Input to FRAV/VMAD

ODD Based Scenario Framework
Determining Traffic Scenarios and Functional Requirements

- Nominal scenarios
- Critical scenarios
- Unavoidable scenarios
Scenario Generation Methods

Data based scenarios:
1. Accident databases
   - What are the causes of known accidents?
2. Real world data
   - Telematics, Insurance claims
   - What are the near-miss events?

Knowledge based scenarios:
3. Analytical Hazard Based Approach
   - (STPA analysis)
   - What are the potential causes of failures?

Scenario library: Safety Pool™ Scenario Database
Scenario description language
Parameter identification & randomisation
Overall Summary

Road Traffic rules

Functional Requirements

Nominal Scenarios

Critical Scenarios

Failure Scenarios

Nominal Scenario Tests

Critical Scenario Tests

Failure Scenario Tests

Test Methods (simulation, track tests)

Common High-Level Description

Harmonized Methodology
Overall Summary

- Probability
  - Assumptions
    - Real World Analysis
  - ODD Analysis
    - Nominal Scenarios
    - Driving Scenario Analysis
    - OEDR Analysis
- Critical Scenarios
  - Nominal Scenario Tests
  - Critical Scenario Tests
  - Likelihood
  - Failure Scenario Tests
- Test Methods (simulation, track tests)

Functional Requirements
- Road Traffic rules
- In-use

Knowledge based
- Harmonized Methodology
  - Knowledge based
  - Data based
    - Data based

- Common High-Level Description
  - Likelihood
SOTIF

ISO 34502

Real World Analysis

FUSA

Common High-Level Description

NATM

Harmonized Methodology

Conventional TA

Road Traffic rules

Functional Requirements

Safety Target

ODD Analysis

Driving Scenario Analysis

Nominal Scenarios

OEDR Analysis

Core Nominal Scenarios

Assumptions

Probability

Critical Scenarios

Likelihood

Critical Scenario Tests

STPA

Identify Failure Modes

Response Analysis

Failure Scenarios

Functional Requirements

Failure Scenario Tests

In-use

Test Methods (simulation, track tests)

Nominal Scenario Tests

Identify Failure Modes

Response Analysis

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Core Nominal Scenarios

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Likelihood

Critical Scenario Tests
Safety Target

Road Traffic rules

Functional Requirements

Nominal Scenario Tests

Nominal Scenarios

Driving Scenario Analysis

ODDR Analysis

Core Nominal Scenarios

Probability

Assumptions

Critical Scenarios

Critical Scenario Tests

Likelihood

Test Methods (simulation, track tests)

Identify Failure Modes

STPA

Response Analysis

Failure Scenarios

Failure Scenario Tests

ADS Analysis

Common High-Level Description

Harmonized Methodology
### ODD Framework Toolbox

<table>
<thead>
<tr>
<th>Scenario Categorization</th>
<th>Natural Language scenarios description</th>
<th>Scenarios description</th>
<th>Scenario Database</th>
<th>Core Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 34502</td>
<td>StiEF, WMG-SDL</td>
<td>ASAM OpenDRIVE, ASAM OpenSCENARIO, M-SDL, H-SDL, ADSL, WMG-SDL</td>
<td>Safety Pool, TNO, CATARC, SAKURA, France</td>
<td></td>
</tr>
<tr>
<td>Assumptions</td>
<td>TNO, HEADSTART</td>
<td>PAS 1883, ISO 34503</td>
<td></td>
<td>NHTSA Test Cases, Safety Pool, ISO 34502, Japan, Foretellix, Germany, Netherlands/Singapore, Waymo, M-CITY</td>
</tr>
<tr>
<td>Safety Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>STPA, FTA, FMEA</td>
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</tr>
</tbody>
</table>

- A Number of tools are needed to support the ODD based framework. FRAV/VMAD framework should define what tools are needed but shouldn’t specify which tool is most appropriate.
- Core scenario list may be Harmonized after review of existing tools.
- With more real world experience, and when ADS is to be regulated then specific tools may be harmonized where needed.
Summary

• ADS certification consists of a scenario-based assessment

• The ODD description by the Manufacturer will support determination of applicable requirements and scenarios generation
  ➢ The ADS is expected to comply with all requirements in these scenarios

• Nominal scenario are derived from ODD and OEDR analysis
  ➢ The ADS is expected to comply with all requirements in these scenarios

• Critical scenarios are derived from STPA and real world data / Assumption of other road users (IEEE P2846)
  ➢ The performance threshold in critical scenarios is compared to accident data

• Failure scenario derived from FMEA and STPA
  ➢ The ADS is expected to comply with all requirements in these scenarios
Nominal Scenarios

- Regulation should provide a framework that allows manufacturers to derive requirements for nominal behaviour.
- Nominal scenarios and requirements can be derived from the ODD and the expected behaviour competency (Analysis of Highway code and ADS functional requirements)
- The EU’s implementing act should define a common categories of behaviour competencies that are applicable to all EU members states. The type approval should focus on assessing the ADS ability to perform these behaviours in the ODD.
- Behaviour competencies may be different between: highway, interurban, urban and parking.

Perform analysis to identify the characteristics of the ODD.

Perform driving scenario analysis.
- Expected hazards (e.g., vehicles, pedestrians, etc.);
- Unspecified/unexpected events (e.g., construction zones, emergency vehicles, etc.); and
- Key infrastructure elements (e.g., traffic signs and signals, road markings, etc.).

Perform analysis to identify OEDR behaviors and corresponding responses.
Nominal Scenarios – ODD Analysis

- ODD Analysis
  - Is used to identify the characteristics of the ODD
  - Characteristics may consist of: physical infrastructure, operational constraints, environmental conditions, connectivity etc
  - PAS 1883 may be used as a reference

Nominal Scenarios – Driving Scenario Analysis

- The developed baseline ODDs were used to identify important objects and events that ADS could feasibly encounter within those ODDs
- Interactions with obstacles were indicated as occurring in a frontal, side, or rear zone.

<table>
<thead>
<tr>
<th>Objects</th>
<th>Events/interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicles (e.g., cars, light trucks, heavy trucks, buses, motorcycles)</td>
<td>Lead vehicle decelerating (frontal), lead vehicle stopped (frontal), lead vehicle accelerating (frontal), changing lanes (frontal/side), cutting in (adjacent), turning (frontal), encroaching opposing vehicle (frontal/side), entering roadway (frontal/side), cutting out (frontal)</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>Crossing road – inside crosswalk (frontal), crossing road – outside crosswalk (frontal), walking on sidewalk/shoulder</td>
</tr>
<tr>
<td>Pedalcyclists</td>
<td>Riding in lane (frontal), riding in adjacent lane (frontal/side), riding in dedicated lane (frontal/side), riding on sidewalk/shoulder, crossing road – inside crosswalk (frontal/side), crossing road – outside crosswalk (frontal/side)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Objects</th>
<th>Events/interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animals</td>
<td>Static in lane (frontal), moving into/out of lane (frontal/side), static/moving on shoulder</td>
</tr>
<tr>
<td>Debris</td>
<td>Static in lane (frontal)</td>
</tr>
<tr>
<td>Other dynamic objects (e.g., shopping carts)</td>
<td>Static in lane (frontal/side), moving into/out of lane (frontal/side)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Objects</th>
<th>Events/interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic signs</td>
<td>Stop, yield, speed limit, crosswalk, railroad crossing, school zone</td>
</tr>
<tr>
<td>Traffic signals</td>
<td>Intersection, railroad crossing, school zone</td>
</tr>
<tr>
<td>Vehicle signals</td>
<td>Turn signals</td>
</tr>
</tbody>
</table>
Nominal Scenarios – OEDR Analysis

- Based on the objects and events identified it is possible to map the appropriate response of the ADS:
  - The ADS should adapt its behaviour in line with safety risks
  - The ADS should comply with road traffic rules.
  - The ADS behaviour should not disrupt the flow of traffic
  - The ADS should interact safely with other road users
  - etc

<table>
<thead>
<tr>
<th>Event</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead vehicle decelerating</td>
<td>Follow vehicle, decelerate, stop</td>
</tr>
<tr>
<td>Lead vehicle stopped</td>
<td>Decelerate, stop</td>
</tr>
<tr>
<td>Lead vehicle accelerating</td>
<td>Accelerate, follow vehicle</td>
</tr>
<tr>
<td>Lead vehicle turning</td>
<td>Decelerate, stop</td>
</tr>
<tr>
<td>Vehicle changing lanes</td>
<td>Yield, decelerate, follow vehicle</td>
</tr>
<tr>
<td>Vehicle cutting in</td>
<td>Yield, decelerate, stop, follow vehicle</td>
</tr>
<tr>
<td>Vehicle entering roadway</td>
<td>Follow vehicle, decelerate, stop</td>
</tr>
<tr>
<td>Opposing vehicle encroaching</td>
<td>Decelerate, stop, shift within lane, shift outside of lane</td>
</tr>
<tr>
<td>Adjacent vehicle encroaching</td>
<td>Yield, decelerate, stop</td>
</tr>
<tr>
<td>Lead vehicle cutting out</td>
<td>Accelerate, decelerate, stop</td>
</tr>
<tr>
<td>Pedestrian crossing road – inside crosswalk</td>
<td>Yield, decelerate, stop</td>
</tr>
<tr>
<td>Pedestrian crossing road – outside of crosswalk</td>
<td>Yield, decelerate, stop</td>
</tr>
<tr>
<td>Pedestalclist riding in lane</td>
<td>Yield, follow</td>
</tr>
<tr>
<td>Pedestalclist riding in dedicated lane</td>
<td>Shift within lane</td>
</tr>
<tr>
<td>Pedestalclist crossing road – inside crosswalk</td>
<td>Yield, decelerate, stop</td>
</tr>
<tr>
<td>Pedestalclist crossing road – outside of crosswalk</td>
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<td>Lead vehicle decelerating</td>
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<td>Decelerate, stop</td>
</tr>
<tr>
<td>Lead vehicle accelerating</td>
<td>Accelerate, follow vehicle</td>
</tr>
</tbody>
</table>
Critical Scenarios - Assumptions

- Critical scenarios can be derived from the nominal scenarios and STPA. Test scenario parameters can be defined from:
  - Accident database
  - Real world data
  - Assumptions of real driving behaviour
Critical Scenarios - STPA

STAMP/STPA is based on Systems Engineering and considers system safety as a control problem

- Safety is a control problem (property of a system as a whole, not individually)
- Breach of control laws (constraints) cause accidents

Should consider ‘recognition limitation’ and ‘vehicle disturbances’ for casual factors
failure Scenarios

An FMEA / STPA can generally be broken down into the following steps.

• Identify potential failure modes
• Identify potential causes and effects of those failure modes
• Prioritize the failure modes based upon risk
• Identify an appropriate corrective action or mitigation strategy

The FMEA was broken down by architecture subsystems to identify potential key failures at each step through the ADS “pipeline.”

• Sensing and communication
• Perception
• Navigation and control
• HMI

After completing the FMEA for the ADS architecture, the various failure modes and effects can be summarized and mapped to the relevant tactical maneuver and OEDR behaviors
## Failure Response

- **Failure modes and effects**

<table>
<thead>
<tr>
<th>Behavior Failure</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fail to maintain lane</td>
<td>Impact adjacent vehicle or infrastructure</td>
</tr>
<tr>
<td>Fail to maintain safe following distance</td>
<td>Impact lead vehicle</td>
</tr>
<tr>
<td>Fail to detect and respond to maneuvers by other</td>
<td>Impact lead or adjacent vehicles</td>
</tr>
<tr>
<td>vehicles</td>
<td></td>
</tr>
<tr>
<td>Fail to detect relevant obstacles in or near lane</td>
<td>Impact obstacles</td>
</tr>
<tr>
<td>Fail to identify ODD/OEDR boundary</td>
<td>Operate outside of ODD/OEDR capabilities</td>
</tr>
</tbody>
</table>

- **Fail safe**

  The primary goal of an FS strategy is to rapidly achieve an MRC where the vehicle and occupants are safe. Three candidate FS mechanisms were considered for further evaluation.
  - Transition to fallback-ready user control
  - Safely stop in lane of travel
  - Safely move out of travel lane and stop

- **Fail operation**

  FO strategies allow the ADS to continue to function, even in the event of one or more failures. It may only be supported for a limited duration, or potentially with a reduced set of capabilities.
  - Hardware/software redundancy
  - Adaptive compensation
  - Degraded operations
    - Reduced top speed
    - Reduced level of automation
    - Reduced ODD
    - Reduced maneuver capabilities
    - Reduced OEDR capabilities