

IEEE Standard for Assumptions in Safety-Related Models for Automated Driving Systems

IEEE Vehicular Technology Society

Developed by the
Intelligent Transportation Systems Committee

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IEEE Standard for Assumptions in Safety-Related Models for Automated Driving Systems

Developed by the

Intelligent Transportation Systems Committee
of the
IEEE Vehicular Technology Society

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Abstract: This standard applies to road vehicles. It defines a minimum set of reasonable assumptions and foreseeable scenarios that shall be considered in the development of safety-related models that are part of an automated driving system (ADS).

Keywords: ADS, ADS-operated vehicle, automated driving system, assumption, automated vehicle, autonomous vehicles, AV, decision-making, IEEE 2846™

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Introduction

This introduction is not part of IEEE Std 2846-2022, IEEE Standard for Assumptions in Safety-Related Models for Automated Driving Systems.

While automated driving system (ADS)-operated vehicles hold the potential for safety improvement compared to human drivers, the recognition that transportation will continue to entail some level of risk has to be considered.

Human drivers rely on extensive daily experience in their interactions with other agents on the road, which helps them craft assumptions about *reasonably foreseeable* behavior of other road users. For example, when following another vehicle, human drivers implicitly make assumptions about the behaviors of other road users (e.g., the possible deceleration rate of the vehicle in front of them), so that they may appropriately adjust their following distance. As illustrated in Figure A, the ego vehicle (blue vehicle) makes an assumption about the deceleration rate of the vehicle in the front (yellow vehicle) and adjusts its following distance as a consequence. Such assumptions enable human drivers to follow at a “natural” distance that allows for a smooth flow of traffic. A careful balance between conservativeness, safety considerations, and natural driving can be established, so that for this example, following distances may be adapted based on assumptions about reasonably foreseeable behaviors of other road users, not necessarily accounting for the theoretical worst-case capabilities at all times. Such a balance is needed for the efficiency and safety of the overall transportation system, without unnecessarily constraining vehicles on the road (e.g., drivers adopting a behavior based on worst case following distances under all circumstances). For example, studies have shown that even deceleration rates adopted by human drivers in the context of Figure A are often much lower than the maximum feasible decelerations achievable by the vehicles, so braking events in nominal driving conditions are likely to have even lower deceleration rates. If humans made driving decisions based primarily on the theoretical worst case, following distances would generally increase, and traffic flow could be negatively affected as a result of overly conservative driving behavior.

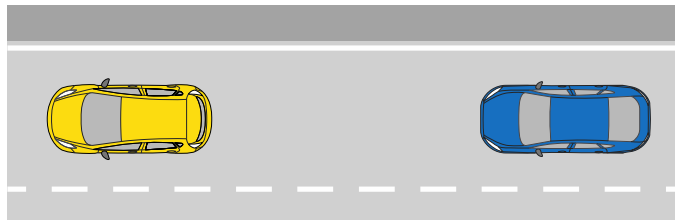


Figure A—An example scenario where the ego vehicle follows another vehicle

The same reasoning applies to interactions with other road users in addition to vehicles, such as pedestrians. Consider the situation depicted in Figure B, where the ego vehicle is being driven on a roadway next to a sidewalk where a pedestrian is walking in the same direction of travel. In this context, the ego vehicle driver implicitly evaluates how reasonable it may be to expect the pedestrian to continue their progression on the sidewalk versus turning into the road. In other words, the ego vehicle driver is making an assumption about how reasonably foreseeable it is that the pedestrian will keep moving in the current direction of travel without a sudden change of direction. Similar to the previously discussed car-following situation depicted in Figure A, accounting for theoretical worst cases (e.g., that every pedestrian could change heading with the fastest speed and agility possible for a human being) would lead to a state where an ADS-operated vehicle might never be able to pass the pedestrian.

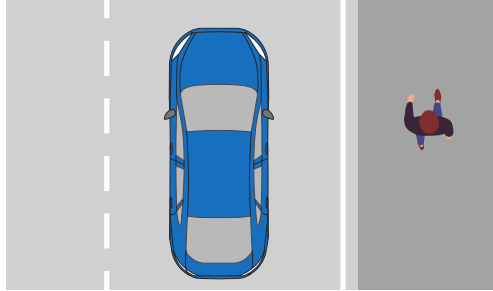


Figure B—An example scenario with the ego vehicle driving alongside a crosswalk with a pedestrian

The aforementioned examples illustrate how assumptions enable the balancing of efficient natural driving and safety considerations based on what is reasonably foreseeable to expect from other road users.

Similarly, ADS-operated vehicles will also need to make assumptions. The purpose of this standard is to define the assumptions about reasonably foreseeable behaviors of other road users that shall be considered for Automated Driving Systems. One use, presented in this standard, for instance, is the role that assumptions play within safety-related models, which provide a representation of safety-relevant aspects of driving behavior pertaining to both ADS-operated vehicles and other road users. In this context, assumptions are represented by bounds (i.e., maxima and/or minima) for a set of kinematic variables, which enable the ADS to make informed decisions with an understanding of what would be reasonably foreseeable behaviors of other road users. Kinematics are used to indicate both physical quantities such as speed/acceleration, but also non-mechanical quantities such as response time. Additional sources of uncertainty, such as prediction (e.g., existence of an occluded road user) or perception errors, are also important but are not explicitly covered in this standard.

Some safety-related models, which consider assumptions that an ADS-operated vehicle should take into account, have been released publicly and considered in development of this standard. The use of assumptions in these example models are varied, for example:

- Assumptions about the reasonable worst-case behaviors of other road users are used to calculate minimum safe longitudinal and lateral distances.
- Assumptions about road users can be used to formalize rules for reasonable driving behavior and help assess whether ADS-operated vehicle trajectories are safe and lawful.
- Assumptions can be used to determine the scope of acceptable vs. unacceptable actions.
- Assumptions on reasonably foreseeable accelerations provide a basis for modeling the bounds of the predicted behavior from other users and allow the model to restrict the predictive agents' profiles (i.e., the points in space occupied by agents in the future) used for the computation of the metrics of interest.

Regardless of the safety-related model utilized, the consideration of assumptions in safety-related models plays a central role in helping an ADS establish bounds for reasonably foreseeable behavior from other road users. The definition of the minimum set of assumptions for reasonably foreseeable behaviors of other roads users helps the ADS-operated vehicle navigate in real world environments more intelligently and safely, facilitating successful deployment and operation within the current transportation network.

While the set of values of the assumptions used in a safety-related model may be specified by regulation or selected by the ADS developer, this standard argues that a minimum set of kinematics-based assumptions can be taken into account under all circumstances, regardless of the model employed.

In this standard, an initial set of high-level scenarios is considered in order to derive a normative set of assumptions for consideration in safety-related models. The documented scenarios are not representative of

all scenarios that an ADS-operated vehicle may encounter; instead, they were chosen as the starting contexts that would allow composability of more complex situations, and helped with the initial identification of the minimum set of assumptions for the road users present in each scenario of interest.

The considered scenarios and the derived minimum set of assumptions regarding the safety of the overall system are not exhaustive, but are proposed as a minimum set that can further increase the robustness of the behavior of an ADS-operated vehicle with respect to other road users.

The content of the standard is as follows:

- Clause 2 provides normative references to other important standards that are complementary to this standard.
- Clause 3 provides key terms and definitions, including key concepts that are central to this standard, such as “safety-related model” and “reasonably foreseeable.”
- Clause 4 defines the normative minimum set of assumptions that shall be considered by safety-related models.
- Clause 5 lists examples of attributes that are common to contributed safety-related models.
- Clause 6 describes methods for possible verification and validation of assumptions in safety-related models.
- Annex A provides further practical examples of how to apply the normative requirements to different application areas within an ADS.
- Annex B is the bibliography for this standard.

Contents

1. Overview	13
1.1 Scope	13
1.2 Purpose	13
1.3 Word usage	13
2. Normative references.....	14
3. Definitions, acronyms, and abbreviations	14
3.1 Definitions	14
3.2 Acronyms and abbreviations	17
4. Minimum set of assumptions about reasonably foreseeable behaviors of other road users to be used in scenarios	17
4.1 Assumptions	17
4.2 Application of assumptions to scenarios.....	22
4.2.1 Rationale for example scenario selection.....	22
4.2.2 Coordinate system.....	23
4.2.3 Scenario definitions.....	26
4.2.3.1 V1-S1: Ego vehicle driving next to other road users	27
4.2.3.2 V1-S2: Ego vehicle driving longitudinally behind another road user	29
4.2.3.3 V1-S3: Ego vehicle driving in between leading and trailing road users.....	30
4.2.3.4 V1-S4: Ego vehicle's path intersecting with VRU crossing the road.....	31
4.2.3.5 V1-S5: Ego vehicle's path intersecting with other road user's path moving in opposite direction.....	33
4.2.3.6 V1-S6: Ego vehicle negotiating an intersection with nonoccluded road users.....	34
4.2.3.7 V1-S7: Ego vehicle negotiating an intersection with occluded road users.....	36
5. Common attributes from contributed safety-related models.....	38
5.1 Safety-related model attributes—verifiable or demonstratable via inspection	38
5.1.1 Incorporates the laws of physics	38
5.1.2 Accommodates acceptable risk	39
5.1.3 Supports reasonably foreseeable scenarios	39
5.1.4 Focuses on motion control	39
5.1.5 Incorporates assumptions	39
5.1.6 Based on current position, heading and velocity of other safety-relevant objects	39
5.1.7 Supports prioritization of safety objectives.....	40
5.1.8 Is sensitive to adjustment in parameter values	40
5.1.9 Supports diverse safety-relevant objects	40
5.1.10 Supports emergency maneuvers.....	40
5.1.11 Defines a hazardous situation.....	41
5.1.12 Defines proper responses	41
5.1.13 Differentiates between initiator and responder	41
5.1.14 Supports directional flexibility.....	41
5.1.15 Supports occlusion scenarios	41
5.1.16 Defines a safety envelope.....	42
5.1.17 Considers reasonably foreseeable events regarding right of way.....	42
5.1.18 Supports a theoretical outcome of no collisions upon universal adoption	42
5.1.19 Supports formal verification	42
5.1.20 Supports creation of performance indicators.....	43
5.1.21 Can be expressed in formal notation	43

5.1.22 Is transparent	43
5.1.23 Considers weather-related environmental conditions and road surface conditions.....	43
5.2 Safety-related model attributes demonstratable via validation	43
5.2.1 Validated through empirical evidence and industry best practices	43
5.2.2 Enables the ADS-operated vehicle to navigate safely.....	43
5.2.3 Exhibits a reasonable level of caution.....	44
5.2.4 Considers human violations of traffic rules	44
5.2.5 Supports regional differences in behavior.....	44
5.2.6 Incorporates empirical, evidence-based methods.....	44
6. Validation and Verification (V&V) methods for assumptions used in safety-related models.....	45
6.1 Systematic process.....	46
6.2 Safety-By-Design architectures	46
6.3 Formal methods	46
6.4 Robustness analysis	47
6.5 Simulation testing	47
6.6 Closed course testing	48
6.7 Public road testing	48
Annex A (informative) Application area: Use of IEEE Std 2846 normative assumptions within scenario-based virtual testing.....	49
A.1 General.....	49
A.2 Scenario-based testing (via simulation)	49
A.2.1 Toward the definition of a kinematic search space	49
A.3 Role of assumptions for test-case generation.....	50
A.4 Exploring the kinematic search space	53
Annex B (informative) Bibliography.....	55

IEEE Standard for Assumptions in Safety-Related Models for Automated Driving System

1. Overview

1.1 Scope

This standard applies to road vehicles. For a set of scenarios, a minimum set of assumptions regarding reasonably foreseeable behaviors of other road users are defined that shall be considered in the development of safety-related models for automated driving systems (ADS).

This standard further defines a list of attributes common to contributed safety-related models and methods to help verify whether a safety-related model takes the minimum set of assumptions into consideration. An informative annex instantiates several examples of how the proposed minimum set of assumptions could be employed in ADS development.

Sources of uncertainty, such as prediction or perception errors, are out of scope to this standard.

This standard does not guarantee the safety of the overall system in all scenarios.

1.2 Purpose

Government and Industry alike need 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.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{1,2}

¹ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

² The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents shall be understood and used for the application of this document, and each referenced document is cited in text and its relationship to this document is explained. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ISO 26262:2018, Road vehicles—Functional safety—Part 1: Vocabulary.

ISO/DIS 21448:2021, Road vehicles—Safety of the intended functionality.

ISO/TR 21974-1:2018, Naturalistic driving studies—Vocabulary—Part 1: Safety critical events.

SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.

SAE J3131, Automated Driving Reference Architecture.

SAE J3216, Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles.

SAE J3164, Taxonomy and Definitions for Terms Related to Automated Driving System Behaviors and Maneuvers for On-Road Motor Vehicles.

The reference documents defined here are those applied most commonly throughout the document. Additional sources can be found in the bibliography in Annex B.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.³ In order to maintain consistent terminology and definition usage, where quoted text is not available, relevant standards are indicated and should be referenced.

acceptable risk: Overall risk sufficient to satisfy the safety case.

automated driving system (ADS): *See:* SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles: 2021.

³*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

conflict: *See:* ISO/TR 21974-1:2018, Naturalistic driving studies—Vocabulary—Part 1: Safety critical events

controllability: *See:* ISO 26262:2018, Road vehicles—Functional safety— Part 1: Vocabulary.

driver: *See:* SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles: 2021.

NOTE—As described in SAE J3016, the levels of driving automation are classified from Level 0 to Level 5, with an increasing level of driving automation from no automation to full automation.

driving policy: *See:* ISO/DIS 21448:2021, Road vehicles—Safety of the intended functionality.

dynamic driving task (DDT): *See:* SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles: 2021.

event: Any change in ADS state or world state relevant to DDT performance.

emergency maneuver: A maneuver performed by a vehicle in case of an event in which the vehicle is at imminent collision risk and has the purpose of avoiding or mitigating a collision.

formal model: Model(s), expressed in formal notation, used in formal verification of system performance.

formal notation: *See:* ISO 26262:2018, Road vehicles—Functional safety— Part 1: Vocabulary.

formal verification: *See:* ISO 26262:2018, Road vehicles—Functional safety— Part 1: Vocabulary.

lateral vehicle motion control: *See:* SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles: 2021.

longitudinal vehicle motion control: *See:* SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles: 2021.

NOTE—See Figure 1 for different axes of vehicle motion.

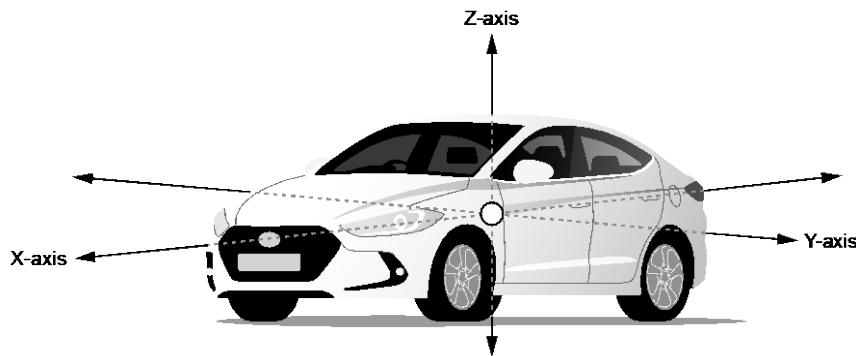


Figure 1—Diagram showing axes of vehicle motion

object and event detection and response (OEDR): *See:* SAE J3016 ,Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles: 2021.

operational design domain (ODD): *See:* SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles: 2021.

reasonably foreseeable: *See:* ISO 26262:2018, Road vehicles—Functional safety— Part 1: Vocabulary.

NOTE—For the purpose of this standard, reasonably foreseeable is considered to be both credible and measurable.

representation: Collection of information perceived about a scene and all its elements including dynamic agents.

NOTE—May be subjective or objective. Only a representation in a simulated world can be all-encompassing (objective). In the real world, it is varied and from one or several observers' points of view (subjective).

response time: The time it takes for a road user to perceive a specific stimulus and start executing a response (e.g., braking/steering/accelerating/stopping) in a given scenario.

NOTE—The definition of response time is compatible with that of SAE J2944 [B27].

risk: *See:* ISO 26262:2018, Road vehicles—Functional safety— Part 1: Vocabulary.

road operators: *See:* SAE J3216, Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles: 2020.

road user: *See:* SAE J3216, Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles: 2020.

safety envelope: A set of limits and conditions, within which the system is designed to operate, subject to constraints or controls, in order to maintain operations within a level of acceptable risk.

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.

safety-relevant object: Any object (excluding ego vehicle), dynamic or static, that may have relevance for the safety performance of the DDT.

safety validation: *See:* ISO 26262:2018, Road vehicles—Functional safety— Part 1: Vocabulary.

scenario: *See:* ISO/DIS 21448:2021, Road vehicles—Safety of the intended functionality.

scene: *See:* ISO/DIS 21448:2021, Road vehicles—Safety of the intended functionality.

traffic participant: *See:* SAE J3216, Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicles: 2020.

[human] user: *See:* SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles: 2021.

[dynamic driving task] vehicle behavior: *See:* SAE J3164, Taxonomy and Definitions for Terms Related to Automated Driving System Behaviors and Maneuvers for On-Road Motor Vehicles: 2022.

verification: *See:* ISO 26262:2018, Road vehicles—Functional safety— Part 1: Vocabulary.

vulnerable road user (VRU): A road user who is not occupying a vehicle such as a passenger car, a public transit vehicle, or a train.

world model: *See:* SAE J3131, Automated Driving Reference Architecture: 2022.

3.2 Acronyms and abbreviations

ADS	automated driving system
DDT	dynamic driving task
ODD	operational design domain
OEDR	object and event detection and response
SOTIF	safety of the intended functionality
VRU	vulnerable road user
V&V	verification and validation
RSS	Responsibility Sensitive Safety
SFF	Safety Force Field

4. Minimum set of assumptions about reasonably foreseeable behaviors of other road users to be used in scenarios

4.1 Assumptions

This clause introduces the minimum set of assumptions about reasonably foreseeable behavior of other road users that shall be considered in safety-related models for an initial set of scenarios to help demonstrate absence of unacceptable risk within a given operational design domain (ODD). The absence of unacceptable risk can be demonstrated through high controllability from other road users, low rates of occurrence, and/or low severity of the outcome of a particular scenario. The definition of the minimum set of assumptions about reasonably foreseeable behaviors of other road users helps the ADS-operated vehicle navigate through the real world more intelligently and safely without unnecessarily constraining its behavior on the road. Scenarios may exist in which acceptable driving behaviors of other road users do not align with these assumptions, and, in these cases, additional refinements may be needed on the part of the ADS developer.

This standard considers scenarios that cover safety-relevant driving situations that an ADS-operated vehicle may encounter in real traffic and in which the use of assumptions about reasonably foreseeable behaviors of other road users can help it to drive more naturally and safely. Safety-related models that are part of or used in the evaluation of an ADS shall consider the minimum set of assumptions made about the behaviors of other road users described within the defined scenarios. This requirement does not imply that all safety-related models consider the assumptions, but instead, assumptions may be considered by some combination of safety-related models. Assumptions about other road users should be continuously in place and updated regularly as required by the safety-related model implementation, taking into consideration information from the most current scene representation.

Within the scope of this standard, the following high-level road user classification shall be considered:

- a) Ego vehicle
- b) Other road users, including: