Submitted by the DDT Performance workstream leader

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FRAV DDT Workstream

Use of Safety Models for measurable criteria derivation

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Introduction

- The group was created to focus on how to derive measurable criteria based on Functional Requirements and Detailed Provisions as per the FRAV Document 5
- Two proposals were considered as a foundation for the group:
  - "FRAV-26-07 (Germany) Vision for FRAV Final Steps" with a focus on "The ADS shall drive safely"
  - "FRAV-27-06 (UK) Rules of Road" focusing on "The ADS shall comply with road traffic rules" and "interact safely with other road users"
- The group grew in number of attendees, including Contracting Parties and Industry representatives (18 participants)
- The group meets on a weekly basis virtually

Objectives and Assumptions

- Provide a guideline to FRAV on how to derive measurable / verifiable criteria
- Considering how different safety models could be applied in the process

Literature Review

Comparison of Safety Models						
Model	*Summary / Assumptions*	*Parametrization*	*Pros*	*Cons*	*Comments*	*Source / Reference*
Fuzzy Safety	Performance model aimed to classify a concrete scenario as preventable or not for a careful and competent human driver The model considers the capability of the competent and careful driver to anticipate a collision by mild decelerations before reaching a safety critical situation The model is based on rear-end collision scenarios	- Lateral safe distance - Longitudinal safe distance according to Fuzzy SSMs - Capacity for calm proactive reaction	- Less parameters needed - Lees information that may induce errors (lane markings) - Cases when the vehicles deceleration causes an accident are avoided - Slow lane changes for vehicles in a distance considered		o Requesting max decel for all non-safe situation is applying a driving policy, this should not be the intention of this model o In fact, the model is used to create a threshold between preventable and unpreventable	UNECE-R157-07-06
Kinematic-LC	Performance model aimed to classify a concrete scenario as preventable or not for a careful and competent human driver The model considers higher speed where braking might not be the most effective action to address unsafe driving scenarios if lane change is allowed The model aims to complement the FSM to cover lane change and it is based on point mass kinematic integration	- Acceleration - Velocity - Jerk	- Few parameters needed (K-LC) - Can be coupled with a triggering decision-making algorithm (K-LC) - Dynamical feasibility of the maneuver qualitatively proved for several vehicle calibration at sufficiently high speed - Noticeably increased safety performance for critical scenarios where speed difference is high	- Impact of lack of mitigation for scenarios where accident is un-avoidable yet to be established - Real-world data validation not yet available	o The point mass kinematic model is already complicated enough and could be used for lane change considerations o Focus on collision avoidance and not response o Model to be used to assess what is preventable vs non-preventable o Trajectory planners are based on complex decision-making algortihms and are to be left with the OEMs	
Last-Point-To-Steer	The model assumes braking is justified when avoidance by steering impossible to avoid a collision. Based on assumptions that only when the driver fails to provide input, the AEB will trigger, no anticipatory behaviour The model is based on Car to Car longitudinal scenario (or vehicle moving in the same direction)	Need 3 parameters: jerk, max decel, TTC brake (depending on vehicle dynamics) Additionally: brake activation delay, sensor processing delay Parameters can come from assessment of state of the art systems	- Possible with current technology - Late Activation (less false act.)	- Anticipation of situation not considered - Safety potential wasted	o Perception of the stimuli and reaction in these scenarios are limited to braking o Detection to control latency might be higher for an ADS as it will include path planning and optimum trajectory assessment to avoid a collision o For last second response, these models can offer good rationale; however they don't cover anticipatory behaviour o However they cannot take into account more sophisticated systems, with path prediction, quality perception where fusion is needed and not only camera based o They can be used for low speed city traffic in specific or extreme situations o Good for cut-in use-cases and some longitudinal traffic situations o Also in those longitudinal traffic cases where anticipation is not always helpful	AEBS-HDV-03-03
Safety Zone	The model assumes braking is justified when entering a "safe zone" Brake at the latest when VRU is in vehicle path (evt.including safety zone/stopping dist) Applicable to Car to VRU scenarios (e.g. crossing, lateral conflict, …)	Need 3 parameters: jerk, max decel, TTC brake (depending on vehicle dynamics) Additionally: brake activation delay, sensor processing delay Parameters can come from assessment of state of the art systems	- Possible with current technology - Late Activation (less false act.)	- Anticipation of situation not considered - Safety potential wasted		AEBS-HDV-03-03
State of the Art	Performance based model aimed to identify state of the art for accident avoidance Assessment based on Euro NCAP CPNC-O	Delay time for threat identification, brake activation Brake system speed Brake system deceleration Steering intervention speed		Only for vehicles with camera systems		FRAV-05-05

Literature Review

- The review needs to be completed taking into account other models (e.g. Intel-RSS, NVIDIA-SFF, Motional-Rulebook, …)
- Safety models may be based on assumptions about behaviour of other road users (e.g. IEEE P2846)
- Some models focus on conflict avoidance (e.g., by maintaining a safety envelope based on reasonable assumptions); others focus on collision avoidance (critical) situations
- Collision avoidance models most relevant when ORU behaves outside the assumed behaviour and ego vehicle must respond
  - By braking or,
  - By applying an evasive manoeuvre

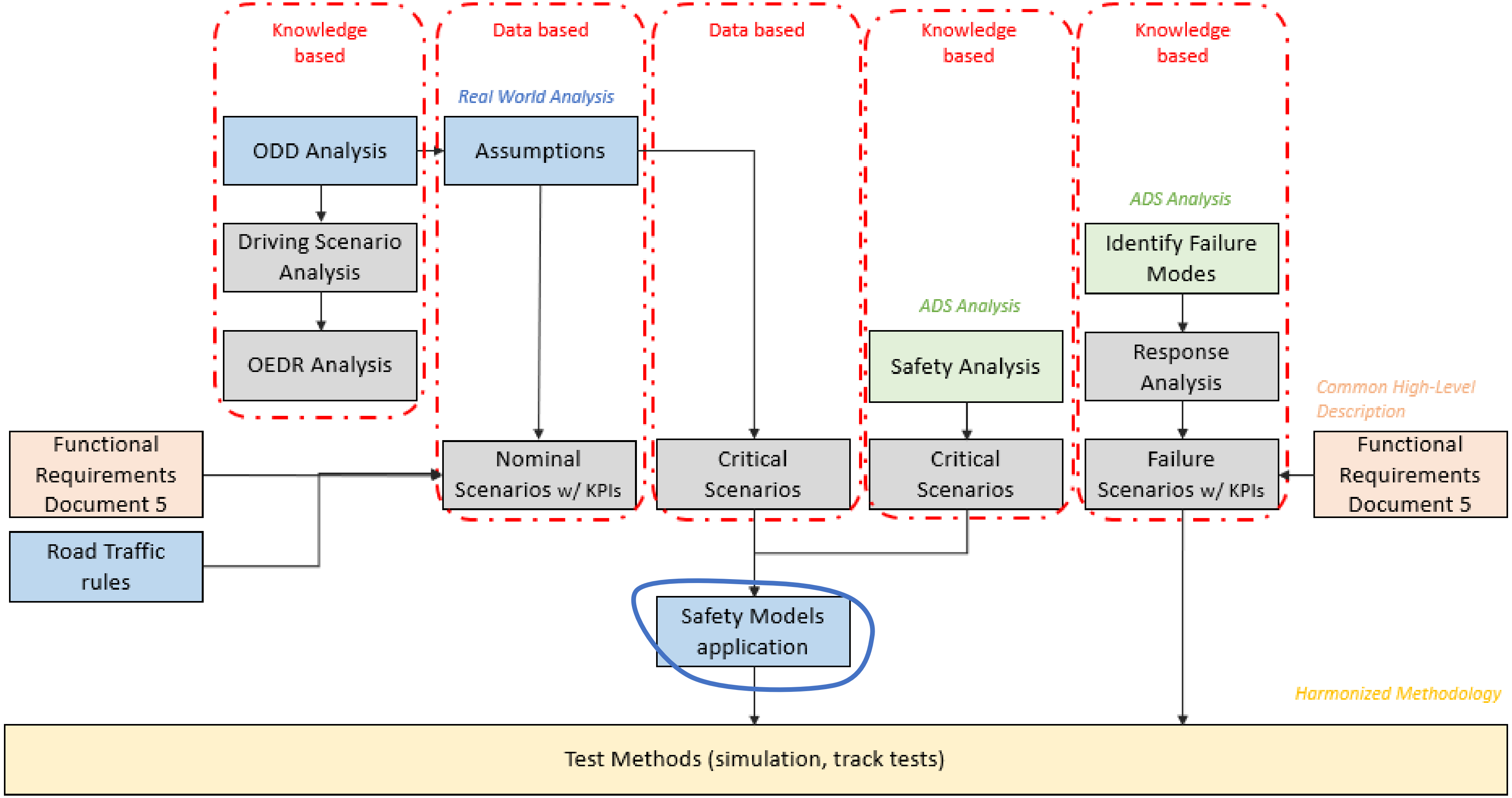
Safety Models analysis

- Safety Models represent a guidance to support the definition of ADS performance
  - They should not prescribe evasive manoeuvres and/or braking performance for collisions avoidance
  - They have intrinsic limitations (e.g. assumptions of ORUs, valid only for those scenarios they aim to address, …)
  - They may be used to define the boundary between preventability and unpreventability
- Safety Models values (assumptions) are ODD specific
  - Whereas behaviour competencies may be ODD agnostic (e.g. braking at a stop sign, turn, …)
  - Some parametrization are ODD specific
- The group aims to develop an approach to derive measurable/ verifiable criteria and not prescriptive requirements
  - An ODD-based approach could be considered to derive measurable Safety Requirements
  - A Rules of Road approach considered for compliance with Road Traffic Rules requirements
  - No pre-determined safety models and parametrization should be mandated

Summary

- Functional requirements as per FRAV D5 can be expanded where harmonisation is possible (e.g. verifiable criteria that are common)
- Defining conditions applicable to the specific ADS
  - ODD description & analysis
- Requirements for the specific application derived from the ODD based framework approach
  - Scenario generation based on ODD
  - Assumptions for nominal situations based on possible ORUs behaviour
  - Verifiable ranges / coverage (VMAD)
  - Edge cases based on unexpected ORUs behaviour
- Safety Models
  - ODD-independent but assumption ODD specific
  - Used to compare ADS performance in edge-cases scenarios

Flowchart


Knowledge based
Data based
Data based
Knowledge based
Knowledge based
Real World Analysis
ODD Analysis
Assumptions
Driving Scenario Analysis
OEDR Analysis
ADS Analysis
Identify Failure Modes
ADS Analysis
Safety Analysis
Response Analysis
Common High-Level Description
Functional Requirements Document 5
Nominal Scenarios w/ KPIs
Critical Scenarios
Critical Scenarios
Failure Scenarios w/ KPIs
Functional Requirements Document 5
Road Traffic rules
Safety Models application
Harmonized Methodology
Test Methods (simulation, track tests)

Next Steps

- Consider the ODD-Based Framework Approach as foundation to develop a methodology to derive measurable criteria
- The approach includes elements of safe driving and compliance with traffic laws
- Safety models could be included in an Annex as tools to support the derivation of metrics for the AV certification
    - Preventability vs Unpreventability evelope

Back-up

Driving Analysis

- It aims to address ORU/Objects safety by ensuring that ADS will respond appropriately to roadway objects
- Detectable properties to differentiate and classify ORU and relevant objects
- OEDR-based detection, recognition, and classification

Objects	Events/Interactions
Vehicles (e.g., cars, light trucks, heavy trucks, buses, motorcycles)	**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), encroaching adjacent vehicle (frontal/side), entering roadway (frontal/side), cutting out (frontal)**
Pedestrians	**Crossing road – inside crosswalk (frontal), crossing road – outside crosswalk (frontal)**, walking on sidewalk/shoulder
Pedalcyclists	**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)**

Objects	Events/Interactions
Animals[5]	Static in lane (frontal), moving into/out of lane (frontal/side), static/moving in adjacent lane (frontal), static/moving on shoulder
Debris[6]	**Static in lane (frontal)**
Other dynamic objects (e.g., shopping carts)	**Static in lane (frontal/side), moving into/out of lane (frontal/side)**

Objects	Events/Interactions
Traffic signs[7]	Stop, yield, speed limit, crosswalk, railroad crossing, school zone
Traffic signals[7]	Intersection, railroad crossing, school zone
Vehicle signals	Turn signals

Table 1 – Dynamic elements and their properties

OEDR Analysis : Behaviour Competency Identification

- ADS safety recommendations for interactions with subsets of ORU
- Behaviour competences that can be applied to the events characterizing the ODD to ensure compliance with the applicable regulatory and legal requirements

Event	Response
Lead vehicle decelerating	Follow vehicle, decelerate, stop
Lead vehicle stopped	Decelerate, stop
Lead vehicle accelerating	Accelerate, follow vehicle
Lead vehicle turning	Decelerate, stop
Vehicle changing lanes	Yield, decelerate, follow vehicle
Vehicle cutting in	Yield, decelerate, stop, follow vehicle
Vehicle entering roadway	Follow vehicle, decelerate, stop
Opposing vehicle encroaching	Decelerate, stop, shift within lane, shift outside of lane
Adjacent vehicle encroaching	Yield, decelerate, stop
Lead vehicle cutting out	Accelerate, decelerate, stop
Pedestrian crossing road – inside crosswalk	Yield, decelerate, stop
Pedestrian crossing road – outside of crosswalk	Yield, decelerate, stop
Pedalcyclist riding in lane	Yield, follow
Pedalcyclist riding in dedicated lane	Shift within lane[9]
Pedalcyclist crossing road – inside crosswalk	Yield, decelerate, stop
Pedalcyclist crossing road – outside crosswalk	Yield, decelerate, stop
Lead vehicle decelerating	Follow vehicle, decelerate, stop
Lead vehicle stopped	Decelerate, stop
Lead vehicle accelerating	Accelerate, follow vehicle

Table 2 – Behaviour competences for given events

Safety Models

- Propose multiple modeling methodologies. (safety envelopes, scenario-based, driver modeling, technology state-of-the-art, etc.)
- Compare ADS performance against benchmarks for expected behavior (e.g., ADS performance vs model performance)
- Address collision-avoidance/crash-mitigation boundaries

Verifiable Criteria

- Global requirements with verifiable criteria established via an ODD-based approach
- DDT performance requirements will not be prescriptive
- Approach allows for local constraints and parameters
- Performance acceptable if satisfies model expectation
- Example for Lane-Keeping in FRAV-25-11