IEEE SA
STANDARDS ASSOCIATION

OVERVIEW OF IEEE 2846

JAN 18, 2022

IEEE

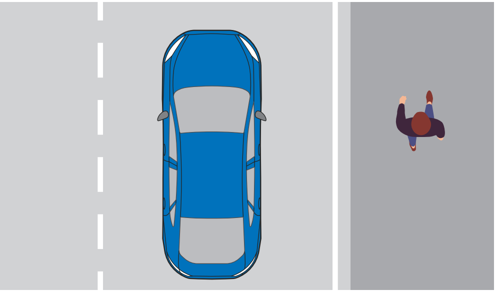
INTRODUCTION

- Human Drivers rely their interaction experience with other road users
- In particular, what is **reasonably foreseeable** to expect from others
- Consider a simple car-following scenario:

- What do we, as human drivers, often assume about the leading vehicle?
- Do we consider the theoretical worst case sudden maximum braking?
- Or do we, based on our experience, consider what is **reasonably foreseeable?**

INTRODUCTION

- Consider what is **reasonably foreseeable** to expect from pedestrians
- A common scenario:



- What would we, as the human driver of the blue car, expect of the pedestrian?
- Would we consider they could jump laterally into the road at moment's notice?
- Or do we, based on our experience, consider what is **reasonably foreseeable?**

PURPOSE

- Government and Industry alike are in need of an open, transparent, and technology-neutral **standard that provides guidance useful for evaluating the performance of an ADS**. This guidance consists of a minimum set of assumptions with bounds on **reasonably foreseeable behaviors of other road users** used in the development of **safety-related models**.

IEEE 2846 SCOPE

- **Minimum set of assumptions** regarding **reasonably foreseeable behaviors of other road users** that shall be considered in the development of safety-related models for automated driving systems (ADS)
- List of **attributes** common to contributed safety-related models
- **Methods** to help verify whether a safety-related model considers the minimum set of assumptions
- **Examples** of how the proposed minimum set of assumptions could be employed in ADS development

MEMBERS OF IEEE P2846

Representing OEM's, MaaS Providers, Tier 1's, Suppliers, Universities and Governments, globally! Liaison agreement with ISO and SAE-ITC

THE AV SAFETY ASSURANCE STANDARDS HIVE OF ACTIVITY

How did you define/develop/test
Systematic Process Standards

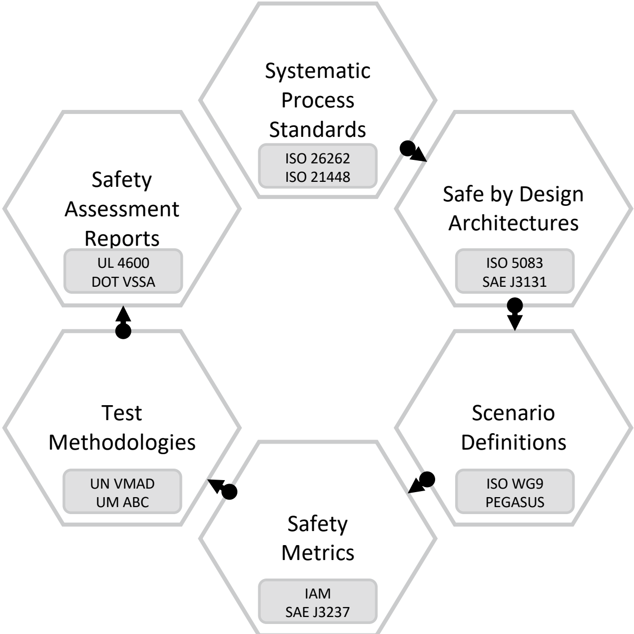
The design of what you built
Safe by Design Architectures

What scenarios should you test
Scenario Definitions

What is Pass or Fail in a scenario
Safety Metric

How you tested the scenario
Test Methodologies

Why you think it's safe
Safety Assessment Reports



THE AV SAFETY ASSURANCE STANDARDS HIVE OF ACTIVITY

Safety Assurance is a Framework

However, following these standards only ensures an AV built to best practices…

…not necessarily one that achieves acceptable risk

Only IEEE 2846 provides a framework for acceptable risk

PRECEDENT FOR ASSUMPTIONS

UNECE ALKS Regulation

- In a Car following, Automatic Lane Keeping Systems (ALKS)
- “Any longitudinal deceleration demand of **more than 5.0 m/s²** of the system shall be considered to be an Emergency Manoeuvre (EM)” (5.3.1.1)
- The regulation is defining what is **reasonably foreseeable** and what is not, and thus should be considered something requiring an EM

PRECEDENT FOR ASSUMPTIONS

Germany AV Regulation

- In a Car following, Automatic Lane Keeping Systems (ALKS)
- "With regard to vehicles in front, it **can be assumed** that these vehicles decelerate with a maximum of 10 m/s^2"
- The regulation is defining what is **reasonably foreseeable** to assume about a leading vehicle

However, these are the only "assumptions" currently in regulation

KEY NORMATIVE DEFINITIONS

RELEVANT DEFINITIONS

reasonably foreseeable: technically possible and with a credible or measurable rate of occurrence

safety-related model: Representation of safety-relevant aspects of driving behavior based on assumptions about reasonably foreseeable behaviors of other road users.

NOTE 1—Examples of safety-related models can include those related to motion planning, as well as on-board and off-board safety checkers and analyzers.

NOTE 2—Safety-related models could apply to both an ADS and representations of other road users.

NOTE 3—Safety-related models can take many forms. Example formulations may include: definition of a driving policy; definitions as a formal mathematical equation, or as a set of more conceptual rules, or as a set of scenario-based behaviors, or a combination thereof.

NORMATIVE CONTENT

MINIMUM SET OF ASSUMPTIONS

The normative content of the standard includes:

- Minimum set of assumptions about reasonably foreseeable behavior of other road users for an initial set of scenarios

Goal of defining assumptions about reasonably foreseeable behavior:

- To help the ADS-operated vehicle navigate through the real world more intelligently and safely without unnecessarily constraining its behavior on the road
- Assumptions may be considered by some combination of safety-related models

MINIMUM SET OF ASSUMPTIONS

The minimum set of assumptions are based on **kinematic properties** of other road users

Notation	Description	Measurement Unit
v^{lon}, v^{lat}	Longitudinal and lateral velocity of a road user	m/s
$\alpha^{lon}, \alpha^{lat}$	Magnitude of longitudinal and lateral acceleration of a road user	m/s^2
β^{lon}, β^{lat}	Magnitude of longitudinal and lateral deceleration of a road user	m/s^2
h	Heading angle (yaw) of a road user	° (degrees)
h'	Heading angle rate of change (yaw rate) of a road user	$°/s$
ρ	Response time of a road user	s
λ	Lateral fluctuation margin for lateral movements within a lane performed by a road user when moving in forward motion	m

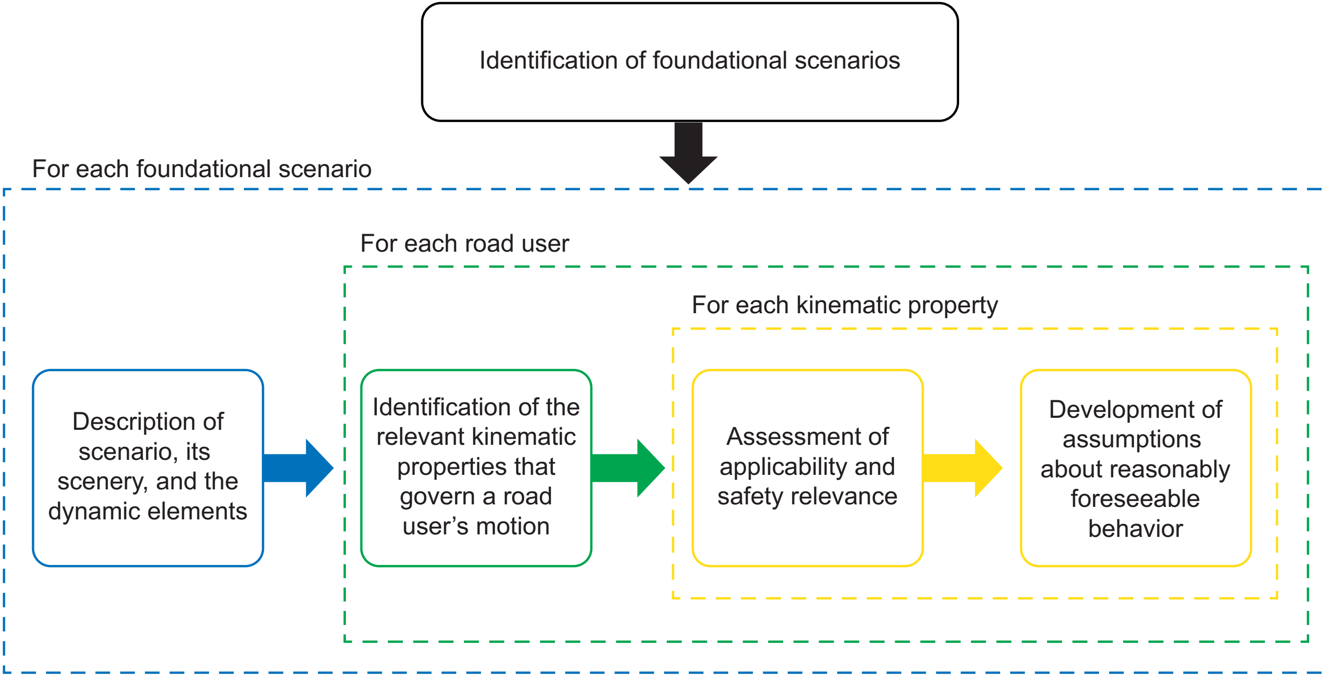
ROAD USERS CONSIDERED

- Ego vehicle
- Other road users (ORU):
  - Pedestrians
  - Cyclists
  - Other VRUs
  - Vehicles (human-driven or ADS-operated)

DRIVING SCENARIOS IN 2846

- The scenarios are high-level descriptions of common driving situations, including interactions with VRUs and occlusions
- The scenario selection is **not** meant to be interpreted as an exhaustive taxonomy
- The scenarios provide **building blocks** for more complex scenarios
- The scenarios can accommodate variations of the road users' attributes (e.g., speed), and variations of different ODD definitions

METHODOLOGY FOR ASSUMPTIONS DERIVATION



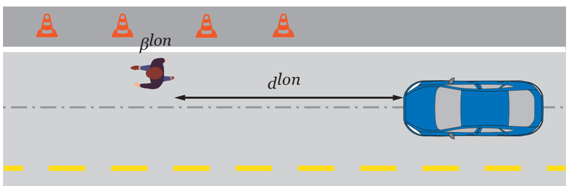
INITIAL SCENARIOS CONSIDERED

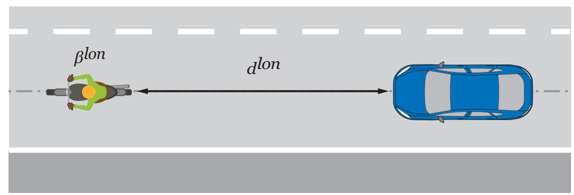
Scenario name	Scenario ID
Ego vehicle driving next to other road users	V1-S1
Ego vehicle driving longitudinally behind another road user	V1-S2
Ego vehicle driving in between leading and trailing road users	V1-S3
Ego vehicle’s path intersecting with VRU crossing the road	V1-S4
Ego vehicle’s path intersecting with other road user’s path moving in opposite direction	V1-S5
Ego vehicle negotiating an intersection with nonoccluded road users	V1-S6
Ego vehicle negotiating an intersection with occluded road users	V1-S7

EGO VEHICLE DRIVING LONGITUDINALLY BEHIND ANOTHER ROAD USER

Scenario Description:

The ego vehicle is travelling along a road longitudinally behind other road users moving in the same direction. There is no road user following behind the ego vehicle. A potential frontal collision is assessed as avoidable and no emergency maneuver is required.



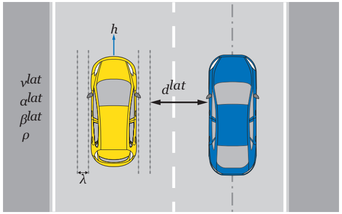


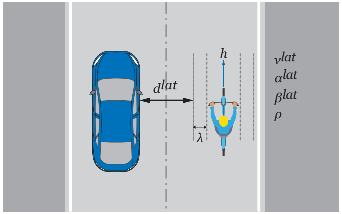
Minimum set of assumptions			
Pedestrians	**Cyclists**	**Other VRUs**	**Vehicles**
$\beta^{lon}(t) \leq \beta^{lon}_{max}$	$\beta^{lon}(t) \leq \beta^{lon}_{max}$	$\beta^{lon}(t) \leq \beta^{lon}_{max}$	$\beta^{lon}(t) \leq \beta^{lon}_{max}$

EGO VEHICLE DRIVING NEXT TO OTHER ROAD USERS

Scenario Description:

The ego vehicle is travelling along a road next to other road users. The other road user stays in its path, which does not intersect with the ego vehicle's path. The lateral separation between the other road user and the ego vehicle could be small. The ego vehicle and the other road user could be travelling in opposite directions.



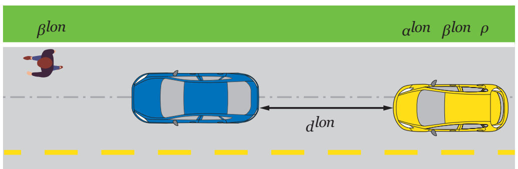


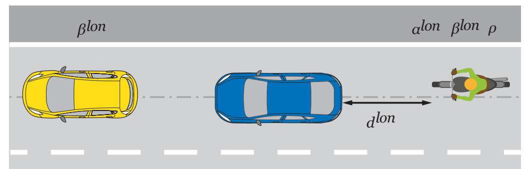
Sample: Minimum Set of Assumptions			
Pedestrians	**Cyclists**	**Other VRUs**	**Vehicles**
$v^{lat}(t) \leq v^{lat}_{max}$	$v^{lat}(t) \leq v^{lat}_{max}$	$v^{lat}(t) \leq v^{lat}_{max}$	$v^{lat}(t) \leq v^{lat}_{max}$
$\alpha^{lat}(t) \leq \alpha^{lat}_{max}$	$\alpha^{lat}(t) \leq \alpha^{lat}_{max}$	$\alpha^{lat}(t) \leq \alpha^{lat}_{max}$	$\alpha^{lat}(t) \leq \alpha^{lat}_{max}$
$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$

EGO VEHICLE DRIVING IN BETWEEN LEADING AND TRAILING ROAD USERS

Scenario Description:

The ego vehicle is travelling along a road longitudinally behind another road user (leading road user) and longitudinally in front of another road user (trailing road user). All road users are moving in the same direction. A potential frontal collision is assessed as avoidable, and no emergency maneuver is required.



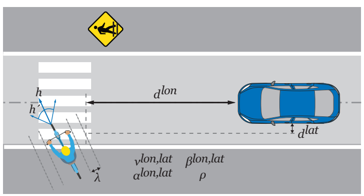


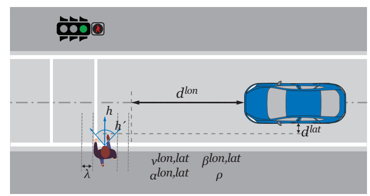
Sample: Minimum set of assumptions for following road user			
Pedestrians	**Cyclists**	**Other VRUs**	**Vehicles**
$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$	$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$	$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$	$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$
$\beta^{lon}(t) \geq \beta^{lon}_{min}$	$\beta^{lon}(t) \geq \beta^{lon}_{min}$	$\beta^{lon}(t) \geq \beta^{lon}_{min}$	$\beta^{lon}(t) \geq \beta^{lon}_{min}$
$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$

EGO VEHICLE'S PATH INTERSECTING WITH VRU CROSSING THE ROAD

Scenario Description:

The ego vehicle is travelling along a road in which other vulnerable road users, such as pedestrians, are already on the road in or near the crosswalk zone or entering a crosswalk to cross the road. If traffic signals are present in the scene, it could be that the vulnerable road user is crossing against the controlling signal (e.g., a pedestrian crossing against the pedestrian crossing signal).



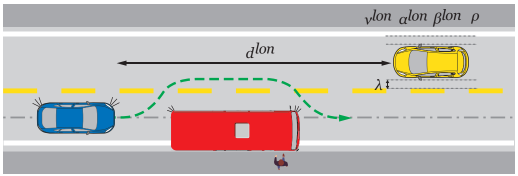


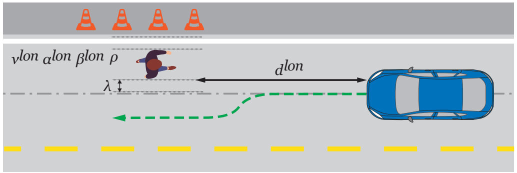
Sample: Minimum Set of Assumptions			
Pedestrians	**Cyclists**	**Other VRUs**	**Vehicles**
$v^{lon}(t) \leq v^{lon}_{max}$	$v^{lon}(t) \leq v^{lon}_{max}$	$v^{lon}(t) \leq v^{lon}_{max}$	**N/A**
$\|h'(t)\| \leq h'_{max}$	$\|h'(t)\| \leq h'_{max}$	$\|h'(t)\| \leq h'_{max}$	**N/A**
$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$	**N/A**

EGO VEHICLE'S PATH INTERSECTING WITH OTHER ROAD USER'S PATH MOVING IN OPPOSITE DIRECTION

Scenario Description:

The ego vehicle is travelling along a road with other road users moving in the opposite direction at a non-junction. The ego vehicle's path may temporarily intersect with the other road user's path (e.g., while performing a legal passing maneuver). A potential front collision is assessed as avoidable; therefore, no emergency maneuver is required.



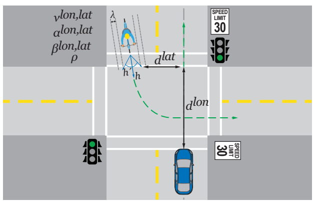


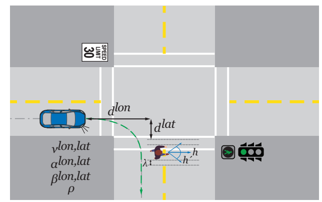
Sample: Minimum set of assumptions			
Pedestrians	**Cyclists**	**Other VRUs**	**Vehicles**
$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$	$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$	$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$	$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$
$\beta^{lon}(t) \geq \beta^{lon}_{min}$	$\beta^{lon}(t) \geq \beta^{lon}_{min}$	$\beta^{lon}(t) \geq \beta^{lon}_{min}$	$\beta^{lon}(t) \geq \beta^{lon}_{min}$
$\|\lambda(t)\| \leq \lambda_{max}$	$\|\lambda(t)\| \leq \lambda_{max}$	$\|\lambda(t)\| \leq \lambda_{max}$	$\|\lambda(t)\| \leq \lambda_{max}$

EGO VEHICLE NEGOTIATING AN INTERSECTION WITH NONOCCLUDED ROAD USERS

Scenario Description:

The ego vehicle is approaching an intersection. The right of way of the ego vehicle and other road users is directed by the traffic laws of the particular scene (e.g., stop signs). Other road users may violate or give up the right of way (e.g., another vehicle going against the controlling signal).



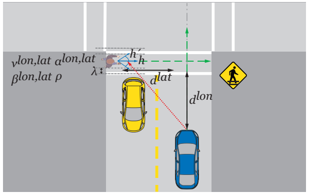


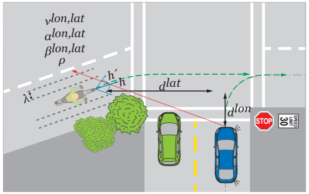
Sample: Minimum set of assumptions			
Pedestrians	**Cyclists**	**Other VRUs**	**Vehicles**
$\beta^{lon}(t) \leq \beta^{lon}_{max}$	$\beta^{lon}(t) \leq \beta^{lon}_{max}$	$\beta^{lon}(t) \leq \beta^{lon}_{max}$	$\beta^{lon}(t) \leq \beta^{lon}_{max}$
$\beta^{lon}(t) \geq \beta^{lon}_{min}$	$\beta^{lon}(t) \geq \beta^{lon}_{min}$	$\beta^{lon}(t) \geq \beta^{lon}_{min}$	$\beta^{lon}(t) \geq \beta^{lon}_{min}$
$\lvert h'(t) \rvert \leq h'_{max}$	$\lvert h'(t) \rvert \leq h'_{max}$	$\lvert h'(t) \rvert \leq h'_{max}$	$\lvert h'(t) \rvert \leq h'_{max}$
$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$	$\rho \leq \rho_{max}$

EGO VEHICLE NEGOTIATING AN INTERSECTION WITH OCCLUDED ROAD USERS

Scenario Description:

The ego vehicle is approaching an intersection. The right of way of the ego vehicle and other road users is defined by the traffic laws of the particular scene (e.g., stop signs). Visibility of other safety-relevant objects is temporarily blocked due to static objects (e.g., a tree, a building, a sharp curve, or a hill) or dynamic objects (e.g., a bus, a vehicle) in the scene.





Sample: Minimum set of assumptions about potentially occluded road users			
Pedestrians	**Cyclists**	**Other VRUs**	**Vehicles**
$\beta^{lon}(t) \leq \beta^{lon}_{max}$	$\beta^{lon}(t) \leq \beta^{lon}_{max}$	$\beta^{lon}(t) \leq \beta^{lon}_{max}$	$\beta^{lon}(t) \leq \beta^{lon}_{max}$
$\lvert h'(t) \rvert \leq h'_{max}$	$\lvert h'(t) \rvert \leq h'_{max}$	$\lvert h'(t) \rvert \leq h'_{max}$	$\lvert h'(t) \rvert \leq h'_{max}$
$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$	$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$	$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$	$\alpha^{lon}(t) \leq \alpha^{lon}_{max}$
$\alpha^{lat}(t) \leq \alpha^{lat}_{max}$	$\alpha^{lat}(t) \leq \alpha^{lat}_{max}$	$\alpha^{lat}(t) \leq \alpha^{lat}_{max}$	$\alpha^{lat}(t) \leq \alpha^{lat}_{max}$

INFORMATIVE CONTENT

COMMON ATTRIBUTES FROM CONTRIBUTED SAFETY-RELATED MODELS

- Commonalities and differences from contributed safety-related models used in the Dynamic Driving Task (DDT)
- Attributes for safety-related models used in the DDT has been compiled and documented based on:
  1. attributes that can be demonstrated through inspection of the model
  2. attributes that can be demonstrated by verification and validation testing

EXAMPLE SAFETY-RELATED MODEL ATTRIBUTES – VERIFIABLE OR DEMONSTRATABLE VIA INSPECTION

- Incorporates the laws of physics
- Accommodates acceptable risk
- Supports reasonably foreseeable scenarios (including occlusion)
- Incorporates assumptions
- Supports prioritization of safety objectives
- Defines a hazardous situation
- Defines proper responses
- Supports emergency maneuvers
- Differentiates between initiator and responder
- Focuses on motion control

EXAMPLE SAFETY-RELATED MODEL ATTRIBUTES DEMONSTRATABLE VIA VALIDATION

- Validated through empirical evidence and industry best practices
- Enables the ADS-operated vehicle to navigate safely
- Considers human violations of traffic rules
- Supports regional differences in behavior

VALIDATION AND VERIFICATION (V&V) METHODS FOR ASSUMPTIONS USED IN SAFETY-RELATED MODELS

- V&V methods that can be used to verify and validate the use of the minimum set of assumptions in a safety-related model
  - Does not define an exhaustive set of methods for verification
  - Does not define specific pass/fail criteria for a given scenario

- V&V Methods:
  - Systematic process
  - Safety-By-Design architectures
  - Formal methods
  - Robustness analysis
  - Simulation testing
  - Closed course testing
  - Public road testing

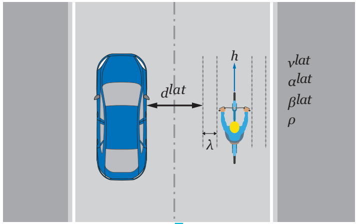
EXAMPLE V&V METHOD

Safety-By-Design architectures	
Method description (in general terms)	A product design method that is compliant with accepted reference architectures.
How method can be applied for this standard	Demonstrate the use of the minimum set of required reasonably foreseeable assumptions in the design of the reference architecture.
Regulations/standards/ best practices example(s)	SAE J3131 ISO/TR 4804 [B16]
Example of use based on scenario of 4.2.3.2	The ADS architecture contains a trajectory planner as well as a trajectory monitoring system: The trajectory monitoring system evaluates the output of the trajectory planner in the ADS to confirm that the assumptions specified in the safety-related model are considered in the planned trajectory(-ies).
V-Model stages	Requirements and Architecture; Detailed Design

ANNEX: USE OF 2846 ASSUMPTIONS WITHIN SCENARIO-BASED VIRTUAL TESTING

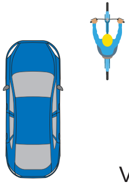
- High-level considerations for the generation of relevant test-cases using **bounded kinematic search space**, established by the minimum set of assumptions defined
- Makes use of scenarios defined in the standard as “seeds” to define concrete scenarios by:
  - **Parametrizing and formalizing the kinematic search space** of interest, and road users involved
  - Defining **valid and physically possible ranges of interest** for the identified variables
  - Selecting actual values of those parameters for the specific test-case

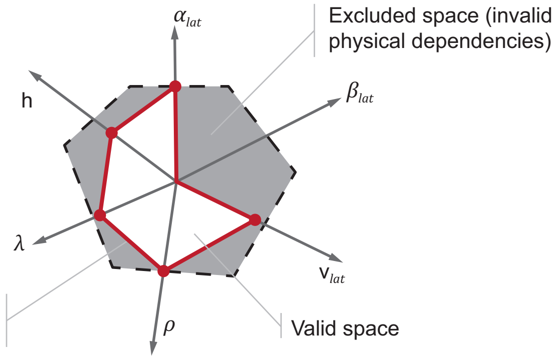
EXAMPLE OF VIABLE SEARCH SPACE FOR A SCENARIO



Within each considered test-case:

Valid combinations of the assumptions' values constrain the feasible space



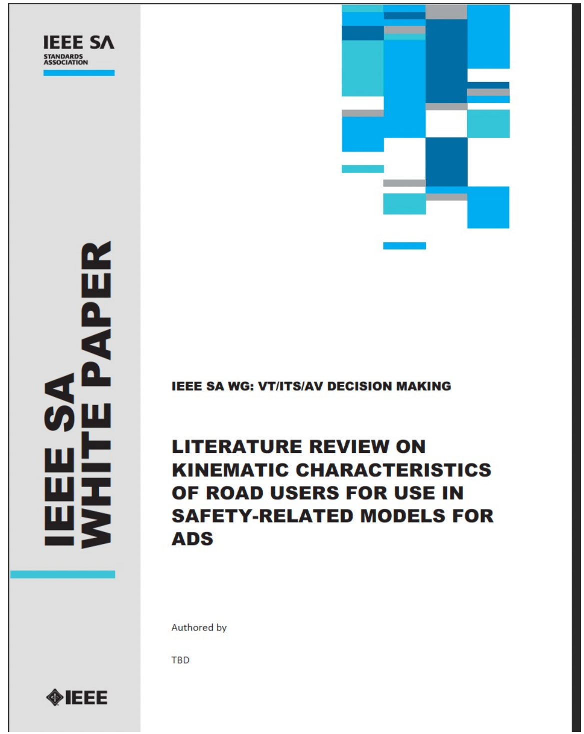


COMPANION WHITEPAPER

LITERATURE REVIEW ON KINEMATIC PROPERTIES OF ROAD USERS FOR USE ON SAFETY-RELATED MODELS FOR AUTOMATED DRIVING SYSTEMS

Presents a review of relevant literature (e.g., standards, regulations, and scientific publications) that investigated kinematic behavior of road users:

- Overview of research-derived road user behaviors that could inform safety-related models in ADS
- Highlights existing gaps and limitations found on the literature



LITERATURE REVIEW

The Literature review contextualizes each reviewed document based on:

- **Year**
- **Country**
- **Experimental**
- **Driving Scenario**
- **Roadway Type**
- **Weather-Related Environmental Conditions**
- **Operational Constraints**
- **Sensors**
- **Data Sample Size**

LITERATURE REVIEW

- Review of 30 technical documents
- Summary on values for kinematic properties of **Pedestrians**, **Bicyclists** and **Vehicles**
- Discussion on reasonably foreseeable behavior of road users is presented, based on findings
- Discussion on the gaps found in the literature review (e.g., gaps in different geo-locations, or other VRUs) is presented

- WG intends to expand and update the literature in the future

EXAMPLE OF PEDESTRIANS LONGITUDINAL SPEED VALUES FOUND

Ref	v^{lon} [m/s]	Driving Scenario
[10]	4.6 (Max) 1.8 (Avg)	Intersection, jaywalker
[11]	1.5 (Avg)	Intersection, unsignalized, crosswalk
[12]	1.93 (Avg)	Intersection, crosswalk
[13]	(Walking) 1.8 (Max) (Jogging) 4.0 (Max)	Longitudinal, laboratory
[14]	(Walking) 1.5 [SD 0.2] (Avg) (Jogging) 2.5 [SD 0.3] (Avg Peak)	Longitudinal, laboratory
[15]	-	Intersection, crosswalk
[16, 17, 18] *	(Running) 12.4 (Max)	Intersection, jaywalker

WHAT'S NEXT?

- An additional white paper publication analyzing contributed safety models against the common attributes
- Draft Standard is currently in 10-day "re-circulation" with the Ballot Group
- On the agenda for the Q1'2022 "RevCom" Committee for final approval
- Engaging with policy makers and regulators around the world on how IEEEE 2846 can help in the creation of regulatory framework's for Automated Vehicles