Final Report

CONNECTED AND AUTONOMOUS VEHICLES
INTERFACE ANALYSIS

Prepared for

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Agenda

- Project approach and executive summary
- Step 1: Baseline CAV definition
- Step 2: Interface analysis
- Step 3: Criticality assessment
- Contacts
- Appendix

FEV will deliver a study on the relevant interfaces of an autonomous vehicle and the information extracted from these

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Background

- The Netherlands are very actively engaged in innovation around connected and autonomous vehicles (CAV)
- This also includes ensuring that the enabling infrastructure for CAV is ready at the applicable points in time
- This infrastructure falls under the responsibility of the Ministry of Infrastructure and Water Management (IenW)
- To fulfill the tasks associated with this responsibility, IenW is currently investigating the impact of CAV on the infrastructure in the Netherlands
- Within this context, IenW approached FEV to conduct a study on the interfaces of a CAV with its environment and the role of the interfaces in the autonomous driving task

Objectives

- Within this study, FEV, while leveraging its deep knowledge of the automotive market, will answer the following questions:
  - What information does an autonomous vehicle extract from its environment using its sensors?
  - To retrieve this information, what are the strengths and weaknesses of the individual relevant sensor types (e.g. radar)?
  - What additional information has to be integrated into the vehicle using digital interfaces (“V2X“) to fulfill the driving task safely?
  - How critical are the individual sets on information for the driving task?
- This study will be undertaken for a single reference vehicle representing a CAV functionality status in ~ 2025

Source: FEV

We will conduct the study along a three step approach

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PROJECT APPROACH

1 Step 1: Baseline Definition

- Define baseline connected and automated vehicle for the study
- Includes the following dimensions:
  - Vehicle type
  - SAE level of automation
  - Realized automation functionality
  - Sensor types used
  - Available data interfaces
- Brief outline of key differences for LCV[1] and HD[2] CAV applications

2 Step 2: Interface Analysis

- Analysis of the different interfaces of the defined baseline CAV
- Includes the analysis of the information extracted through the following interfaces:
  - Sensor based
  - Connectivity / V2X
- Strengths and weaknesses of the different sensor types for extracting the relevant sets of information

3 Step 3: Criticality Assessment

- Assessment of the criticality regarding the automated driving task for the different sets of information identified previously
- Identification of most critical sets of information and their origin (e.g. only from LiDAR)

1) Light Commercial Vehicles; 2) Heavy Duty
Source: FEV

The 2025 baseline CAV entails Highway Pilot, AEB and Parking Chauffer enabled by means of multiple sensors and communication

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1 Step 1: Baseline Definition | 2 Step 2: Interface Analysis | 3 Step 3: Criticality Assessment

BASELINE CONNECTED AND AUTOMATED VEHICLE

SAE LEVEL 4

Vehicle type

- Executive / luxury car
- Premium segment

Automation functions

- Highway Pilot (L4)
- AEB (L1)
- Parking Chauffeur (L3)

Sensor types

- Ultrasonic
- Camera (surround, tri-camera, infrared)
- Radar (SR/MR/LR)
- LiDAR (solid state)
- GNSS, HD Map

BASELINE CAV

2025

Data interfaces

- Network uplink for V2N
- Direct communication interface (technology agnostic)

Note: CAV = Connected and Automated Vehicle; SR = Short-range; MR = Mid-range; LR = Long-range; AEB = Autonomous Emergency Braking; V2N = Vehicle-to-Network
Source: FEV

Picture Sources: SAE, Apple

In comparison, sensor types have dedicated strengths and weaknesses depending on the desired functionality

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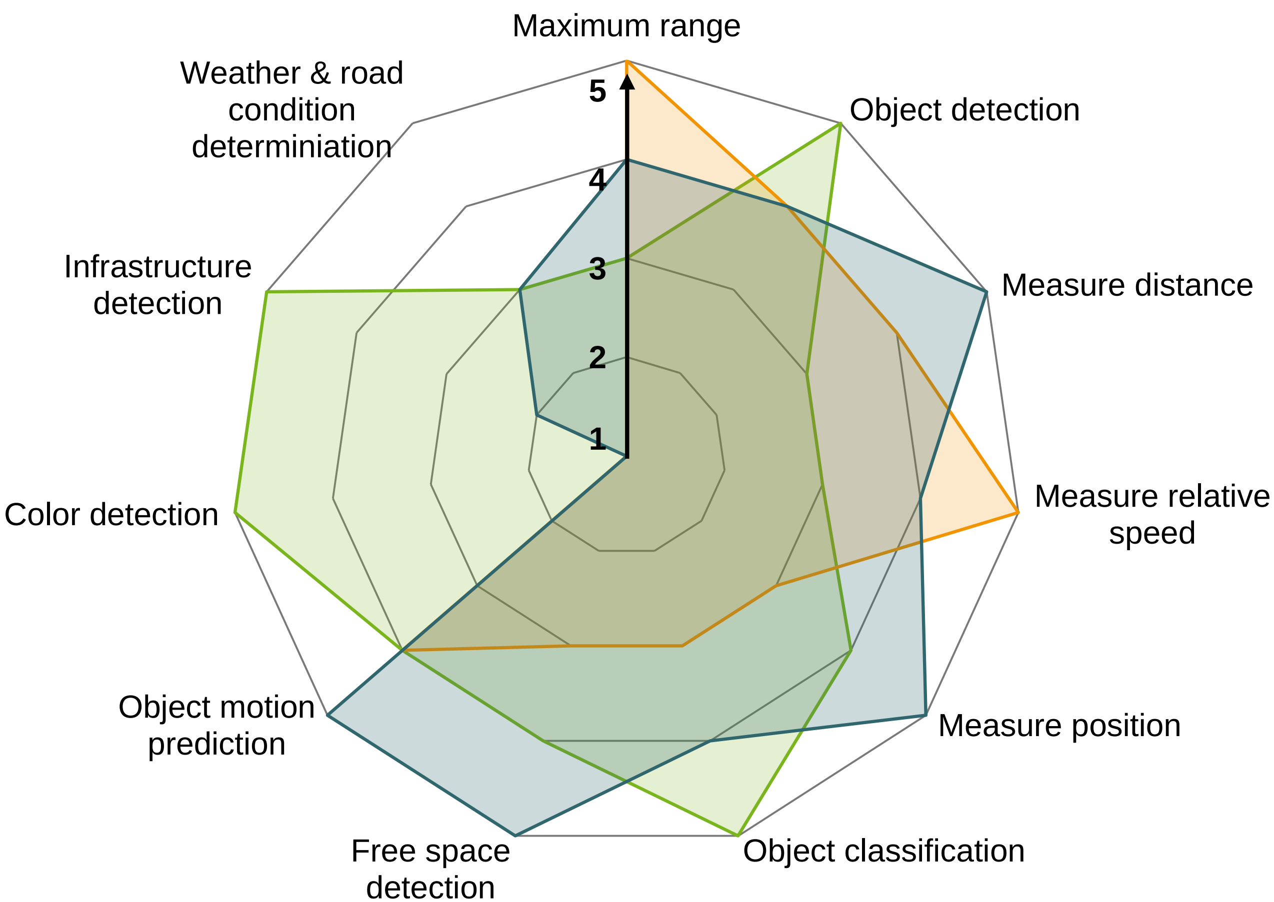
1 Step 1: Baseline Definition | 2 Step 2: Interface Analysis | 3 Step 3: Criticality Assessment

KEY SENSOR COMPARISON: CAMERA, RADAR AND LIDAR



Key Comments

- Camera has a broad set of strengths, especially regarding detection and classification
- Radar's key strengths are the measurement of relative speed (native by doppler effect) and long range
- LiDAR is especially suitable for spatial recognition, trajectory prediction and measurement
- Visibility conditions have a significant impact on sensor performance
  – Largest negative effect on camera
  – Radar performance most robust
  – Medium impact on LiDAR

Camera | Radar | LiDAR

1 = worst → 5 = best

Source: FEV

Sets of information have been defined implementation-agnostic; Tri-cam and LiDAR are among the most important sensor types for CAVs

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1 Step 1: Baseline Definition | 2 Step 2: Interface Analysis | 3 Step 3: Criticality Assessment

CAV INTERFACES AND INFORMATION SETS

Characteristics of information sets

Implementation-agnostic

Free of overlaps

Information set group	Set of information
Vehicle data	Gear mode
Objects	Obstacle validity
Objects	Relative position X
Objects	Relative speed X
Objects	Length
Objects	Width
Objects	Height

Before processing

Common level of detail

Based on driving environment

Key statistics of interface analysis

Total # of sets of information by automation feature

AEB ~ 18 PC ~ 28 HWP ~ 45

Total # of sensor types analyzed

~12

Sensors contributing to largest # of information sets

1. Tri cam **&** LiDAR ~ 40
3. Surround cam ~ 39
4. Vehicle ~ 35
5. Radar ~ 33

Sensors with largest # of top ratings for suitability

1. Vehicle ~ 35
2. Tri cam ~ 32
3. LiDAR ~ 15
4. HD-Map ~ 14

Note: AEB = Autonomous Emergency Braking; PC = Parking Chauffeur; HWP = Highway Pilot
Source: FEV

The sets of information: relative speed, lane marking type and lane curvature are highly critical and restricted in availability by the sensors

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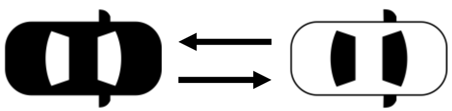
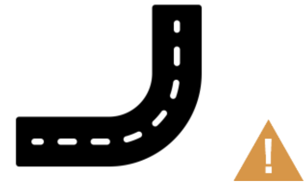
HIGHLY CRITICAL SETS OF INFORMATION WITH RESTRICTED AVAILABILITY



Relative speed of objects (e.g. vehicles) in longitudinal or lateral direction

Lane marking type includes information on geometry, color, style and material of lanes



Lane curvature describes the radius of a curve on the roadway

	AD FEATURE	LOW AVAILABILITY REASONING	HIGH CRITICALITY REASONING
Relative speed	AEB HWP	Very high accuracy of relative speed only with radar; other sensors are using either indirect measurement (e.g. LiDAR) or algorithms (e.g. camera)	Accurate and continuously available information on **relative speed** of objects required for automation features (i.e. AEB, HWP) to assure reliability and safety
Lane marking type & lane curvature	HWP	Information on **lane type** & **curvature** primarily extracted by cameras → performance strongly fluctuates with changing environmental conditions	**Lane marking type** and **lane curvature** required to centralize ego vehicle between two lanes; the former additionally to determine type of roadway (e.g. exit lane)

Note: AEB = Autonomous Emergency Braking; HWP = Highway Pilot
Source: FEV

⚠ *Also core IenW field*

The sets of information: road boundaries, markings as well as traffic signs & HD Map Updates are highly critical and are within core fields of the IenW

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HIGHLY CRITICAL SETS OF INFORMATION IN CORE IenW FIELDS WITHOUT RESTRICTED AVAILABILITY

	AD FEATURE	HIGH CRITICALITY REASONING
Road boundaries include artificial or natural boundaries (e.g. curb, guardrail, bushes)	PC HWP	Accurate information on **road boundaries** (e.g. curb) required to detect parking lot boundaries when parking sideways (PC) and to avoid collisions e.g. in road work segments (HWP) where guardrails may represent lane boundaries
& **Road markings** include arrows, words and symbols on roads (e.g. zig zag line); **Traffic signs** include regulations for speed limits, overtaking, etc.	HWP	**Road markings** and **traffic signs** relevant to comply with traffic regulations (e.g. speed limits, no overtaking); thus both sets of information have an impact on safety
HD Map Updates from supplier or through crowdsourcing via network uplink	HWP	In HWP mode, the **HD Map** is a key sensor to provide information on the road network and positioning; both information set groups are covered by a low no. of sensors with rather low suitability → up-to-date HD Map information are key for safety; Public sector considered to be a relevant data owner

Note: PC = Parking Chauffeur; HWP = Highway Pilot
Source: FEV

Authorities should ensure that they have full transparency of and reliable access to their data to maximize the potential of CAV

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KEY TAKEAWAYS FOR CAV POLICY (1/2)

- It is deemed beneficial for CAV deployment to ensure adequate lane markings especially in hot spots[1] and CAV ODDs; possibly usage of tailored reflective lane markings to increase „availability“ by improving extraction of information via radars and LiDARs
- Authorities are recommended to increase efforts in data mining and engineering; i.e. because there is less divergence on the use cases than on implementation technologies, authorities can facilitate technology-agnostic deployment by identifying and preparing the required data as well as backend systems
- For high volume CAV deployment scenarios, it is recommended to assess the impact of interferences on different sensors (esp. LiDAR and Radar) and congestion on radio channels
- Full coverage with roadside units not expected to be a prerequisite to ensure functional reliable and safe automated driving features by 2025; External data provision in selected hot spots[1] deemed beneficial for CAV deployment (because selected vehicles are expected to have the required means for interaction)

Note: 1): spots where danger of accidents accumulates
Source: FEV

Mobile network availability as well as interface security are considered to be key enablers for safe CAV deployment

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KEY TAKEAWAYS FOR CAV POLICY (2/2)

- It is recommended to establish systems and frameworks which can leverage large CAV fleet data (e.g. detected obstacles such as potholes) to improve road network operation
- Authorities should actively consider and seek engagement to contribute to HD Maps by identifying internal data sources ("data mining") and establish framework to share data with map providers
- The broad availability of high-performance mobile networks is considered to be a core enabler of CAV (e.g. to improve availability for SW/HD map updates)
- Given the large amount of interfaces of future CAVs, the different attack vectors and related risk should be considered during vehicle licensing/homologation
- Infrastructure should allow for coexistence of automated and non-automated driving cars in 2025, e.g. provide public car parks that enable mixed applications rather than car parks with dedicated drop-on/drop-off zones for CAVs only

Source: FEV

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In the first step, we have defined CAV characteristics of a baseline vehicle in 2025

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Source: FEV

Agenda

- Step 1: Baseline CAV definition
  - Dimensions of baseline CAV
  - Key differences for Shuttle and LCV / HD CAV applications

The current standard for automated vehicle classification differentiates between six automation levels

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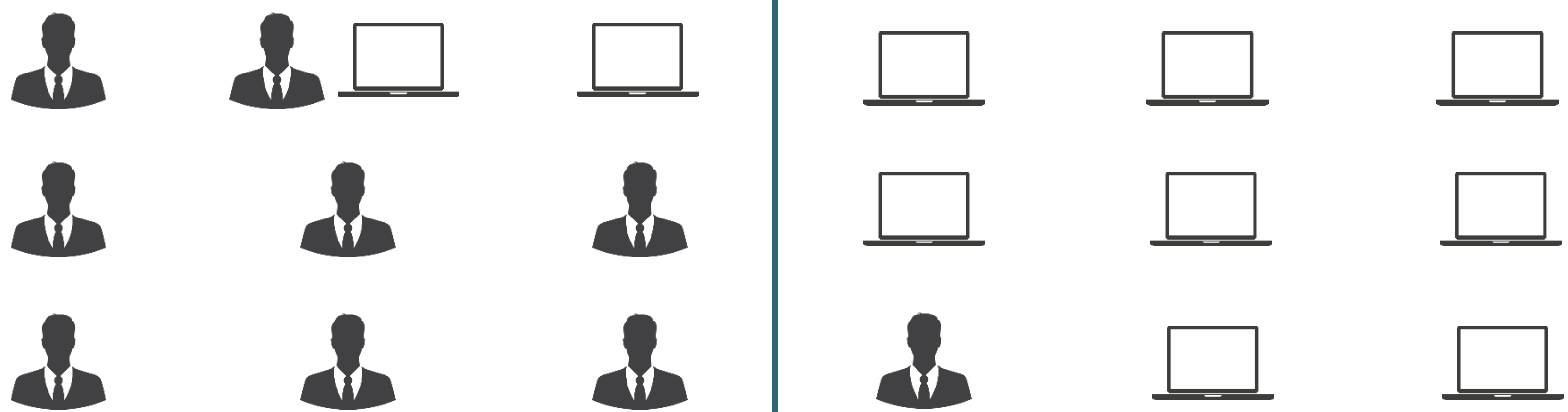
	Driver Liability			(Partial) System Liability		
Automation Level (SAE)	0 - No Automation	1 - Driver Assistance *(long. or lateral)*	2 - Partial Automation *(long. and lateral)*	3 - Conditional Automation *(Driver fallback)*	4 - High Automation *(No driver fallback in ODD)*	5 - Full Automation *(No restrictions)*
						?
Execution of Steering and Acceleration/ Deceleration						
Monitoring of Driving Environment						
Fallback Performance of Dynamic Driving Task						
System Capability (Driving Modes)	n/a	Some driving modes	Some driving modes	Some driving modes	Some driving modes	All driving modes



Note: ODD = Operational Design Domain
Source: SAE, FEV

Picture Sources: Lada, VW, BMW, Audi, Waymo

The 2025 baseline CAV entails Highway Pilot, AEB and Parking Chauffer enabled by means of multiple sensors and communication

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BASELINE CONNECTED AND AUTOMATED VEHICLE

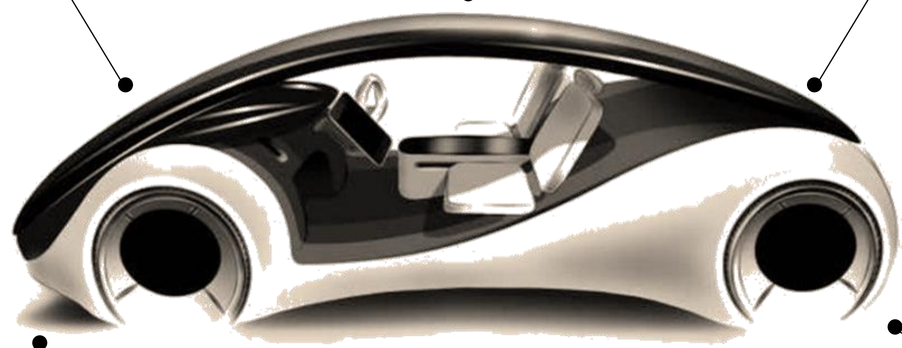
SAE LEVEL 4

Vehicle type

- Executive / luxury car
- Premium segment

Automation functions

- Highway Pilot (L4)
- AEB (L1)
- Parking Chauffeur (L3)



Sensor types

- Ultrasonic
- Camera (surround, tri-camera, infrared)
- Radar (SR/MR/LR)
- LiDAR (solid state)
- GNSS, HD Map

BASELINE CAV

2025

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Source: FEV

Picture Sources: SAE, Apple

The vehicle type of the 2025 baseline CAV was defined as a premium segment executive / luxury car

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BASELINE CAV – VEHICLE TYPE: EXECUTIVE AND LUXURY CARS (PREMIUM SEGMENT)

Mercedes E-Class

Tesla Model S

Porsche Panamera

1. Mainstream vehicles (i.e. small and medium cars) not expected to have advanced automation functions beyond L2 by 2025
2. Premium cars are technological pioneers esp. within multi-brand companies (e.g. Audi→VW); delta until premium AD features go mainstream expected at 3-7 a (OEM specific)
3. L1/L2 ADAS functions already implemented in most premium cars (e.g. ACC, LKA/LCA, AEB, PA); selected vehicles already with L3 TJC (e.g. Audi A8)

Note: ADAS = Advanced Driver-Assistance System; ACC = Adaptive Cruise Control; LKA = Lane Keep Assist; LCA = Lane Change Assist; PA = Park Assist; TJC = Traffic Jam Chauffeur
Source: ACEA, FEV

Picture Sources: Daimler, Tesla, Porsche

By 2025 superordinate automation functions in premium vehicles are expected to be AEB (L1), Parking Chauffeur (L3) and Highway Pilot (L4)

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BASELINE CAV – AUTOMATION FUNCTIONS: HIGHWAY PILOT, PARKING CHAUFFEUR AND AEB

FUNCTION	DESCRIPTION	SAE LEVEL	ODD
Autonomous Emergency Braking (AEB)	Warns driver, prompts to intervene and simultaneously preconditions brakes for faster response in case of imminent danger of collision. If no action is taken and collision is still expected, brakes are applied autonomously to avoid or mitigate a collision and (in some cases) vehicle & restraint system are prepared for impact	SAE LEVEL 1	Anywhere

- AEB is state-of-the-art in most executive / luxury cars (e.g. Audi A6, Volvo S90) → required by EURO NCAP for 5-star rating
- In the past functionalities required by EURO NCAP regularly became part of EU directive 2007/46 (e.g. ABS, ESP)

FUNCTION	DESCRIPTION	SAE LEVEL	ODD
Parking Chauffeur	Allows to complete maneuvering into and out of dedicated parking spaces, garages or driveways. During the parking maneuver driver does not have to be inside the vehicle. If system is not capable to complete maneuver, the vehicle is brought to standstill and driver is requested to take over control	SAE LEVEL 3	Parking lots

- PA / Remote PA (L2) already state-of-the-art (e.g. BMW 5er); Parking lots favorable for higher automation due to e.g. low speed
- No exclusive public premium car parks for Valet Parking (L4) exp. by 25'; L3 Parking feasible in mixed environments (AD/no AD cars)

FUNCTION	DESCRIPTION	SAE LEVEL	ODD
Highway Pilot	Automated Driving up to 130 kph on motorways or similar roads from entrance to exit, incl. overtaking. System must be deliberately activated and can be constantly overridden or switched off by the driver. Within ODD, driver does not have to monitor system nor take-over operation, as system works fail operational	SAE LEVEL 4	Highway

- Highway comparatively favorable environment for L4 (No VRU / oncoming traffic / intersection, dedicated emergency / exit lane, etc.)
- L4 highway applic. have been extensively tested by OEMs; TJC (L3) already commercially available in Audi A8[1] and Cadillac CT6

Note: 1): Only technically usable – not permitted by regulations yet; ODD = Operational Design Domain; PA = Park Assist; VRU = Vulnerable Road Users (e.g. pedestrians, cyclists)
Source: FEV

Picture Sources: SAE

Multiple, in part redundant sensors including ultrasonic, camera, radar and LiDAR are required to ensure functional reliability of baseline CAV

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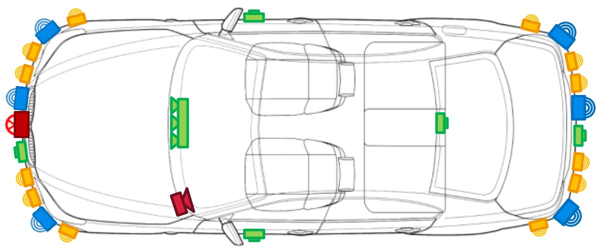
BASELINE CAV – SENSOR TYPES: ULTRASONIC, CAMERA, RADAR & LIDAR



LiDAR | Surround / rear cam | Radar
Ultrasonic | Tri-cam | Infrared cam

VIEW		SENSORS
Front	M/L-range	LiDAR, Radar, Tri-cam
Front	S-range	Radar, Surround cam, Tri-cam, Ultrasonic
Rear	All ranges	Radar, Surround / rear cam, Ultrasonic
Driver behavior		Infrared cam

Note: M/L-range = Mid- and Long-range; S-range = Short-range
Source: FEV

- Baseline CAV will require a comprehensive sensor set
  - sensor set provided represents most likely combination based on series, concept and fleet test applications of different OEMs as well as technology roadmaps of major Tier-1 suppliers
- Only fusion of multiple sensors will offer required performance under all circumstances, as sensor functionality may be limited by
  - technical boundaries (e.g. field of view, object classification, velocity resolution, etc.) and
  - environmental conditions (e.g. weather, illumination)
- High redundancy required for L4 Automation, as system shall be fail operational
  - driver behavior only tracked by infrared cameras, as driver is not required as fallback level
- GNSS & HD Map reduce reliance purely on HW-sensors
- Sensors must enable 360° view for e.g. parking

Picture Sources: here, punto flotante

Baseline CAV is equipped with network uplink and interface for direct communication; V2N and possibly V2I will be used for AD functionalities

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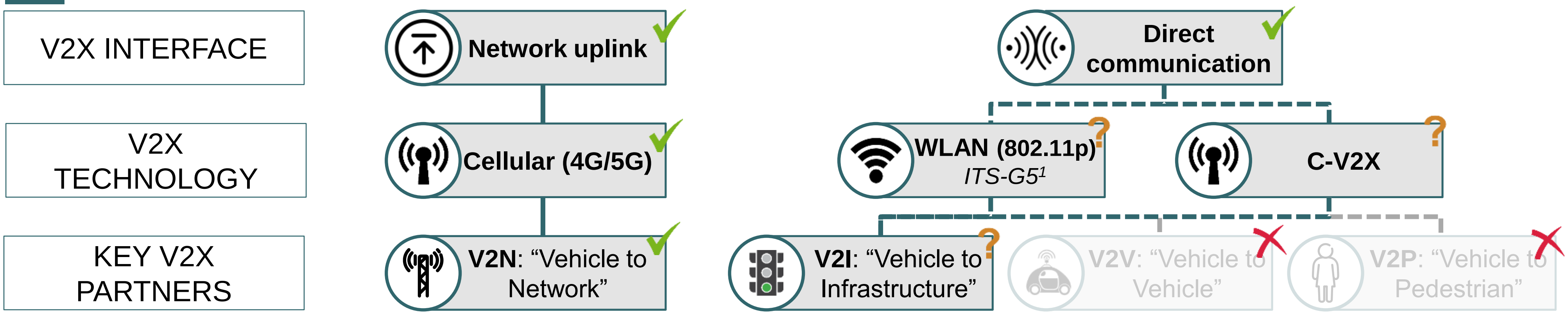
BASELINE CAV – DATA INTERFACES



- Cellular uplink enabling V2N expected to be implemented in all premium vehicles by '25 (→ already state-of-the-art)
- Hardware interface for direct communication expected to be installed in most premium vehicles by '25, but not final decision on technology focus yet; competing technologies are C-V2X (3GPP Rel 14 and higher) and 802.11p
  - Chinese govt decided on C-V2X mandate; EU incorporated 802.11p in latest draft, but no final decision yet
  - US was pushing 802.11p in the past but has recently stopped proceedings without providing further background
  - VW already implements 802.11p interface in selected mainstream vehicles (e.g. VW GOLF) starting '19
- Most likely first direct communication path is V2I; V2V and V2P expected later due to larger interdependencies and uncertainties:
  - software communication standards are not yet defined (e.g. different authentication protocols) and
  - unclear interoperability across different vehicle brands

Note: 1) Since our baseline vehicle region is Europe the according standard is selected
Source: FEV

Agenda

- Step 1: Baseline CAV definition
  - Dimensions of baseline CAV
  - Key differences for Shuttle and LCV / HD CAV applications

Compared to the baseline CAV, shuttles have higher requirements towards short range sensors while long range sensors are of minor importance

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HIGH LEVEL COMPARISON – PASSENGER BASELINE CAV VS. SHUTTLE

BASELINE CAV

VS.

SHUTTLE

KEY EXPECTED DIFFERENCES

- State of the art vehicle today follows a "virtual" track (GNSS waypoint)
  - more restricted ODD
- Vehicle speed is (very) low (depending on the passenger restraints system) and in any case much lower than the baseline CAV
- More extensive VRU interaction
- Prediction of VRU's behavior is more complex than in an highway environment
- Vehicles usually are under the (remote) control of an operator / steward

» Less long range sensors are needed

» High importance of short range detection sensors

» More direct communication reliance

Source: FEV

Picture Sources: Navya, Apple

Market introduction of highly automated functions is expected to be delayed in HD / LCV as long as driver cannot be omitted by regulation

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HIGH LEVEL COMPARISON – PASSENGER BASELINE CAV VS. HD / LCV

BASELINE CAV

VS.

HD / LCV

KEY EXPECTED DIFFERENCES

- Highly TCO sensitive
  - Higher cost for development due to numerous vehicle variants (e.g. with / without trailer) & changing vehicle weights (affects e.g. braking)
  - Large benefits only when driver can be omitted
- Longer development cycle than passenger vehicles
- First automation functions focused on traffic safety (e.g. AEB, BSD, Sideguard Assist)
- Direct communication may enable both, V2I (mainly depot handling) and V2V (mainly platooning)

» Delayed introduction of highly automated functions[1]

» High take rates after (delayed) market introduction

» More complex sensor set-up and control algorithm

» Direct communication highly important for HD

Note: 1): Earlier deployments in selected, closed ODDs possible; HD = Heavy Duty; LCV = Light Commercial Vehicles; BSD = Blind Spot Detection
Source: FEV

Picture Sources: Daimler, Apple

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In the second step, we will analyze the set of information that the CAV extracts through its sensors and communication

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1) Light Commercial Vehicles; 2) Heavy Duty
Source: FEV

We have defined relevant sets of information based on multiple data sources; Sets of information were abstracted to same level of detail

DATA SOURCES FOR INTERFACE ANALYSIS

Sets of information extracted through sensors and data interfaces were **consolidated** based on

FEV network knowledge

Data logger of FEV smart vehicle demonstrator

CAV projects with OEM/Tier-1, e.g. function calibration or benchmarking

Desktop research / technical literature review

Target was to abstract to a **common level of detail** to derive an **implementation-agnostic** information list

Source: FEV

Picture Sources: Apple

Agenda

- Step 2: Interface analysis
  - Strengths and weaknesses of sensor types
  - Feature list: Autonomous Emergency Braking
  - Feature list: Parking Chauffeur
  - Feature list: Highway Pilot

Ultrasonic sensors are applicable for short distance obstacle detection; maximum range of cameras strongly depends on implemented lenses

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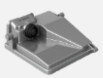
STRENGTHS AND WEAKNESSES OF SENSOR TYPES (1/4)

		Description	Selected applications	Distance	Strengths	Challenges
Ultrasonic		■ Detects echo from a signal to determine distance and motion of an object ■ Mainly used for short distance obstacle detection (0.2-5.0 m range)	■ Park Assist ■ Blind Spot Monitor ■ Side View Assist ■ Rear cross traffic alert	< 10 m	■ Color and reflectivity don't affect ultrasound ■ Functions in wet environments ■ Low cost ■ Size	■ Low range ■ Dirt ■ Susceptible to pressure or wind ■ Horizontal resolution
(Surround) Camera	 	■ Combination of lens, imager, processor and dedicated computer vision algorithms in single housing ■ Used for object classification, measuring distance and velocity – Mono cam: creates 3D image by time-Δ of 2 successive images – Stereo cam: creates 3D image by using two cameras	■ ACC ■ LDW / LKA / LC ■ FCW / AEB ■ TSR ■ TJA ■ Object Detection ■ Pedestrian Detection	< 250 m (depen-ding on lenses)	■ Object classification ■ Can see lanes and traffic signs – Able to distinguish colors ■ Detects objects of any composition	■ Low illumination ■ Weather conditions ■ Data volume ■ Size (only for multiple lenses) ■ Dirt
Tri-focal camera		■ Uses 3 mono cams with different lenses for different detection ranges – Short-range: ~140° FOV – Mid-range: ~45° FOV – Long-range: ~34° FOV				

Note: FOV = Field of view; LDW = Lane Departure Warning; LC = Lane Centering; TSR = Traffic Sign Recognition; TJA = Traffic Jam Assist; FCW = Front Collision Warning
Source: FEV

Picture Sources: Bosch, Continental, ZF, Mobileye

LRR and LiDARs applied for object detection at far range; short-mid range radars utilized in addition to ultrasonic and cameras at near range

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STRENGTHS AND WEAKNESSES OF SENSOR TYPES (2/4)

		Description	Selected applications	Distance	Strengths	Challenges
Short-mid range radar		▪ Radio waves emitted to determine range, angle, or velocity of objects ▪ Used to detect forward & peripheral objects at near range – Frequency[1]: 77 GHz – Accuracy: ± 0.2 m – HFOV[2]: ~100°-170°	▪ Blind Spot Detection ▪ Parking Assist ▪ Cross Traffic Alert ▪ Lane Change Assist	< 100 m	▪ Precise range and velocity tracking ▪ Works at night ▪ Reduced weather dependence ▪ Robustness	▪ Placement on vehicle ▪ Angular resolution ▪ Interference ▪ Object classification
Long range radar		▪ Radio waves emitted to determine range, angle, or velocity of objects ▪ Used to detect objects at far range – Frequency: 77-79 GHz – Accuracy: ± 0.1 m – HFOV[1]: ~20°-60°	▪ ACC ▪ FCW / AEB ▪ …necessary in nearly all other AD level 2-4 functions	< 250 m		
LiDAR	 	▪ Lasers emitted to determine range, angle, or velocity of objects ▪ Provides real-time 3D images – Solid-state LiDAR: non-rotating scanner with ~25-140° FOV – Scanning LiDAR: rotating scanner with 360° FOV	▪ ACC ▪ FCW / AEB ▪ Cross-traffic alert ▪ Parking Assist ▪ Object detection	< 300 m	▪ May provide 3D and 360° surround view w/ one sensor unit ▪ Precise distance and angular measurement	▪ Costs ▪ Difficult to integrate ▪ Weather conditions ▪ Dirt ▪ Degradation of rotating mechanical parts (only for scanning)

Note: 1): Currently used 24 GHz radars will be replaced by 77 GHz; 2): Highly range depending; HFOV = Horizontal field of view
Source: FEV

Picture Sources: Velodyne, Bosch, Continental

Infrared cameras used to monitor drivers' behavior; HD Maps and GNSS enable to pin-point the vehicle's location with high accuracy

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STRENGTHS AND WEAKNESSES OF SENSOR TYPES (3/4)

		Description	Selected applications	Distance	Strengths	Challenges
Infrared		▪ Uses infrared radiation to detect the infrared energy emitted, transmitted or reflected by different objects ▪ Hence, it is able to detect objects in darkness ▪ Also used for in-cabin driver monitoring	▪ Object detection ▪ Pedestrian detection ▪ Night vision ▪ In-cabin driver monitoring	< 100 m	▪ Low Cost ▪ Enhances night vision ▪ Enables driver monitoring	▪ Sensitive to glare from headlights ▪ Cannot be positioned behind regular glass
GNSS		▪ GNSS consists of a satellite network in precise orbits transmitting location and time information (coded radio signals) ▪ Receiver measures distance to all satellites whose signals it receives and determines its position	▪ GNSS combined with tachometers, altimeters and gyroscopes used to pin-point the vehicle's location with high accuracy	NA	▪ Many augmentation methods available	▪ Orbital errors create location inaccuracies ▪ Spoofing
HD Map		▪ Maps for automated driving with high accuracy, commonly – 10 cm longitudinal & 5 cm lateral ▪ Target is constant updates from supplier or through crowdsourcing	▪ Used for environmental models for AD	NA	▪ Reduces reliance purely on HW sensors ▪ Highly accurate ▪ Real-time capable	▪ Full functionality requires constant data connection (& sometimes high bandwidth)

Source: FEV

Picture Sources: here, punto flotante, Speedir

Network uplinks enables the communication between vehicle and network; Direct communication enables V2I, V2V and V2P use cases

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STRENGTHS AND WEAKNESSES OF SENSOR TYPES (4/4)

		Description	Selected applications	Distance	Strengths	Challenges
Network uplink		■ Network uplink enables communication between the vehicle and the network (V2N) ■ Operation in cellular broadband spectrum	■ Software update of vehicle / HD Map ■ Hazard warnings ■ Weather information ■ Traffic information ■ Remote video conferencing	NA	■ Leverages existing cellular infrastructure ■ Benefits from current tech evolution (4G → 5G) ■ Large number of applications possible	■ Not operational without network coverage ■ Dependency on local network performance ■ Cybersecurity ■ Possible subscription fees required
Direct communication		■ Direct communication enables direct peer-to-peer communication between the vehicle & – infrastructure (V2I) – other vehicles (V2V) and – pedestrians (V2P) ■ Operation in the ITS 5.9 GHz band	■ In-vehicle signage ■ Slow or stationary vehicle(s) & traffic ahead warning ■ Emergency brake lights ■ Pedestrian warning ■ Traffic signal priority request by designated vehicles	< 1 km	■ Operational without network coverage ■ No subscription required ■ Low latency & high bandwidth	■ Unclear technology focus (C-V2X vs. 802.11p) ■ Interoperability across different brands and regions ■ High required fleet penetration for use cases ■ Cybersecurity

Source: FEV

Picture Sources: Cohda, Motorola

In comparison, sensor types have dedicated strengths and weaknesses depending on the desired functionality

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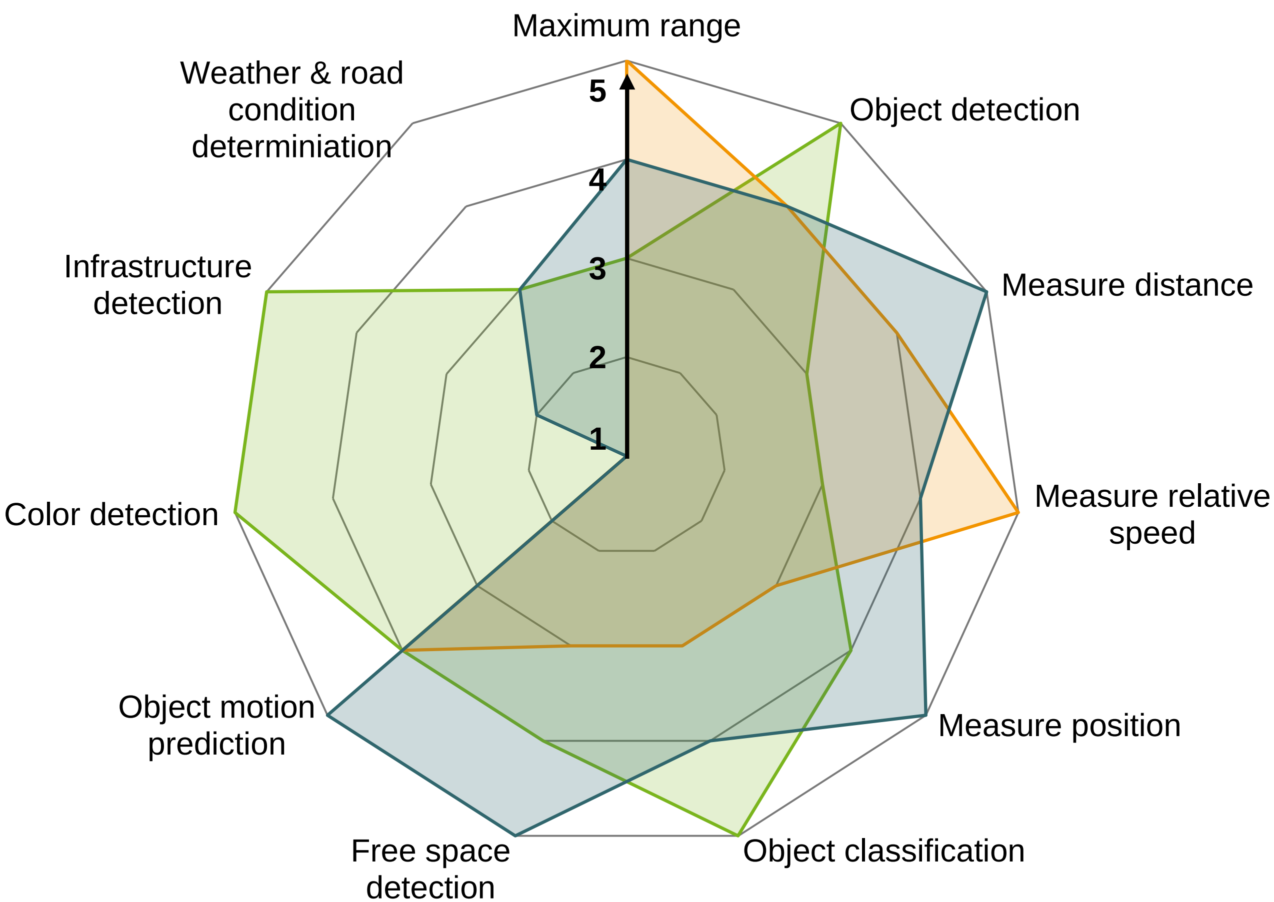
AGGREGATED COMPARISON OF KEY CAV SENSORS: CAMERA, RADAR AND LIDAR



Key Comments

- Camera has a broad set of strengths, especially regarding detection and classification
- Radar's key strengths are the measurement of relative speed (native by doppler effect) and long range
- LiDAR is especially suitable for spatial recognition, trajectory prediction and measurement
- Visibility conditions have a significant impact on sensor performance
  - Largest negative effect on camera
  - Radar performance most robust
  - Medium impact on LiDAR

Camera Radar LiDAR

1 = worst → 5 = best

Source: FEV

Agenda

- Step 2: Interface analysis
  - Strengths and weaknesses of sensor types
  - Feature list: Autonomous Emergency Braking
  - Feature list: Parking Chauffeur
  - Feature list: Highway Pilot

Connected and Autonomous Vehicles Feature List

FEV CONSULTING

AUTONOMOUS EMERGENCY BRAKING – LONGITUDINAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
Vehicle data	ABS status	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Engine status	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Restraint system status	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Steering angle	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Vehicle acceleration	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Throttle pedal position	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Vehicle deceleration	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Brake pedal position	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Vehicle speed	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Yaw rate	●	○	○	○	○	○	○	○	○	○	○	○

- AEB is activated by default when engine is switched on
- AEB is deactivated when malfunction of ABS, engine or restraint system is detected
- No autonomous braking of AEB, if driver interaction is detected (e.g. Δ steering angle, Δ brake pedal position)
- Yaw rate is the angular velocity of a rotation around the yaw axis of the vehicle (vertical axis)

Source: FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Connected and Autonomous Vehicles
Feature List

FEV CONSULTING

AUTONOMOUS EMERGENCY BRAKING – LONGITUDINAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
Vehicle data	Gear mode	●	○	○	○	○	○	○	○	○	○	○	○
Objects	Obstacle validity	○	○	○	●	○	●	●	●	●	○	○	○
Objects	Relative position X	○	○	○	●	○	◑	●	◕	◑	○	○	○
Objects	Relative speed X	○	○	○	◑	○	◑	◕	●	○	○	○	○
Objects	Length	○	○	○	●	○	◑	◑	◑	○	○	○	○
Objects	Width	○	○	○	●	○	◑	●	◕	○	○	○	○
Objects	Height	○	○	○	●	○	◑	◑	◑	○	○	○	○
Updates	Vehicle software update	○	●	○	○	○	○	○	○	○	○	○	○

- AEB is deactivated if reverse gear is engaged, but some OEMs currently work on reverse AEB
- Identification of relative position, relative speed and dimensions of objects (e.g. vehicle, pedestrian, cyclist) in environment to warn driver or mitigate / avoid collision
  - Object dimensions required to determine its boundaries and classify objects (e.g. in vehicles, pedestrian, etc.)
  - Object detection data is validated by sensors
- Over-the-air software updates for vehicle features (e.g. specific ECUs)

Source: FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Agenda

- Step 2: Interface analysis
  - Strengths and weaknesses of sensor types
  - Feature list: Autonomous Emergency Braking
  - Feature list: Parking Chauffeur
  - Feature list: Highway Pilot

Connected and Autonomous Vehicles Feature List

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PARKING CHAUFFEUR – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
HMI input	Parking Chauffeur on/off	●	○	○	○	○	○	○	○	○	○	○	○
HMI input	Parking spot selection	●	○	○	○	○	○	○	○	○	○	○	○
HMI input	Driving direction	●	○	○	○	○	○	○	○	○	○	○	○
HMI input	Parking maneuver start/stop	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Steering angle	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Vehicle acceleration	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Throttle pedal position	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Vehicle deceleration	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Brake pedal position	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Vehicle speed	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Yaw rate	●	○	○	○	○	○	○	○	○	○	○	○

- Driver must activate Parking Chauffeur (on/off), select parking spot from recommendation(s) of system, choose driving direction (forward/reverse) and initiate or stop parking maneuver
- During parking procedure, vehicle data (e.g. steering angle, throttle pedal position, vehicle speed) is monitored and adapted according to requirements of specific parking situation

Source: FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Connected and Autonomous Vehicles Feature List

FEV CONSULTING

PARKING CHAUFFEUR – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
Objects	Obstacle validity	○	○	○	●	●	●	●	●	●	○	○	○
Objects	Relative position X	○	○	○	●	●	●	●	◕	◕	○	○	○
Objects	Relative position Y	○	○	○	●	●	●	●	◕	◕	○	○	○
Objects	Relative speed X	○	○	○	◑	◑	◑	◕	●	○	○	○	○
Objects	Relative speed Y	○	○	○	◑	◑	◑	◕	●	○	○	○	○
Objects	Length	○	○	○	●	◕	◕	◑	◑	◕	○	○	○
Objects	Width	○	○	○	●	◕	◕	●	◕	◕	○	○	○
Objects	Height	○	○	○	●	◕	◕	◑	◑	◕	○	○	○

- Identification of relative position, relative speed and dimensions of objects (e.g. vehicle, pole, bicycle) in parking environment
  - Object dimensions required to determine its boundaries
  - Object detection data is validated by sensors

Source: FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Connected and Autonomous Vehicles
Feature List

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PARKING CHAUFFEUR – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
Traffic regulation	Traffic signs	○	◕	●	●	○	●	◑	○	○	○	○	●
Road	Lane marking type	○	○	○	●	●	●	◑	○	○	○	○	◕
Road	Lane curvature	○	○	○	●	●	●	◑	◔	○	○	○	●
Road	Road markings	○	○	○	●	●	●	◑	○	○	○	○	●
Road	Road boundary	○	○	○	●	●	●	◕	◕	○	○	○	●
Parking space size	Length	○	○	○	●	◕	◕	●	◕	◕	○	○	○
Parking space size	Width	○	○	○	●	◕	◕	●	◕	◕	○	○	○
Updates	HD Map update	○	●	○	○	○	○	○	○	○	○	○	○
Updates	Vehicle software update	○	●	○	○	○	○	○	○	○	○	○	○

- Detection of traffic signs (e.g. disabled parking, restricted parking time) and road attributes for parking spot selection
  - Lane marking type includes information on geometry, color, style and material of lanes (e.g. u-shaped parking spot marking)
  - Road markings include arrows, words and symbols (e.g. zig zag line); road boundaries include artificial or natural boundaries (e.g. curb, guardrail, bushes)
- Detection of parking space dimensions and simultaneous comparison with vehicle dimensions to determine parking spot suitability
- Updates for dynamic (e.g. accidents, congestion, weather), semi-static (e.g. road closures, speed limit changes) and static layer (e.g. road boundaries, lane centerlines) of HD Map

Source: FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Agenda

- Step 2: Interface analysis
  - Strengths and weaknesses of sensor types
  - Feature list: Autonomous Emergency Braking
  - Feature list: Parking Chauffeur
  - Feature list: Highway Pilot

Connected and Autonomous Vehicles Feature List

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HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
HMI input	HWP set speed	●	○	○	○	○	○	○	○	○	○	○	○
HMI input	HWP resume/cancel	●	○	○	○	○	○	○	○	○	○	○	○
HMI input	HWP on/off	●	○	○	○	○	○	○	○	○	○	○	○
HMI input	Drive mode	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Steering angle	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Vehicle acceleration	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Throttle pedal position	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Vehicle deceleration	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Brake pedal position	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Vehicle speed	●	○	○	○	○	○	○	○	○	○	○	○

- Highway Pilot settings include maximum vehicle speed, temporary function interruption and activation/deactivation
- Drive Mode alters vehicle's driving characteristics by changing aspects such as steering, engine or gearbox settings
- Vehicle data (e.g. steering angle, throttle pedal position, vehicle speed) is monitored and adapted according to requirements of driving task

Source: FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Connected and Autonomous Vehicles
Feature List

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HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
Vehicle data	Wheel torques	●	○	○	○	○	○	○	○	○	○	○	○
Vehicle data	Yaw rate	●	○	○	○	○	○	○	○	○	○	○	○
Positioning	Longitude	○	○	○	○	○	○	○	○	○	○	●	●
Positioning	Latitude	○	○	○	○	○	○	○	○	○	○	●	●
Positioning	Altitude	○	○	○	○	○	○	○	○	○	○	●	●
Positioning	Timestamp	○	○	○	○	○	○	○	○	○	○	●	○
Road	Lane marking type	○	○	○	●	○	◕	◑	○	○	○	○	◕
Road	Lane assignment	○	○	○	●	○	◕	◑	◔	○	○	○	●
Road	Lane curvature	○	○	○	●	○	◕	◑	◔	○	○	○	●
Road	Road markings	○	○	○	●	○	◕	◑	○	○	○	○	●

- Localization of vehicle to determine its position in driving environment (e.g. lane assignment, vicinity of junctions)
- Detection of road attributes for longitudinal and lateral control of vehicle
  - Lane marking type includes information on geometry, color, style and material of lanes (e.g. solid/dashed lanes)
  - Lane assignment describes allocation of the vehicle to a lane on the road network
  - Road markings include arrows, words and symbols (e.g. speed limits, highway symbol)

Source: FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Connected and Autonomous Vehicles Feature List

FEV CONSULTING

HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
Road	Road boundary	○	○	○	●	○	◕	◕	◕	○	○	○	●
Road	Junction	○	○	○	●	○	◑	◑	◔	○	○	○	●
Road	Overpass	○	○	○	●	○	◑	◕	◕	○	○	○	●
Objects	Obstacle validity	○	○	○	●	●	●	●	●	●	○	○	○
Objects	Relative position X	○	○	○	●	◕	◑	●	◕	◑	○	○	○
Objects	Relative position Y	○	○	○	●	◕	◑	●	◕	◑	○	○	○
Objects	Relative speed X	○	○	○	◑	◑	◑	◕	●	○	○	○	○
Objects	Relative speed Y	○	○	○	◑	◑	◑	◕	●	○	○	○	○
Objects	Yaw angle	○	○	○	◕	◑	◑	●	◕	○	○	○	○
Objects	Yaw rate	○	○	○	◕	◑	◑	●	◕	○	○	○	○

- Detection of additional road attributes like junctions and overpasses (e.g. highway bridges)
- Identification of relative position, relative speed and yaw rate / angle of objects (e.g. vehicle, animal, pot hole) in driving environment to keep safety distance and avoid hazardous situation
  - Object detection data is validated by sensors

Source: FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Connected and Autonomous Vehicles Feature List

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HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
Objects	Length	○	○	○	●	◕	◑	◑	◑	○	○	○	○
Objects	Width	○	○	○	●	◕	◑	●	◕	○	○	○	○
Objects	Height	○	○	○	●	◕	◑	◑	◑	○	○	○	○
Traffic regulation	Traffic signs	○	◕	●	●	○	○	◑	○	○	○	○	●
Driver Monitoring	Body posture tracking	○	○	○	○	○	○	○	○	○	●	○	○
Driver Monitoring	Eye tracking	○	○	○	○	○	○	○	○	○	●	○	○
Weather	Weather conditions	●	◕	◕	◕	◑	◑	◑	○	○	○	○	◕
Updates	HD Map update	○	●	○	○	○	○	○	○	○	○	○	○
Updates	Vehicle software update	○	●	○	○	○	○	○	○	○	○	○	○

- Identification of object dimensions (i.e. length, width, height) to determine object boundaries and classify objects (e.g. in vehicles, animals, pot holes, etc.)
- Detection of traffic signs (e.g. speed limit, no overtaking, construction)
- Constant monitoring of driver's body posture and eye movement to determine his/her condition
  - In case driver cannot respond to TOR (take-over request), system goes into safe mode (e.g. vehicle stopped on safe lane)
- Weather conditions influence vehicle dynamics such as braking distance

Source: FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Connected and Autonomous Vehicles Feature List

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HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
Non Line-of-Sight (NLOS)	Other hazardous notifications	○	◕	●	○	○	○	○	○	○	○	○	◕
Non Line-of-Sight (NLOS)	Road works warning	○	◕	●	○	○	○	○	○	○	○	○	◕
Non Line-of-Sight (NLOS)	Probe vehicle data	○	◑	●	○	○	○	○	○	○	○	○	○

- **Other hazardous notifications / road works warning**: Road operator may communicate with drivers through V2I communication about road works, restrictions and instructions
- **Probe vehicle data** is data generated by vehicles. Contains vehicle positional information, timestamp and motion as well as driver actions and information on the environment (e.g. steering, braking, flat tire, windscreen wiper status, air bag status, weather and road surface conditions)
  – Probe data is used to manage traffic flows, maintain roads and to alert users in hot spots, where the danger of accidents accumulates

Source: c-roads, FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Connected and Autonomous Vehicles Feature List

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HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Vehicle	Network	Direct	Tri cam	Rear cam	Surround cam	LiDAR	Radar	Ultra-sonic	Infrared cam	GNSS	HD Map
Non Line-of-Sight (NLOS)	Shockwave damping / local hazard warning	○	◕	●	○	○	○	○	○	○	○	○	◕
Non Line-of-Sight (NLOS)	Slow or stationary vehicle(s) & traffic ahead warnings	○	◕	●	○	○	○	○	○	○	○	○	○
Non Line-of-Sight (NLOS)	Emergency vehicle approaching	○	◕	●	○	○	○	○	○	○	○	○	○

- **Shockwave damping / local hazard warning** aims to smooth the flow of traffic, by damping traffic/shock waves. Real-time traffic data is used to feed advisory speeds to cars to smooth out speed variations
- **Slow or stationary vehicle(s) & traffic ahead warnings**: A slow or stationary vehicle can signal its presence to other vehicles. This improves traffic fluidity by encouraging other vehicles to take an alternative route
- **Emergency vehicle approaching:** Information provided by the emergency vehicle to help the driver on how to clear the road, even when the siren and light bar may not yet be audible or visible

Source: c-roads, FEV

○ Not suitable to provide information ◔ Low suitability ◑ Medium suitability ◕ High suitability ● Very high suitability

Agenda

- Project approach and executive summary
- Step 1: Baseline CAV definition
- Step 2: Interface analysis
- Step 3: Criticality assessment
- Contacts
- Appendix

In the third step, we will assess the criticality of information extracted from the environment and identify the most critical sets of information

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PROJECT APPROACH

1 Step 1: Baseline Definition

- Define baseline connected and automated vehicle for the study
- Includes the following dimensions:
  - Vehicle type
  - SAE level of automation
  - Realized automation functionality
  - Sensor types used
  - Available data interfaces
- Brief outline of key differences for LCV[1] and HD[2] CAV applications

2 Step 2: Interface Analysis

- Analysis of the different interfaces of the defined baseline CAV
- Includes the analysis of the information extracted through the following interfaces:
  - Sensor based
  - Connectivity / V2X
- Strengths and weaknesses of the different sensor types for extracting the relevant sets of information

3 Step 3: Criticality Assessment

- Assessment of the criticality regarding the automated driving task for the different sets of information identified previously
- Identification of most critical sets of information and their origin (e.g. only from LiDAR)

1) Light Commercial Vehicles; 2) Heavy Duty
Source: FEV

We have assessed the previously identified sets of information in two main dimension: availability and criticality

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ASSESSMENT DIMENSIONS IN THE CRITICALITY ASSESSMENT

Availability

Describes the degree of reliability with which a set of information is actually available. Mainly determined by the number and suitability of sensors to provide a particular set of information as well as the robustness of the sensors

- **Number of sensors**
  Is the set of information provided by a single sensor unit or multiple independent sensor units?
- **Suitability of sensors**
  How is the suitability of the applied sensors to provide the particular set of information?
- **Robustness of sensors**
  How robust are the applied sensors against changing environmental conditions?

Criticality

Describes how critical a set of information is to ensure functional capability and safety of an automated driving function. Mainly determined by functional and safety relevance of a set of information as well as its contextuality

- **Functionality**
  Is the set of information relevant to ensure functionality of the AD function?
- **Safety**
  Is the set of information relevant to ensure permanent safety of the vehicle when the AD function is active?
- **Contextuality**
  Can the set of information be abstracted from other information that are extracted from the environment?

Note: AD = Automated Driving
Source: FEV

Agenda

- Step 3: Criticality assessment
  - Availability & criticality: Autonomous Emergency Braking
  - Availability & criticality: Parking Chauffeur
  - Availability & criticality: Highway Pilot
  - Conclusion

Connected and Autonomous Vehicles
Availability & Criticality Assessment

FEV CONSULTING

AUTONOMOUS EMERGENCY BRAKING – LONGITUDINAL CONTROL

Information set group	Set of information	Availability	Criticality
Vehicle data	ABS status	●	●
Vehicle data	Engine status	●	●
Vehicle data	Restraint system status	●	●
Vehicle data	Steering angle	●	●
Vehicle data	Vehicle acceleration	●	●
Vehicle data	Throttle pedal position	●	●
Vehicle data	Vehicle deceleration	●	●
Vehicle data	Brake pedal position	●	●
Vehicle data	Vehicle speed	●	●
Vehicle data	Yaw rate	●	●

- Availability of vehicle data is ensured by safety regulations (e.g. VDA, ISO26262) and OEM specific requirements (e.g. HW input, CAN redundancy) → high robustness
- Criticality very high for all vehicle data information sets as they are the backbone for the functionality
  - Status of ABS, engine and restraint system required for functional capability of AEB
  - Vehicle dynamics (e.g. vehicle acceleration, yaw rate) required to determine necessary braking pressure
  - Information on changing vehicle characteristics (e.g. steering angle, brake pedal position) required to detect driver intervention

Note: AEB = Autonomous Emergency Barking
Source: FEV

○ No availability / criticality ◔ Low availability / criticality ◑ Medium availability / criticality ◕ High availability / criticality ● Very high availability / criticality

Connected and Autonomous Vehicles
Availability & Criticality Assessment

FEV CONSULTING

AUTONOMOUS EMERGENCY BRAKING – LONGITUDINAL CONTROL

Information set group	Set of information	Availability	Criticality	
Vehicle data	Gear mode	●	◔	
Objects	Obstacle validity	◕	●	
Objects	Relative position X	◕	●	
Objects	Relative speed X	◑	●	⚠
Objects	Length	◑	◑	
Objects	Width	◕	●	
Objects	Height	◑	◑	
Updates	Vehicle software update	◑	◔	

⚠ Highly critical and restricted in availability

- If gear mode is unknown, AEB is continuously activated → no impact on functionality of AEB
- Accurate and continuously available information on relative position & speed of objects required for AEB to assure reliability and safety
- Object width more critical than length and height, as it is only relevant parameter to calculate overlap ratio between ego and target vehicle → information set relevant to assure safety
- Over-the-air software updates of vehicle should not have an immediate impact on safety or functionality of automation features
- High redundancy and suitability of sensors to provide information on rel. position & object width
- Very high accuracy of relative speed only with radar, as other sensors are using either indirect measurement or algorithms → low suitability
- Information availability strongly fluctuates with changing environment. conditions (esp. limitations of cameras at low visibility) → low robustness

Note: AEB = Autonomous Emergency Barking
Source: FEV

○ No availability / criticality
◔ Low availability / criticality
◑ Medium availability / criticality
◕ High availability / criticality
● Very high availability / criticality

Agenda

- Step 3: Criticality assessment
  - Availability & criticality: Autonomous Emergency Braking
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Connected and Autonomous Vehicles
Availability & Criticality Assessment

FEV CONSULTING

PARKING CHAUFFEUR – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Availability	Criticality
HMI input	Parking Chauffeur on/off	●	●
HMI input	Parking spot selection	●	●
HMI input	Driving direction	●	◔
HMI input	Parking maneuver start/stop	●	●
Vehicle data	Steering angle	●	●
Vehicle data	Vehicle acceleration	●	●
Vehicle data	Throttle pedal position	●	○
Vehicle data	Vehicle deceleration	●	●
Vehicle data	Brake pedal position	●	◕
Vehicle data	Vehicle speed	●	●
Vehicle data	Yaw rate	●	◔

- Criticality very high for most HMI inputs and vehicle data information sets as they are the backbone for the functionality
  - Min. set of HMI inputs to ensure functional capability of PC include on/off, parking spot selection and parking maneuver start/stop
  - Forward driving direction set by the system after a default timeout → low criticality
  - Information on vehicle dynamics (e.g. steering angle, acceleration, yaw rate) required for parking control to assure reliability & safety
- Brake pedal position critical to abort the parking maneuver manually → functional relevance; change of throttle pedal position does not impact PC mode
- Availability of HMI input and vehicle data is ensured by safety regulations (e.g. VDA, ISO26262) and OEM specific requirements (e.g. HW input, CAN redundancy) → high robustness

Note: PC = Parking Chauffeur
Source: FEV

○ No availability / criticality ◔ Low availability / criticality ◑ Medium availability / criticality ◕ High availability / criticality ● Very high availability / criticality

Connected and Autonomous Vehicles
Availability & Criticality Assessment

FEV CONSULTING

PARKING CHAUFFEUR – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Availability	Criticality
Objects	Obstacle validity	●	●
Objects	Relative position X	●	●
Objects	Relative position Y	●	●
Objects	Relative speed X	◕	◕
Objects	Relative speed Y	◕	◕
Objects	Length	◕	◕
Objects	Width	●	◕
Objects	Height	◕	◔

- Relative speed of objects less critical than relative position as parking environment is rather static → lower impact on reliability and safety
- Object length and width relevant to determine object boundaries during parking maneuver → high safety relevance; height information primarily used for object classification
- Very high redundancy and suitability of sensors to provide information on relative position of objects (multiple cameras, radar, LiDAR and ultrasonic)
- Very high accuracy of relative speed only with radar, as other sensors are using either indirect measurement or algorithms → low suitability
- Higher suitability of sensors (i.e. LiDAR, radar) to detect width than to detect length and height
- Less impact of changing environmental conditions due to focus on short-range object detection → lower requirements towards robustness of sensors, thus generally higher availability

Source: FEV

○ No availability / criticality ◔ Low availability / criticality ◑ Medium availability / criticality ◕ High availability / criticality ● Very high availability / criticality

Connected and Autonomous Vehicles
Availability & Criticality Assessment

FEV CONSULTING

PARKING CHAUFFEUR – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Availability	Criticality	
Traffic regulation	Traffic signs	◕	◔	
Road	Lane marking type	◕	◑	
Road	Lane curvature	◕	◔	
Road	Road markings	◕	◔	
Road	Road boundary	◕	●	⚠
Parking space size	Length	●	●	
Parking space size	Width	●	●	
Updates	HD Map update	◑	◔	
Updates	Vehicle software update	◑	◔	

⚠ Highly critical & core IenW field

- Traffic signs (e.g. disabled parking), road markings and lane curvature to detect valid parking lots; driver is fallback level for decision making as parking maneuver is initiated manually → low impact on functionality and safety
- Lane marking type used to centralize vehicle in parking lot; otherwise centralization between two objects / boundaries → functional relevance
- Detection of parking space size and simultaneous comparison with vehicle dimensions required for functional capability (i.e. select parking spot)
  - Road boundaries (e.g. curb) required for parking sideways and to avoid collision
- HD Map data complements sensor data; continuous availability of updates not safety or functional relevant
- Very high redundancy and suitability of sensors to provide information on parking space size
- Less impact of changing environmental conditions due to focus on short-range object detection

Source: FEV

○ No availability / criticality ◔ Low availability / criticality ◑ Medium availability / criticality ◕ High availability / criticality ● Very high availability / criticality

Agenda

- Step 3: Criticality assessment
  - Availability & criticality: Autonomous Emergency Braking
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  - Conclusion

Connected and Autonomous Vehicles Availability & Criticality Assessment

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HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Availability	Criticality
HMI input	HWP set speed	●	○
HMI input	HWP resume/cancel	●	○
HMI input	HWP on/off	●	●
HMI input	Drive mode	●	○
Vehicle data	Steering angle	●	●
Vehicle data	Vehicle acceleration	●	●
Vehicle data	Throttle pedal position	●	◑
Vehicle data	Vehicle deceleration	●	●
Vehicle data	Brake pedal position	●	◑
Vehicle data	Vehicle speed	●	●

- HWP set speed only relevant for maximum preferred velocity of driver in case valid speed limit and traffic situation allows for it
  → functionality or safety are not affected
- HWP canceled if driver actively changes steering angle/vehicle speed; resume function only to take over previous settings (i.e. max. speed)
- Drive mode affects time gap between vehicles in HWP mode; safety distance maintained in all driving modes by object detection
- Actual vehicle steering angle, acceleration and deceleration are control functions of vehicle speed
  - Vehicle speed required for safe operation (e.g. measurement of safety distances)
- Brake/throttle pedal position not critical, as system must work fail operational (→ no mandatory take-over request) → no impact on functionality / safety
- Availability of vehicle data is ensured by safety regulations (e.g. VDA, ISO26262) and OEM specific requirements (e.g. CAN redundancy)

Note: HWP = Highway Pilot
Source: FEV

○ No availability / criticality ◔ Low availability / criticality ◑ Medium availability / criticality ◕ High availability / criticality ● Very high availability / criticality

Connected and Autonomous Vehicles
Availability & Criticality Assessment

FEV CONSULTING

HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Availability	Criticality	
Vehicle data	Wheel torques	●	●	
Vehicle data	Yaw rate	●	●	
Positioning	Longitude	●	◑	
Positioning	Latitude	●	◑	
Positioning	Altitude	●	○	
Positioning	Timestamp	◑	◑	
Road	Lane marking type	◑	●	⚠ ⚠
Road	Lane assignment	◑	◑	
Road	Lane curvature	◑	●	⚠ ⚠
Road	Road markings	◑	◕	⚠

⚠ Highly critical & core IenW field ⚠ Highly critical and restricted in availability

- Wheel torques for vehicle stabilization and control algorithm while accelerating and decelerating
- Positioning data not critical, as sensors can determine relative position of vehicle for a distance up to ~300 m in line of sight; functionality not restricted by missing positioning data
- Lane marking type and curvature required to centralize vehicle between two lanes; former additionally to determine type of roadway → vehicle centering relevant for safety
- Lane assignment can be contextualized by information on lane types (e.g. emergency exit lane to the right / fast lane to the left)
- Road markings (e.g. speed limit) relevant to comply with traffic regulation
- Positioning data provided by GNSS and HD Map, both not affected by visibility constraints → higher robustness
- Information on lane type and curvature primarily collected by cameras → performance strongly fluctuates with changing environmental conditions

Source: FEV

○ No availability / criticality ◔ Low availability / criticality ◑ Medium availability / criticality ◕ High availability / criticality ● Very high availability / criticality

Connected and Autonomous Vehicles
Availability & Criticality Assessment

FEV CONSULTING

HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Availability	Criticality	
Road	Road boundary	◕	●	⚠
Road	Junction	◕	◑	
Road	Overpass	◕	◑	
Objects	Obstacle validity	◕	●	
Objects	Relative position X	◕	●	
Objects	Relative position Y	◕	●	
Objects	Relative speed X	◑	●	⚠
Objects	Relative speed Y	◑	●	⚠
Objects	Yaw angle	◑	◑	
Objects	Yaw rate	◑	◑	

⚠ Highly critical & core IenW field ⚠ Highly critical and restricted in availability

- Detection of road boundaries necessary to avoid collisions e.g. in road work segments where guardrails may present lane boundaries → safety
- Junction is an exception on highways; usually combined with a speed limit reduction and indications by lane- / road markings → information can be contextualized
- Detection of overpasses to minimize risk of e.g. side winds drifts; supplementary safety feature
- Accurate and continuously available information on relative position & speed of objects required for HWP to assure reliability and safety
- Yaw rate/angle relevant to predict objects' trajectory; supplementary safety feature
- Information on road boundaries, junctions and overpasses supplemented by HD Map → higher number of sensors and increasing robustness
- High redundancy and suitability of sensors to provide information on object position
- Motion prediction affected by visibility; very high accuracy of relative speed only with radar

Note: HWP = Highway Pilot
Source: FEV

○ No availability / criticality ◔ Low availability / criticality ◑ Medium availability / criticality ◕ High availability / criticality ● Very high availability / criticality

Connected and Autonomous Vehicles
Availability & Criticality Assessment

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HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Availability	Criticality	
Objects	Length	◐	◐	
Objects	Width	◕	●	
Objects	Height	◐	◐	
Traffic regulation	Traffic signs	◕	●	⚠
Driver Monitoring	Body posture tracking	◕	◐	
Driver Monitoring	Eye tracking	◕	◐	
Weather	Weather conditions	●	◐	
Updates	HD Map update	◐	◕	(⚠)
Updates	Vehicle software update	◐	◔	

⚠ Highly critical & core IenW field

- Object width more critical than length and height, as it is only relevant parameter to calculate overlap ratio between ego and target vehicle → information set relevant to assure safety
- High criticality of traffic signs, as HWP has to comply with traffic regulation
- Driver must not respond to take-over request, as system must work fail operational → if driver behavior cannot be assessed safety still assured
- Weather conditions influence vehicle dynamics such as braking distance → contributes to safety
- Updated HD Map data important for road detection (→ very critical) and positioning
- Restricted suitability of LiDAR and radar to provide information on object length and height
- Information on traffic signs supplemented by HD Map → higher no. of sensors and robustness
- Infrared sensor is inside vehicle (no dirt, fog, etc.)
- HD Map and vehicle software update solely rely on network uplink → low number of sensors

Note: HWP = Highway Pilot
Source: FEV

○ No availability / criticality ◔ Low availability / criticality ◐ Medium availability / criticality ◕ High availability / criticality ● Very high availability / criticality

Connected and Autonomous Vehicles
Availability & Criticality Assessment

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HIGHWAY PILOT – LONGITUDINAL AND LATERAL CONTROL

Information set group	Set of information	Availability	Criticality
Non Line-of-Sight (NLOS)	Other hazardous notifications	◕	◑
Non Line-of-Sight (NLOS)	Road works warning	◕	◑
Non Line-of-Sight (NLOS)	Probe vehicle data	◑	◑
Non Line-of-Sight (NLOS)	Shockwave damping / local hazard warning	◕	◔
Non Line-of-Sight (NLOS)	Slow or stationary vehicle(s) & traffic ahead warnings	◑	◔
Non Line-of-Sight (NLOS)	Emergency vehicle approaching	◑	◑

- OEMs are deemed unlikely to rely on communication interface data to perform safety critical tasks and hence NLOS info sets are assessed to have lower criticality
- HW sensors are commonly sufficient to mitigate immediate safety hazards
- Other hazardous notifications, road works warning and probe vehicle data add safety by proactively informing the ego vehicle about hazards (e.g. road works / restrictions ahead, hot spots where danger accumulates)
- Shockwave damping / local hazard warning and slow or stationary vehicle(s) & traffic ahead warnings primarily aim to smooth the flow of traffic
- Emergency vehicle approaching supports vehicle in proactively clearing the road
- Information on other hazardous notifications, road works warning and shockwave damping / local hazard warning supplemented by HD Map
  → higher number of sensors and increasing robustness
  - Other NLOS information solely rely on network link and direct communication

Source: FEV

○ No availability / criticality ◔ Low availability / criticality ◑ Medium availability / criticality ◕ High availability / criticality ● Very high availability / criticality

Agenda

- Step 3: Criticality assessment
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The sets of information: relative speed, lane marking type and lane curvature are highly critical and restricted in availability by the sensors

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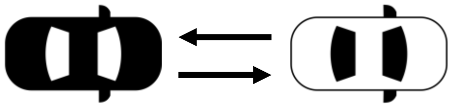
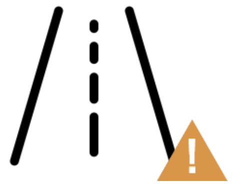
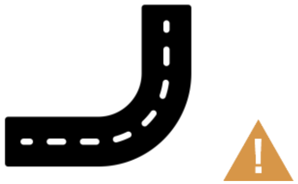
HIGHLY CRITICAL SETS OF INFORMATION WITH RESTRICTED AVAILABILITY



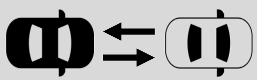
Relative speed of objects (e.g. vehicles) in longitudinal or lateral direction



Lane marking type includes information on geometry, color, style and material of lanes



Lane curvature describes the radius of a curve on the roadway

	AD FEATURE	LOW AVAILABILITY REASONING	HIGH CRITICALITY REASONING
	AEB HWP	Very high accuracy of relative speed only with radar; other sensors are using either indirect measurement (e.g. LiDAR) or algorithms (e.g. camera)	Accurate and continuously available information on **relative speed** of objects required for automation features (i.e. AEB, HWP) to assure reliability and safety
	HWP	Information on **lane type** & **curvature** primarily extracted by cameras → performance strongly fluctuates with changing environmental conditions	**Lane marking type** and **lane curvature** required to centralize ego vehicle between two lanes; the former additionally to determine type of roadway (e.g. exit lane)

Note: AEB = Autonomous Emergency Braking; HWP = Highway Pilot
Source: FEV

⚠ *Also core IenW field*

The sets of information: road boundaries, markings as well as traffic signs & HD Map Updates are highly critical and are within core fields of the IenW

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HIGHLY CRITICAL SETS OF INFORMATION IN CORE IenW FIELDS WITHOUT RESTRICTED AVAILABILITY

	AD FEATURE	HIGH CRITICALITY REASONING
Road boundaries include artificial or natural boundaries (e.g. curb, guardrail, bushes)	PC HWP	Accurate information on **road boundaries** (e.g. curb) required to detect parking lot boundaries when parking sideways (PC) and to avoid collisions e.g. in road work segments (HWP) where guardrails may represent lane boundaries
& **Road markings** include arrows, words and symbols on roads (e.g. zig zag line); **Traffic signs** include regulations for speed limits, overtaking, etc.	HWP	**Road markings** and **traffic signs** relevant to comply with traffic regulations (e.g. speed limits, no overtaking); thus both sets of information have an impact on safety
HD Map Updates from supplier or through crowdsourcing via network uplink	HWP	In HWP mode, the **HD Map** is a key sensor to provide information on the road network and positioning; both information set groups are covered by a low no. of sensors with rather low suitability → up-to-date HD Map information are key for safety; Public sector considered to be a relevant data owner

Note: PC = Parking Chauffeur; HWP = Highway Pilot
Source: FEV

Agenda

- Project approach and executive summary
- Step 1: Baseline CAV definition
- Step 2: Interface analysis
- Step 3: Criticality assessment
- Contacts
- Appendix

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Aachen # Munich # Auburn Hills

Agenda

- Project approach and executive summary
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List of definitions

Definitions

802.11p	WLAN based direct communication for V2X
ADAS	Advanced driver-assistance systems, e.g. Adaptive Cruise Control, Lane Keep Assist
CAV	Connected and automated vehicle
C-V2X	Cellular based direct communication for V2X
EURO NCAP	The European New Car Assessment Programme is a European car safety performance assessment program which is standard throughout Western Europe
FOV	Field of view describes the solid angle through which the detector of a sensor is sensitive to electromagnetic radiation. Angle of view can be measured horizontally, vertically or diagonally
ODD	Operational Design Domain describes specific conditions under which a driving automation system is designed to function (refering to J3016). This limitations include: Temporal, Environment (day, night, weather, etc.), Speed (low, high), Traffic (low, high, interaction with specific road users), Roadways (urban, highways, ...), Geographic (campus, districts, ...)
Peer-to-peer	Data can be shared directly between systems on the network without the need of a central server
V2I	Vehicle-to-Infrastructure is direct communication between the vehicle and the infrastructure
V2N	Vehicle-to-Network is communication over a network uplink between the vehicle and the network
V2P	Vehicle-to-Pedestrian is direct communication between the vehicle and pedestrians
V2V	Vehicle-to-Vehicle is direct communication between vehicles
V2X	Vehicle-to-everything is communication between a vehicle and any entity that may affect the vehicle, and vice versa
VRU	Vulnerable Road Users are non-motorized road users, such as pedestrians and cyclists as well as motor-cyclists and persons with disabilities or reduced mobility and orientation

Source: FEV

Comment Integration Tracker

FEV CONSULTING

Source	Comment	Consultant's Response
Vincent Habers, E-Mail, April 16th	The reference vehicle that you describe is based on FEV's knowledge of OEM's & Tier 1's RfQ/RfP's. Could you also comment on disruptors like Tesla and Waymo who seem to accelerate development and time to market when it comes to the use of sensors and offering of highly automated functions? It would seem that they diverge from the industry average, not only now but probably also very much moving towards 2025	We have defined the attributes of the baseline CAV not only by considering OEM's & Tier 1's RfQ/RfP's, but also based on internal / external expert interviews and workshops as well as desktop research. It is true that some players on the market including Tesla and Waymo diverge from the industry average. However, we don't expect them to commercialize their technology in passenger vehicles much before 2025, because they also have to comply with the legal framework which is not in place yet to allow it. Tesla is the first to see a car as a "software" product. They indeed differ from conventional OEMs in the communication around their products, and in the risk they are sometimes taking to rapidly release "new" features to the market. At a technical level today, the Tesla Autopilot does not diverge much from the standard driver assistance systems offered since years by the more conventional OEMs. The conventional OEMs are usually very sensitive to image loss due to recall campaign and hence limit on purpose the performance of their systems, whereas Tesla (thanks to its pioneer image) release less conservative features. As Tesla also has to comply with the legal framework to sell its products on the market, they will not be able to sell higher level of automation features earlier than the other OEMs. (Please note that the first vehicle on European roads with a "true" Level 3 system is the Audi A8, not a Tesla). Waymo is a little bit different, as they are not aiming at selling cars on the market. From the start, they wanted to develop higher level of automation systems, not a vehicle. This means that they did not really focus on the automotive specific regulation in terms of functional safety, etc. but they rather focused on developing a powerful development framework (data collection, automatic analysis, update of control algorithm based on field test, etc.). This powerful framework can be used by more conventional OEMs in order for them to speed-up their internal development and in particular the validation part.

Source: FEV

Comment Integration Tracker

Source	Comment	Consultant's Response
Vincent Habers, E-Mail, April 16th	Could you comment on drastic moves that Volkswagen and others seem to be undertaking when they want to rapidly and fundamentally move towards entire new platforms for EV's across their product line. Would that have an effect on the capabilities that will become available in 2025 (because a legacy vehicle architecture will phase out more rapidly)?	The use of modular platforms with more or less standard sub-systems has been around at the major OEMs since a few years now. The basic idea behind is to be able to reuse as many sub-systems/components as possible independently from the powertrain type (conventional, hybrid, electric) and across brands of a same group as well as across vehicle types and variants of a same brand. This is to enable a high offer to the end customer while limiting the huge invests in terms of the necessary specific tooling equipment. The Electric/Electronic architecture (the most relevant aspect for CAV) is undergoing a similar mutation. The OEMs are now developing the next generation of their E/E architecture in order to accommodate these different powertrain architectures as well as CAV and the other upcoming challenges. These architectures will be based on a backbone network with different (rather powerful) domain controllers (ADAS, Powertrain, Infotainment, Chassis, etc.). It is not expected that the new E/E architectures will be the mainstream in 2025 yet but in the end, these architectures will support more frequent software updates (and hence more rapid "feature" releases) than today.
	Please do not over accentuate the SAE levels as deciding measurements of vehicles capabilities as classification because in our opinion this clouds the issue. There is still a divergent interpretation of these Levels and the actual sensors, requirements and intelligence per level. Your focus on actual available sensors and subsequent capabilities is much more helpful. If you think a classification is needed or helpful, we think the ACSF categories would be more effective	We have defined sensor types, data interfaces and the according information that the vehicle extracts from the environment based on automation features (e.g. highway pilot) in a given driving environment (e.g. highway) rather than on SAE Levels. The reference to the SAE levels is there to highlight the responsibility split between the system and the driver in terms of the driving task in the given environment, hence supporting at a later stage the rationale behind the criticality analysis of the information provided by the sensors. Moreover, the SAE levels are added as they are a common reference point in discussions.

Source: FEV

Comment Integration Tracker

Source	Comment	Consultant's Response
Vincent Habers, E-Mail, April 16th	Slide 15: it is mentioned that compared to the baseline CAV, a shuttle is characterized by "more direct communication reliance". What is the reasoning behind that statement? Is this motivated by the sentences "more extensive VRU interaction" and "Prediction of VRU's behavior is more complex than in an highway environment" on that same slide? Or is there another motivation?	The two points "More extensive VRU interaction" and "Prediction of VRU's behavior is more complex than in an highway environment" result in larger requirements towards short range detection sensors of shuttles, as dangerous situations involving VRUs (e.g. pedestrians, cyclist) generally evolve in short ranged (blind) spots of the vehicle. For example, if a cyclist takes over the shuttle ahead of a right turn or when a pedestrian suddenly intends to cross the road. "More direct communication reliance" is attributed to the fact that shuttles usually follow a "virtual" track (GNSS waypoint) which can be independent from the existing road infrastructure. As a result communication e.g. with traffic lights at intersections along the "virtual track" or with telescopic retractable bollards and other obstacles to prevent other vehicles to enter this zone is required.

Source: FEV

Comment Integration Tracker

Source	Comment	Consultant's Response
Vincent Habers, E-Mail, April 16th	Slide 16: the following is mentioned: “direct communication highly important for heavy duty”. What is the reasoning behind that statement? Are the mentioned depot handling and platooning use cases the main reasons? And if so, why would depot handling require direct communication instead of V2N communication? And are HD vehicles still expected to platoon if they are L4 capable (which is mentioned as important for the business case of automated HD), since L4 vehicles do not need a leading vehicle driven by a human anymore to help them with the driving task?	Indeed, depot handling could also be implemented via V2N, as it is non-time critical. From our perspective, direct communication will remain relevant for platooning when HD vehicles are capable of L4. This is because in order to benefit from the potential fuel savings of platooning (especially in regions with long, continuous highway sections without exits e.g. in US, China or Canada), the trucks will have to drive very close to each other (i.e. with a time gap <1s). This minor gap forces the trucks to exchange information directly between each other in order to ensure the safety of the entire platoon (i.e. to ensure the last truck of the platoon will also react pro-actively when the first truck performs an emergency braking and not only when the truck in front of it starts to brake). In addition, depot handling and platooning are not the only use cases for direct communication of heavy duty vehicles. Another use case is the direct communication between the truck and the trailer. The background is the high diversity in vehicle variants (type of trailer, length, weight, etc.) and the related challenge when it comes to covering the 360° view around the whole vehicle. Some sensors will have to be placed on the trailers and a possible solution to connect them to the vehicle control unit of the truck might be over direct communication. In addition, in a L4, the senses of the driver will also have to be replaced (i.e. the driver can feel, smell or see that something goes wrong with the trailer or with the goods transported inside the trailer and hence react / stop the truck. In a L4, the truck might go on driving while burning for many kilometers). This monitoring will hence also have to be automated and surely distributed over the truck and the trailer and hence a communication between them might also be necessary in this case

Source: FEV