slight' have been imputed using the % shares from the most similar member state Austria

Country	Labels	Location	Fatal	Serious	Slight	UknSeverity	% Serious	% Slight
France	Junction	Motorway	0	0.29	0.71	1		
	Junction	Rural	12	68.76	114.24	183		
	Junction	Urban	17	243.08	1235.92	1479		

The EU country clusters derived in section A.2.1 were used to identify most similar member states. Overall, data was imputed for Finland using Irelands shares, France using Austrias shares, and Italy using Croatia's shares. Additionally, Estonian shares were imputed using Germanys shares, despite Estonia forming a cluster on its own and having no direct substitute. However, Germany was assessed to be most suitable substitute of the nearest dissimilarity cluster that includes Estonia (see Figure A2.1).

The column 'UknInjured' (unknown if injured) had only very small numbers for all member states except Estonia. However, the contribution of Estonian's crashes to the total of EU member state crashes were so small that the neglection of these crashes did not lead to a substantial change of the aggregated results.

The summarized statistics for the specified scenario for the EU member states are shown in . These can be then compared to the statistics for Germany (Table A2.16).

Table A2.15 Summarized statistics for the EU member states for the specified scenario.

EU	Junction	Motorway	1	14.29	73.71
EU	Junction	Rural	140	1286.88	3545.12
EU	Junction	Urban	190	7276.31	35246.69
Region	Label	Location	Fatal	Serious	Slight
EU	Junction	Motorway	0.00%	0.03%	0.15%
EU	Junction	Rural	0.29%	2.69%	7.42%
EU	Junction	Urban	0.40%	15.23%	73.78%

Table A2.16 Summarized statistics for Germany for the specified scenario.

Region	Label	Location	Fatal	Serious	Slight
Germany	Junction	Motorway	0	2	9
Germany	Junction	Rural	42	566	1425
Germany	Junction	Urban	50	3044	20053
Region	Label	Location	Fatal	Serious	Slight
Germany	Junction	Motorway	0.00%	0.01%	0.04%
Germany	Junction	Rural	0.17%	2.25%	5.66%
Germany	Junction	Urban	0.20%	12.08%	79.60%

From the comparison of the relative percentages of the stratum defined by crash location and crash severity, the weights to make Germany representative for the EU member states were calculated (Table A2.17).

Table A2.17 Weights to make Germany representative for the EU member states

Weights	Fatal	Serious	Slight
Motorway	NA	3.766	4.319
Rural	1.758	1.199	1.312
Urban	2.004	1.260	0.927

These weights were applied to the GIDAS data sample that holds the same selection criteria then the CARE cases.
The generation of the weights is straight-forward but limited. The reliability of the weighted results is limited by two assumptions:

- The share of car-to-cyclist scenarios within the junction-cluster is similar across the EU member states.
- The share of slightly and seriously injured crashes is reflected by the similarity of countries in their VRU fatality rate.

Baseline approach
The baseline approach C2P was selected. To stochastically generate test scenarios from these 222 cases, 14 variables related to environment (e.g., coefficient of friction, curve radius), vehicle (e.g., length, width), motion (e.g., initial speed, breaking), and collision (e.g., collision angle, impact points) were used. The dataset was split in three sub-datasets based on the impact point on the car (front collision, side collision, rear collision). For each dataset a multivariate distribution model was built (Wu, Flannagan, Sander & Bärgman, 2024). The synthetic test scenarios were then generated by sampling form the generated models in proportion to the sample size of each sub-dataset. One thousand synthetic baseline test scenarios were generated.

Models
The AEB was developed within the V4SAFETY project and harmonised across project partners to allow a comparison of the baseline generation approach. The activation of AEB was dependent on the predicted time-to-collision (TTC) based on constant acceleration. The TTC thresholds were derived from an internal analysis that focuses on the minimisation of false-positive activations, i.e., prevention of safety measure activation when the cyclist still can stop within comfort boundaries before entering the road. The sensor is represented by a simplified and idealised model that only takes geometric constraints of the field of view (range: 100 m, angle: 100 °) into account and is mounted on the longitudinal axis with an offset of 1.9 m from the front bumper.

Table A2.18 TTC thresholds for FCW and AEB activation based on vehicle speed

Vehicle speed [km/h]	5	10	20	30	60	80	100	120
TTC AEB activation [s]	0.4	0.6	0.6	0.8	0.8	1.2	1.5	1.5

Simulation configuration

The simulations were conducted in Volvo Cars proprietary pre-crash simulation environment. The trajectories cover 10 seconds before the crash and up to 5 seconds beyond the original point in time when the collision happened in the baseline scenarios.

Results

The results of all treatment simulations are summarised in A2.19. Of the 987 test scenarios resulting in a crash, 4.9% could be avoided by implementation of a cyclist AEB system in Germany. If the same safety measure would be implemented to 100% of the vehicle fleet in the EU, the crash avoidance rate increases to 7.2". Bother Germany and EU have a crash mitigation rate of just over 8%.

Table A2.19 Results of the treatment simulations covering different regions of application

	Baseline	Treatment AEB in Germany	Treatment AEB in the EU
Number runs	993	993	993
Crash avoidance rate	-	4.9% [3.6%, 6.4%]	7.2% [5.6%, 8.9%]
Crash mitigation rate	-	8.2% [6.6%, 10.1%]	8.2% [6.5%, 10.0%]

Discussion and conclusion

The estimated effectiveness of AEB in the investigated car-to-cycle scenario is small compared to a priori assessments of e.g., pedestrian AEB in a straight crossing. Challenges lie in the distribution of the angle of car and cycle to each other just prior to the collision, which has a peak at around 25°. The TTC of the AEB algorithm has been set conservatively to reduce false positives.

The limitations of the study are the following:
The sensor model is idealised and neither considers uncertainties in the position of the cycle nor degrades with inclement weather or low light conditions. The parameterisation of the AEB was done to minimise false-positives, however, only the time-to-collision was used as an input for decision-making.
Only data from Germany, specifically the GIDAS project, was used for the projection towards the EU member states. Access to in-depth crash data in the EU is most often restricted to specific consortium members and sharing of raw data is usually not allowed.
It is feasible to generate stochastic scenarios from marginal distributions derived from processed statistics of other regions. However, for a representative scenario generation, the joint distributions must be known, requiring access to raw or 'near'-raw data.
Overall, the design of the models may not represent the real-world behaviour of in-production functions.

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