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# Impact analysis of Advanced Driver Assistance Systems (ADAS) regarding road safety – computing reduction potentials

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## Abstract

In the present study road safety impact analysis for certain advanced driver assistance systems (ADAS) was conducted. Based on a literature review, expert interviews and current adaptations in legislation, the most promising nine ADAS were selected. The impact was analysed based on statistical crash data from Austria. Factors such as infrastructure and weather conditions, market penetration, expected functionality of sensors, user acceptance and risk homeostasis were considered. A software tool was developed to calculate the crash reduction potential of the selected ADAS for the scenarios 2025, 2030 and 2040.

The results show that the ADAS related to warning/braking have the greatest future reduction potential and could lead to a reduction of up to 8,700 crashes and 70 fatalities in Austria in 2040. In addition, the Intelligent Speed Assistance system would lead to an overall crash reduction of 8% compared to current crash numbers in Austria in 2040. The Turning Assistant for heavy goods vehicles shows the lowest reduction in crashes and casualties, but due to the highest severity per crash (93 fatalities per 1,000 crashes), it nevertheless provides an important contribution to the reduction of fatalities in road traffic.

However, to benefit from the ADAS safety potential, it is highly relevant that these systems are used in a correct manner. In the future, it will be necessary to provide users with more information on the correct use, benefits and limitations of the respective ADAS and to integrate the use of these systems into driver education procedures and tests.

**Keywords** ADAS, Reduction of accidents, Impact on crashes, Road safety impact

## 1 Introduction

Advanced driver assistance systems (ADAS) are often associated with positive effects in terms of road safety [1, 2], and with the EU Regulation 2019/2144 the European Commission mandated a range of ADAS for all new vehicle types and newly registered vehicles [3]. The

potential safety effects for individual ADAS have already been presented in numerous studies by using simulations and retrospective crash studies (see e.g. [4, 5]). However, retrospective crash studies that determine the effectiveness of ADAS by means of a specific retrospective comparison of crashes or crash rates or insurance claims for vehicles with and without such systems are not feasible in many cases due to a lack of available data. In the past, extensive studies have therefore been carried out on the crash reduction potential of ADAS, considering the specific national crash data. For example, such studies exist for Germany (e.g. [6]), the USA (e.g. [7, 8]) or Switzerland (e.g. [9]). Table 1 gives an overview of existing studies on the crash reduction potential of ADAS.

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For the USA, [7] determined the number of crashes, injuries and fatalities that could be avoided with the ADAS technologies Forward Collision Warning (FCW), Automatic Emergency Braking (AEB), Lane Departure Warning (LDW), Lane Keeping Assistance (LKA) or Blind Spot Warning (BSW). The results were estimates of potentially avoidable or severity-reducing crashes, injuries and fatalities, based on the crash figures in the USA for 2016, assuming that the vehicles involved were equipped with the respective ADAS. The results show that overall, FCW/AEB could prevent 29% of all passenger vehicle crashes. For LDW/LKA, the potential is 7%, for BSW 5%. In terms of fatalities, FCW/AEB and LDW/LKA could each potentially prevent 14% of fatalities (BSW 1%).

Wang [8] analysed the crash reduction potential for the ADAS Forward Collision Prevention (FCW), Lane

Keeping (LDW/LKA), Blind Zone Detection as well as Forward Pedestrian Impact Avoidance and Backing Collision Avoidance based on defined crash scenarios from the national crash database in the USA. For the Forward Collision Prevention, a reduction potential of 29% of crashes is reported, while for the Lane Keeping Assistant a reduction potential of 19% is shown and Blind Zone Detection could reduce 9% of crashes.

Hummel et al. [6] examined the ADAS lane departure warning system, lane change assistant, overtaking warning system, blind spot warning system as well as emergency brake assistants of various levels and reversing assistants for cars, trucks and buses for their safety potential (reduced crashes) in Germany. Results show that in the passenger car sector, emergency brake assistants have the greatest safety potential (11.4% of passenger car crashes with the lowest version of the

**Table 1** Overview of studies on the crash reduction potential of ADAS [6–10]

Authors, year	Country	Systems	Method	Results
Benson et al., 2018 [7]	USA	ADAS Forward Collision Warning (FCW), Automatic Emergency Braking (AEB), Lane Departure Warning (LDW), Lane Keeping Assistance (LKA) or Blind Spot Warning (BSW)	Estimation of crash reduction potential when all vehicles are equipped with respective ADAS	- FCW/AEB: -29% car crashes, -29% injuries, -14% fatalities - LDW: -7% car crashes, -6% injuries, -14% fatalities - BSW: ≤-5% car crashes, injuries and fatalities
Wang et al., 2019 [8]	USA	Forward Collision Prevention (FCW), Lane Keeping (LDW/LKA), Blind Zone Detection, Forward Pedestrian Impact Avoidance, Backing Collision Avoidance	Estimation of the crash reduction potential based on defined accident scenarios (from national accident database)	- Forward Collision Prevention: -29% crashes - Lane Keeping: -19% crashes - Blind Zone Detection: -9% crashes - Forward Pedestrian Impact Avoidance: -2% crashes - Backing Collision Avoidance: -2% crashes
Hummel et al., 2011 [6]	Germany	Automatic Emergency Braking (AEB), Lane Departure Warning (LDW), Blind Spot Warning (BSW), rear-drive assistant for cars, trucks and buses and turning assist for trucks and buses	Estimation of theoretical crash reduction potential when all cars/trucks/buses are equipped with respective ADAS	- AEB: -11.4 to -43.4% car crashes, -6.1 to -12.0% truck crashes, -8.9% to 15.1 bus crashes - LDV: -4.4% car crashes, -1.8% truck crashes, -0.5% bus crashes - Rear drive assistant: -2.3% car crashes, -1.2% truck crashes - BSW: -1.7% car crashes, -7.9% truck crashes, -3.8% bus crashes - Turning assist: -4.4% truck crashes, -2.3 bus crashes
Gwehenberger & Borrack 2015 [10]	Germany	Automatic Emergency Braking (AEB), Lane Departure Warning (LDW)/ Lane Keeping Assistance (LKA), Parking and Manoeuvring Assist (PMA)	Estimation of theoretical crash reduction potential when all vehicles are equipped with respective ADAS based on insurance data	- AEB: -18% to -26% crashes - LDW/LKA: -3% to -18% crashes - PMA: -38% to -44% property damage crashes
Deublein & Zimmermann, 2021 [9]	Switzerland	Automatic Emergency Braking (AEB), Lane Departure Warning (LDW)/ Lane Keeping Assistance (LKA), Blind Spot Warning (BSW), Curve-ABS	Estimation of crash reduction potential for 2030 based on national accident data considering future market penetration and use of the respective ADAS	- AEB: -292 fatalities - LDW/LKA: -10 fatalities - BSW: -1 fatality - Curve-ABS: -12 fatalities

emergency brake assistant (amplification of braking force during initiated braking) to 43.4% with the highly developed version of the emergency brake assistant (includes detection of persons on foot and cyclists, functionality in the dark, autonomous emergency braking)). Lane departure warning systems follow with an avoidance potential of 4.4% of car crashes. In the case of trucks and busses, emergency brake assistants and blind spot warning systems have the greatest potential (6.1% of truck crashes and 8.9% of bus crashes with an emergency brake assistant that detects moving vehicles, warns and intervenes in case of danger; 12% of truck crashes and 15.1% of bus crashes with an emergency brake assistant that additionally detect stationary vehicles; 7.9% of truck crashes and 3.8% of bus crashes for blind spot warning systems), whereby the potential for blind spot warning systems is assumed to be mitigating rather than avoiding.

For Switzerland, [9] analysed the crash reduction potential for different ADAS, i.e. Automatic Emergency Braking, Lane Departure Warning and Blind Spot Warning for cars as well as the ADAS Curve-ABS for motorcycles, for the year 2030 based on national crash data considering future market penetration and use of the respective ADAS. The results show that the ADAS Automatic Emergency Braking has the greatest potential and could reduce 292 fatalities in the year 2030, while the Lane Departure Warning and the Curve-ABS for motorcycles would reduce 10 and 12 fatalities, respectively.

Gwehenberger and Borrack [10] conducted an analysis using insurance crash data for Germany of the crash reduction potential of the ADAS Automatic Emergency Braking, Lane Departure Warning and Parking and Manoeuvring Assist, under the assumption that all vehicles are equipped with the respective ADAS. Results show a reduction potential for the Automatic Emergency Braking in the range of 18% to 26% of crashes and for the Lane Departure Warning/Lane Keeping Assistant in the range of 3% to 18% of crashes. Furthermore, for the Parking and Manoeuvring Assist, a potential reduction of property damage crashes by 38% to 44% is reported.

In Austria, there is a lack of relevant data for conducting retrospective crash studies for ADAS and, moreover, an analysis of the crash potentials of ADAS, considering national crash data, has not yet been conducted. The goal of the present study therefore was to conduct a road safety impact assessment for a set of ADAS based on national Austrian crash data. The crash reduction potential for the different ADAS was calculated for three scenarios – year 2025, 2030 and 2040, using a specifically developed software tool allowing flexibility of data inputs.

The paper is structured as follows: Section 2 describes the methodology used to select the different ADAS and for calculating the crash reduction potential including the data used as well as the software tool. Section 3 presents the calculated crash reduction potential for the different ADAS for the three scenarios and a discussion on the results. Finally, Section 4 provides a conclusion, derives relevant accompanying measures and identifies research gaps in the field and possible future avenues of research.

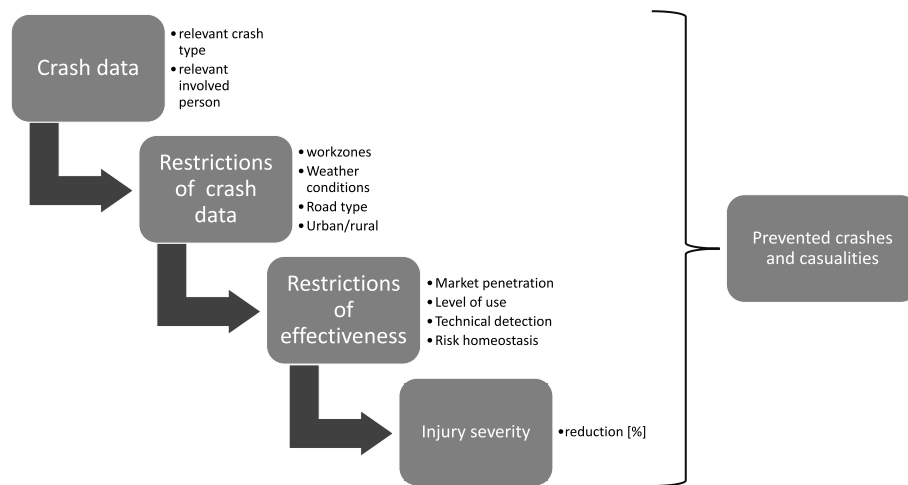
## 2 Methodology

The estimation of the effectiveness of ADAS for Austria was calculated using crash data from the official Austrian crash data base. To determine the affected crash categories and groups of participants for each ADAS, the functionalities of individual ADAS were analysed. In a next step, the crash figures were restricted based on factors such as weather conditions or road type, if these factors have an influence on the functionality and thus effectiveness of the ADAS. In the next step, the limitation of the effectiveness of the ADAS was also considered in terms of factors such as market penetration or technical detection potential. Since these factors in particular are characterized by a change over time (e.g. increasing market penetration), scenarios were developed for the years 2025, 2030 and 2040 with different values for the factors. In the final step, a possible influence on injury severity was considered for each of the nine derived ADAS. Subsequently, the reduction potentials in terms of prevented crashes and casualties could be estimated for each ADAS. The calculation of the reduction potential was carried out using a programmed software tool, which connects to the crash data base, providing the capability to recalculate in case circumstances change in the next years. Figure 1 provides an overview of the methodology for determining the reduction potentials for the derived ADAS for Austria.

### 2.1 Available crash data

Using this methodology, the calculated crash reduction potential is based on officially reported crash data, which is commonly used for monitoring developments and in decision making processes. The methodology uses the underlying available information making it easy to use and limiting inaccuracies that could arise through data fusion. The evolvments in ADAS technology are considered by calculating three scenarios and the flexibility to adjust the parameters easily within the software tool.

The basis for determining the reduction potential of the derived ADAS was formed by the crash figures of the official traffic accident statistics in Austria 2016–2020.



**Fig. 1** Overview of the methodology

It contains 179,120 injury crashes (mean value of 35,824 injury crashes per year), recorded by Austrian police officials. Crashes with property damage only or happening aside public roads are not included in this data set. For each crash, the data are available on three levels: crash, road user and person, covering around 100 attributes of which 46 are mandatory to specify. The most important attributes are listed in Table 2.

For each ADAS, it was determined which crash, road user or person characteristics were relevant or irrelevant.

### 2.1.1 Crash type and crash characteristics

To be able to analyse the safety impact potentials, the potentially avoidable crash types including the crash

characteristics were first determined for each ADAS. The basis for this was the literature screening carried out together with internal project team discussions. For certain systems, such as the alcohol-sensitive immobilizer for example, only crashes involving motorized vehicles with an alcohol-impaired driver are relevant.

### 2.1.2 Involved road users and persons

Since ADAS are often only available for certain vehicles or aim to protect certain road users, the relevant participants for the respective ADAS were determined. This was solved using the “road user type” recorded in the crash database like motorcycle, passenger car or pedestrian. For example, only crashes involving

**Table 2** Excerpt of available attributes from the crash data

Level	Excerpt of attributes (grouped)	Mandatory?
Crash	time and day	yes
	location	yes
	lighting / surface condition / glaring sunlight / artificial lighting / weather / precipitation /	yes / yes / no / no / no / no
	location characteristics: urban or rural / road type / speed limit / occurrence of road works / other tags (i.e., curve, type of crossing)	yes / yes / yes / yes / no
	animal collision	no
	crash type	yes
	assumed main crash cause	yes
Road user	road user type* / trailer included	yes / yes
	license plate number / nationality	no / no
	crash factors related to the road user: manoeuvre / traffic rule compliance / vehicle factors / others	yes / yes / no / yes
Person	involvement (driver, passenger, pedestrian)	yes
	assumed main crash causer	yes
	age / gender / nationality / severity of injury	no / no / no / yes
	holding a license for the vehicle / fitness to drive / type of impairment	yes / yes / yes
	alcohol-impairment**	yes
	seatbelt use / helmet use / airbag	yes / no / yes

\*Road user types cover 33 types, among them cars and M1 vehicles (specified by max. 9 seats), buses (M2 or M3 vehicles), different truck types, different two-wheeler classes, three-wheelers and four-wheelers (i.e. category L2, L2e, L5, L5e, L6e, L7e), pedestrians, cyclists, different types of sports devices or devices for kids, rail vehicles

\*\*Alcohol-impairment is deduced when alcohol is given within “type of impairment”, alcohol impairment was proven by the doctor (mandatory field), alcohol test was refused (mandatory field) or alcohol-impairment was assumed (mandatory field)

powered-two-wheelers are relevant for the ADAS “motorcycle stability control”.

This approach leads to the fact that the individual reduction potentials determined at the end cannot be added up and can only be considered individually, as the systems partly cover the same crash types and similar participants.

## 2.2 Restrictions of relevant crashes based on operating conditions

The relevant crashes determined for each operating conditions of ADAS were also restricted regarding infrastructural features, weather conditions or the type of road or urban/rural area, all available from the crash data used. The factors are used to filter crash figures. To classify the influence, literature and legal standards for the application areas were consulted (e.g. [11], UN regulations) and discussed in the project team and with experts in the field of ADAS, sensor technology and automated driving. These experts were recruited from a wide range of sectors such as industry, suppliers, research and infrastructure operators and brought relevant insights as well as additional literature and studies.

### 2.2.1 Infrastructure

For automated vehicles, some special cases of infrastructure or localities are difficult to cope with, just think of road works, encounter zones and complex intersections. Due to interactions or continuous changing situations, the sensor technology on the vehicle is confronted with major problems. To give expression to these conditions, the crash database was explored for determinable factors that could be easily mapped in the impact analysis. It turned out that especially road works are well recorded as a mandatory field (in contrast to other location parameters). These localities in the road network, where temporary changes in the driving line (orange road markings, lane swings, reduced lane widths, etc.) can always occur, are very challenging for automated vehicles and were therefore included in the evaluations as a separate influencing factor (incl./excl. road works).

### 2.2.2 Weather conditions

Depending on the sensors used, the weather conditions influence the ADAS functionality. It can be assumed that sensor technology, both in terms of hardware and software, will be further developed in the next years, which will improve the functioning. Using the crash database, the following three categories can be formed and were used: 1. Precipitation such as rain, snowfall, hail, freezing rain, 2. Fog, 3. Snow road surface.

### 2.2.3 Road type or urban/rural area

Many ADAS are designed for a specific road type or applicable speed. As speed limits can mostly be divided into categories lower 30 km/h, between 30 and 50 km/h or greater than 50 km/h, the speed is included in a simplified way by means of the road type and whether it is an urban or rural area. The following categories are available and were used for the analysis: Motorways and express highways, rural and urban federal roads, provincial and municipal roads.

## 2.3 Limitation of relevant crash figures on the basis of effectiveness, illustrated by means of scenarios

The relevant crash figures determined in the first two steps were restricted or adapted in a further step, considering factors limiting the effectiveness of ADAS and factors increasing the number of crashes. For this purpose, factors such as market penetration, the level of use, technical limitations, or the technical detection potential as well as negative effects caused by ADAS were used. To take the change of these factors over time (e.g. renewal of the vehicle fleet, changes in training) into account, scenarios for 2025, 2030 and 2040 were used. The estimated values for these factors were derived from the literature and discussed with experts from many relevant institutions (similar to the approach in 2.2).

### 2.3.1 Market penetration

The actual market penetration of the vehicle fleet with a specific ADAS represents the percentage of vehicles that actually have this specific ADAS installed. It therefore represents an average value over the whole vehicle fleet. The market penetration will certainly increase considerably in the next years due to mandatory installation of some ADAS and will become significantly noticeable in future. The most relevant sources regarding the current status as well as future market penetration are Market penetration passenger cars 2019 in [12], presence of ADAS in new registrations 2016 according to [13] and penetration in new vehicles in Germany 2016 in [14]. In addition, it was taken into account whether a ADAS will be mandatory in future according to EU Regulation 2019/2144 (fast diffusion) or not (slow diffusion).

### 2.3.2 Level of use

The level of use of the installed ADAS is defined as the percentage of potential users who actually use the system (deactivation is often possible). This is also noticeable in the future, i.e. in the scenarios, and it was assumed that the quality of the ADAS, as well as the knowledge required to understand it, will also increase which goes hand in hand with an increase in usage.



### 2.3.3 Technical limitations/detection potential (sensors/software/recognition)

Sensors in general, and not just those installed in vehicles, have technical limitations due to constantly changing conditions in real-world driving. In laboratory operation, for example, detection of a specific situation is possible, but cannot be repeated in real-world operation [15]. The overall system from detection to processing and output in a fraction of a second, i.e. the combination of the sensor technology with the underlying, mostly self-learning, algorithms, is crucial. In order to be able to represent this factor in the real operation of a vehicle, this influence was also included in the consideration.

### 2.3.4 Negative ADAS effects, risk homeostasis

Negative ADAS effects result, on the one hand, from incorrect actions of the ADAS (e.g. braking abruptly without the presence of an obstacle) and, on the other hand, from changes in the driving behaviour of the drivers with the knowledge of having one or more ADAS on board. The latter can be attributed to the following reasons by [11]:

- Attention in road traffic decreases.
- The workload decreases, so that non-driving tasks cause greater distraction.
- Over-reliance on the ADAS—the system is not checked for reliability.
- Lack of clarity whether the system is on or off can lead to incorrect behaviour.
- General adaptation of behaviour to the ADAS.

Through improved driver training, which teaches the correct handling of the installed ADAS, increased experience with the function and limits of the ADAS, or also obligatory explanations on the part of the vehicle sellers,

the correlations between speed and injury severity, as the intervention or warning of the ADAS is assumed to reduce the collision speed in accidents.

### 2.5 Determination of potentially preventable accidents and casualties by means of scenarios

Based on the previous steps, the reduction potential of each individual ADAS was estimated in terms of potentially preventable crashes and casualties (fatalities, serious injuries, slight injuries) for the three scenarios 2025, 2030 and 2040.

### 2.6 Software tool to compute reduction potential

A software tool was programmed to compute the calculations for the reduction potential with the underlying crash data. A graphical user interface (currently available in German language) guides the user through the selection of parameters as displayed in Fig. 2, resulting in the reduction potential given in crashes and injuries reduced (number of fatalities, severe casualties and slight casualties) and the costs. For the cost calculation, the costs per person injured (categorized into severeness) can be defined (predefined values are given based on [16]).

The tool works by selecting an ADAS at the beginning, for which the reduction potential will be computed. The crash target group (see Sect. 2.1 and Table 3) is predefined per ADAS, whereas the years to consider from the crash data base, the restrictions based on *infrastructure, weather conditions* and *Road type or urban/rural area, road network* (see Sect. 2.2), the effectiveness limitations in the areas *market penetration, level of use, Technical limitations/detection potential, Negative ADAS effects and risk homeostasis* (see Sect. 2.3), as well as the *influence of injury severity* (see Sect. 2.4) can be selected by the user to offer flexibility. The parameters regarding effectiveness and influence on injury severity can be defined for four different scenarios at once (in this study, three scenarios were used).

The underlying formula for the calculation is:

$$\text{Crash reduction potential} = \frac{\text{Crashes per year}_{\text{filtered}}}{\text{number of years}} - \frac{\sum \text{Crashes per year}_{\text{filtered}} * (1 - f1[\%] * f2[\%] * f3[\%]) * (1 + f4[\%])}{\text{number of years}}$$

it was simplified and assumed that the negative effects would be limited to 0% in 2040.

### 2.4 Influence on injury severity

In the last step, a possible influence on injury severity was considered for each individual ADAS: If an ADAS also or only has an influence on injury severity, and not only on accident prevention, then this factor is also considered in the potential analysis. Here, it is defined how the redistribution of fatalities to seriously injured, to slightly injured, to uninjured proceeds. This assumption was based on

Crashes per year<sub>filtered</sub> ... crashes that meet the criteria from section 2.1 and 2.2

f1, f2, f3 ... market penetration, level of use and technical detection potential

f4 ... negative effects

To calculate the injury reduction potential, the formula is applied using the fatalities, severely injured and slightly injured from the *Crashes<sub>filtered</sub>* instead of *Crashes<sub>filtered</sub>*. Then the influence of injury severity is considered by reducing the injuries by the injuries<sub>reduced</sub> (casualties/severely injured/slightly injured \* influence of injury

ATE-Tool Wirkungsanalyse Fahrerassistenzsysteme

FAS: FAS1\_Adaptive Cruise Control (ACC)

Auswertzeitraum  
 Von: 2016  
 Bis: 2020

Volkswirtschaftliche Unfallkosten 2016 (inkl. menschlichem Leid)  
 Tote [Euro]: 3316309  
 SVL [Euro]: 429517  
 LVL [Euro]: 30575

F4 Infrastrukturelle Besonderheiten (Baustellen): gesamt

F5 Witterungsbedingungen: gesamt

F6 AS-/BLG-Freiland-/BLG-Ortsgebiet: gesamt

Szenario 0 - Iststand 2022

F1 Marktdurchdringung [%]: 0  
 F2 Verwendungsgrad (Studie C) [%]: 0  
 F3 Technisches Detektionspotential (HW/SW) [%]: 0  
 F8 Negative FAS-Effekte/Risikohomeostase [%]: 0

F7 Einfluss auf Verletzungsschwere  
☐ ja  
☒ nein  
 Get->SVL [%]: 0  
 SVL->LVL [%]: 0  
 LVL->UNV [%]: 0

Szenario 1 - 2025

F1 Marktdurchdringung [%]: 0  
 F2 Verwendungsgrad (Studie C) [%]: 0  
 F3 Technisches Detektionspotential (HW/SW) [%]: 0  
 F8 Negative FAS-Effekte/Risikohomeostase [%]: 0

F7 Einfluss auf Verletzungsschwere  
☐ ja  
☒ nein  
 Get->SVL [%]: 0  
 SVL->LVL [%]: 0  
 LVL->UNV [%]: 0

Szenario 2 - 2030

F1 Marktdurchdringung [%]: 0  
 F2 Verwendungsgrad (Studie C) [%]: 0  
 F3 Technisches Detektionspotential (HW/SW) [%]: 0  
 F8 Negative FAS-Effekte/Risikohomeostase [%]: 0

F7 Einfluss auf Verletzungsschwere  
☐ ja  
☒ nein  
 Get->SVL [%]: 0  
 SVL->LVL [%]: 0  
 LVL->UNV [%]: 0

Szenario 3 - 2040

F1 Marktdurchdringung [%]: 0  
 F2 Verwendungsgrad (Studie C) [%]: 0  
 F3 Technisches Detektionspotential (HW/SW) [%]: 0  
 F8 Negative FAS-Effekte/Risikohomeostase [%]: 0

F7 Einfluss auf Verletzungsschwere  
☐ ja  
☒ nein  
 Get->SVL [%]: 0  
 SVL->LVL [%]: 0  
 LVL->UNV [%]: 0

Ausgabe  
☐ Verletzungsgrade pro Verkehrsart berechnen ("ungeschützte Verkehrsteilnehmer" (VRU))

Szenario "Aktive Mobilität"

☐ berechnen

Fußgänger-Steigerung [%]: 5  
 Radfahrer-Steigerung [%]: 15  
 Rest (MIV)-Steigerung [%]: -10

Calculate

**Fig. 2** Software tool—start screen/user interface (German language)

severity [%]) and adding them to the less severe injury class.

The potentially reduced injuries can also be distinguished by road user class, to know the road users that

benefit from each ADAS. Moreover, an increase in active mobility can be considered, by defining the increase in pedestrians, cyclists and other road users (not considered in this paper).

**Table 3** Defined crash target groups per ADAS

<i>Crashes with the following characteristics were relevant</i>				
ADAS	Crash types	Infrastructure	Roads / Environments	Weather
<b>Adaptive Cruise Control (ACC)</b>	Rear-end crashes Min. 2 motor vehicles involved	Without road work zones	Highway and rural roads	All
<b>Adaptive lighting</b>	Crashes in the dark and twilight Min. 1 motor vehicle involved	-	Highway and rural roads	Without fog
<b>Alcohol-Interlock system</b>	Crashes with at least one drunken driver in a multitrack motor vehicle	-	All	All
<b>ADAS referring to warning/breaking for obstacles (AEB, FCW)</b>	Rear-end collisions with at least two motor vehicles involved Crashes with pedestrians or cyclists and at least one motor vehicle Collisions of type “with obstacles” and at least one motor vehicle	Without road work zones	All	Without fog
<b>Intelligent Speed Assistance (ISA)</b>	Single vehicle run-off road crashes in curves, side-swipe and head-on crashes in curves At least one motor vehicle involved	-	All	All
<b>Curve-ABS</b>	Single vehicle run-off road crashes in curves, side-swipe and head-on crashes in curves At least one motorcycle involved	-	Highway and rural roads	Without snowy streets
<b>Lane keeping /departure assistance systems (LKA/LDA)</b>	Run-off, side-swipe and head-on road crashes At least one multitrack motor vehicle involved	Without road work zones	Highway and rural roads	Without rain, fog, snowy streets
<b>Turning assistant</b>	Crashes on crossings with pedestrians or cyclists and at least one heavy vehicle (bus, truck)	-	Urban roads	All
<b>ADAS regarding drowsiness and lack of concentration</b>	Crashes with the mentioned circumstance “distraction”, “disturbance”, or the mentioned reason “fatigue” At least one multitrack motor vehicle involved	Without road work zones	Highway and rural roads	All

### 3 Results and discussion

The crash reduction potentials were calculated for the following ADAS: 1) Adaptive Cruise Control (ACC), 2) Adaptive lighting, 3) Alcohol-Interlock system, 4) ADAS referring to warning/breaking for obstacles (AEB, FCW), 5) Intelligent Speed Assistance (ISA), 6) Curve-ABS, 7) Lane keeping /departure assistance systems (LKA/LDA), 8) Turning assistant and 9) ADAS regarding drowsiness and lack of concentration. For an overview on the functionalities of different ADAS see e.g. [17].

#### 3.1 Defined crash target groups and effectiveness parameters

The crash reduction potentials were calculated based on Austrian crash data, defined crash target groups per ADAS and defined parameters influencing the effectiveness of the ADAS. The crash target groups considered are shown in Table 3. The parameters defined for market penetration, level of use, technical detection potential and negative effects are shown in Table 4.



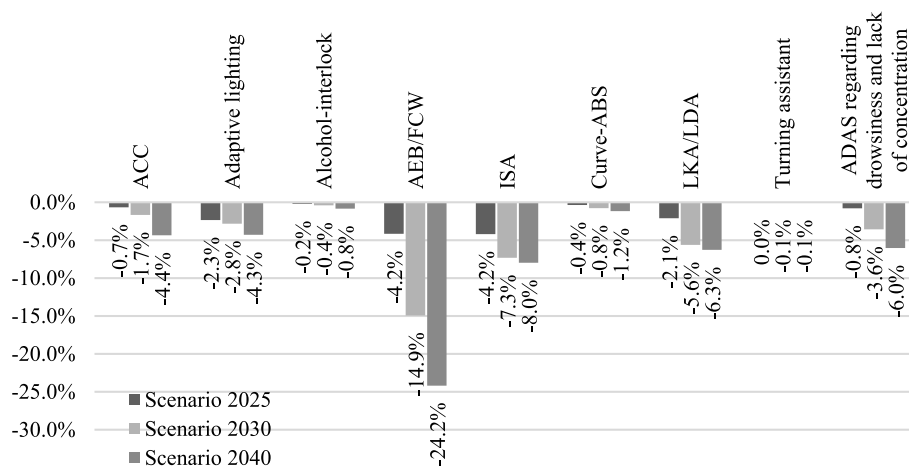
**Table 4** Defined parameters influencing the crash reduction potential of ADAS

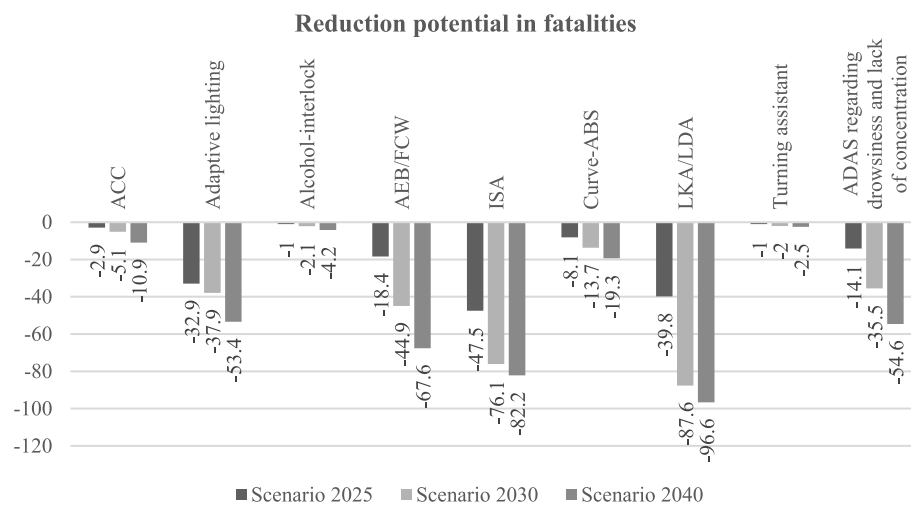
	Scenario	ACC	Adaptive lighting	Alcohol-Interlock system	AEB/FCW	ISA	Curve-ABS	LKA/LDA	Turning Assistant	ADAS regarding drowsiness and lack of concentration
Market penetration	2025	28%	34%	5%	57%	58%	21%	49%	45%	44%
	2030	40%	40%	10%	90%	90%	40%	90%	80%	80%
	2040	80%	60%	20%	95%	95%	60%	95%	95%	95%
Level of use	2025	50%	100%	100%	50%	97%	100%	70%	90%	97%
	2030	75%	100%	100%	75%	100%	100%	90%	95%	100%
	2040	95%	100%	100%	95%	100%	100%	95%	100%	100%
Techn. detection	2025	90%	100%	95%	55%	90%	100%	90%	90%	25%
	2030	95%	100%	95%	75%	95%	100%	95%	95%	50%
	2040	95%	100%	98%	90%	98%	100%	95%	95%	70%
Negative ADAS effects	2025	2%	2%	0%	2%	3%	3%	3%	1%	2%
	2030	1%	1%	0%	1%	1%	1%	1%	1%	1%
	2040	0%	0%	0%	0%	0%	0%	0%	0%	0%

### 3.2 Crash reduction potentials

The results of the crash reduction potential analysis show, that all ADAS support a reduction in crashes (Figs. 3 and 4), fatalities, severely injured and slightly injured even when taking into account the risks that

come with such systems such as inattentive driving and limited functionality. The greatest future reduction potential was shown for the ADAS referring to warning/braking for obstacles (includes Advanced Emergency braking System—AEB, Forward Collision

**Crash reduction potential compared to the 2016–2020 average****Fig. 3** Crash reduction potential in percent of the 2016–2020 average



**Fig. 4** Reduction potential of fatalities compared to the 2016–2020 average

Warning—FCW), potentially leading to a reduction of approximately 8,700 crashes and 70 fatalities in Austria in 2040. This reduction in crashes corresponds to a 24% reduction of crashes compared to the 2016–2020 average of all crashes in Austria. The second most promising ADAS from this study is the Intelligent Speed Assistant, which would lead to an overall crash reduction in 2040 by 8% compared to current crash numbers in Austria, and 7% already in 2030 (here the AEB/FCW is at 15%). The reduction in fatalities is even higher for ISA (70–80 persons killed potentially reduced for 2023/2040). Both mentioned ADAS also don't have overlapping crash types, therefore being able to combine their potential. When only looking at the fatalities, the LKA/LDA systems promise the highest reduction (90–100 killed persons less for 2030/2040). Adaptive cruise control and adaptive lighting systems show less potential in crash and casualty reduction, although the latter promise a reduction of approximately 50 fatalities. The Turning Assistant for HGVs shows the lowest reduction in crashes and casualties in 2040 (30 accidents, 3 fatalities), but due to the highest severity per crash (93 fatalities per 1,000 crashes) it has also an important contribution to the reduction of fatalities in road traffic, in particular fatalities due to HGVs.

Besides the overall potential in reduced crashes and related casualties and fatalities, current shifts towards vision zero, requiring taking into account all users and sustainable transport modes caused to also analyse at the affected road user groups individually to determine the potential for pedestrians, cyclists, motorcyclists and all other road users.

For pedestrians, ADAS referring to warning/braking for obstacles showed the biggest potential for all injury severities (up to 36 fatalities and over 1,000 slightly

injured for 2040). Adaptive lighting has the potential to reduce up to 8 fatalities and 23 slightly injured in 2040. ACC, ISA, Curve-ABS and LDA/LKA have little to no impact on the number of pedestrian victims. For bicyclists, the impact is similar, but the potential of adaptive lighting is smaller, while ISA could lead to 40 less slightly injured bicyclists in 2030. Motorcyclists potentially gain the greatest benefit also from ADAS referring to warning/braking for obstacles, but Curve-ABS designed for motorcycles is similar and has greater effects on the persons killed (up to 19 persons for 2040 vs. 3 for 2040). LDA/LKA systems can potentially reduce 10 motorcyclists killed for 2040, Intelligent speed adaptation has also big effects on the numbers of severely and slightly injured motorcyclists (around 80 severely injured and 150 slightly injured for 2030/2040). For all other road users, LKA/LDA, ISA, adaptive Lighting and the ADAS regarding drowsiness and lack of concentration have the greatest reduction potential—especially among fatalities and serious injuries. Among the slightly injured, the ADAS referring to warning/braking for obstacles, as does ACC. Alcohol-interlock shows the greatest effect here compared to the other road users, but it remains low. Curve-ABS and turning assistant have hardly any effect on the casualties in this group.

### 3.3 Discussion

The results show that there is, for the most part, definite potential for reducing the number of crashes on Austria's roads through ADAS.

FCW/AEB systems show the greatest potential, also because of the large target group, as the system should work with many types of crashes – it aims to prevent any forward collision. As these kinds of systems will be

mandatory for cars and heavy vehicles, the assumption was, that with market penetration this technology will also evolve fast. But, to tap out the potential, especially pedestrian and (motor)cyclists or even micro mobility user detection must be improved, as many systems struggle with the variety of road users.

ISA shows the second highest potential in crash reduction, but in this analysis no pedestrian victims were saved. This is because mainly run-off road crashes were assumed to be avoided. It is clear, that speed is a major issue for pedestrian victims on whether or how severe they will be injured, but it was not possible to extract those crashes where ISA could have played a major role. Therefore, as they were not included, the effect of ISA is possibly higher.

LKA/LDA have a similar but slightly less potential in crash reduction compared to ISA but show its potential when looking at the fatalities. This can be explained by the use of the system mainly in rural areas and on highways where high speeds occur, which are often related to severe injuries and fatalities.

Adaptive lighting systems and ADAS regarding driver drowsiness and lack of concentration were calculated to have some effect on the number of crashes, but the potential to reduce the number of fatalities is their strength. They both play a role when looking at pedestrian casualties and fatalities. The effect of adaptive lighting systems relies heavily on the relevance of lighting in crashes – as this was not possible to determine with the crash data, the effect might be less. For ADAS regarding driver drowsiness and lack of concentration, many systems are still under development, and in a few years, we will be able to see if our assumptions on the technical potential were met.

With all ADAS, the systems should be used (no turning off) and understood (to know the limitations and be able to act accordingly) as well as function properly. The technical detection potential was assumed high for almost all ADAS (except ADAS regarding driver drowsiness and lack of concentration and the AEB/FCW), as many systems are not so new, and the mandatory installation might also put pressure on the ADAS to function properly. This will also have effects on the level of use, although this can also be supported by other measures.

#### 4 Conclusions

In this study, the crash reduction potentials through driver assistance systems for Austria were determined for a total of nine different ADAS. Overall, the results show, that all ADAS examined could be beneficial for road safety. However, it becomes clear that the calculated reduction potential of the ADAS in Austria can only be fully exploited if the systems are used correctly by the

users and further accompanying measures will be implemented in the future. The results of the study and the factors used in the methodology for calculating the accident reduction potentials of the different ADAS lead to following areas for measures:

- Vehicle/technology: Currently there are existing limitations of different ADAS (e.g., recognition of different types of road users by the ADAS “Warning/braking for obstacles”). For this study, it was assumed that these limitations improve over time in the near future due to technological development. However, to foster this development an expansion of manufacturers’ test protocols is needed that take into account current limitations in order to increase the robustness of the systems. In addition, the development of ADAS should be monitored and improved through independent tests and investigations (e.g., by EuroNCAP).
- Infrastructure: For the Intelligent Speed Assistant and the Lane Keeping Assistant, in particular, infrastructural measures could be helpful to increase the functionality and overcome existing limitations. To exploit the full potential of the Intelligent Speed Assistant speed limits and speed restrictions (also temporary at e.g., road works) should be digitally announced or digitised to improve the recognition of the system. For the Lane Keeping Assistant, a good detectability and reflectivity of lane marking should be taken into consideration in any planned road renewal and improved at current accident blackspots.
- Information, awareness raising and training: In order to achieve the identified accident reduction potentials through the various ADAS, an (adequate and correct) use of the systems must be ensured. Information and training measures as well as awareness-raising measures play an important role here. This is particularly relevant because the identified accident reduction effects only take effect gradually: The better the population is informed about the systems, the faster a corresponding penetration and correct use of the systems can be achieved and the earlier the effects can be achieved. The development curves presented in this study with regard to the accident reduction potentials could thus become steeper at the beginning and the reduction effects could be achieved to a greater extent earlier. Here, the following measures should be in the focus: 1) information and awareness raising for the purchase and better understanding of ADAS, 2) integration of ADAS into driver training and 3) establishing a positive image with regard to ADAS and their use by public campaigns.

In addition, further research is needed on the topic of ADAS and the analysis of their impacts on road safety to get further insights on their effects.

This study was only able to calculate accident reduction potentials for ADAS based on existing accident data from the national traffic accident statistics in Austria and assign relevant accidents or accident categories for the individual ADAS via the existing accident database fields, as information on the presence of ADAS is not included in the current national traffic accident statistics. However, since 2023, information on whether an ADAS is present in vehicles involved in an accident will be collected by the executive body as part of the national traffic accident statistics in Austria, based on this, accident analyses of accidents involving vehicles with ADAS should be carried in order, for example, to identify relevant causes of accidents and accident blackspots or to compare accidents with vehicles without ADAS.

In addition to the potential analysis carried out in this study, retrospective accident studies that retrospectively examine accidents involving vehicle models with certain ADAS and vehicle models without certain ADAS are particularly suitable for demonstrating the effectiveness of different ADAS. In other countries, such studies have already been carried out, mostly on the basis of data from insurance companies (see e.g., [4]). For Austria, too, such studies should be carried out together with insurance companies, but also vehicle manufacturers, based on their data.

#### Abbreviations

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
AEB	Automatic Emergency Braking
BSW	Blind Spot Warning
FCW	Forward Collision Warning
ISA	Intelligent Speed Assistance
LDA	Lane departure Assistance
LDW	Lane Departure Warning
LKA	Lane Keeping Assistance

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#### Authors' contributions

Michael Aleksa – Compiled the sources, Devised the workflow, Wrote the section methodology, Revised the draft. Andrea Schaub – Studied the literature, Wrote the section results, Revised the draft. Isabela Erdelean – Studied the literature, Revised the draft. Stephan Wittmann – developed the software tool (reduction potential). Aggelos Soteropoulos – Devised the workflow, Wrote the sections introduction and conclusion, Revised the draft. Alexander Fördös—Wrote the sections introduction and conclusion, Revised the draft.

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#### Availability of data and materials

Austrian crash data base is provided by Statistics Austria ([www.statistik.at](http://www.statistik.at)). Crash potential analysis data and the software tool are not available for public, but requests can be made at AIT.

#### Declarations

##### Competing interests

The authors declare that no competing interests exist.

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