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ARCADE

Aligning Research & Innovation for Connected and Automated Driving in Europe

Proceedings of workshop on Edge cases

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Contents

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Executive Summary

On 11 May 2021, ARCADE arranged an online workshop with between 70 and 80 participants on edge cases: rare scenarios that are needed for safety assessment of CCAM.

In a webinar and three break-out sessions, a large number of approaches and challenges for edge cases were identified and discussed.

The German project V&V Methods and the recent European project Hi-DRIVE[8] push edge cases in a positive direction. The new AWARD EU project[3] will examine automated trucks in long-time industrial operations and will face many weather-related edge cases.

Conclusions were among others:

- Work on standardising terminology for edge cases and related terms needs to continue. DIN SAE SPEC 91381 and UNECE IWG VMAD use different definitions.
- Many approaches to edge cases exist. We see two main streams:
    - 1st a system engineering based approach where possible edge cases are deduced using a comprehensive analysis;
    - 2nd an observational, more data-driven approach, where new edge cases are considered unpredictable or unforeseen by definition and need to be identified through monitoring of vehicles on the road.
- There is a clear consensus that a shared library of edge cases is beneficial for all stakeholders.
- Edge cases should create a learning loop for developers and requires an ongoing data collection for public use.

The results have been published on connectedautomateddriving.eu and are related to the ARCADE work on Evaluation Methodology in the EU CAD Knowledge Base. The topic of edge cases will be further elaborated under European projects such as Hi-DRIVE and in the CCAM partnership.

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1. Introduction

On 11 May 2021, an online workshop o3n Data sharing in the CCAM area was held with between 70 and 80 participants. The agenda was as follows:

- 10:30 Webinar for wider audience
  - 5 Speakers showing various approaches to edge cases
  - Finish with audience Padlet brainstorm on topics to be addressed
- 12:00 Webinar end
- 14:00 Interactive workshop with 3 break-outs
  1. Views on definitions of edge cases
  2. Approaches for identifying, collecting and sharing edge cases
  3. Using edge cases in safety validation

The online workshop began with a morning webinar (see Chapter 2). After an introduction of the CCAM Working Group 2 and its ambition for edge cases, an introduction and five presentations on approaches for edge cases were given. The morning webinar was concluded with audience input on edge case topics to be addressed (see 2.9).

The webinar continued into an afternoon Workshop (see Chapter 3). Three expert break-out sessions were held to further explore previously selected topics of interest. The meeting ended with a plenary wrap-up (see 3.4).

The results have been made available on the EU CAD Knowledge Base event library (**Error! Reference source not found.**).

1.1. Purpose of the document

This document is meant to capture the results of the workshop on 11 May 2021 and to progress the ARCADE work on Evaluation Methodology.

1.2. Intended audience

Experts, stakeholders and those interested in the field of edge cases in the domain of Connected and Automated Driving.

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1.3. Acronyms

Acronym	Full text
AI	Artificial Intelligence
CAD	Connected & Automated Driving
CCAM	Connected Cooperative & Automated Mobility
CVE	Common Vulnerabilities and Exposures
DG	Directorate General, a part of the EC organisation
EU CAD	European website and knowledge base for Connected and Automated Driving
FOT	Field Operational Test
GDPR	General Data Protection Regulation
GPS	Global Positioning System
NAP	National Access Point
NDS	Naturalistic Driving Study
SRIA	Strategic Research and Innovation Agenda
SRTI	Safety-Related Traffic Information
VMAD	Validation Methods for Automated Driving (informal working group of UNECE)
WG	Working group

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2. Webinar

2.1. Welcome

The workshop was opened by the ARCADE project coordinator Stéphane Dreher (ERTICO) with a brief introduction to the ARCADE project and project contribution to Connected, Cooperative and Automated Mobility (CCAM) (7) and Strategic Research and Innovation Agenda (SRIA) (17).

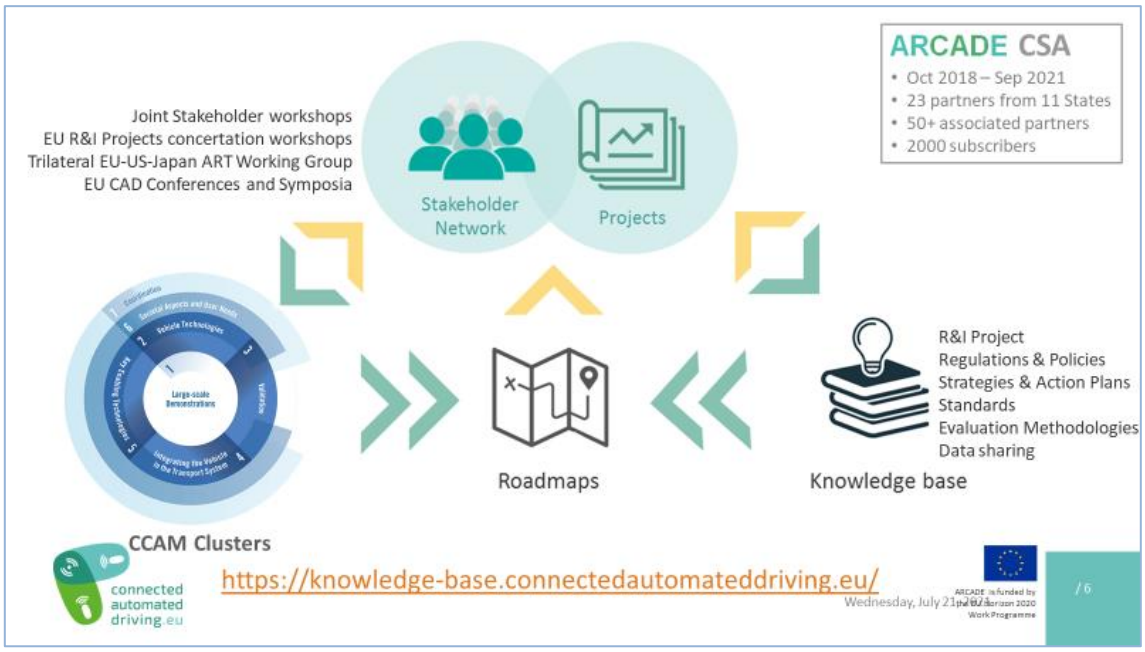
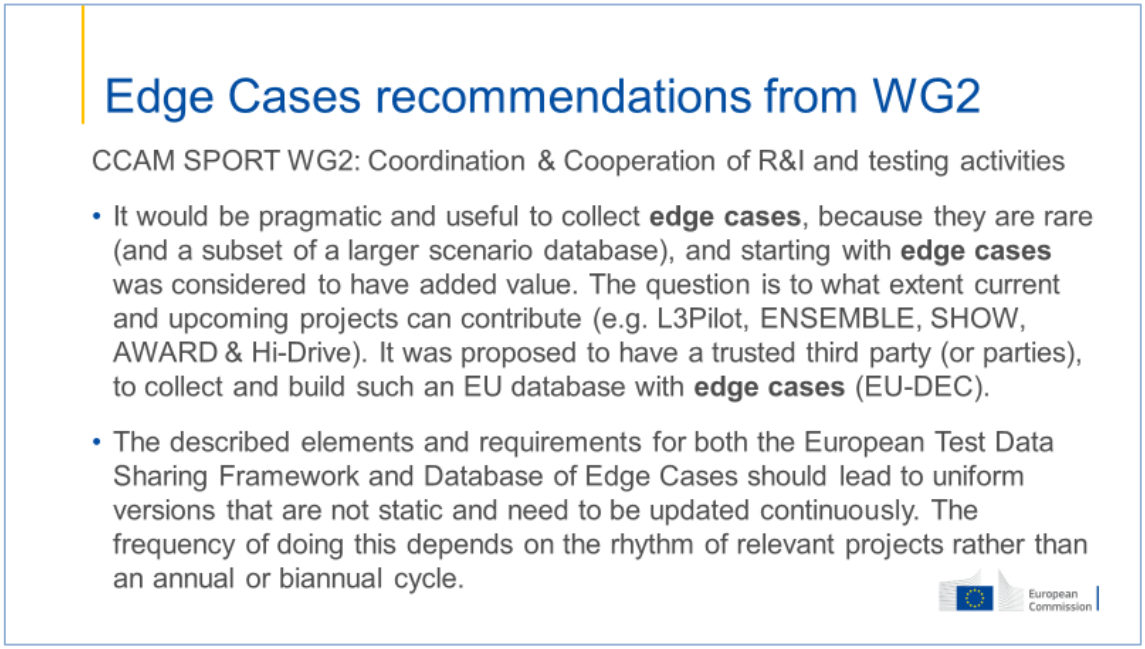


Figure 1: Stakeholder Contribution cycle presented by Stéphane Dreher

2.2. Importance of Edge Cases for CCAM, by Tom Alkim (EC DG R&I)

Tom Alkim of DG Research & Innovation introduced the CCAM Partnership and explained its objectives. Tom Alkim and Guus van de Schouw lead Working Group 2 (WG2) on Coordination and cooperation of research and innovation. Tom Alkim introduced the topic from European Commission perspective and highlighted the need of discussing, harmonizing and establishing collaboration within the area of edge case databases.



2.3.Introduction to edge cases, by Sytze Kalisvaart (TNO)

Sytze Kalisvaart, TNO, gave a background on edge cases in automated driving with the question: how to address and mitigate scenarios that are highly unlikely, still something that can happen. As an example, a fatal accident is an extremely rare event, which occurs every 226 million km of driving on German roads. Also, humans are quite good at handling more harmful but complex situations and assess the risks, whereas an automated function must learn how to address unthinkable events while driving. If we can collect, store and share such situations, we can have algorithms to train on and overcome them.

In a wider meaning, this can lead to the ability to ensure the safety of a function by validating it against edge case databases (as part of many other validations steps). To take the next steps, we need to have a common definition of an edge case, we must be able to collect edge cases, and we must find ways to validate the functions with the overall ambitions to build public acceptance for automated vehicles.

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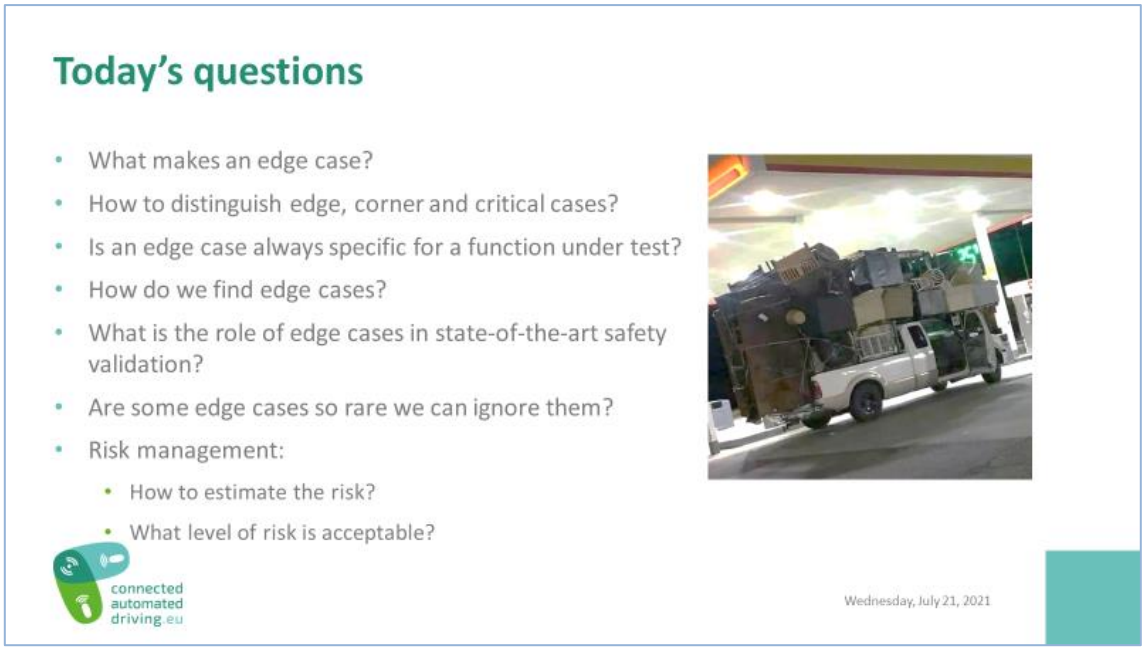
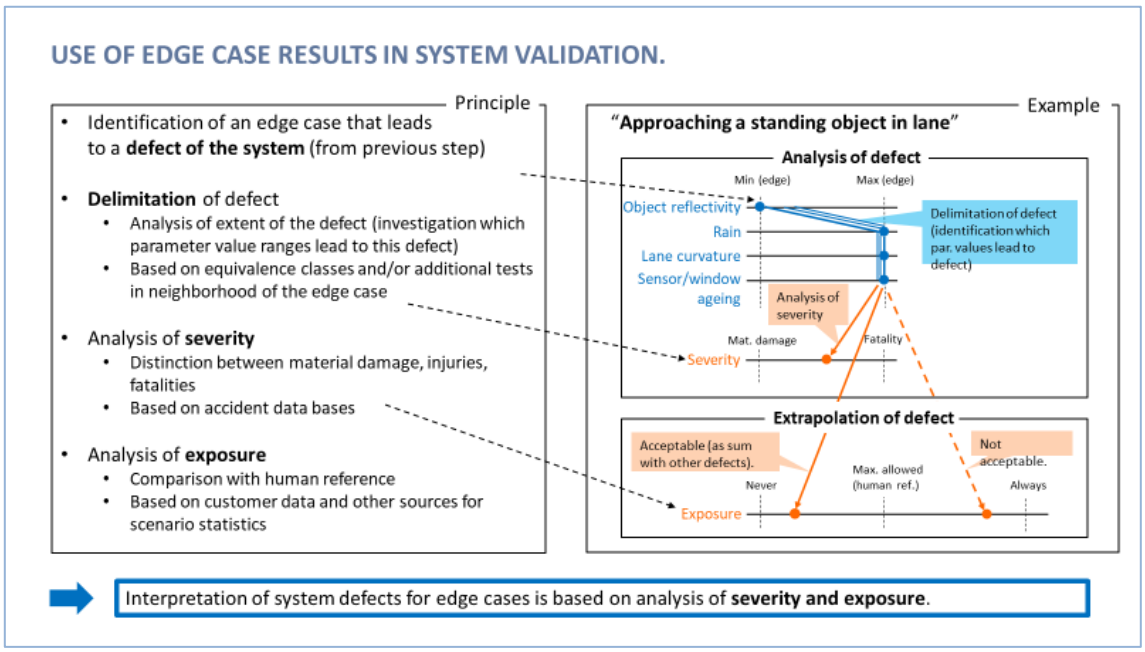


The workshop continued with five presentations on the topic: "Approaches to edge cases".

2.4. The use of edge cases for the development of automated driving. (Benoit Vanholme, Verification & Validation Expert, BMW)

Benoit Vanholme, stated that edge cases is a challenge but also an opportunity. He continued to discuss that we need a different approach to todays' testing, taking into account an iterative approach to both testing and validation. Vanholme presented a concept on defining edge cases from the concept of scenario selection, its influencing factors and measuring those against exposure, severity and controllability (ESC-criterias).



More research is needed on validity and transferability of edge cases. Also, the issue of sharing and harmonizing edge cases need further collaboration. Finally, we should learn

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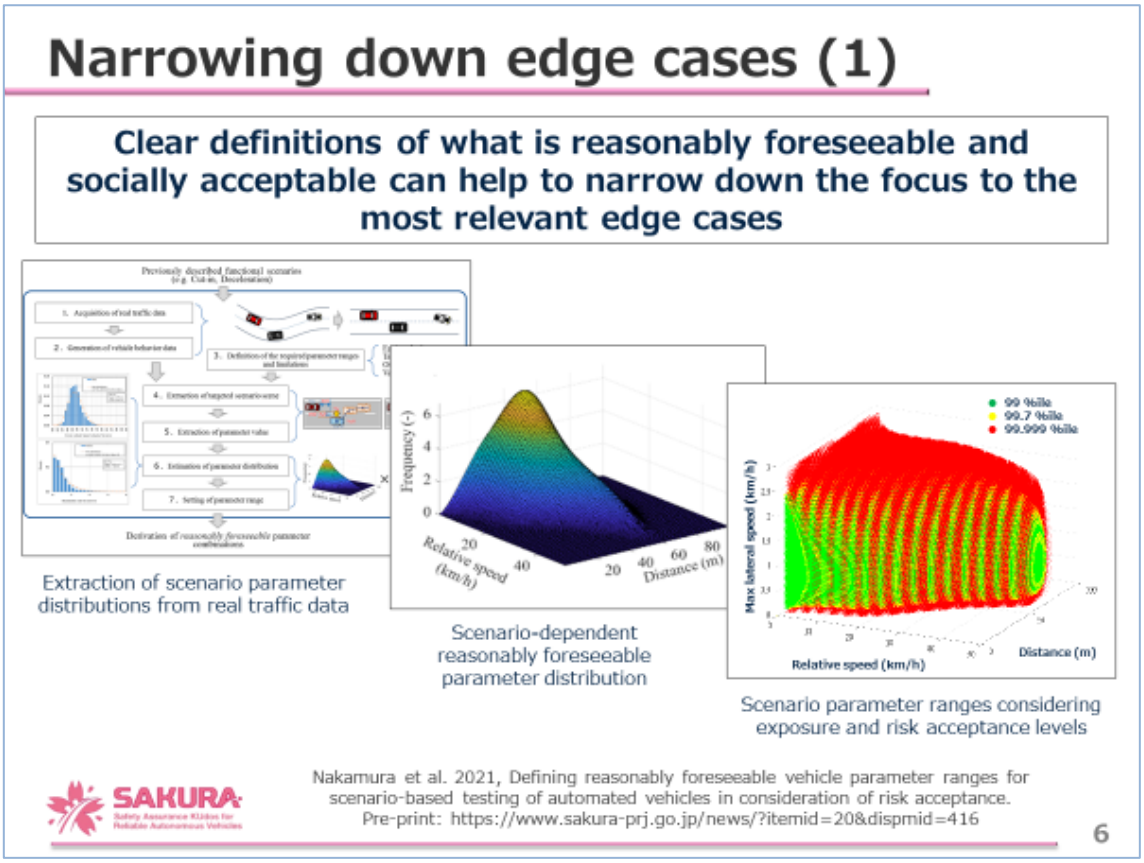
from other domains (medicine/vaccine and aviation) on how to work with edge cases to build public trust.

2.5. Narrowing down edge cases (Jacobo Antona-Makoshi, AD Safety Research & Standardization Group Leader, JARI, SAKURA project)

Next, Jacobo Antona-Makoshi, presented edge cases as part of "safety of the intended functionality" (SOTIF). It was highlighted that we must have clear definitions on what is reasonably foreseeable and what is acceptable risk from societal perspective [12].

It was then proposed to narrowing down edge cases based on grouping dynamic driving tasks, subtasks, sensor and physical principles [10].



Moreover, learning from the past, using accident (iGLAD, NHTSA, PASTAS) and naturalistic driving databases was highlighted, but also establishing an AD safety valuation eco-system to also learn from the future.

2.6. Criticality Analysis as part of the VVMethods Safety Argumentation (Dr. Christian Neurohr, Senior Researcher, OFFIS e.V. – Institute for Information Technology)

The next presentation was done by Dr. Christian Neurohr, on the project V&V Methods. The project is a follow-up to the well-known Pegasus project and Neurohr presented the sub-project on "critically analysis".

Edge cases depend on (often many) influencing factors which is defined as criticality phenomena. The criticality phenomena are identified from experience or data within a

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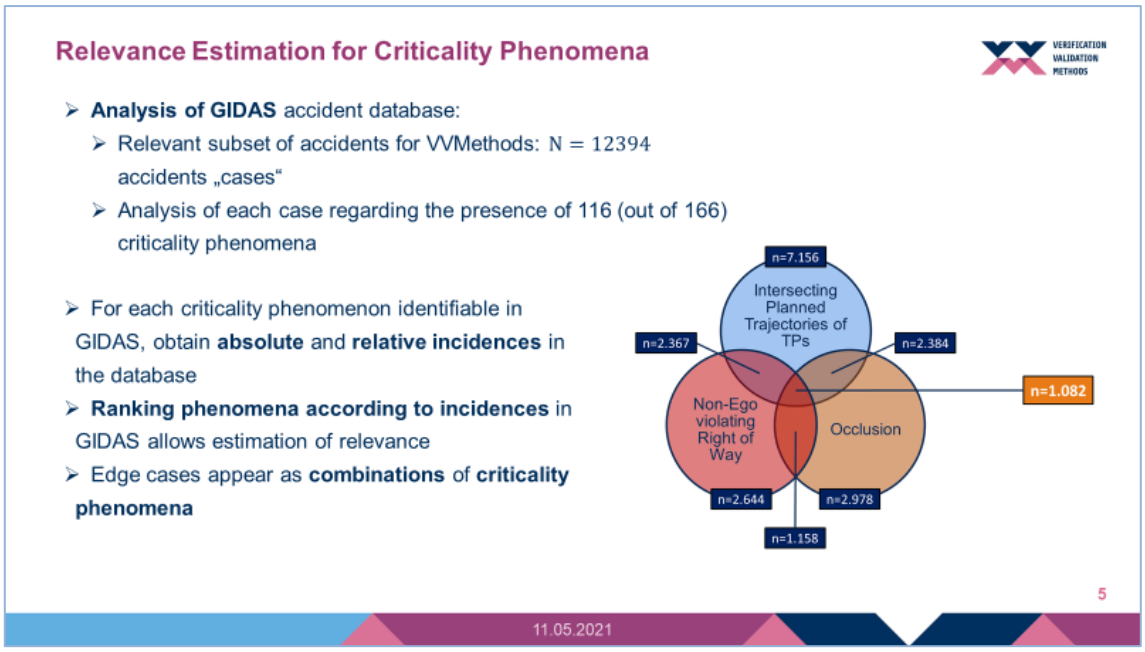
plausible causality, including the estimation on relevance. The set of criticality phenomena is limited and manageable which gives a finiteness (of artifacts). (C. Neurohr, L. Westhofen, M. Butz, M. H. Bollmann, U. Eberle and R. Galbas, "Criticality Analysis for the Verification and Validation of Automated Vehicles," in IEEE Access.)

A phenomenon can be defined by 1) find adequate level of abstraction, 2) establish an ontological representation, and 3) use accident databases for empirical evidence whether the phenomenon is relevant.



Within the V&V Methods project the principles have been applied on the GIDAS accident database. More than 12 000 accidents have been analyzed by adding its criticality phenomenon. Edge cases stand out as combinations of phenomena. The safety argumentation is then key to get a positive risk balance. The artifacts of the criticality analysis appear as claims and sub-claims which need rigorous reasoning in the safety argumentation.

2.7. MOSAR Solution Concept – Scenario library for the design & validation of ADS (Abdelkrim Doufene, PhD, Head of Strategy and Programmes, IRT SystemX)

Abdelkrim Doufene presented the MOSAR solution concept, a scenario library for the design and validation of autonomous driving systems. The platform includes different datasets (UDRIVE, MOOVE, accident databases), common formats and tools, where a data processing suite has been established creating relevant driving scenarios. More information can be found in Reference 8.

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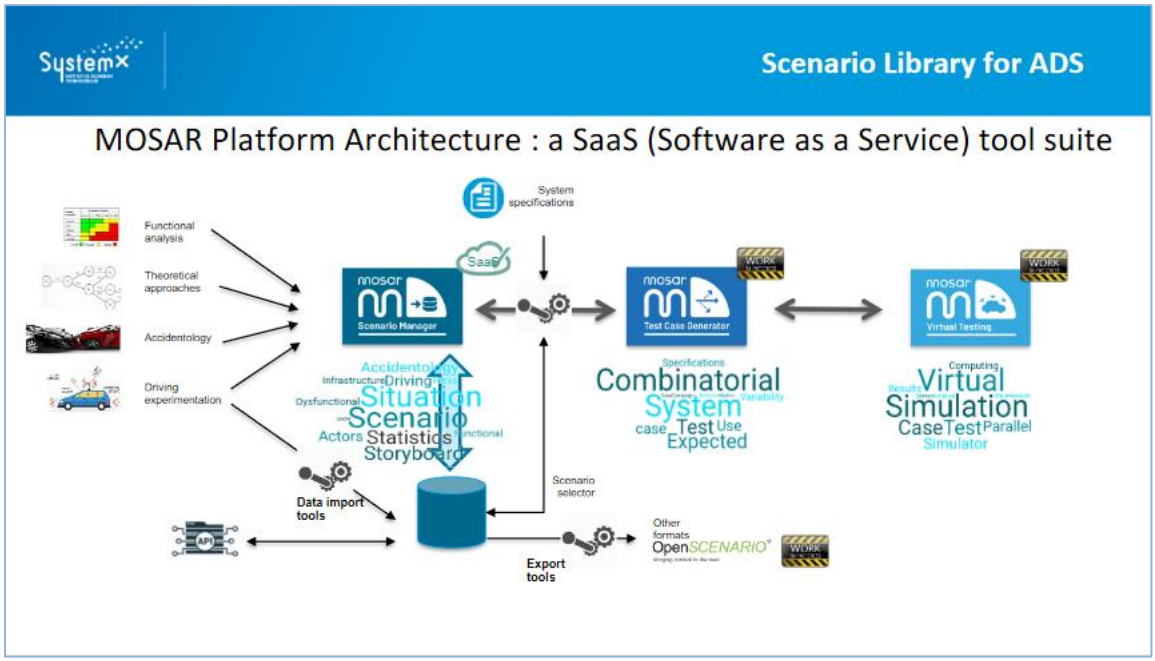
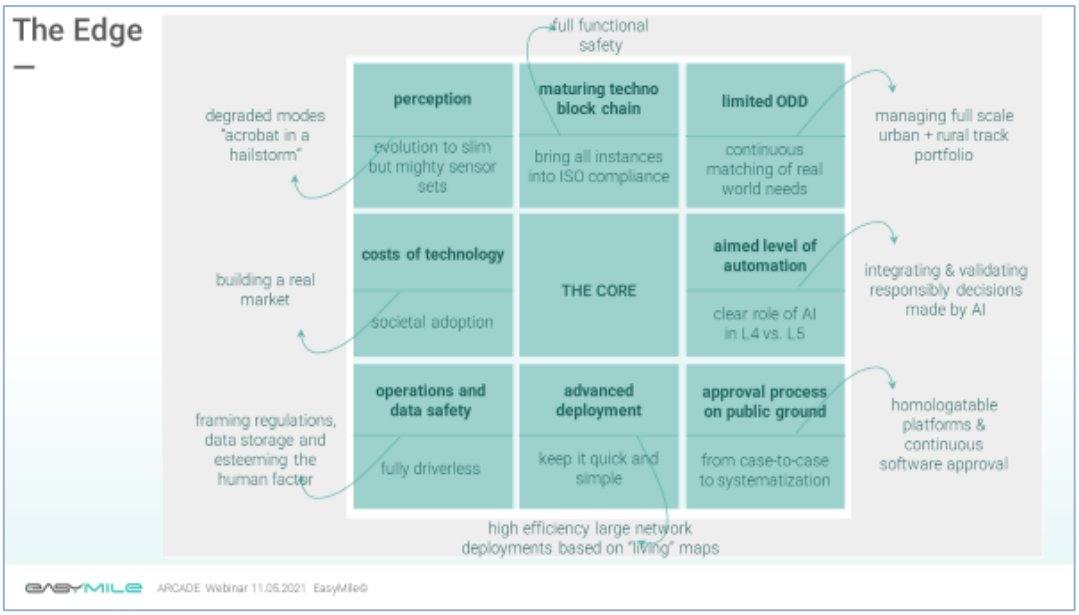


2.8. Current edges to enable large scale adoption of autonomous driving technology in Europe (Arwed Schmidt, Head of Technical Sales, EasyMile)

The last presentation was done by Dr Ing Arwed Schmidt, EasyMile. He argued for a more holistic view on edge cases, where software should be part of eliminating these situations. The forward-looking presentation described the different steps needed to come to a transport solution, perceived as better and safer than today. The eight areas defined by EasyMile are: perception technology, full functional safety, move away the limiting factor of ODD (which is seen as a development step rather than a building block for a service), responsibility decisions made by AI, approval processes for public ground, reducing the time for large scale deployment, operations and data safety, and cost of technology and public acceptance. EasyMile will work on weather-related edge cases in the newly started AWARD EU project that will demonstrate automated industrial trucks.



2.9. Inventory of edge case topics to be addressed

The webinar audience was asked which topics they thought should be addressed in edge cases using a Padlet (14).

This resulted in a rich list of topics. This was used as input for the afternoon expert workshops. You can find the readable form of the results in Annex 1 Inventory of edge case topics to be addressed.

A selection was made by the organisation team:

- Should edge cases be selected by severity or criticality or another metric?
- We need to aim for universal edge cases that are not specific to a vehicle model. That will not always be possible.
- We need to distinguish between internal (failure) and external (extreme scenario) edge cases.
- Accident databases have limited validity for CCAM as most accidents are human caused. For CCAM, there may be other edge cases.
- The definitions vary and corner cases and edge cases are used in similar meanings. DIN SAE SPEC 91381:2019, “Terms and Definitions Related to Testing of Automated Vehicle Technologies”[5] is an important reference. UNECE VMAD has other definitions[18], including critical scenarios. Terms like rare / known / unknown / foreseeable / not foreseeable / expected / unexpected need to be related to edge cases and corner cases.

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3. Break-out sessions

3.1.Break-out 1: Views on definitions of edge cases

The break-out started with two presentations. Sami Koskinen (VTT, Finland) explained several edge case definitions, from general ones like “An unusual or unforeseen situation where something may fail to work properly or as expected” (Oxford Dictionary) to more specific ones such as “Scenario in which the extreme values or even the very presence of one or more parameters results in a condition that challenges the capabilities of the system” (DIN SAE SPEC 91381).

Automated vehicles have different difficulties than human drivers, specifically achieving reliable environmental sensing and understanding complex situations. The relation with dangerous situations can be shown as areas in Safety Of The Intended Functionality (SOTIF, ISO/PAS 21448).

Sami raised several discussion points:

- Testing ODD’s edge vs testing edge cases? Is the definition of an edge case about one unique system’s ODD, or about listing dangerous situations for many systems? An edge case for lidar may not be an edge case for radar, and vice versa.
- Edge cases seem to have very different likelihoods (and then each has to be mitigated so that the accident risk remains small)? Are they so many/different that they are extremely difficult to cover?
- To what level should AV anticipate worst cases and try to avoid them? List “all” cases and analyse liability?

The second presentation was from Christoph Feichtinger (Digitrans, Austria) and the AWARD EU project. He presented Digitrans’ framework for validation and verification of HAVs, using Legal Human Limit Edge Cases LHLEC. The goal is to establish the LHLEC for every Scenario and compare it to simulation. In this way one can focus on what is (legally) acceptable driving behavior for a human and require that the vehicle stays within these limits and perform meaningful tests. LHLEC seeks the acceptance of users, courts and safety experts. The reason for using the concept of human limit is illustrated as follows:

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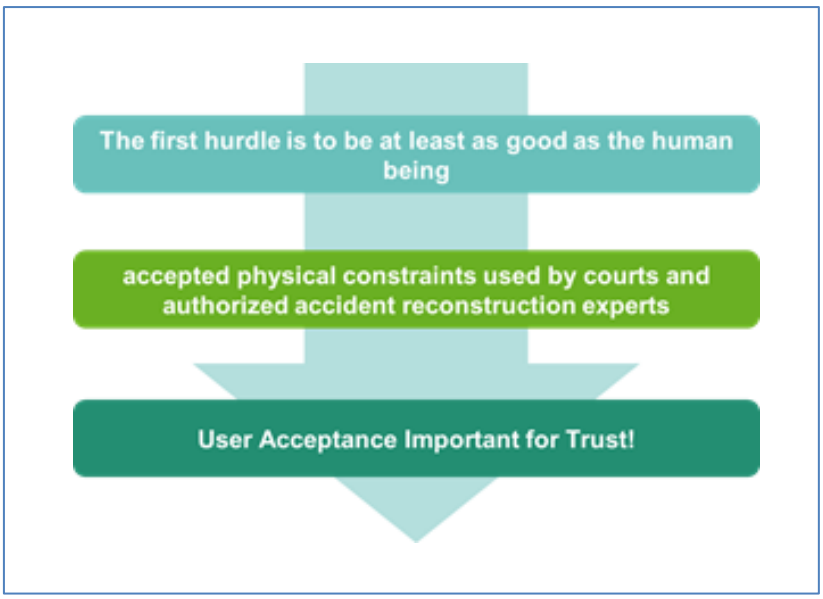

For discussion with the audience, a Padlet was used. The conclusions from the discussion can be summarised as follows:

Definitions are diverse and not precise, but definitions are important for systematic investigation. Edge cases can be safety-critical, but not necessarily. However, confusion is always dangerous. Safety is not the only criterion for AVs. Not fulfilling the driving mission, such as stopping and not moving because the AV cannot deal with a situation, may also be a problem. Categories of edge cases may relate to perception, behaviour, weather, vehicle/system capabilities, and unknown objects/obstacles.

In order to derive edge cases, the systems' limits and ODD (Operational Design Domain) need to be defined in detail and transparently. We have to keep changing environment in mind as well as numerous scenarios that could happen in mixed traffic with human drivers. Edge cases must be collected so they can be dealt with in the future. Parameters of edge cases can be external (rare events) and internal (the level of ability of the system to detect them or react properly).

As the problem for AV is the interpretation and understanding of complex situations, we could look at human drivers as reference to what an AV should be able to handle. However, edge cases could also be caused by humans. Human reference in scenarios is needed, looking at the risk balance between human and AV. New topics are the edge cases related to teleoperation and cyberattacks.

The full breakout session recording can be found at the ARCADE YouTube channel: https://www.youtube.com/watch?v=Ip3ym38puUg

3.2.Break-out 2: Possible approaches to edge cases

Breakout session 2 covered the topic of "Approaches for identifying, collecting and sharing edge cases". The session had three short introductions followed by a discussion centred from a Padlet sketch board. The session had between 18-20 participants.
Sytze Kalisvaart, organizer of the workshop and project manager StreetWise scenario database[14], TNO, introduced the session and presented six approaches to collecting or identifying edge cases:

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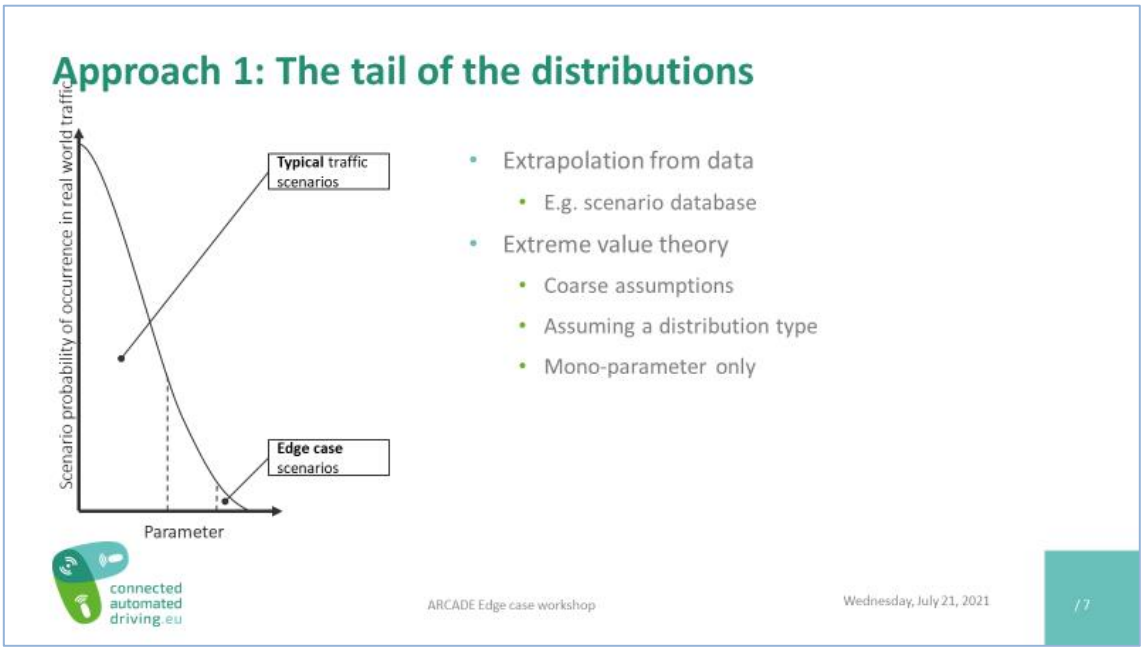
1. Look at the tail of distributions
   This was exemplified by the Japanese approach in UNECE VMAD where the events should be reasonably foreseeable.
2. Derive from accident databases
   Not all accidents are edge cases, not all edge cases are accidents. Also, non-fatal accidents are underreported.
3. Let the public report critical cases
   This might be a messy source, have issues in data privacy and might have (risky) location bias. Although, this might help public acceptance.
4. Road operator as source
   Could cover static areas, but also data from drones. Could be based on video, trajectory or radar point cloud. An important point to consider is the exposure.
5. Synthesize from triggering events
   The database can be generated from triggering events, and usually combinations of events. But doing so these events might become corner cases rather than edge cases.
6. Searching for critical zone
   Combining events (like in 5) but assessing the foreseeable risk in relation to its criticality.



The next presentation was done by Wolfram Klar, team leader Automation, AustriaTech on “Edge cases – a new approach for safe testing in Austria”.
AustriaTech is the national contact point on AV in Austria. Klar first described the test process from the initial consultation to the final reporting.
As part of the process, AustriaTech propose to use edge cases as part of a validation step during simulations and proving grounds. The edge cases should be shared as a standard catalogue. For sure, some edge cases might be country or domain specific, but the majority could be general. Independent auditors should be responsible for the process and is approved a certificate for testing is granted.

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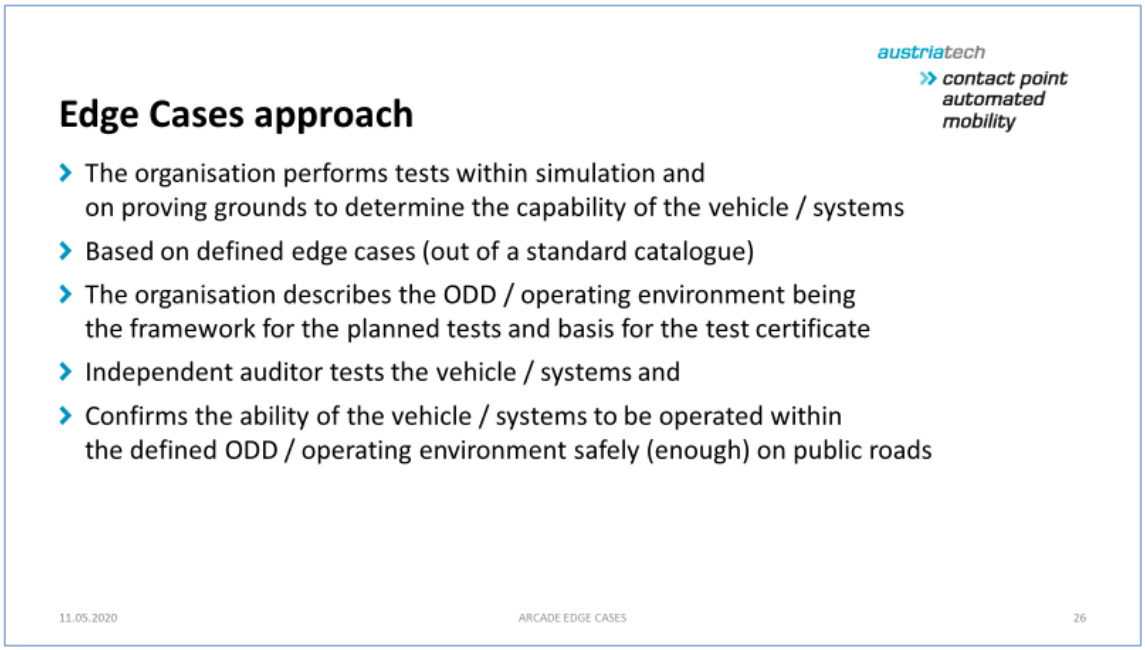
The standard catalogue of edge cases raised a few questions. The catalogue will not be populated by AustriaTech, it is important that it is shared. The number of cases could not be stated as it depends on its definition: as few as possible but as many as necessary.
A more strict approach should limit the number of cases. The edge cases must be manageable in the test process and the cases should be edges and not normal driving. It is though obvious that this is an opportunity for collaboration, research and also from a business perspective.



The last presentation was done by Dr. Christian Neurohr, OFFIS on “V&V Methods Approach for dealing with Edge Cases”.
Dr. Neurohr continued his presentation from the morning by going more in-depth into the topic of criticality phenomena applied to GIDAS accident database. The conclusions from an analysis of accidents with human drivers are that they are multi-causal. Most accidents have four or more influencing factors (not necessary grading the impact each have on the accident) and ~55% have 4 to 7 influencing factors.
The accidents are described in natural language, and then converted to descriptive data. It was discussed whether this is an edge case or corner case. By grading the influence, a specific factor has to an accident you could have accidents where more than one influencing factor could have large impact, thus indicating a corner case.

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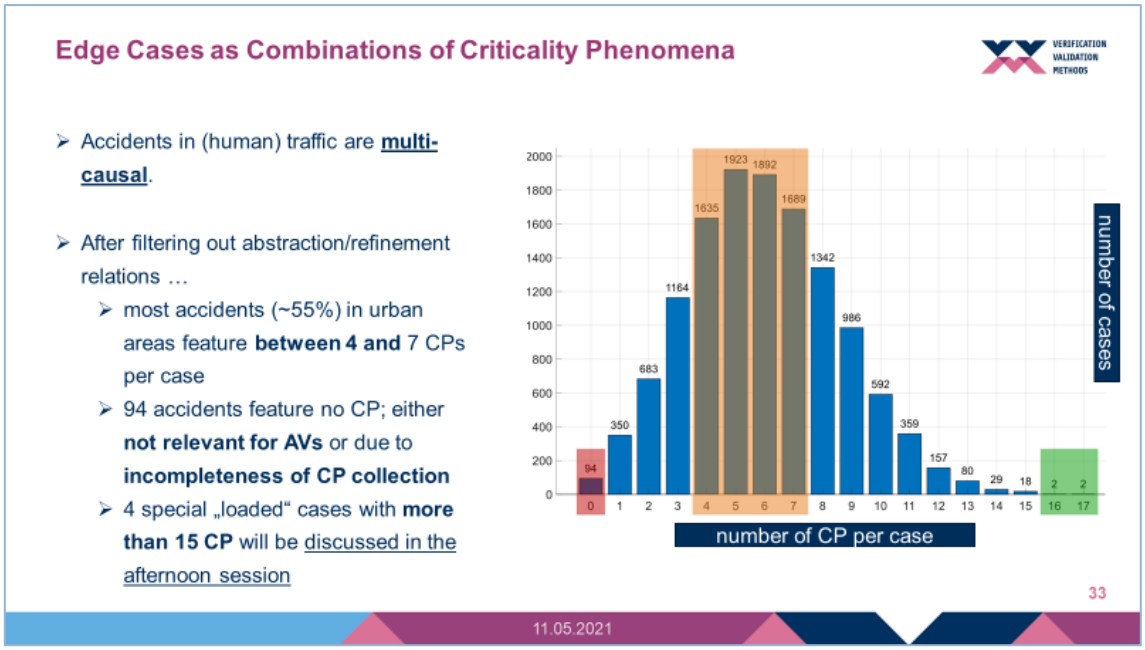

It was then discussed that these cases still are within ‘common sense: should there be a ‘rare’ and ‘extraordinary’ edge cases? From Dr. Neurohr’s perspective this is not relevant, at least not on accident databases.

The workshop continued adding topics for discussion in a Padlet. There was a clear consensus on sharing edge cases, something that e.g. will be explored in the Hi-Drive project.
Liability was discussed from the point of if an accident happens even if the function is validated against a common edge case database. It was stated that this could be quite positive from an OEM perspective. A function can be validated against a set of cases, and the database could be updated over time. A set of principles must then be defined in terms of how often a function should be tested and what happens if a function does not pass a test.
In addition to vehicle centric data (accidents, naturalistic driving data) infrastructure data should also be explored.

To summarize the discussion on the three topics: identifying, collecting and sharing edge cases.

- Identify
  Of course, this depends on the definition (breakout session 1) but from a validation perspective (breakout session 3) the set of edge cases shall be “as few as possible but as many as necessary”.
- Collect
  Quite a few approaches to collect edge cases were proposed, many looking at existing data sources (accidents, naturalistic driving, drone coverage) but one source is still obviously missing: collecting edge cases from AV in traffic.
- Share
  It was agreed to share knowledge and examples of edge cases between actors to build validation or certification steps in order to build public acceptance. The process would benefit from being transparent and the certification step might help OEM:s to

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roll out AV faster (as the liability risk could be reduced). It was also stated that the complete process of identifying, collecting and validating (as part of approval process) needs to have an iterative approach where new edge cases are shared among independent actors and certification bodies.

The full breakout session recording can be found at the ERTICO YouTube channel: https://www.youtube.com/watch?v=T0Fc0cp_7lw

3.3.Break-out 3: Using edge cases in safety validation

Breakout session 3 covered the topic "Using edge cases in safety validation". The session had two short presentations followed by a discussion based on the questions from a Padlet sketch board. The session had approximately 20 participants.

Laura Sanz and Julien Bou introduced the session and presented the objectives of the discussion as well as moderated the Padlet board. Satu Innamaa reported on the key aspects and conclusions from the discussions.

The first speaker, Siddartha Khastgir (Head of Verification & Validation, Intelligent Vehicles, WMG, University of Warwick), presented a Systems Approach to Scenario Generation for Automated Driving Systems (STPA) and described how it can be used as part of the scenario identification for edge cases. Siddartha also introduced the topic of how an edge case is defined itself.

When it comes to the identification of test scenarios and establishing confidence on an ADAS or AD system it is important to ask "how a system fails" instead of "how a system works". The hazard-based testing is divided in three steps:

1. Hazard identification.
2. Test scenario generation via accident databases and insurance claim records, real-world data and knowledge-based or analytical hazard-based approach.
3. Identification of pass criteria for the corresponding scenario

Focusing on step 1, Siddartha described the STPA approach[10]. STPA is a system controls engineering based concept to identify hazards within complex systems. It considers the safety of the system as a control problem: any breach of control laws causes a hazard which is the interesting from edge case perspective. STPA provides the most elaborated combination of hazards.

STPA itself follows a 4-step process (Figure 2):

- Definition of the complex system (AD system) itself (system type, ODD) and definition of the losses and hazards (not just from safety point of view, but also from the consumer satisfaction point of view).
- Definition of the control structure of the ADAS/AD system.
- Analysis of control actions and how they can lead to unsafe control actions
- Analysis of causal factors for the unsafe control actions to happen, that is the identification of "loss scenarios".

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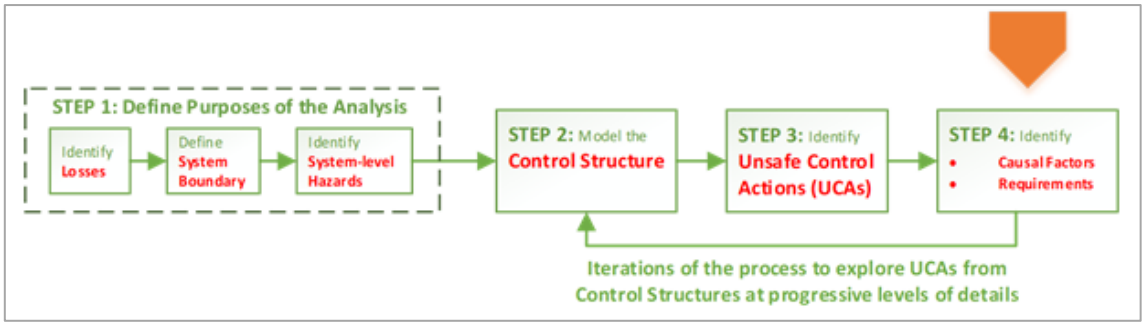

Figure 2 STPA process

The loss scenarios are then extended to test scenario identification or edge case identification by parametrising the context of unsafe control action, the causal factors and the pass criteria.

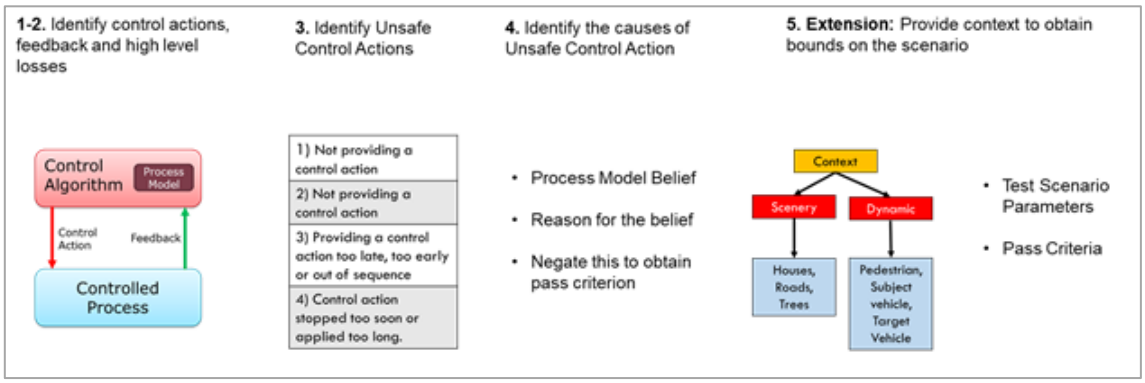

Figure 3 Elaborate view of STPA process

More details about the STPA method are available in the Reference 11.

To finalise, Siddartha also raised the important question “How many edge cases are actually enough?”. When it comes to the testing process it is necessary to have the scenarios, the environment, and the safety argument. The first step could be to create a repository of edge cases. Safety Pool[16] is capturing all edge cases from STPA as well as using accident databases and insurance claim records analysis. It is developed from the perspective of development but also from government and research perspective.

Several questions from the morning session were addressed:

- Question: Is an edge case always an accident?
- Answer: this question is related to hybrid generation of scenarios. First, edge cases are a function of the system design itself (an edge case may be so for a system A but not for system B), that’s the reason for using the term scenarios more than edge cases.
- The main reason for needing a hybrid approach to edge case generation is the following: while some of the edge cases come from severity situations, accidents, others may come from the system design i.e. function design, ODD, the sensor configuration - how the system design could lead to deficiencies in the system performance.

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- Question: How critical scenarios for humans might not be critical scenarios for systems?
- Answer: That statement assumes that everything that the human can do can be also done but the automated system, and this is a wrong assumption.

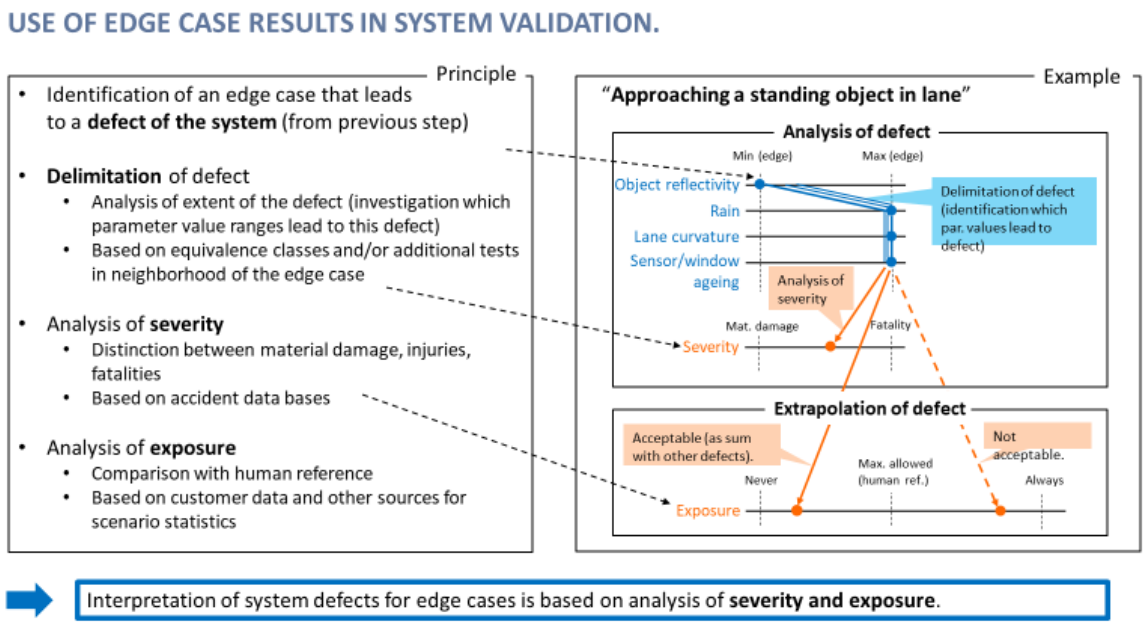
The second presenter, Benoit Vanholme (Verification & Validation Expert, BMW) continued the morning discussions and went more in detail on specific Research Questions about using edge cases for the development of Automated Driving.

The idea to approach the edge cases for the validation of an AD function is to first select safety relevant scenarios, to select influence factors that are challenging for the system (from vehicle and environment point of view, and considering all sub-systems involved in sensing, planning, and acting), and combine these factors to select Edge Cases taking into account Exposure, Severity and Controllability (ESC) criteria by the system.

The selection of edge cases is done by 1) expert knowledge and 2) real world data. Other two sources 3) customer data and 4) accident databases as they are nowadays can be an inspiration. However, they are based on human driving in L0-L2 systems. That's why the main sources nowadays are 1) and 2) until there is data available for L3+ systems.

For the use of edge cases in system validation, it is important to select those which may lead to a defect of the system. Then, the extent of the defect is analysed by identifying the different parameters that lead to it, as well as severity and the acceptance/not acceptance of the defect is finally decided taking into account the level of exposure.

The example "Approaching a standing object in lane" is used to explain the different steps of the process.



Benoit shared relevant Research Questions related to this method:

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- Validity: is the design of edge cases an efficient means to find safety-relevant defects of automated driving systems? In the other way, are safety-relevant defects caused by specific influence factors, or do they occur randomly?
- Transferability: does a safe system behavior for edge cases imply a safe system behavior for easier cases? Does the investigation of edge cases allow reducing the number of tests?
- Sharing: which knowledge on edge cases can be shared between companies: methodical, abstract, concrete? (As Siddartha Khastgir mentioned in the first presentation, edge cases are a function of the AD system, however a level of commonality among systems may be found).
- Other sectors: how are edge cases dealt with in medicine, aviation and other safety-relevant sectors?

The speakers addressed additional questions raised by the audience:

- Question: usually there is some relationship between the parameters related to a defect (i.e. rain, dirt, etc.). Is the correlation among parameters taking into account in the statistics used in this method?
- Answer: Yes, the correlation between co-dependent parameters is taken into account for the statistics.
- Question: do you think that the analysis of the defects has to be adapted for a given market/region to cover all edge cases? (In the direction of the ODD, different use of the system in a different environment, driving conditions, etc.)
- Answer: Yes, different participants, different countries, infrastructure, different regional situations are taken into account. Otherwise, if an edge case cannot be solved there is always the possibility to reduce the operation of the system to a more reduced ODD.
- Question: should we have two global database for homologation, one catalogue of functional scenarios (from regulation) for testing nominal driving behavior of ADAS/AD systems, and a specific database enhanced scenarios more on the direction of sub-systems i.e. perception, decision making, motion control?
- Answer: even from the regulation point of view there will be need to cover both types of scenarios. For ADAS systems you could have a split between 1 and 2, however as we move forward on removing the driver from the active tasks there will be need to include both types of scenarios since any failure, at any level may be fatal.

The workshop continued with the discussion based on the Padlet questions.

- It is the general opinion that since there is no safety argument or definition of what is safe enough, edge cases cannot be the only base for measuring and defining that the system is safe enough. Also, societal aspects have to be considered as a strong basis for an homologation process.
- Considering the international markets, edge cases may differ among regions and this have to be considered for the regulatory process.
- Can we define a number (i.e. 1000) edge cases that can count for all possible customer situations?
- Which test modalities should be used to validate against test cases (and requirements for these validation tools)? Simulation could be used to identify which edge cases have to be covered in real world. Both simulation and real world have a

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role but it depends on the objective: i.e. from the type approval certification, simulation of edge cases may not be valid, only the real world would be valid (unless the simulation itself is validated to have a correlation to the real world).

- Also the use of different test platforms depend on the sub-system to be tested. Simulation could have a role in the development, and from the general system perception.
- Do we need to consider edge cases at component level? Yes. Some edge cases are just for some of the system components and still need to be considered. i.e. in a system with radar, camera, lidar, there may be an edge case for the radar, not from the sensor fusion and still needs to be considered since the Lidar and camera may fail and the perception may rely just on the radar.
- It is doubtful that there will be a closed set of edge cases for specific systems. As soon as the system changes (even just the training data for the perception system), you change the scenarios that will be problematic for the AV. Applying this difficulty to how to deal edge cases when the vehicle goes on the road, it is necessary to have a repository to handle and update as we encounter edge cases, and the industry needs a mechanism to let this happen.
- New edge cases should be shared so everyone in industry can work on the same basis. There should not be competition when it comes to safety of AD since this would be detrimental for the industry.
- Experts along the full AD value chain needs to be involved in the edge case identification and validation and challenging the system.
- During the life of the vehicle it is important to do field monitoring of the system behaviour (similar to other sectors).
- Edge cases themselves are not enough, we need to look at the pass criteria. We need to look at what the system is expected to do in these cases, to define the “good system behavior”. Driving codes for automated systems are necessary to be developed (as well as we have human driving codes).

The full breakout session recording can be found at the ARCADE YouTube channel https://www.youtube.com/watch?v=o47R0GakYJw&t=810s

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3.4. Wrap-up and next steps

The workshop was concluded with the wrap up of the breakout sessions.

This led to the following conclusions:

Break-out 1: Views on definitions of edge cases

- Definitions are diverse and not precise, but definitions are important for systematic investigation. Edge cases can be safety-critical, but not necessarily. However, confusion is always dangerous.
- Safety is not the only criterion for AVs: it could also be to not fulfil the driving mission,
- Categories of edge cases may relate to perception, behaviour, weather, vehicle/system capabilities, and unknown objects/obstacles.
- The systems' limits and ODD (Operational Design Domain) need to be defined in detail and transparently.
- Edge cases must be consistently collected so they can be dealt with in the future. Parameters of edge cases can be external (rare events) and internal (ability of the system to detect them or react properly).
- Edge cases could also be caused by humans. Human performance as a reference in scenarios is needed, looking at the risk balance between human and AV.

Break-out 2: Possible approaches to edge cases

- Identify: the set of edge cases shall be "as few as possible but as many as necessary".
- Collect: Quite a few approaches to collect edge cases were shown using existing data sources (accidents, naturalistic driving, drone coverage) but one source is still obviously missing: collecting edge cases from AV in traffic.
- Share: It was agreed that sharing know-how and edge cases is essential to speed up validation or certification and to build public acceptance. This might help OEMs as well.
- The complete process of identifying, collecting and validating needs to have an iterative approach where new edge cases are shared among independent actors and certification bodies.

Break-out 3: Using edge cases in safety validation

- A systematic analysis of possible hazards based on systems engineering approaches provides a comprehensive overview of possible edge cases.
- An edge case for one system may not be an edge case for another system.
- Edge cases should create a learning loop for developers and requires an ongoing data collection for public use.
- Edge cases should be used both on a subsystem and a full vehicle level.

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4. Conclusion

We extracted the following possible conclusions from the workshop:

- Categories of edge cases may relate to perception, behaviour, weather, vehicle/system capabilities, and unknown objects/obstacles.
- Parameters of edge cases can be external (rare events) and internal (ability of the system to detect them or react properly).
- Many approaches to edge cases exist. We see two main streams:
    - 1st a system engineering based approach where possible edge cases are deduced using a comprehensive analysis (e.g. speakers Antona-Makoshi, JARI; Vanholme, BMW; Khastgir, University of Warwick; Neurohr, OFFIS and V&V Methoden);
    - 2nd an observational, more data-driven approach, where new edge cases are considered unpredictable or unforeseen by definition and need to be identified through monitoring of vehicles on the road (e.g. Koopman, CMU and Edge case research; Tesla).
- The set of edge cases shall be “as few as possible but as many as necessary”.
- There is a clear consensus that a shared library of edge cases is beneficial for all stakeholders.
- The sensitivity of individual vehicle models for these edge cases needs to remain confidential, assuming the normal mechanism for correcting critical safety issues in a production vehicles remains in place. Monitoring of driving data may reveal such issues at an early stage so that harm is limited.
- Edge cases should create a learning loop for developers and requires an ongoing data collection for public use.

Recommendations

- Work on standardising terminology for edge cases and related terms needs to continue. DIN SAE SPEC 91381 and UNECE IWG VMAD use different definitions.
- Edge cases must be consistently collected so they can be dealt with in the future.
- The complete process of identifying, collecting and validating needs to have an iterative approach where new edge cases are shared among independent actors and certification bodies.
- A public database of edge cases should be set up.

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6. Annex 1 Inventory of edge case topics to be addressed

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Topics to be addressed for edge cases

ARCADE Workshop on Edge cases

SYTZEKALISVAART APR 20, 2021 01:16PM

What are the main challenges for edge cases?

The metric used to "define" edge cases (criticality/severity).

Can real edge cases, which you could not think of be measureable, predictable, extrapolatable at all? — FEKE1

Are cyber attacks / hacking edge cases?

Minimization

Could you explain what minimization means? — I

Finding the ones that are also common beyond a single occurrence only — ANONYMOUS

Universal edge-cases

Definition of universal edge-cases, instead of vehicle model specific ones.
What is an edge-case for a specific vehicle model, might not be one for another vehicle brand or model.

Define the min/max thresholds while talking on edge spectrum

We should also talk about the middle ground too! Not just the 25% and 75% but also the critical 50% —

Completeness of scenario pool with edge cases

Edge cases may mean differently depending on the configuration of the ADS, is there any common ground?

That you do not know them in advance.

What should we not forget?

Severity

Is an edge case always defined as an accident?

What are measures to reduce criticality/severity of an "edge case" outside of car design? — ANONYMOUS

I still believe we should first categorise cases into internal and external — I

Bad roads

weather conditions

Connectivity may be critical in the future and may introduce new risks

Good point! I have reviewed a TRB paper on cybersecurity pertaining to AVs and though this is unlikely to happen (unless targeted), it is still worth looking into! — I

Critical Scenarios for humans might not be critical for AVs (and the other way around). --> Accident databases have limited validity, we cannot assume the same scenarios are critical for AVs

System failure

corner vs. edge vs. critical cases

As It was very well noticed by many participants: the definition is not consistent between communities.

- One definition would be recommended to avoid confusions: rare / known / unknown/ foreseeable / not foreseeable / expected / not expected?
- Clarify if corner / edge / critical cases are synonyms?

There are many references:

1. SOTIF:

“A corner case is a scenario in which two or more parameter values are each within the capabilities of the system, but together constitute a rare condition that challenges its capabilities. An edge case is a scenario in which the extreme values or even the very presence of one or more parameters results in a condition that challenges the capabilities of the system"[50].

Where 50 refers to [50] DIN SAE SPEC 91381:2019, “Terms and Definitions Related to Testing of Automated Vehicle Technologies”

2. Discussions going on in the UNECE IWG WMAD, SG1 Traffic Scenarios, the New Assessment and Test Method concept paper:

VMAD-16-03 provisional consolidated NATM MD.doc

‘Edge Case’ is a rare situation that still requires specific design attention for it to be dealt with by the AV in a reasonable and safe way. The quantification of “rare” is relative, and generally refers to situations or conditions that will occur often enough in a full-scale deployed fleet to be a problem but may have not been captured in the design process. Edge cases can be individual unexpected events, such as the appearance of a unique road sign or an unexpected animal type on a highway.

‘Critical Scenarios’ means a traffic scenario containing a situation in which the ADS needs to perform an emergency maneuver in order to avoid/mitigate a potential collision, or react to a system failure.

3. Prof. P. Kopmann paper ‘Credible Autonomy Safety Argumentation’. Where he refers to frequency (and UL 4600)

We define an edge case as a rare situation that will occur only occasionally, but still needs specific design attention to be dealt with in a reasonable and safe way.

It is useful to distinguish edge cases from corner cases. Corner cases are combinations of normal operational parameters. Not all corner cases are edge cases, and the converse. An example of a corner case could be a driving situation with an iced over road, low sun angle, heavy traffic, and a pedestrian in the roadway.

4. Other definitions mentioned by speakers like VV Methoden, other R&D projects…

Another issue would be how we can distinguish between case types since some may overlap with another – |

❋❋❋❋❋❋