Ensuring life time performance of Advanced Driver Assistant Systems:

Risk Analysis of Lane Keeping Assistant Systems / WP.29

Dr. Matthias Schubert / TÜV Rheinland

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CITA International Motor Vehicle Inspection Committee

TRL

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New vehicle types approved from July 2022 will be ADAS equipped, giving great safety benefits when new but posing challenges to road safety as they begin to fail

Summary

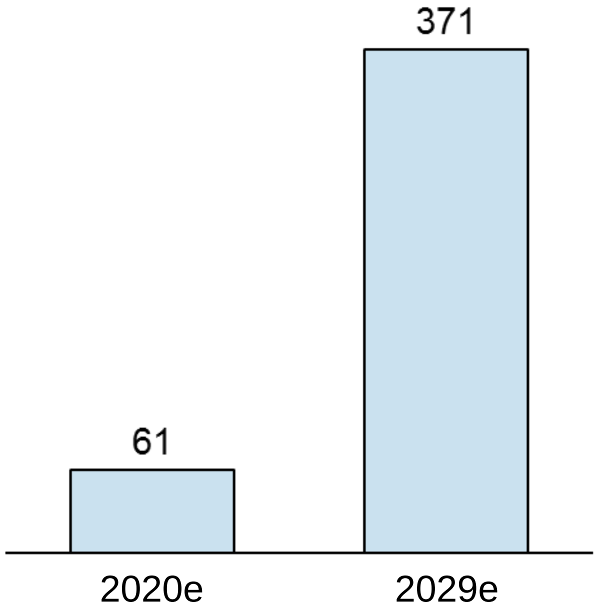
ADAS features mandatory for new vehicle types from 07/2022 on[1]

Mandatory for all vehicles registered from 07/2024

- Emergency Lane Keeping
- Advanced Emergency Braking
- Driver Drowsiness Monitoring
- Intelligent Speed Assistance
- Reversing Safety

Number of vehicles on the road with ADAS camera fitted windscreens[2]

Vehicles in mio.



Implications

- Proper functioning of these systems may be affected over time, e.g. through collisions, ageing, or repair work
- As our study proved, malfunctions can appear without any MIL indication
- For Lane Keeping Assistant Systems (LKA) alone, this could result in ~790k risk events in the EU by 2029[3]
- Given these implications on road safety, making ADAS functions a mandatory part of PTI might be considered
- In order to ensure road safety while keeping economic factors in mind, a cost-benefit study could help to drive a well informed decision on potential next steps

1) As per Regulation (EU) 2019/2144 | 2) Proxy for ADAS equipped vehicles 3) Medium scenario, range from 0.2 mio. risk events (Low scenario) to 2.3 mio. risk events (Upper scenario)
Source: TRL, TÜV Rheinland

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On behalf of TÜV Rheinland and CITA, TRL carried out a risk analysis of LKA-systems in order to answer a set of safety relevant questions in the ADAS context

Goals

Using LKA as a “representative” for ADAS, the study’s goal is:

- Identify failure mechanisms that affect the performance of the LKA system and which are not indicated by the vehicle’s MIL
- Focus: Defects that could result in the violation of the system’s functional safety goals and that are caused by faults in the LKA sensor, the LKA system, and/or the LKA actuator

Approach

The risk analysis is created on the basis of a combination of

- Literature search
- Stakeholder consultations
- Physical testing

Guiding Questions

1. What can go wrong?
2. How often it may go wrong?
3. What happens when it goes wrong?
4. What can be done to prevent it from going wrong?

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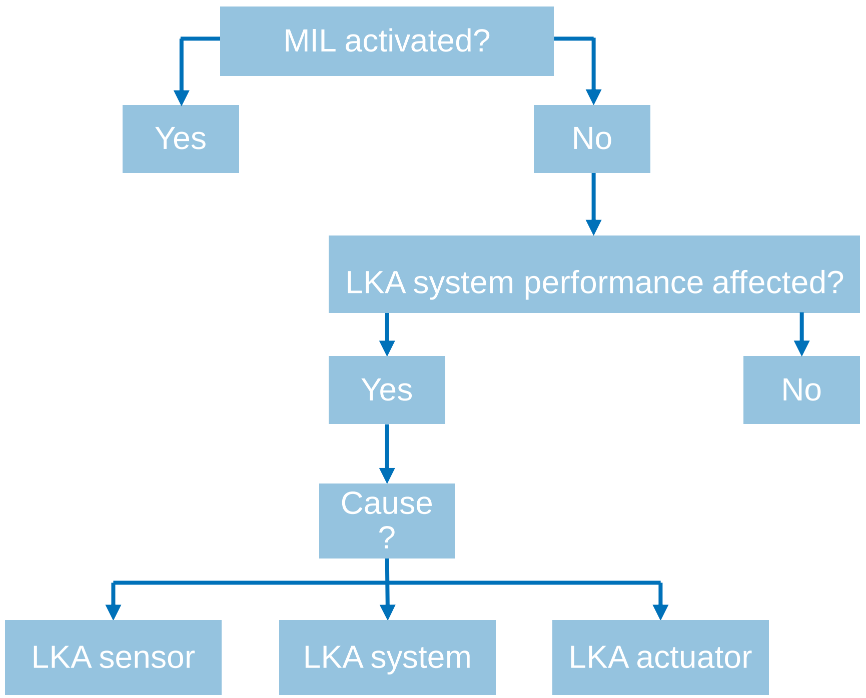
Using a logic tree, the risk analysis study looked at faults and malfunctions in the LKA sensor, the system, and the actuators

Underlying logic tree



Scope of the risk analysis

We have looked at failure mechanisms that my affect the:

The LKA sensor

- Collision and vibration / shocks affecting sensor position
- Windscreen, view damage, poor or no camera calibration at replacement
- Aftermarket fitment of SAE Level 2 systems
- External electromagnetic interference (EMI) or electrostatic discharge (ESD)

The LKA system

- Electrical degradation
- Degraded data from other sensors/ECUs
- Software error

The LKA actuators

- Degraded LKA actuation components, e.g. braking or steering actuators

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The study investigates the main causes of potential LKA-system malfunctions

1. What can go wrong?
2. How often it may go wrong?
3. What happens when it goes wrong?
4. What can be done to prevent it from going wrong?

In order to achieve a lasting positive impact of the system, it is important to avoid the following aspects

- Incorrect installation or retrofitting
- Effects of ageing, degradation
- Impact of (minor) accidents, replacement of parts and components
- Camera position affected by minor collision, replacement/no calibration, screen damage in front of camera
- Software error or vital software updates not done
- Incorrect sensor fusion
- Tampering

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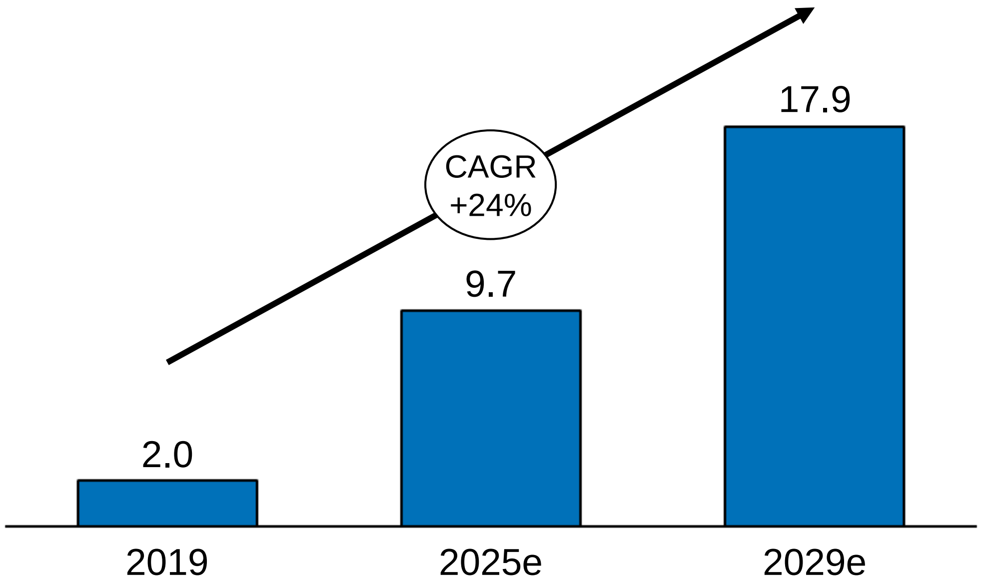
We have used specific case examples to quantify the number of potential risk events

Case example windscreen replacement

Driven by increasing penetration rates, the number of windscreen replacements with cameras will strongly increase

Total number of replacements of windscreens with cameras (In EU, in mio.)



As a result, potential risk events caused by replacement of windscreens with integrated cameras will increase

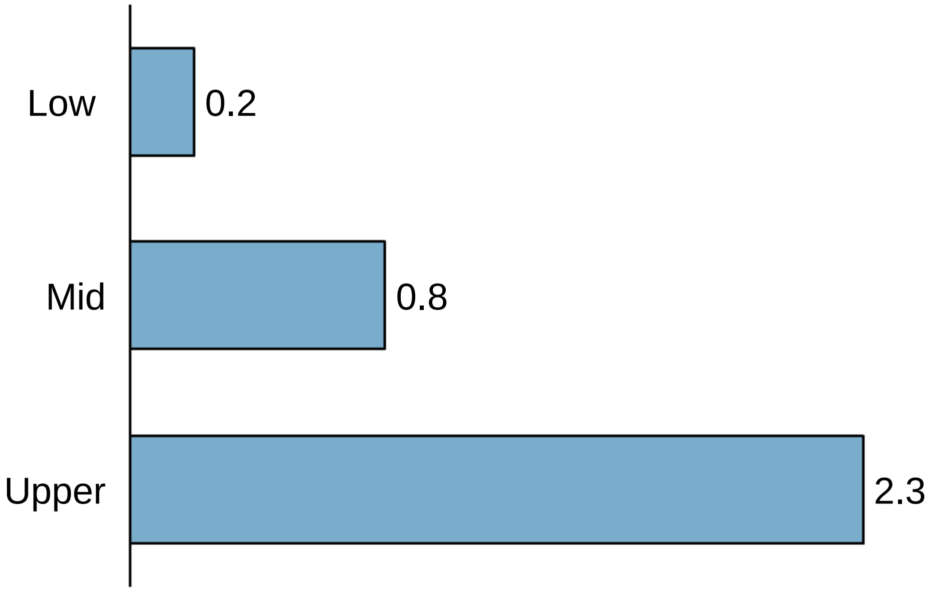
- Estimated number of replacements with no or incorrect calibration in 2029: 1.81 – 7.89 mio.
- LKA performance could be affected in 5% - 20% of these cases
- This could result in an estimated medium number of ~500k risk events[1] per year by 2029 resulting solely from incorrect windscreen replacement and camera calibration

1) Defined as a failure mechanism that leads to degraded ADAS performance
Source: TRL

Based on the TRL model, the number of risk events driven by LKA malfunctions in the EU could range between 0.2 and 2.3 mio p.a. by 2029

Estimated total number of LKA related risk events in the EU in 2029

Events in mio. by scenario



- On top of the windscreen camera calibration aspect, estimated impact from collision and vibration on LKA functionality take the mid estimate to a total of ~790k risk events p.a.
- Ageing and electrical degradation would further increase this number but frequency data is not yet available for this fault type
- The failure rate of AEB and other ADAS systems would further increase the number of annual risk events

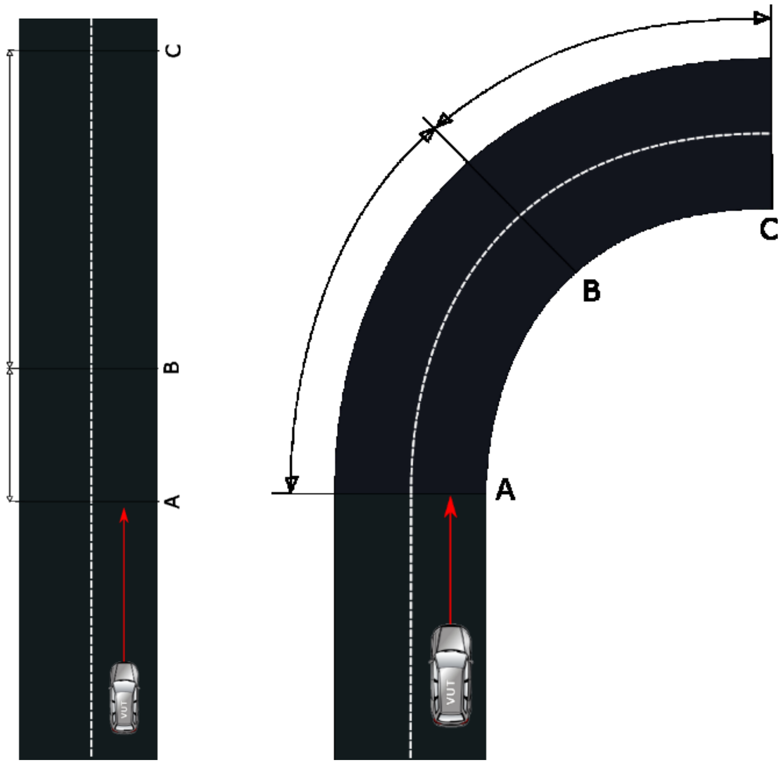
Source: TRL; TÜV Rheinland

We have simulated LKA malfunctions in a real-life test environment in order to get a better understanding of the effects of such malfunctions (1/3)

Test setup

Requirements from ISO 11270:2014 and EURO NCAP were taken into account when designing test specifications with the following adaptions:

- Two test track types were used: straight track and curved track
- Tests included error injections in static and dynamic conditions
- To ensure comparability, tests were performed at constant vehicle speeds as far as possible
- At the starting point, the test vehicle was accelerated to the specified speed with the LKA system turned on and activated (point "A“). Here, the LKA system controlled the complete lateral movement of the vehicle so that the test driver did not keep his hands on the steering wheel
- In the case of a test with error injection in the dynamic condition, the error was applied in the area "B"
- On the section between "B" and "C“, the LKA behavior was analyzed



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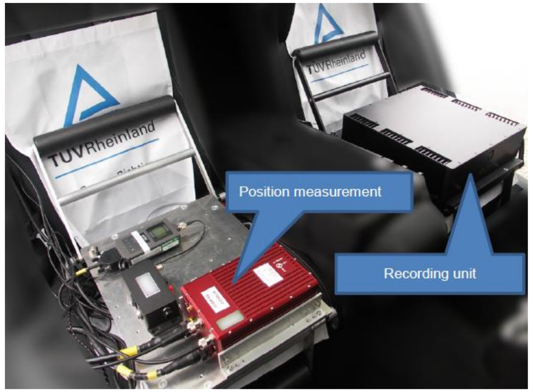
We have simulated LKA malfunctions in a real-life test environment in order to get a better understanding of the effects of such malfunctions (2/3)

Vehicle preparation

- Test vehicle is officially approved for use on public roads and is equipped with a state-of-the-art ADAS including LKA
- An Electrical Switching Unit (ESU) was installed. The ESU was connected directly to the on-board electrical system of the vehicle without destroying the on-board electrical system integrity
- Test vehicle was equipped with measurement equipment
- Depending on test scenario, changes were made to the vehicle, including:
  - Windscreen: Apply stain or damage screen (stone chips)
  - Install smaller than approved wheels
  - Manipulate wipers with abrasive paper

Control Unit of the ESU

Measurement Equipment



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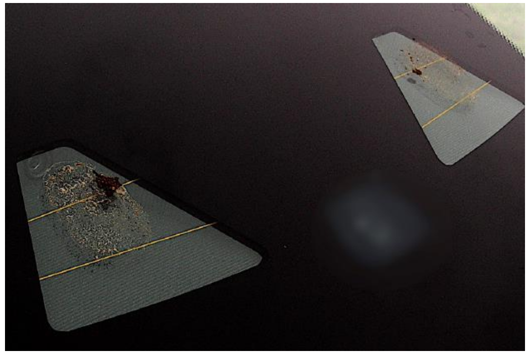
We have simulated LKA malfunctions in a real-life test environment in order to get a better understanding of the effects of such malfunctions (3/3)

Test scenarios

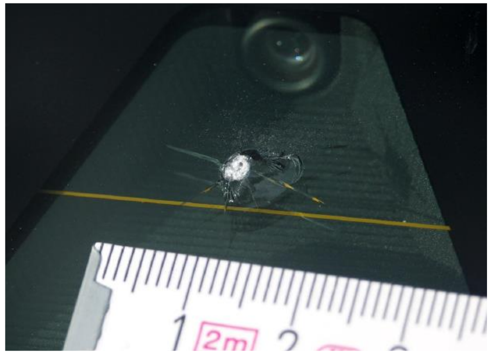
Various impairments of the sensor functions occurring in practice were investigated. The manipulations or simulated fault patterns were mapped in various test scenarios, which can be grouped as follows:

- Power supply (e.g. loose contact of the ground wire of Electrical Power Steering)
- Data communication (e.g. interruption of data communication from LKA camera)
- Hardware (e.g., ageing of the camera lens: mechanical defect, turbidity)
- Calibration (e.g., Incorrect or missing calibration after replacement of the windscreen)
- Restriction of visibility on the windscreen (e.g., dirt stain, defective wiper)
- Damage to the windscreen (e.g., stone chips, cracks)
- Changes to the chassis (e.g., different wheel sizes)

Dirt Stain in front of cameras



Stone chip in front of camera



Film in front of cameras

Different wheels (original wheel on the right)

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LKA-system error effects[1] may appear in situations where the driver expects the system to work – with potentially dangerous consequences (1/2)

1. What can go wrong?
2. How often it may go wrong?
3. **What happens when it goes wrong?**
4. What can be done to prevent it from going wrong?

Test scenario	Description	What we have observed
▪ Poor calibration	▪ Incorrect calibration within the tolerance. Calibration target is positioned laterally to the center line of the vehicle	▪ Incorrect system reaction, a strong pull towards one side and sporadic self-disabling during the first 10 minutes of the drive ▪ After approx. 10 min of driving, stabilization and correct operation of the system[2] reoccurred
▪ Stone chips and cracks in windscreen	▪ Stone chip of medium size (6-9 mm) in the field of view of the cameras	▪ Functional degradation and sporadic system deactivation without warning ▪ These effects led e.g. to vehicle leaving the lane in the bend
▪ Restriction of visibility	▪ A thin film of dirt was applied to the windscreen directly in front of the camera	▪ Vehicle moved out of the lane without warning ▪ MIL warning only activated when the vehicle significantly moved out of the lane in the curved section

1) Focus is on error effects for which no MIL warning is activated | 2) Other vehicles under other conditions might show a different reaction

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LKA-system error effects[1] may appear in situations where the driver expects the system to work – with potentially dangerous consequences (2/2)

Test scenario	Description	What we have observed
▪ Restriction of visibility on the windscreen	▪ A film of dirt on the windshield combined with a defective (specially prepared) windshield wiper led to the formation of streaks in front of the camera	▪ Sporadic system deactivation without acoustic warning ▪ These effects led to e.g. vehicle leaving the lane in the bend ▪ Increasing the level of dirt eventually led to a system failure with MIL warning
▪ Loose connection in the wires of power supply and data communication[2]	▪ An electrical switching unit (ESU) specially developed by TÜV Rheinland was used to generate the contact interruptions in the data wire and the supply wire during the steering manoeuvre	▪ Error injection in the dynamic condition (in the middle of a steering manoeuvre) led to the system immediately deactivating and the MIL was active ▪ The abrupt return of the steering wheel to the middle position surprised the driver and the vehicle moved significantly into the adjacent lane

1) Focus is on error effects for which no MIL warning is activated | 2) Affected modules: LKA-camera, electrical power steering, electronic stability control and similar

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A set of system- and process-related measures might help to increase vehicle life compliance and increase road safety

1. What can go wrong?
2. How often it may go wrong?
3. What happens when it goes wrong?
4. What can be done to prevent it from going wrong?

System-related

- Improvement of the on-board diagnostics capability, including a common standard to ensure that OBD can detect the mechanisms highlighted, flag these via the MIL and exhibit the desired fail-safe response
- Refinement of the technical requirements of ADAS: include the facility to access system status data to enable verification by a third-party
- In the longer-term future, high level autonomy (SAE level 4 and 5) will demand 'fail operational' capability which will require system redundancy from multiple sensors; these will allow in-use calibration and superior onboard diagnostics.

Process-related

- Regular inspection is necessary, e.g. during PTI
  - Updated software versions can be as critical as hardware calibration
  - Verification of system status
  - Inspection of glazing damage in the areas around ADAS sensor(s)
  - Standardized test method should be developed for third party application as required
- All ADAS equipped vehicles should facilitate a standardized test method as a type approval requirement

Based on our findings, we recommend the following steps and initiatives

1 Conduct a cost-benefit analysis

- Help substantiate and further develop this discussion by:
  - Including additional ADAS systems, e.g. AEB
  - Increasing scope, e.g. to low-end systems
  - Providing an assessment of the economic impact of a potential inspection regime

2 Develop approaches to ensure ADAS functionality over the entire vehicle life

- The results could be used to develop approaches that enable the whole vehicle life functionality of safety systems and to determine what level of action is justified to address ADAS systems during PTI

3 Drive standardization initiatives

- Access to system performance data for independent third parties is a prerequisite for regular inspection
- An approach to develop standardized access across OEMs would therefore be needed

Appendix

Definition of “malfunction” and “risk event” in the context of the LKA risk assessment

Malfunction

For an Emergency LKA system, i.e. one which helps a driver (often when inattentive) by nudging the car back into lane when it is leaving lane, there are two possible types of disbenefit:

- That the potential accident that would be prevented with a fully functional E-LKA occurs, e.g. system does not respond or responds late
- That the system malfunctioning causes accidents with false positives, e.g. system alters vehicle course when not necessary and vehicle runs out of lane or off road

Risk Event

A failure mechanism that leads to degraded ADAS performance.

Source: TRL