Traffic safety of e-bikes and technical solutions to increase cycling safety

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Traffic safety of e-bikes

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Definition of e-Bike

EU classification for EPACs and Light Electric Vehicles

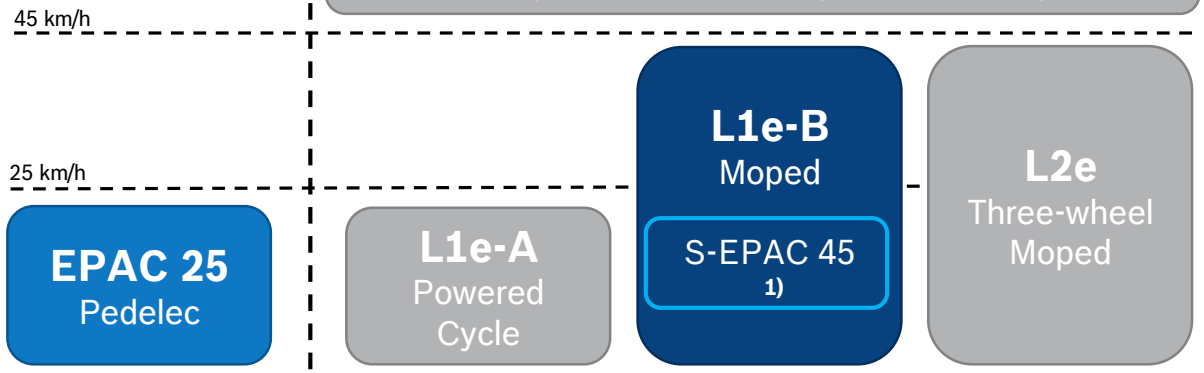
No type-approval

EPAC 25
- **is a bicycle with equal rights and duties**
- EN 15194 “EU EPAC Standard” & CE conformity
- No type-approval
- Use of bicycle lanes / trails
- No insurance mandatory, no license plate

L3e / L4e / L5e / L6e / L7e
Motorcycle / Powered Tricycle & Quadricycle

Type-approval

S-EPAC 45
- Sub-class within collective category L1e-B
- (EU) 168/2013
- Type-approval with some simplification measures
- Right and use like Moped
- Insurance & license plate



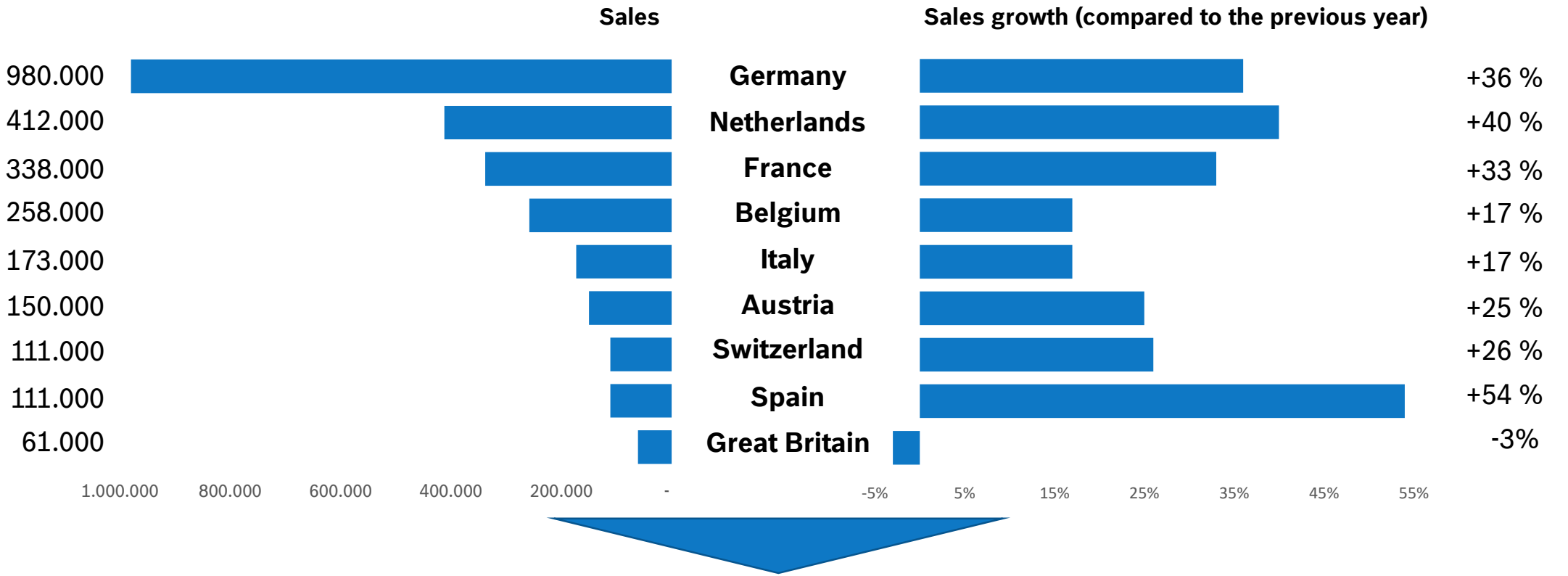
Regulation	Machinery Directive EN 15194	(EU) 168/2013	
Max. Speed km/h (support)	25	25	45
Pedal / Throttle	Pedal	Pedal + Throttle	Pedal + Throttle / Throttle
Max. Continuous rated power W	250	1000	4000
Helmet	No	Yes	
Mandatory Insurance	No	Yes	
Bicycle lane / trails	Yes	No	

Current state
- EU market share:
  EPAC 25 >99%
  S-EPAC (L1e-B) <1%
- EPAC 25 is a „bicycle“ → main reason for consumer acceptance
- EN 15194:2017 with tuning detection eff. 2019

Market Check in Europe

The most important EPAC markets at a glance

2018



▶ In about five years every second new bicycle sold in European core markets could be an EPAC

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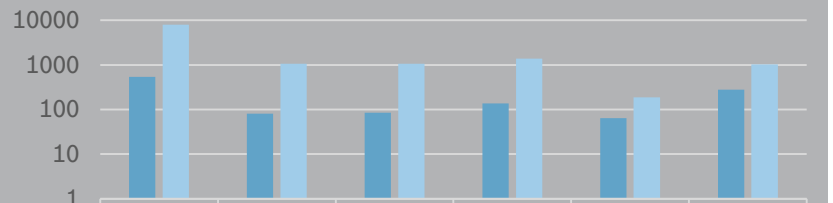
Accident Number Check in Europe
Market Penetration based Accident Risk

2019

Available EPAC accident data

- **Green** Data available
- **Red** No dedicated data
- **Grey** No data available

EPAC stock and accidents

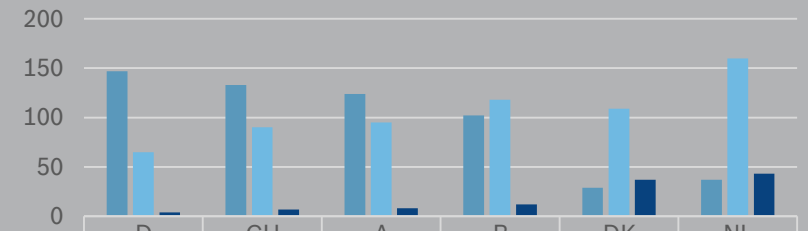


	D	CH	A	B	DK	NL
Stock in 10k	540	80	85	136	64	278
Accidents	7928	1065	1054	1388	187	1032

Market penetration based accident risk

Calculations:

- Accident risk = $\frac{\text{Amount of accidents}}{\text{EPAC stock}} \cdot 100k$
- Market penetration = $\frac{\text{EPAC stock}}{\text{Inhabitants}} \cdot 1k$
- Safety in Numbers (SiN) coefficient = $\frac{\text{Market penetration}}{\text{Accident risk}} \cdot 10$



	D	CH	A	B	DK	NL
Accident risk	147	133	124	102	29	37
Market penetration	65	90	95	118	109	160
SiN Coef.	4	7	8	12	37	43

▶ Hugh variance in the Safety in Numbers coefficient for EPACs among Europe

Note: numbers for 2019 are preliminary

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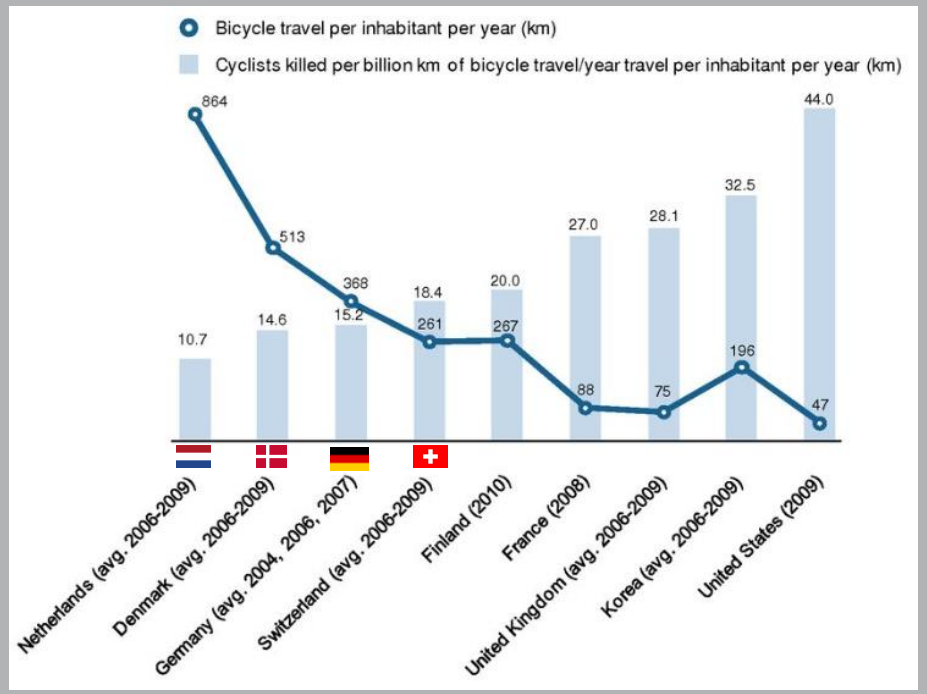
Accident Number Check in Europe

Safety in Numbers Effect for EPACs – Why not?

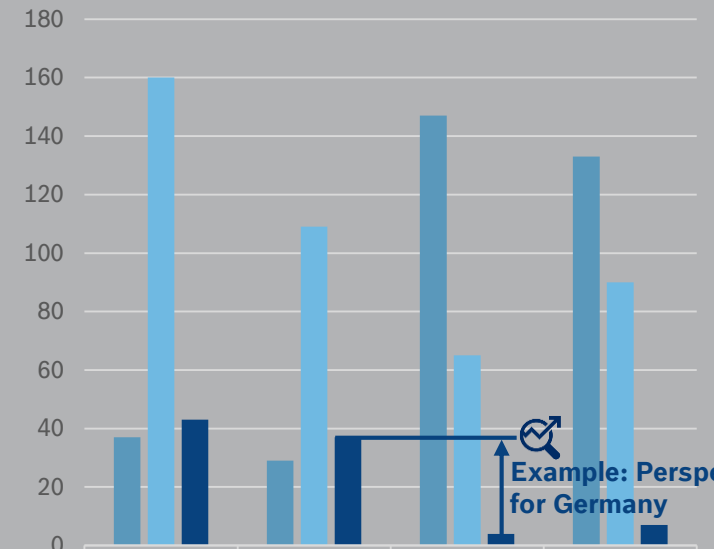
2019

Bicycle travel and fatalities correlation*



Market penetration based accident risk

Note:
Diagram from previous slide



	Netherlands	Denmark	Germany	Switzerland
Accidents per 100k Pedelecs [#]	37	29	147	133
Pedelecs per 1k inhabitants [#]	160	109	65	90
"Safety in Number" Coef. (x10)	43	37	4	7

▶ A widespread distribution of EPACs correlates with a higher traffic safety

(assuming similar developments as for all bicycles due to comparable accident patterns)

Note: numbers for 2019 are preliminary | *Source: OECDpublishing "Cycling, Health and Safety", p.116, fig.3.12, DOI: https://doi.org/10.1787/9789282105955-en

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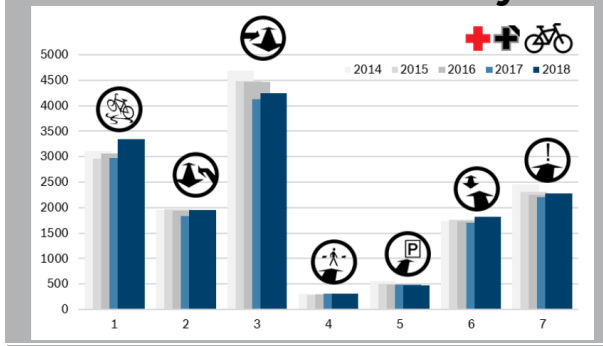
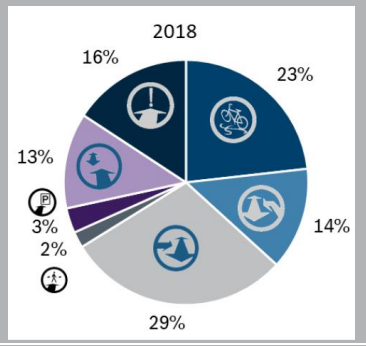
German Accident Data Analysis
Accident Type Distribution

DESTATIS Statistisches Bundesamt

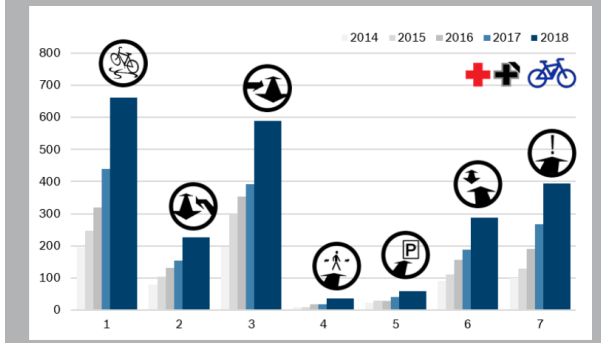
2018

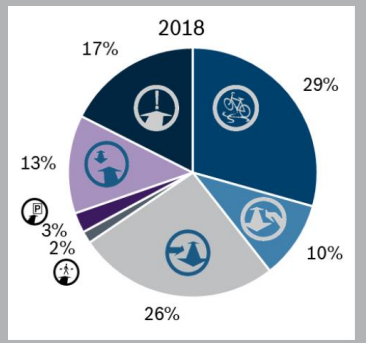
Bicycles





EPACs





Findings

- The underreporting rate for accidents with no/ slight injuries is high among all bicycles and different between bicycles and EPACs
  → Only accidents with severe and fatal injuries evaluated
  → Strong need for riding behavior and accident data collection
- Among accidents with severe and fatal injuries, the accident type distribution between bicycles and EPACs are quite similar
- Share of crossing and bending accidents involving EPACs (26+10%) slightly lower than accidents involving bicycles (29+14%)
  → EPAC not yet fully established as an all day every day solution and rather used for recreational activities in rural areas
- Share of riding accidents involving EPACs (29%) slightly higher than accidents involving bicycles (23%)
  → Higher average user age increase the likelihood of balance problems (e.g. ride-off) and falls lead to more serious injuries

▶ Accidents patterns of bicycles and EPACs are very similar

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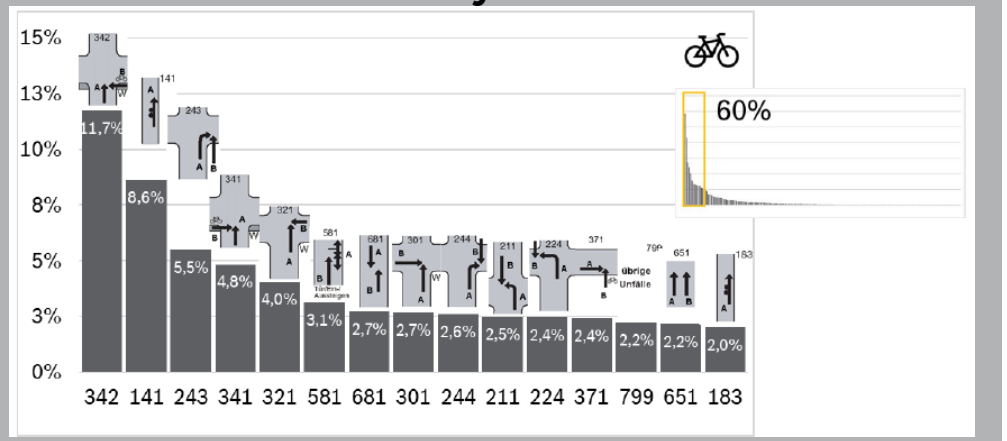
German Accident Data Analysis
Detailed Accident Type Distribution

GIDAS GERMAN IN-DEPTH ACCIDENT STUDY

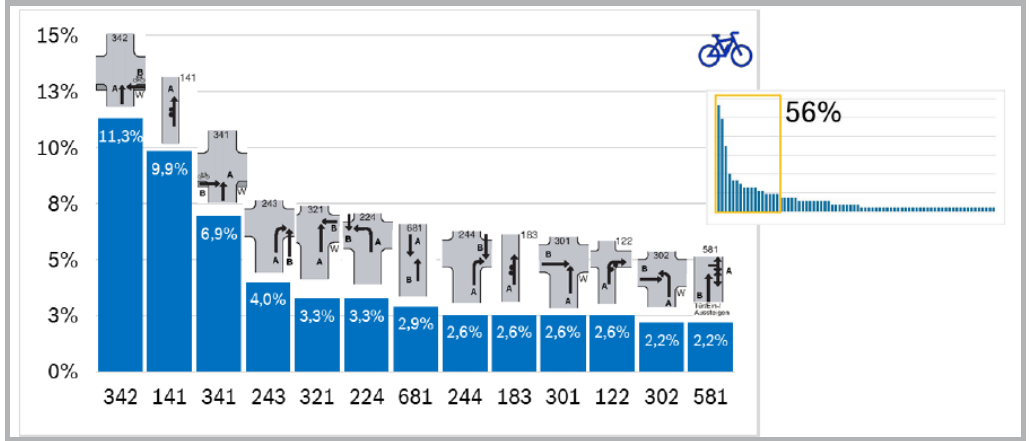
2005-2019

Bicycles



Accident types (>2%) 3-digit bicycle accidents (n=9235)

EPACs



Accident types (>2%) 3-digit Pedelec accidents (n=272)

- Most frequent accident types: Intersection scenarios where the bicycle or EPAC crosses on the footpath/cycle path
  → These situations are often accompanied by impaired visibility
- Most important field of actions:
  - **Infrastructure**: more bicycle lanes, dedicated traffic lights, smart traffic control (e.g. during rush hour)
  - **Road safety education**: knowing traffic rules, interpreting movement patterns, awareness of technology changes (e.g. autonomous vehicles)
  - **Bike equipment & cycling gear**: increase cyclist visibility by bike lights, wearing light-reflecting vest, B2X communication (e.g. shared trajectory)

Accident countermeasures should be clearly focused on solving crossing & bending issues

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Technical solutions

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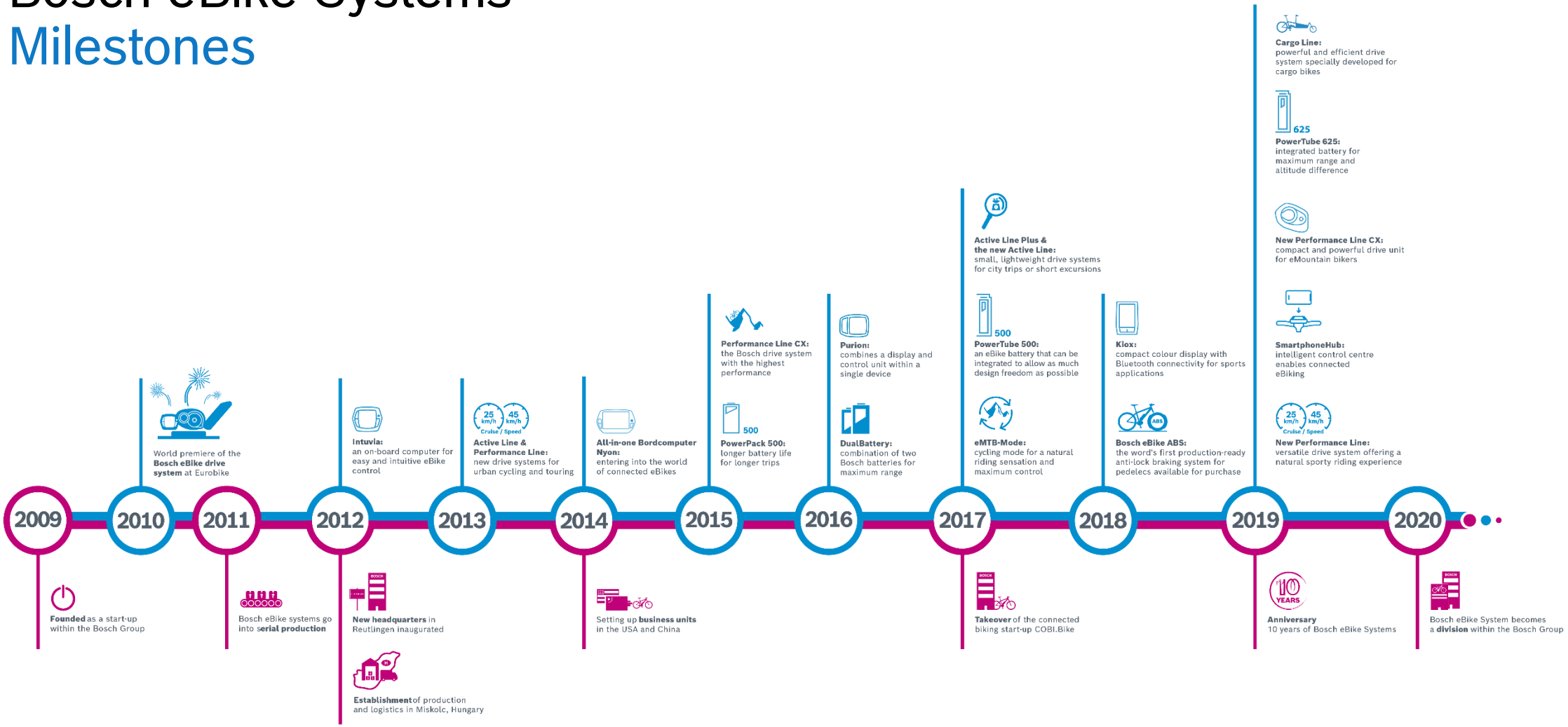
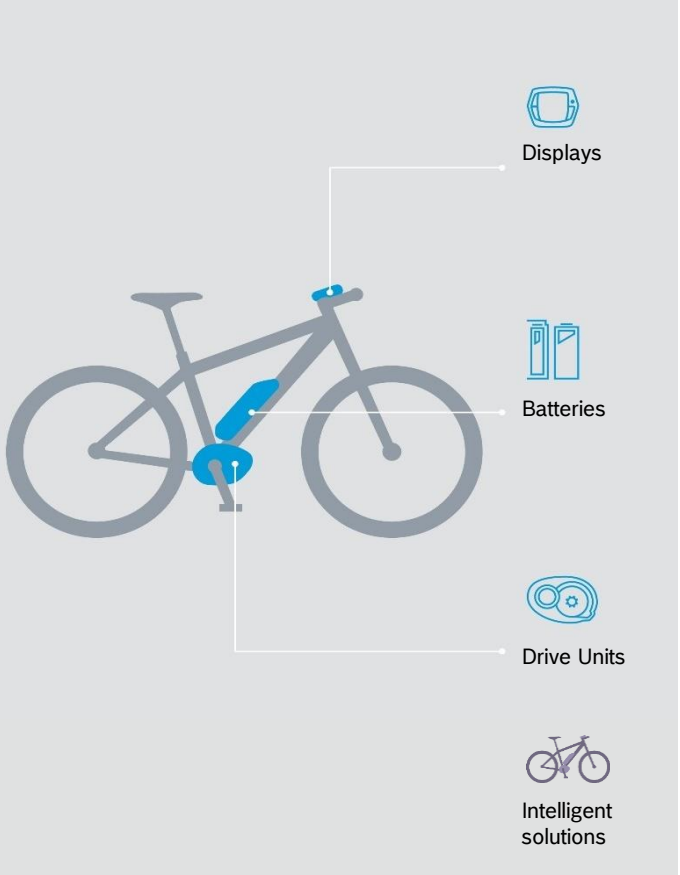
Bosch eBike Systems
Milestones



Bosch eBike Systems
Product Portfolio




Purion


Intuvia


Kiox


Nyon


SmartphoneHub


PowerPack 300/400/500


PowerTube 400/500/625


DualBattery


Compact Charger


Standard Charger


Fast Charger


Active Line


Active Line Plus


Cargo Line/Speed


Performance Line/Speed


Performance Line CX


Bosch eBike ABS


Lock


eMTB mode

eShift

Bosch eBike Systems
Anti-Tuning/ Anti-Tampering Measures

Bosch eBike Systems acts **proactively against tuning**/ tampering of EPACs

Measures:

- Association and standardization work
  (ZIV, CONEBI, DIN / CEN / ISO e.g. EN 15194:2017)
- Technical solutions
  (see on the right side)
- Contact to regional authorities
- Public relation activities
  (e.g. training of dealers)

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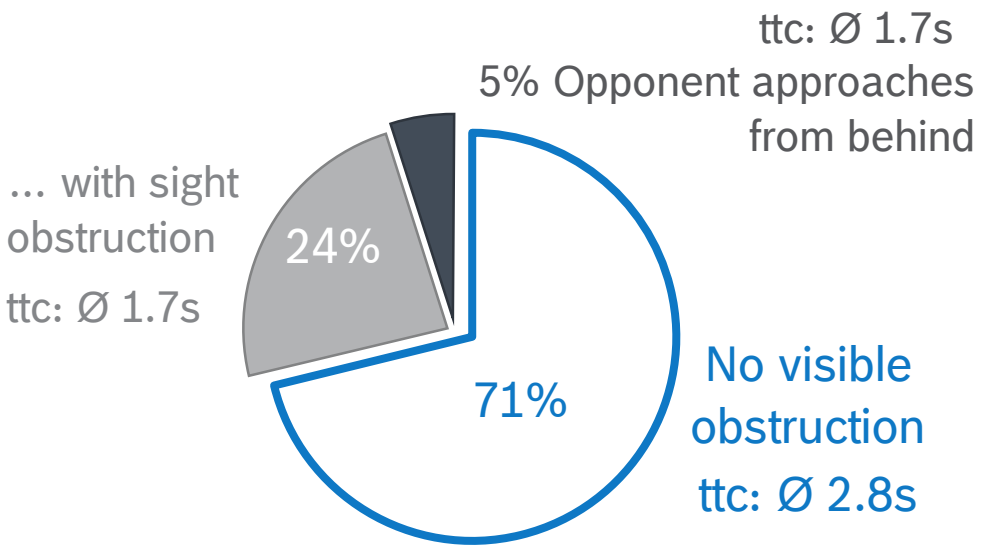
Bosch eBike ABS
The product at a glance

- The **world's first production-ready ABS** enhances the EPAC's stability under harsh braking conditions
- **Technology transfer** from motorized vehicles with over 40 years experience
- Developed according to highest standards (ECE-R78) and approved by DEKRA
- When the front wheel is over-braked,
  - the **front wheel slip control** finds the best trade-off between deceleration and controllability for the given riding situation
  - the **rear wheel lift-off control** reduces the risk of being thrown over the handlebars
- Available since MY18 for City-/Trekkingbikes
  (EPAC types with highest market share)

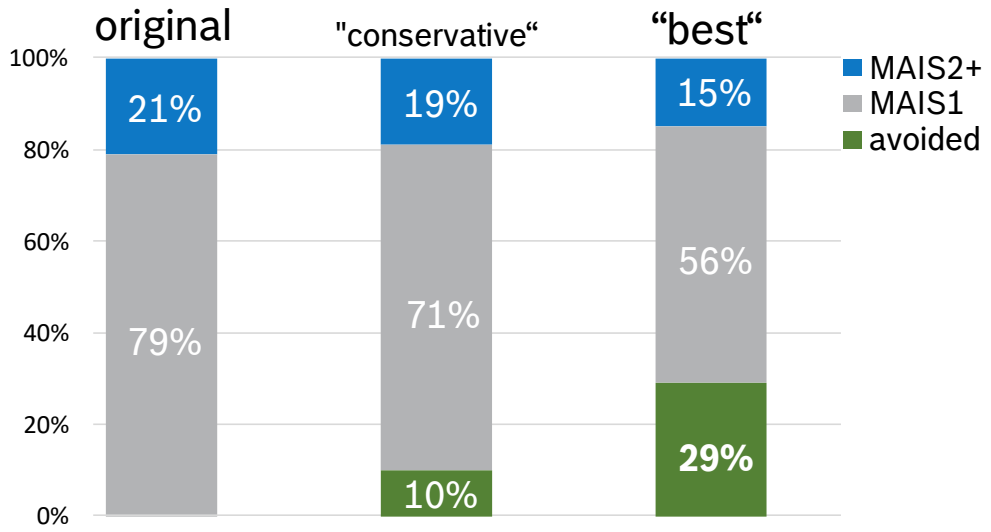
Bosch eBike ABS
What's the benefit on cycling safety?

GIDAS GERMAN IN-DEPTH ACCIDENT STUDY

- **Study**: single case analysis based on GIDAS database including 2 366 different conflicts
- **Result (1)**: Visibility and reaction time given:



- **Result (2)**: Potential benefit of ABS for Germany in all accident scenarios:



Potential 2017:
(All EPACs with ABS*)
≈ 1500 avoided accidents

* Brake reaction assumed

→ Braking in majority of cases possible

Publication at ICSC 2018: „Benefit estimation of an Antilock-Braking System (ABS) for Pedelecs based on simulation of real world accidents" by Mönnich, Lich, Maier, Georgi

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Bosch Help Connect
The Feature at a glance

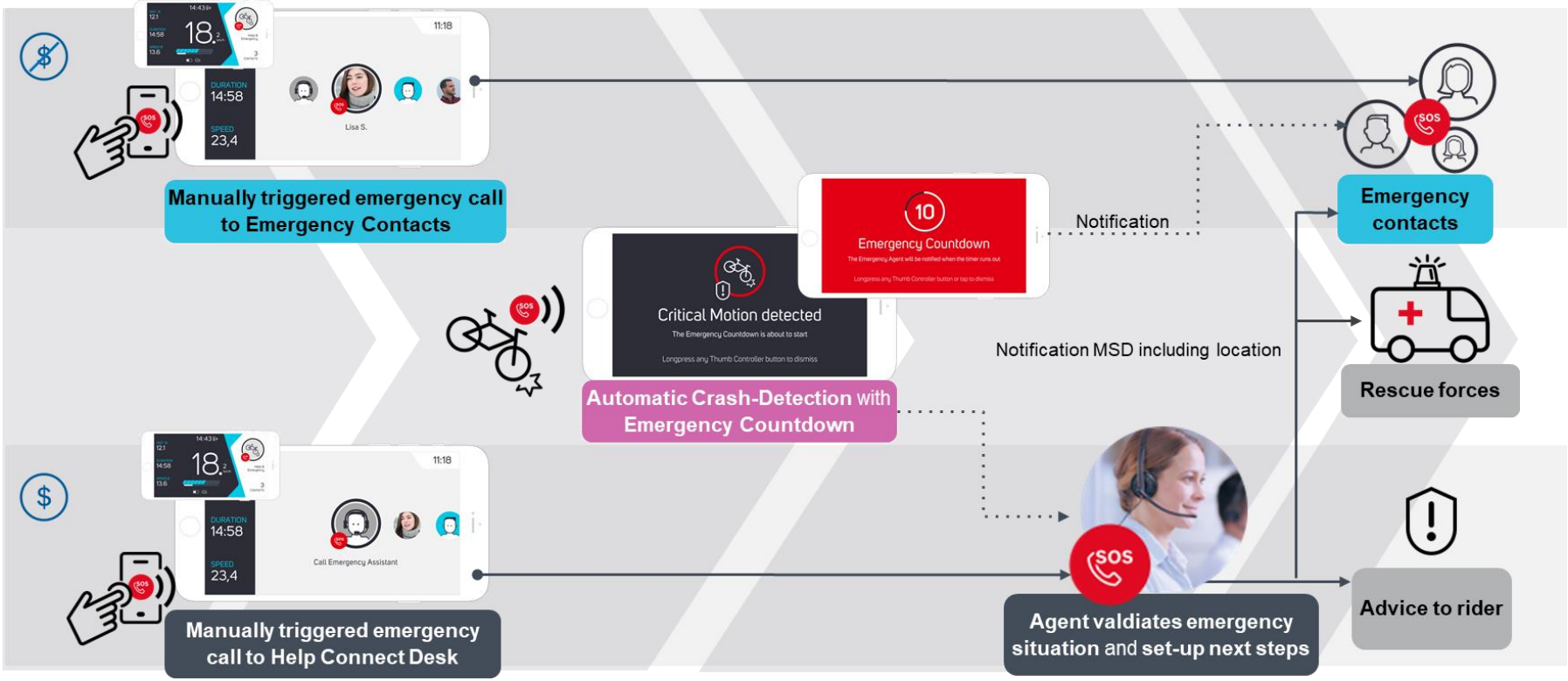
Quick guide

- Critical motion detected
- No motion subsequently
- Emergency countdown

- Location determined via COBI.Bike app
- Professionally trained service staff provide help 24/7
- Rescue procedure initiated

- Rescue team knows location
- Fast and effective help

Detailed process flow



Research – Lateral Stabilization of Bicycles

What can we do to tackle control issues at low speeds?

BikeAssist – Lateral Stabilization of Electrically Assisted Bicycles at Low Speed

M.Sc. Yannick Hanakam, Prof. J. Wrede, Prof. Dr. M. Pfeiffer, Prof. Dr. S. Hillenbrand, Prof. Dr. P. Heidrich, Prof. Dr. C. Wehner
(Pforzheim University, Institute for Smart Bicycle Technology, *bikeassist@hs-pforzheim.de*)

Project Objectives

To keep a bicycle stable at low speed, the cyclist needs to stabilize the bicycle with steering movements and/or by weight shift using the upper body. To help the cyclist maintain balance at low speed, the project »BikeAssist« aims to develop a stabilizing assistant system for EPACs. By reducing the cyclist's control actions required for stabilizing, a pedelec equipped with an assistance system can improve riding performance and riding safety at low speed.

Tasks

- Research on subjective safety when riding a pedelec at low speed and linking it to measurement data of test rides.
- Investigation of lateral dynamics of the rider-bicycle-system using simulation models and riding tests.
- Identification of basic requirements for stabilizing assistant systems for pedelecs at low speed.
- Investigation and implementation of control strategies, sensors, and actors to increase the stability of pedelecs while considering the cyclist's control actions.
- Evaluation of an active stabilizing assistant system using riding tests.

State of Project

- A pedelec was equipped with measuring devices to record several quantities that provide information on the motion of the pedelec, e.g. steering angle, roll angle and trajectory.
- A study with more than 60 cyclists was conducted to explore the relations between riding safety and actual measurements of bicycle stability. During a field-test each participant had to perform different low speed maneuvers including mounting and dismounting with an instrumented bicycle. Before and after each riding task each participant was asked to give a self-assessment regarding riding safety and riding performance. The study is currently being evaluated.
- To investigate the system dynamic behavior and lateral stabilization, a customizable multibody simulation model of a bicycle-rider system was developed. This model is used to evaluate different control strategies and actuator concepts interacting with the cyclist's control actions for stabilizing a bicycle.
- Different concepts and control strategies to improve the stability of a pedelec-rider system are being investigated.

Publications

Several publications are planned for 2021. The results of the study will be presented at the ICSC 2021.

Source of the Onepager: Hanakam, Pforzheim University

Research – Lateral Stabilization of Bicycles
One promising solution: Steer-Assist System

- **Main project**: Citius altius sanius – injury-free exercise for everyone
- **Sub project**: Fall prevention in elite and consumer cycling
- *Founded by NWO, project lead: A. Schwab, timeline: 01/2018 – 12/2022, 5 years*

- **Goal for consumer cycling**: Assess effectiveness of steer-assist bicycle
- *WP1*: Theoretical potential steer-assist bicycle based on historic crash data
- *WP2*: Theoretical simulation of set of disturbances for which a cyclist and a steer-assist bicycle can recover balance
- *WP3*: Experimental validation steer-assist bicycle (cycling fall experiment)
  - Prototype bicycle is being designed and build is in progress
- *WP4*: Experiment to measure user-experience and acceptance of steer-assist bicycle

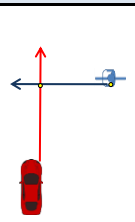
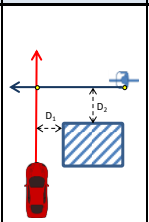
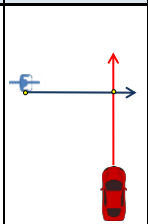
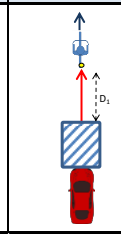
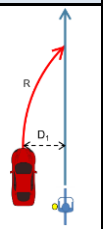
Publication at ICSC 2021: „A Proposal for a Standard Set of Cycling Fall Causes" by Reijne, van der Helm, Schwab

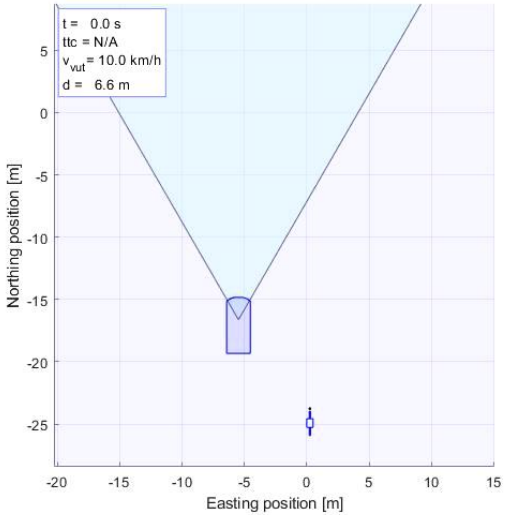
Research – Bike2X Communication

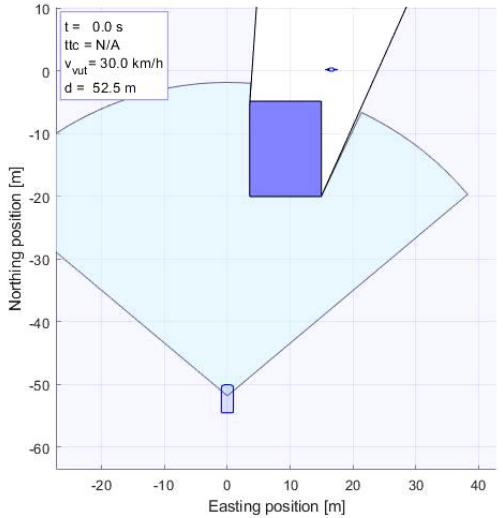
What's the benefit of adding B2C to AEB? (AEB= Automated Emergency Brakes)

Simulation Study by TNO together with Bosch eBike Systems and Shimano

- 5 most critical accident scenarios (car vs bike) were simulated, covering ~60% of all fatalities / serious injuries
- 4 classes of AEB systems (representing different performances of EuroNCAP2019 test participants)
- Multiple communication technology representatives (indirect 45ms - direct 10ms)
- 2 sensor strategies in AEBs: use B2X (1) only for preparation and (2) as fully trusted sensor
- Overall >1500 simulations

	CVNBU	CVNBO	CVFB	CVLBO	CVBB
	Car-to-VRU Nearside Bicyclist Unobstructed	Car-to-VRU Nearside Bicyclist Obstructed	Car-to-VRU Farside Bicyclist	Car-to-VRU Longitudinal Bicyclist Obstructed	Car-to-VRU Blindspot Bicyclist
Vehicle speed	5 - 60 km/h	5 - 50 km/h	5 - 60 km/h	20 - 80 km/h	5-30 km/h
Cyclist speed	15 km/h	10 km/h	20 km/h	15 km/h	10 km/h
Obstruction	-	D1 = 3.55m, D2 = 4.80m	-	D1 = 10.0m	-
Overlap hitpoint	50%	50%	25%		50% at 45° with D1=5.5m, R=10m
# tests	12	10	12	13	6
Coverage (K)	22%	22%	11%	5%	0%
Coverage (SI)	22%	22%	11%	1%	3%
Layout sketch					





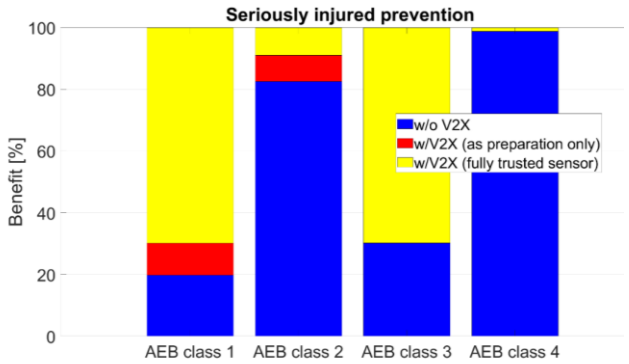
Publication at ICSC 2021: „CAN BIKE-TO-CAR COMMUNICATION PREVENT CYCLIST FATALITIES?" by Uittenbogaard, de Jongh, Wienss, Deschuymer

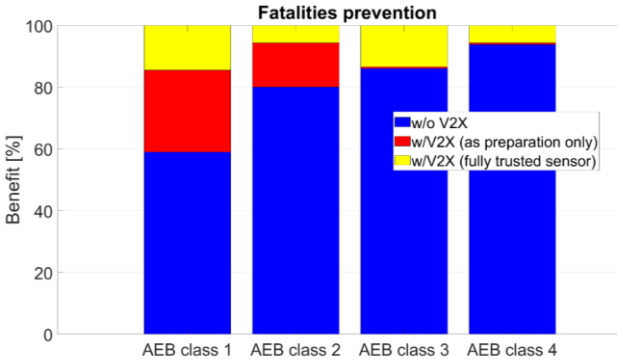
Research – Bike2X Communication

What's the benefit of adding B2C to AEB? (AEB= Automated Emergency Brakes)

Results

- B2X only as preparation:
  - large added benefit for „poor"-performing AEB systems;
  - almost no added benefit for „best-in-class" AEB systems, at least in EuroNCAP test scenarios
- B2X as fully-trusted sensor:
  - solves basically all situations, but B2X as fully trusted sensor in AEB is not realistic from safety point of view
  - results might be used as indicator for high potential of collision warnings
- Latency effect of different communication technologies not significant (e.g. 4G vs ITS-G5/5G-PC5)
- 250 - 500ms intention prediction („cyclist will brake or not") is essential; little added benefit w/o intention prediction





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Research – Rider Warning

How to transmit safety-related information to cyclists?

Motivation

- Increasing safety through transmitting safety-related information
- Reduce number of cycling crashes through information about imminent critical situations[1]
- Information could be related to other road users or cycling conditions increasing the risk of single-bicycle crashes[1]
- Limited knowledge on how cyclists perceive and react to warnings

Objective

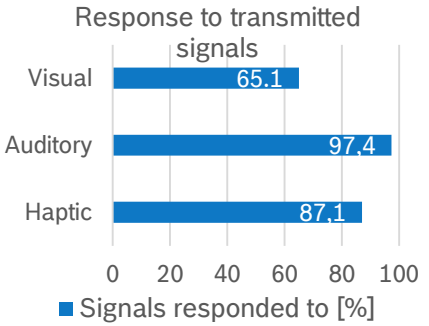
- Derive how information can be effectively and efficiently transmitted to and accepted by cyclists
  1. Which modality is reliably perceived during cycling? Which modality is preferred by cyclists? (Field study about perception 08/2019 [1])
  2. How do cyclists react to warnings? Which warning modality leads to an appropriate reaction in a warning scenario? (Field study 08/2020)

Perception Study[1]

- Transmission of visual, auditory and vibro-tactile signals to participants while cycling in road traffic
- Route covers different environment conditions: baseline and interference condition(visual distraction, noise interference, road surface related vibrations)
- Participants pressed a button if a signal was perceived

Results

- Participants responded reliably to auditory and vibro-tactile signals, more than 30% of visual signals were missed
- Environment conditions influence signal perception: strongest effect seen for vibro-tactile signals on bumpy road surface



PUBLICATIONS

[1] Erdei, E. H., Steinmann, J., & Hagemeister, C. (2020). Comparing perception of signals in different modalities during the cycling task: a field study. *Transportation research part F: traffic psychology and behaviour*, *73*, 259-270, https://doi.org/10.1016/j.trf.2020.06.011.

[2] Erdei, E. H., Steinmann, J., & Hagemeister, C. (currently under review). Modal preferences for information transmission to cyclists after experiencing a naturalistic setting.

THANK YOU, STAY HEALTHY AND PLS WEAR A HELMET ☺

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