Automated Driving Safety Evaluation Framework

Ver4.0

Japan Automobile Manufacturers Association, Inc.,

Automated Driving Safety Evaluation Subcommittee

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Contents

Revision History

Version	Date	Description of Revision
Ver.1	2020-10-30	Initial release of the document
Ver.2	2021-12-28	Addition of Annexes ・ Annex E : Principle models and evaluation scenarios for perception disturbances ・ Annex F : (Reference) Guidelines for validating virtual environments used for perception-disturbance evaluation ・ Annex G : Validation of simulation tools and simulation test methods related to UN Regulation No. 157
Ver.3	2023-01-15	・ Revisions related to traffic-disturbance scenarios The content, previously limited to controlled-access highways, has been revised to also cover general roads. Traffic-disturbance scenarios for general vehicles on general roads have been added, and ITARDA data has been incorporated into Annex D. ・ Revisions related to perception-disturbance scenarios Content from Annexes E and F has been newly added ・ Revisions related to vehicle-dynamics disturbance scenarios Boundary conditions for Preventability / Unpreventability on general roads have been added.
Ver.4	2026-03-01	・ Revision of document structure ・ Addition of Terms and Definitions ・ Additions and Modifications to Each Chapter (Main Items Below): Added the conceptual framework for traffic-vulnerable user (bicycle) scenarios Added traffic-vulnerable user (pedestrian) scenarios Added general-road considerations to obstructed-view scenarios within perception-disturbance scenarios ・ Added coverage verification for traffic-vulnerable users (Cyclist and pedestrians) to Annex D ・ Revised the document structure of Annexes E and F and added explanatory content

Introduction

1.1. Background and Objectives

In recent years, the practical implementation and widespread adoption of automated vehicles have increasingly been regarded as essential steps toward realizing a safer, more efficient, and more accessible mobility society. However, confirming that automated vehicles possess sufficient safety performance remains a significant global challenge from both institutional and technical perspectives.ge, from both institutional and technical perspectives.

Against this backdrop, this document summarizes the proposal of the Japan Automobile Manufacturers Association (JAMA). The proposal aims to provide an optimal framework for safety argumentation structures, safety evaluation methods, and safety determination methods for automated driving, ensuring logical completeness, feasibility, and transparency.

As automated driving technologies continue to mature and expand in practical use, the associated safety evaluation and determination methods may require revision. Accordingly, the contents of this document will be reviewed and updated as necessary in response to technological progress and changes in societal conditions.

Objectives:

This document is intended to serve as a guideline for evaluating and verifying safety throughout each phase of the development process—including planning, design, and evaluation—in order to improve both safety and development efficiency.

In addition, this document aims to:

- establish a common technical understanding that supports the development of international standards and regulations; and
- clarify JAMA’s approach when promoting collaboration with domestic and international projects.

1.2. Safety Principles for Automated Driving

The United Nations World Forum for Harmonization of Vehicle Regulations (UN/WP29), which is responsible for international harmonization of vehicle regulations, defines the safety principles (“safety vision”) for automated vehicles as follows:

“Automated vehicles shall not cause any non-tolerable risk, meaning that, under their operational domain, shall not cause any traffic accidents resulting in injury or death that are reasonably foreseeable and preventable “

(Source：*UN/WP29, 2019, WP29-177-19, Framework document on automated/autonomous vehicles*)

The concepts of reasonably foreseeable and preventable can be considered independent axes. Accordingly, situations encountered by automated vehicles can be classified into four quadrants based on whether they are foreseeable and whether they are preventable（Figure 1 A-D）.

The safety concepts applicable to each quadrant are described below.

A. Foreseeable and Preventable Events
   Events in this domain shall be avoided under the safety principle. Any accident occurring within this quadrant therefore indicates insufficient system safety.

B. Foreseeable and Unpreventable Events
   Events in this domain cannot be avoided due to technological limitations or physical constraints. In such cases, the system shall focus not on avoidance but on mitigating harm.

C. Unforeseeable and Preventable Events
   Events in this domain are difficult to predict at present but may become foreseeable through future improvements in Automated Driving Systems (ADS). Such events should therefore be collected and utilized as knowledge for system enhancement.

D. Unforeseeable and Unpreventable Events
   Events in this domain cannot be addressed by the system alone and should be managed through societal measures, such as insurance or other safety nets.

The safety principle defined by UN/WP29 thus establishes a fundamental evaluation framework for the safety assurance of automated vehicles. The organization of situations into these four quadrants forms the basis for both system design and policy decision-making.

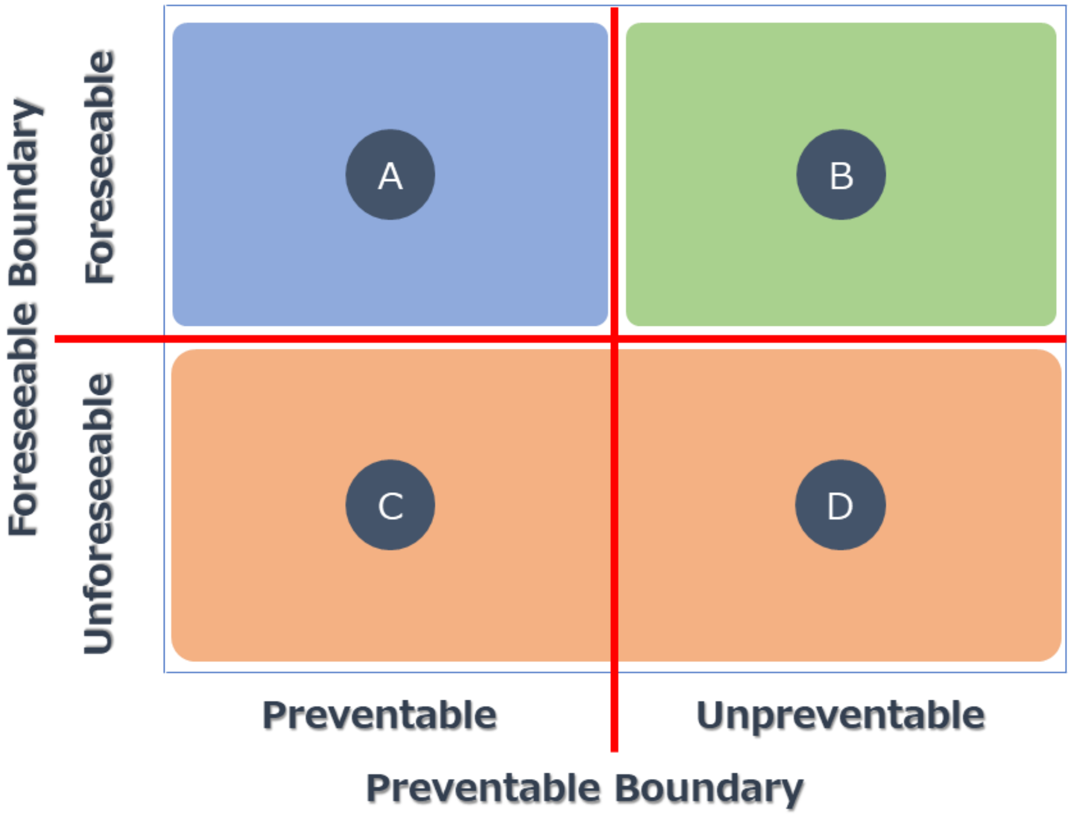


Figure 1. Relationship between Foreseeability and Preventability

1.3. Scope of Safety Evaluation

In the framework document presented by WP29, the safety aspects of ADS are defined. These safety and organized hierarchically, as shown in Figure 2. Within this structure, the scope addressed by this document corresponds to the domain referred to as “Validation for system safety.”
(Reference: *UN/WP29, 2019, WP29-177-19, Framework document on automated/autonomous vehicles*)

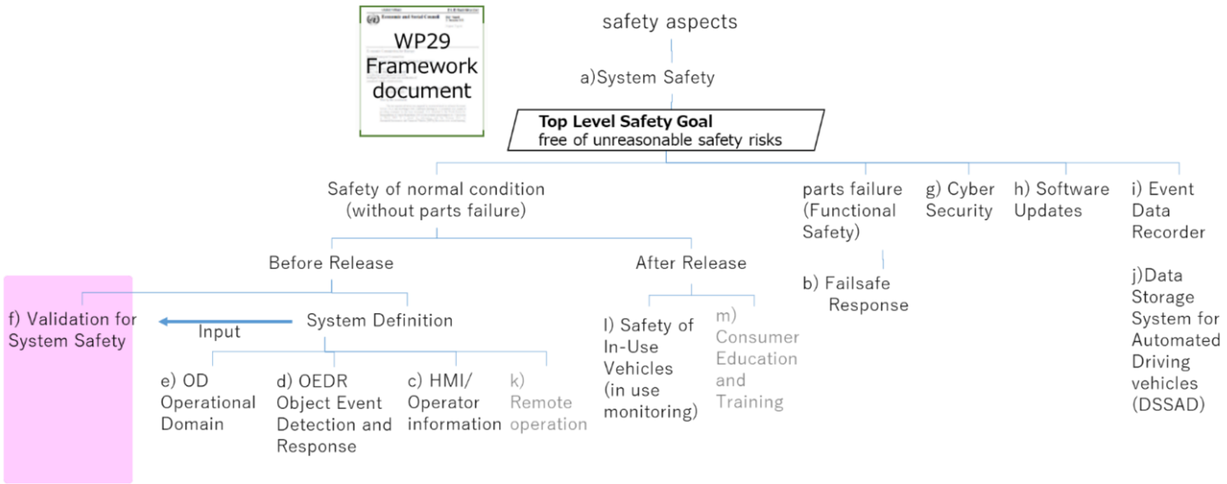


Figure 2. Hierarchical diagram of Safety Aspects

When “validation for system safety” is decomposed based on UN/WP29 safety vision, the resulting structure can be organized as shown in Figure 3. The safety principles (Safety Vision) for automated driving vehicles presented in Chapter 1.2 are positioned as the Safety Goal, and the scope of verification is stratified into four quadrants based on foreseeability and preventability.

Quadrants B, C, and D represent accidental events that are addressed on a best-effort basis and are therefore excluded from the scope of evaluation. In contrast, Quadrant A consists of events that are both reasonably foreseeable and preventable and is consequently included within the evaluation scope.

Quadrant A is further subdivided into two categories:

- A-1: Normal situations, which include functional evaluations such as lane keeping or compliance with traffic regulations; and
- A-2: Trigger situations, in which safety is evaluated under non-normal conditions where disturbances or anomalies occur and risk is emerging.

Both categories are included within the scope of evaluation.

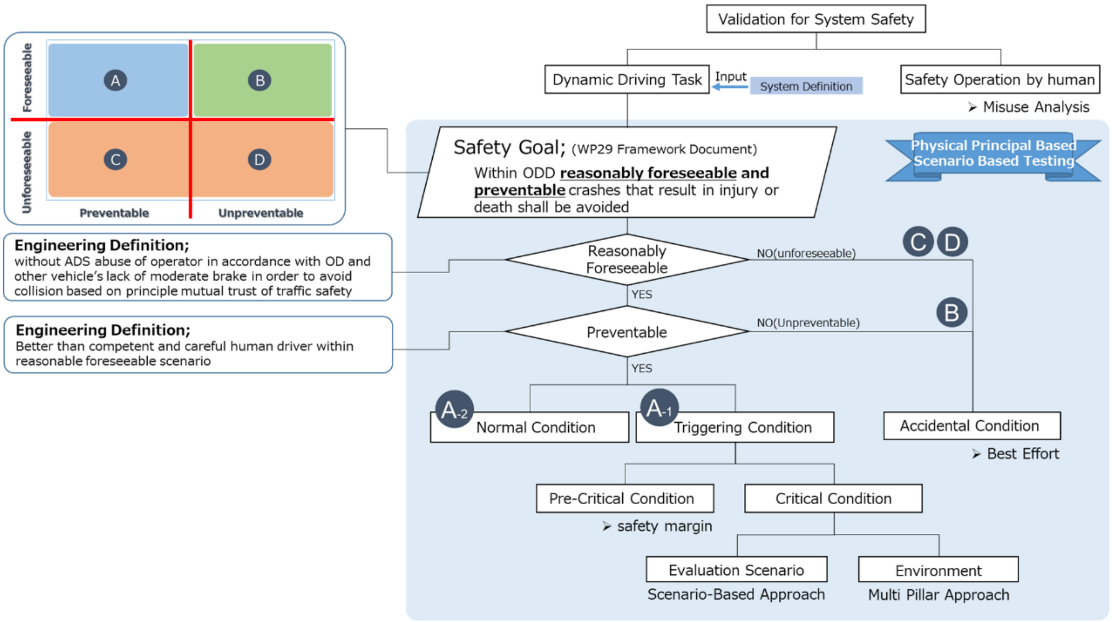


Figure 3. Diagram of the Safety Argumentation Structure

Situations encountered by ADS during the Dynamic Driving Task (DDT) can also be classified according to the degree of risk, as follows:

- Normal Condition : a normal driving state in which no risk exists
- Pre-critical Condition : a latent risk state in which contributing factors exist but do not immediately lead to a hazard
- Critical Condition : a state in where risk has materialized and directly affects the DDT; and
- Unavoidable Condition : a state in which the system cannot respond appropriately and accident avoidance is no longer possible.

In practice, the progression toward a specific hazard (accident) occurs as a stepwise transition from a Normal Condition to a Pre-critical Condition and then to a Critical Condition. If the system fails to respond appropriately, the situation ultimately reaches an Unavoidable Condition.

In this document, the occurrence of a "Critical Condition," which directly affects Object and Event Detection and Response (OEDR), is defined as the trigger condition and is included within the scope of safety evaluation.

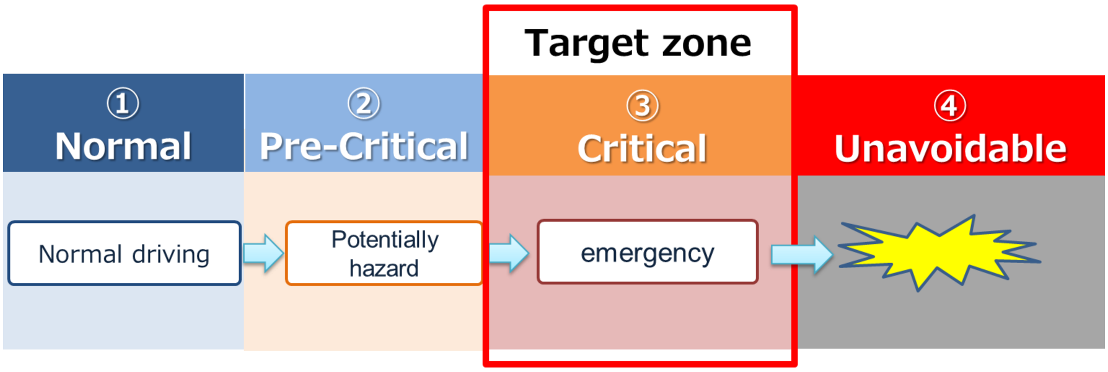


Figure 4. Safety Evaluation Scope

The "Pre-critical Condition" involves anticipatory system design and is therefore considered part of competitive development. As a result, uniform evaluation at this stage is not appropriate. For example, a situation in which a leading vehicle is carrying cargo that appears likely to fall belongs to this category. At this stage, whether a collision will occur is not yet determined, and defining uniform scenarios or evaluation criteria is therefore inappropriate.

1.4. Issues in Existing Approaches

1.4.1. Safety assurance through Long-Distance / Long-Duration Testing

One commonly used approach to ensuring the safety of an automated driving system is long-distance and long-duration operation within its Operational Domain (OD), combined with statistical evaluation of risk exposure (e.g., *Kalra et al., Driving to Safety, RAND Corporation, 2016*). In such testing, a safety driver typically monitors system operation, and the frequency of driver interventions (overrides) is analyzed.

Some estimates suggest that approximately 11 billion miles (about 17.7 billion kilometres) of driving are required to demonstrate automated driving safety at a 95% confidence level. Furthermore, when a system is modified, similar long-distance testing must be repeated within the updated OD.

While repeated long-distance testing in real-world traffic environments can contribute to system performance improvement, it provides only probabilistic assurance beyond a certain threshold. In addition, the evaluation results are generally treated as confidential and are not publicly disclosed. Even when regulatory authorities conduct audits, reanalyzing such large datasets is difficult, which poses challenges for ensuring transparency.

Moreover, this approach explains the sufficiency of evaluation primarily in probabilistic terms, based on the frequency of interventions relative to distance or time driven. However, it does not guarantee that all relevant traffic and environmental factors influencing system safety are covered. Although longer driving distances increase the likelihood of encountering diverse conditions, there is no assurance that unobserved factors will not lead to hazardous events after deployment.

1.4.2. Data-driven/classification-type scenario-based approach

To address limitations in applying traditional pilot testing and Advanced Driver Assistance Systems (ADAS) development processes to safety assurance for SAE Level 3 and higher automated driving, classification-type scenario-based approaches have been proposed, such as the PEGASUS project （*https://www.pegasusprojekt.de/en/about-PEGASUS*）.

These approaches construct scenario databases by categorizing accumulated traffic-flow observation data and accident data into structured scenarios. From both regulatory and manufacturing perspectives, this method is attractive because it enables the development of a verification ecosystem based on publicly available data, independent of proprietary datasets.

However, this approach does not fully resolve the fundamental issue of ensuring the sufficiency of pre-release verification. Scenario coverage still depends on the quantity of accumulated data, and complete coverage of future phenomena cannot be guaranteed. In addition, publicly available driving data primarily consist of images and trajectories and often lack information on the underlying causes of perception errors or vehicle-dynamics issues. As a result, such approaches cannot provide a deterministically complete verification range.

1.4.3. Overview of the “Physical Principle Approach Process”

To address the limitations in evaluation range and criteria found in existing approaches, this document proposes an engineering framework referred to as the Physical Principle Approach Process. This framework is a scenario-based approach grounded in fundamental physical principles.

Because the combinations of natural phenomena and traffic flow are effectively infinite, it is unrealistic to classify the driving environment comprehensively. Instead, as shown in Table 1, the Dynamic Driving Task (DDT) is decomposed into the core processes required for automated driving: perception, decision, and operation. For each process, disturbance factors that influence system outcomes are identified and categorized, based on physical principles, into perception disturbances, traffic disturbances, and vehicle-dynamics disturbances.

By structuring scenario families for each process（Figure 5, Figure 6）, a finite, safety-oriented , and systematically comprehensive set of scenarios can be identified.

Table 1 Processes of the Driving Task and Physical Principles

Process	Processing Outcome	Disturbance	Physical Principle
Perception	Position information of surrounding traffic environment, self-position, and traffic information	Perception disturbance	Principle-based disturbances corresponding to sensor mechanisms (e.g., camera: visible light; millimeter-wave radar: radio waves; LiDAR: infrared light)
Decision	Trajectory and target velocity instruction	Traffic disturbance	Geometric relationships between road structure and surrounding traffic participants, as well as behaviors of traffic participants
Operation	Distribution of motion-control commands to actuators in order to achieve target trajectory and velocity	Vehicle-dynamics disturbance	Physical disturbances acting on the vehicle due to road shape or natural phenomena, and disturbances transmitted to tires due to road-surface/tire conditions

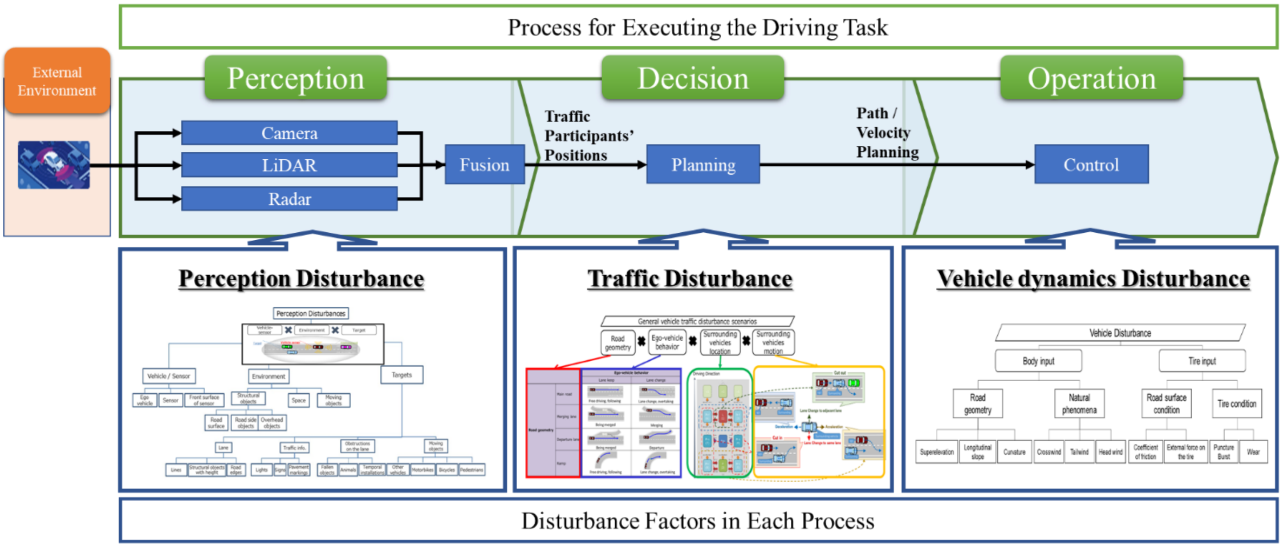


Figure 5. Driving Tasks and Disturbance Factors

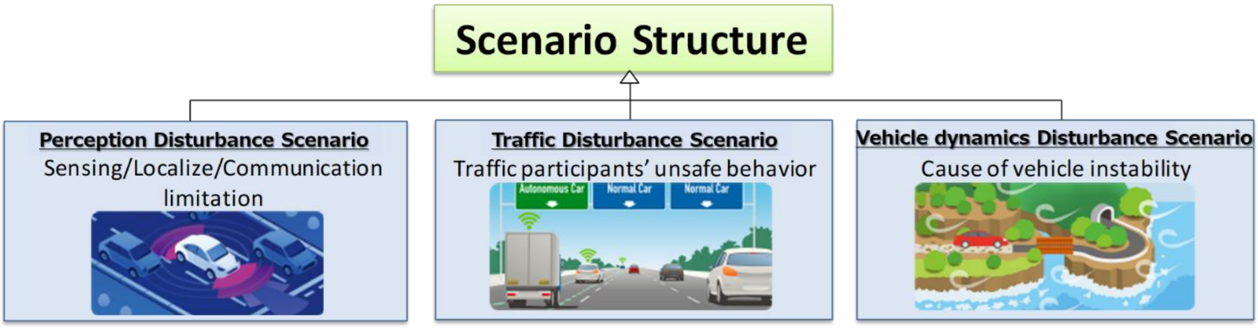


Figure 6. Three Scenario Taxonomies based on Physical Principles

A *perception disturbance* refers to a situation in which the sensor system is unable to correctly perceive hazards due to intrinsic or extrinsic factor reasons related to the sensors or the vehicle itself.
Intrinsic factors include, for example, component-installation issues (such as instability related to sensor mounting or manufacturing variations), and vehicle conditions (such as vehicle tilting caused by uneven loading that alters sensor orientation, or sensor occlusion due to externally mounted items such as a bicycle

rack).
Extrinsic factor include environmental conditions induced by surrounding vehicles (such as sensor fogging, contamination, or adverse lighting conditions), as well as obstructed views.

A *traffic disturbance* refers to a potentially hazardous traffic situation arising from a combination of road geometry (for example, a branch section), ego-vehicle behavior (for example, a lane change), and the positions and movements of surrounding vehicles (for example, lane changes by nearby vehicles close to the ego vehicle — Cut-in).

A *vehicle dynamics disturbance* refers to a situation in which perception and decision functions operate correctly, but the vehicle is unable to adequately control its own dynamics. Such situations may result from internal vehicle factors (such as total vehicle mass or mass distribution) or external factors acting on the vehicle (such as road surface irregularities and gradients, or wind).

Accumulated traffic-flow observation data and accident data can be used to verify whether the scenario framework —constructed theoretically based on real-world conditions—contains no significant omissions. In addition, these data enable the qualitative scenario framework to be supplemented with quantitative physical parameters, expressed as probabilistic ranges, indicating how frequently such events occur in actual traffic environments.

2. Terms and Definition

2.1. ODD（Operational Design Domain）

A set of operating conditions under which a particular driving automation system or its functions are specifically designed to operate.

This set includes, but is not limited to, environmental, geographical, and time-of-day constraints, and/or the presence or absence of specific traffic conditions or road characteristics.

[SOURCE: ISO 34501:2022, 3.26]

2.2. OD（Operational Domain）

A set of operating conditions.

This includes, but is not limited to, environmental, geographical, and time-of-day constraints, and/or requirements regarding the presence or absence of specific traffic conditions or road characteristics.

Note :

This set may be used to describe real-world conditions in a specific environment, geographical conditions, synthetic conditions for testing, and various other purposes.

[SOURCE: ISO 34503:2023 ,3.9]

2.3. DDT(Dynamic Driving Task）

A collective term for all real-time operational (tasks related to stable vehicle operation) and tactical (tasks related to decision-making and maneuvers during driving) functions necessary for vehicle driving in road traffic.

Strategic functions such as route planning or the selection of destinations/waypoints are not included.

[SOURCE: ISO/SAE PAS 22736:2021, 3.10, modified- All notes have been deleted.]

2.4. OEDR（Object and Event Detection and Response）

A subtask of the Dynamic Driving Task (DDT), referring to the sequence of actions required to detect, recognize, classify, and respond to objects and events in the driving environment.

[SOURCE: ISO/SAE PAS 22736:2021, 3.19]

2.5. Perception disturbance

A factors or events that prevent an automated vehicle’s sensor systems (e.g., camera, LiDAR, radar, GNSS, etc.) from correctly detecting or recognizing the surrounding environment due to intrinsic or extrinsic causes related to the sensors or vehicle.

2.6. Traffic disturbance

A potentially hazardous traffic situation that arises from combinations of road geometry, ego-vehicle behavior, and the positions and movements of surrounding traffic participants, resulting in an unanticipated impact on the planned travel of an automated driving system.

2.7. Vehicle dynamics disturbance

A situation in which perception and decision functions operate normally, but the vehicle is unable to adequately control its dynamic motion ─such as acceleration, deceleration, steering, or lane keeping— due to internal vehicle factors or external influences from the road or environment.

2.8. Validation

The confirmation, through objective evidence, that an implemented system satisfies safety requirements for intended functionality when used in its intended operational environment.

2.9. Competent and Careful Human Driver（C&C Driver）

A human driver who possesses the necessary skills and knowledge, complies with applicable road traffic laws, remains continuously attentive, and operates a vehicle with appropriate capability and care while maintaining awareness of surrounding traffic participants.

2.10. Avoidance behavior

An emergency maneuvers executed by an automated driving system to prevent an accident when a traffic hazard or collision risk is recognized.

2.11. Critical parameter

A variable or condition that has a direct and significant impact on system or functional safety or performance. Deviation of a critical parameter may lead to hazardous states or degradation of system performance.

Examples: vehicle velocity, headway distance, weather conditions, road friction coefficient.

2.12. Preventable/Unpreventable

Events that can normally be avoided based on past cases, contextual circumstances, or expert knowledge, and events that, from a common-sense perspective, are difficult to avoid in advance under real-world traffic conditions.

2.13. Foreseeable/Unforeseeable

Events that can normally be anticipated based on past cases, contextual circumstances, or expert knowledge, and events that are difficult to anticipate even from a common-sense perspective and for which prior measures cannot reasonably be taken.

2.14. Validation environment

The environment—real, virtual, or hybrid—used to validate that a target system satisfies its intended functionality and operates safely.

2.15. Critical Condition

A condition in which risk has materialized and directly affects the Dynamic Driving Task (DDT).

It represents a traffic situation in where a collision or hazard is imminent and immediate avoidance through appropriate perception, decision, and operation is required.

2.16. Pre-critical Condition

A latent risk condition in which contributing factors exist but do not immediately lead to a hazard.

Although a collision is not imminent, inadequate perception, decision, or operation may allow the situation to progress to a Critical Condition.

2.17. Validation for system safety

The confirmation, through verification and objective evidence, that an implemented system—when integrated into its intended operational environment—achieves an acceptable level of safety, taking into account functional limitations and reasonably foreseeable situations.

2.18. Physical Principle Approach Process

A systematic process that begins with the physical principles or phenomena on which a system relies, identifies functional limitations and safety risks, and links them to evaluation and validation activities.

2.19. Scenario Database

A systematically collected, organized, and managed database of traffic scenarios used for the verification and validation of ADS (or driver assistance systems).

2.20. Data-Driven Approach

An approach that uses real-world data—such as driving data, accident data, and sensor data—to extract scenarios, construct models, and perform safety evaluation.

2.21. False Negative

A detection error in which the system fails to detect an object or event that is actually present (e.g., obstacle, pedestrian, traffic signal).

2.22. False Positive

A detection error in which the system incorrectly detects an object or event that does not exist.

2.23. Adhesion Utilization Rate

An index representing the degree to which a tire utilizes the available frictional (adhesive) force between the tire and the road surface.

2.24. On driving path

A state in which an object is located on the driving path of the ego vehicle.

2.25. Into driving path

A state in which an object is initially located outside the ego vehicle’s driving path and subsequently enters it from a lateral or crossing direction.

2.26. Obstructed-view scenario

A scenario in which visibility of a vehicle or object is physically obstructed by surrounding vehicles, road structures, or road geometry, resulting in structural occlusion within the traffic environment.

Note:

In this document, the term obstructed-view refers specifically to physical obstruction of line-of-sight caused by external traffic or roadway elements. It does not include driver blind spots arising from vehicle components such as mirrors, pillars, or similar interior features.

3. Safety Argumentation Structure of Automated Driving Systems

This chapter describes the safety argumentation structure of ADS with respect to the Dynamic Driving Task (DDT) for SAE automation level 3 and above.
The objective of this chapter is to establish a logically consistent framework that links safety principles to concrete evaluation and determination methods through structured scenarios.

3.1. Scenario-Based Safety Assurance Process

Safety assurance of Advanced Driver Assistance Systems (ADAS) and ADS requires not only compliance with the functional safety standard ISO 26262, but also consideration of Safety of the Intended Functionality (SOTIF) as defined in ISO 21448.
ISO 26262 focuses on eliminating unreasonable risks caused by malfunctions of electric and electronic (E/E) systems through Hazard Analysis and Risk Assessment (HARA). In contrast, ISO 21448 addresses potentially hazardous behaviors that may arise in the absence of system malfunctions, for example due to limitations in perception, decision logic, or interactions with other traffic participants. Although the sources of risk addressed by these standards differ, both share the common objective of eliminating unreasonable risk. In ADS, where system behavior depends heavily on perception of the external environment and interpretation of complex traffic situations, it is essential to address both malfunction-related risks and risks arising from insufficient intended functionality.

Accordingly, scenario-based safety evaluation plays a central role in ADS safety assurance. It enables systematic identification of potential hazards and the definition of mitigation measures based on representative scenarios that reflect diverse driving environments, traffic participants, road conditions, and weather.

Figure 7 illustrates the overall scenario-based safety assurance process aligned with ISO 21448. The process identifies risk factors affecting intended functionality, derives critical scenarios, and defines a structured workflow for demonstrating the absence of unreasonable risk. Applying this process not only in late development stages but also from the concept phase—such as sensor configuration design aligned with the ODD and early software verification—contributes to improved development efficiency and robustness.

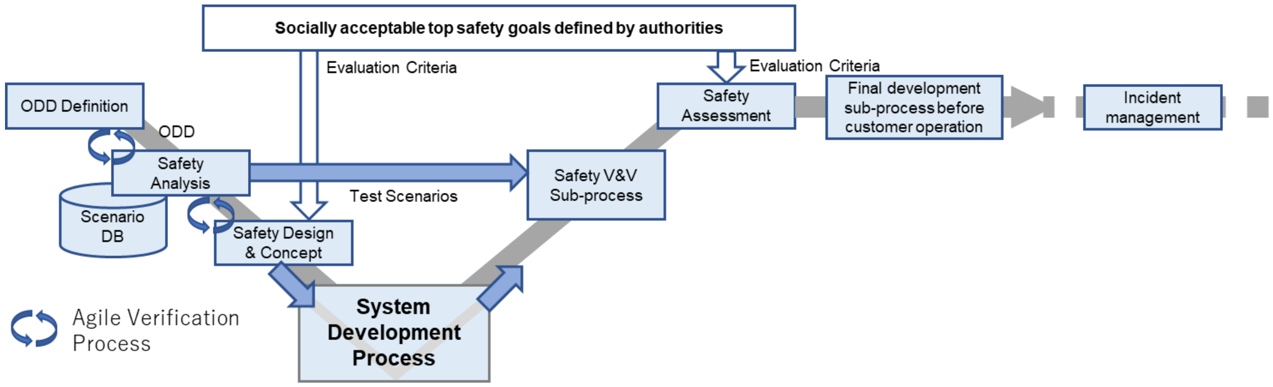


Figure 7. Overall Scheme of the Scenario-Based Safety Assurance Process

3.1.1. Safety Assurance Process Scheme

3.1.1.1. Definition of ODD

Definition of the ODD is the first essential step in the scenario-based safety assurance process. The ODD clearly specifies the scope and conditions under which the target system or function is intended to operate. The ODD describes, from technical, functional, and operational perspectives, the environments and conditions in which the ADS is designed to perform the DDT. At a minimum, it includes information on road types, lane configurations, vehicle velocity ranges, and environmental conditions.

In addition, a fallback strategy for transitioning beyond the ODD boundary shall be designed, and the ADS shall be capable of detecting whether it is operating within the defined ODD.
The defined ODD must also be communicated to users through means such as owner's manuals and human–machine interfaces (HMI), enabling users to understand the system's capabilities and limitations.

（Reference: *Khastgir, Birrell, Dhadyalla, & Jennings , "Calibrating trust through knowledge: Introducing the concept of informed safety for automation in vehicles", 2018*）

3.1.1.2. Safety Analysis and Scenario Database

To identify reasonably foreseeable scenarios and systematically organize scenario-related information, it is not sufficient to rely solely on combinatorial enumeration of environmental conditions. Instead, the ODD and scenarios should be defined from a technically exhaustive perspective grounded in physical principles.

For example, while the term "rain" may be sufficient for human understanding, an ADS must interpret rain in terms of its physical effects—such as attenuation of sensor signals or reduction of tire–road friction.

Instead, the effects of rain must be interpreted from a physics-based viewpoint—or example, the potential impact of raindrops on sensor performance or the influence of rainfall on vehicle dynamics, such as reduced tire–road friction on wet pavement.

To describe the ODD in a technical and system-oriented manner, the system is categorized into three groups based on physical principles (Figure 6). These groups systematically organize situations in which factors that hinder normal operation may arise with respect to perception systems, traffic flow, and vehicle dynamics, forming perception-disturbance scenarios, traffic-disturbance scenarios, and vehicle-dynamics-disturbance scenarios, respectively.

As shown in Figure 8, mapping the ODD structure to these three scenario categories enables the appropriate selection of evaluation scenarios consistent with the ODD scope. The resulting test scenarios can be stored in a scenario database and reused in subsequent development phases as well as in new development projects.

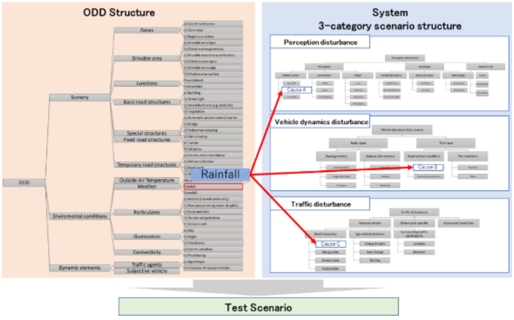


Figure 8. Relationship between the ODD structure and the System (Three-category scenario framework)

Figure 9 provides an overview of the scenario database. The highest-level qualitative scenario structure, referred to as the Functional Scenario, is defined based on the three elements of driving behavior—“perception,” “decision,” and “operation”—and is organized into the three corresponding disturbance categories: “perception disturbance,” “traffic disturbance,” and “vehicle-dynamics disturbance”. This structure enabling comprehensive coverage of safety-relevant scenarios.

The Logical Scenario extends the Functional Scenario by introducing quantitative parameter ranges. For example, in traffic-disturbance scenarios, parameters such as relative velocity or cut-in velocity can be defined using a data-driven approach, in which vehicle trajectories are extracted from real-world traffic-flow data and parameter ranges are derived using statistical distributions. These data sources include traffic-monitoring and observation data, driving data, accident databases, and map and road data.

Finally, the Concrete Scenario consists of individual, specific evaluation conditions. Such scenarios are derived from safety-determination boundaries or other criteria that distinguish safe states from unsafe states.

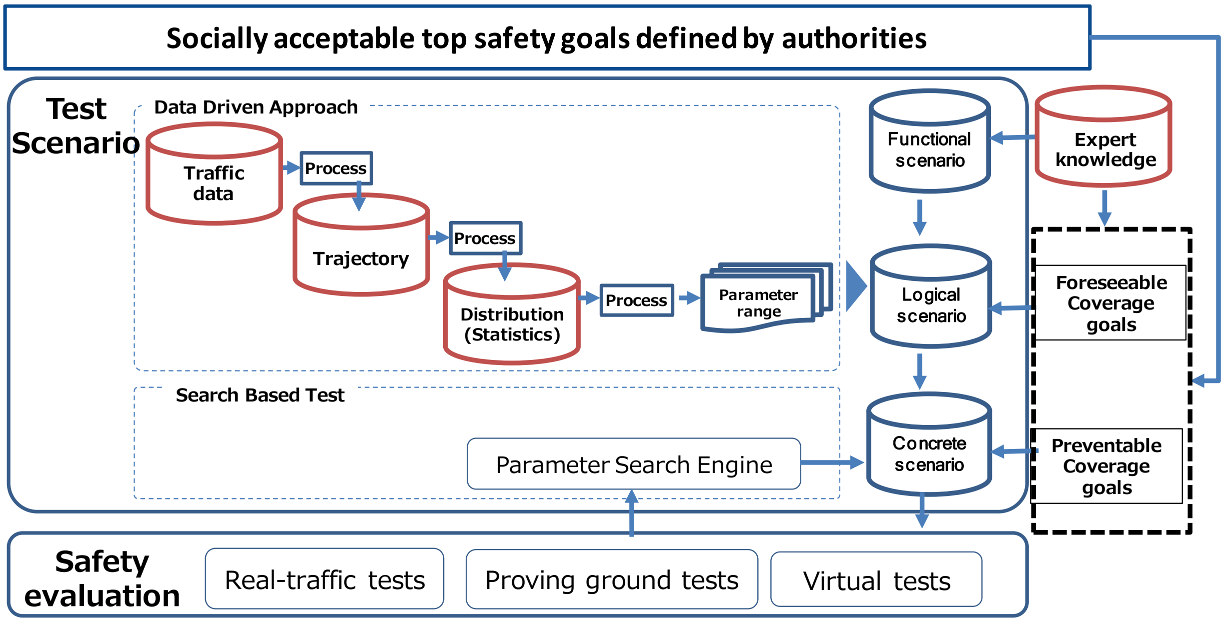


Figure 9 Overview of the Scenario Database

3.1.1.3. Safety Design and Safety Concept

System safety requirements shall be derived based on the results of the safety-analysis steps. In this process, safety goals—referred to as judgment criteria—defined by regulatory authorities are incorporated into the development cycle and considered within system design.

As layers with varying levels of complexity are added during safety design, the safety-analysis cycle may be iteratively integrated with this process and with preceding development stages, provided that the outputs of each stage remain consistent with the safety-analysis steps. To avoid unnecessary specification changes during system development, it is essential to ensure consistency between the Operational Design Domain (ODD) and the derived system requirements. This underscores the critical role of the safety-analysis steps within the overall development process.

Note:

In this document, judgment criteria refer to quantified criteria derived from principles defined by the United Nations World Forum for Harmonization of Vehicle Regulations (WP29), such as:

“Automated driving systems must not cause any reasonably foreseeable and preventable personal-injury accidents. *(See UN R-157 Annex 3 and Chapter 6)*

3.1.1.4. System Development Process

The system development process implements the system requirements derived through safety design by translating them into concrete hardware and software components. Through this process, the actual ADS is constructed.

3.1.1.5. System and Vehicle Verification and Validation (Safety V&V Sub-process)

At this stage, strategies for verifying and validating system-level and vehicle-level safety without driver intervention are defined. Verification and validation activities combine virtual evaluation with physical testing conducted in real-world traffic environments and on dedicated test courses.

- Verification sub-process:

  The verification sub-process confirms the mathematical and physical correctness of the system, developed functions, and implemented safety measures. It also verifies that all safety specifications and requirements established during safety analysis—including sensor-related, algorithm-related, and actuator-related measures—are satisfied.

- Validation sub-process:

  The validation sub-process confirms that the system, including its safety measures, does not impose unreasonable risk on traffic participants.
  Safety is demonstrated by verifying that the defined validation objectives have been achieved.

3.1.1.6. Safety Assessment

Safety assessment quantitatively and systematically evaluates the safety of the final product and determines pass/fail outcomes based on internationally defined judgment criteria.
This process includes, but is not limited to:

- relevant inspections;
- documentation reviews;
- certification activities; and
- ensuring traceability through scenario-based test cases developed as evidence of evaluation results

These activities collectively ensure the completeness and validity of the safety evaluation.

3.1.1.7. Final Pre-release Confirmation Sub-process

The final pre-release confirmation sub-process represents the last stage for comprehensively verifying the safety and reliability of the ADS and determining its readiness for market release.
This process confirms that:

- residual risk remain within acceptable limits; and
- sufficient evaluation has been conducted under diverse and representative ODD-based scenarios, including scenarios involving extreme conditions.

For this evaluation, Behavioral Safety Assessment (BSA) and similar techniques are applied to verify compliance with predefined behavioral criteria and safety goals. In addition, fallback strategies and fail-safe behaviors are reviewed to confirm that safety can be maintained under system-limit conditions. It is also verified that users can correctly understand and appropriately operate the system's functions and limitations through the HMI design and documentation.

Finally, this process confirms readiness for incident management and post-deployment field-data collection, ensuring a smooth transition to post-release monitoring and continuous improvement. This supports long-term reliability and sustained safety performance.

3.1.1.8. Incident Management

To ensure the long-term safety of ADS, it is essential not only to perform verification and validation during the design and development phases, but also to continuously collect, analyze, and respond to incidents that occur during operation. When an incident occurs, a rapid reporting mechanism for users shall be established, and notifications shall be provided to regulatory authorities or certification bodies as required. Collected incident data are systematically analyzed through root cause analysis (RCA), and the findings are reflected in system design updates, software revisions, and operational documentation as measures for recurrence prevention and safety improvement.

By systematically integrating these feedback loops into the safety-assurance process, the number of situations classified as unpredictable decreases over time. As illustrated in Figure 10, this expands the range of scenarios that become predictable and preventable. Ultimately, this contributes to continuous safety improvement and supports the long-term evolution and reliability of ADS.

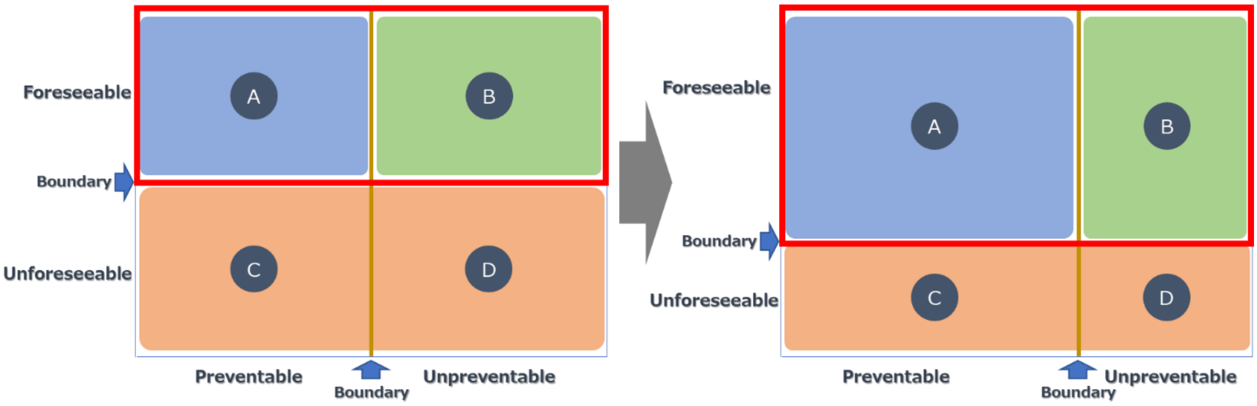


Figure 10. Expansion of Foreseeable and Preventable Domains through the Evolution of ADS

3.2. Overview of the Scenario Framework

The scenario framework for evaluating the safety of ADS is constructed by decomposing the Dynamic Driving Task (DDT) into the three fundamental processes: “perception,” “decision,” and “operation” (Figure 11). For each process, potential risk factors grounded in physical principles are identified and categorized into perception disturbances, traffic disturbances, and vehicle-dynamics disturbances, thereby ensuring completeness coverage of safety-relevant situations (Figure 12).

The three disturbance categories are defined as follows:

- Perception disturbances:
  Uncertainties or degradations in perception arising from sensor limitations or environmental conditions.
- Traffic disturbances:
  Risks arising from road geometry or from the positions and behaviors of surrounding traffic participants.
- Vehicle-dynamics disturbances:
  Instabilities in vehicle dynamics caused by road-surface conditions or external physical forces acting on the vehicle.

These disturbance categories are expanded in a stepwise manner across three levels of scenario abstraction. At the highest level, Functional Scenarios represent abstract, qualitative descriptions of traffic situations. These are then refined into Logical Scenarios by introducing quantitative parameter ranges. Finally, Concrete Scenarios define specific evaluation conditions used for simulation or physical testing.

By systematically organizing and managing Functional, Logical, and Concrete Scenarios within a scenario database, the framework provides comprehensive coverage of situations that are predictable and preventable. This structured approach supports consistent and traceable safety evaluation of ADS across development phases.

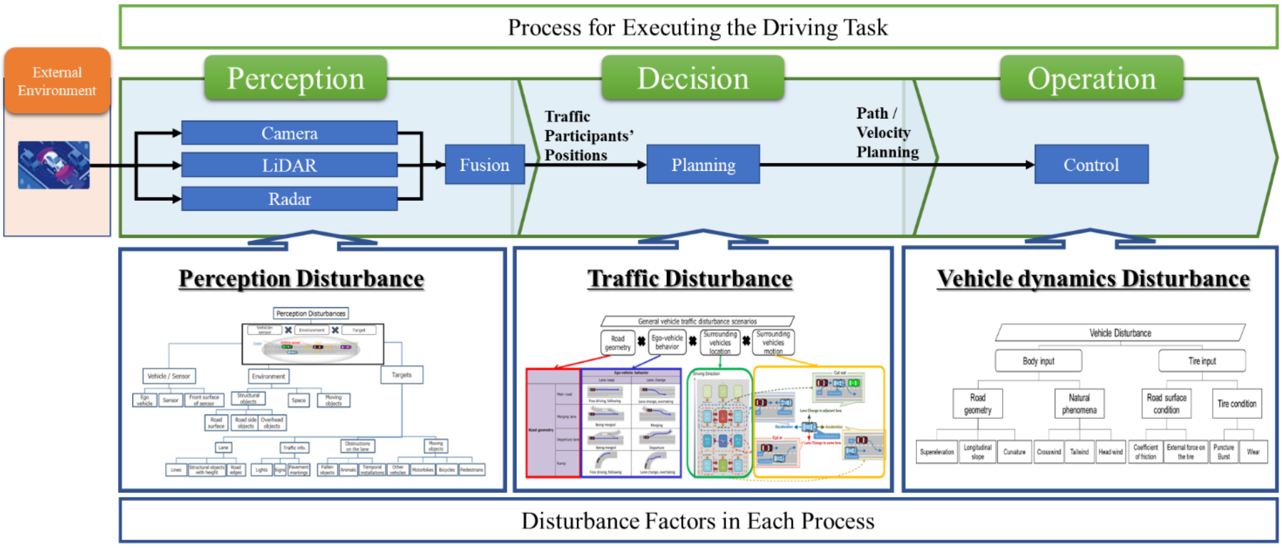


Figure 11 Scenario Structure

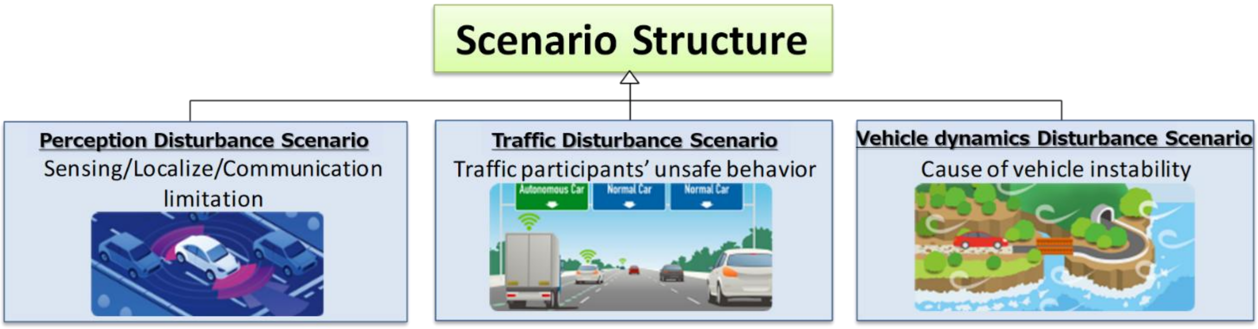


Figure 12 Three Scenario Frameworks based on Physical Principles

3.3. Concepts Behind Safety Determination Methods

As a framework for translating safety principles into concrete evaluation methods, the safety determination approach presented in this document is based on the recognition that the fundamental safety risk during the Dynamic Driving Task (DDT) in automated driving is collision with surrounding traffic participants or obstacles.

Accordingly, collision-related risks are first systematized in the form of traffic-disturbance scenarios. Within this framework, the ranges of reasonably foreseeable conditions and preventable conditions are defined, thereby converting the safety principles established by UN/WP29 into engineering-measurable criteria.

Based on these traffic-disturbance scenarios, overall system safety is evaluated by verifying that collisions are avoided within the defined ranges, even when additional disturbance factors—such as perception disturbances or vehicle-dynamics disturbances—are superimposed on the baseline traffic scenario (Figure 13).

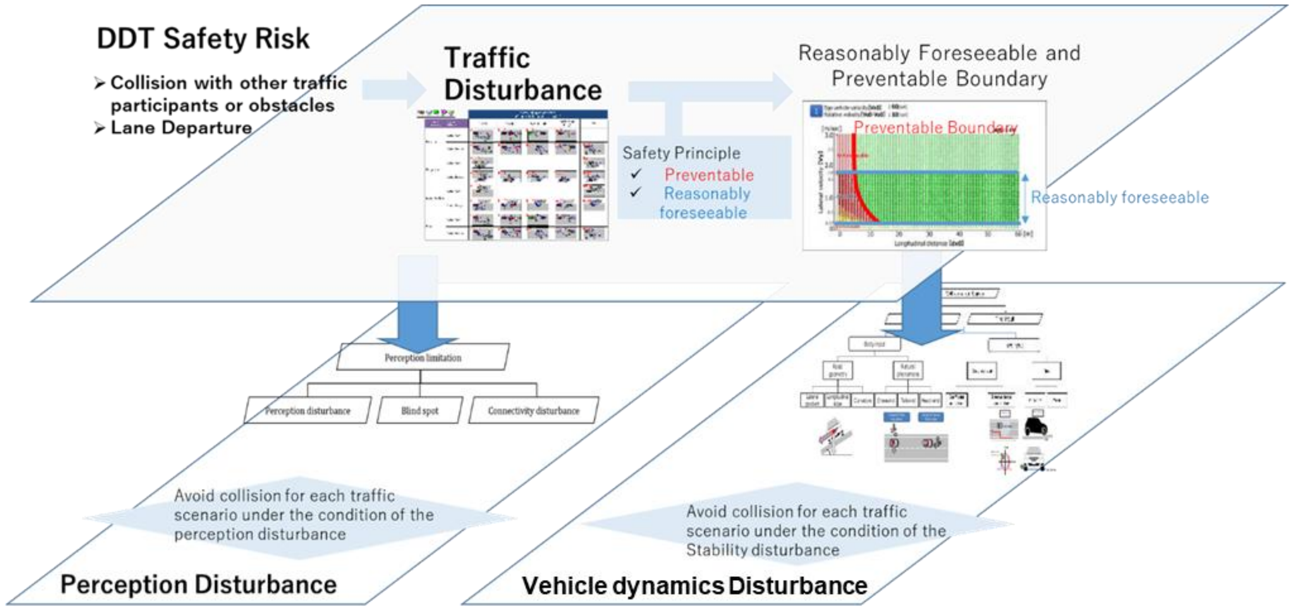


Figure 13. Overview of the Safety Determination Method

3.3.1. Safety Determination Method for Traffic Disturbances

As described above, the fundamental concept underlying the safety criteria is as follows:

> “Within the reasonably foreseeable range, an ADS shall demonstrate collision-avoidance performance equal to or greater than that of a Competent and Careful human Driver (C&C Driver).”

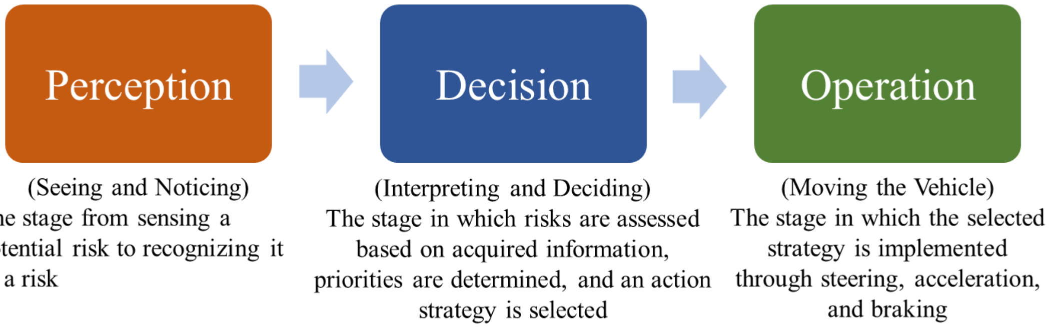
To apply this concept to traffic disturbances, it is necessary to define and model the performance of the C&C Driver. By implementing this driver model within a simulation environment and deriving the range in which a C&C Driver can avoid a collision, safety criteria for traffic-disturbances can be quantitatively established.

In defining the C&C Driver model, the following considerations related to social acceptability are taken into account:

- With respect to the determination of criminal negligence, “the driving capability of an ordinary driver” is commonly used as the reference standard.
- In real traffic environments, actual driver performance is often lower than that observed in controlled experimental settings due to factors such as distraction or hesitation. Therefore, by defining the performance target based on reference drivers from experimental data—who exhibit stable attention and no hesitation—it is reasonable to expect that ADS, which do not suffer from such human limitations, will achieve accident-reduction effects.

Accordingly, the target C&C Driver is defined as a driver who:
- remains continuously alert;
- maintains situational awareness of surrounding vehicles; and
- possesses appropriate driving capability and carefulness.

Furthermore, the C&C Driver model is structured based on the three elements of driving behavior: perception, decision, and operation (Figure 14). For each element, performance-related parameter and coefficients are defined based on objective evidence.



(Seeing and Noticing)
The stage from sensing a potential risk to recognizing it as a risk

(Interpreting and Deciding)
The stage in which risks are assessed based on acquired information, priorities are determined, and an action strategy is selected

(Moving the Vehicle)
The stage in which the selected strategy is implemented through steering, acceleration, and braking

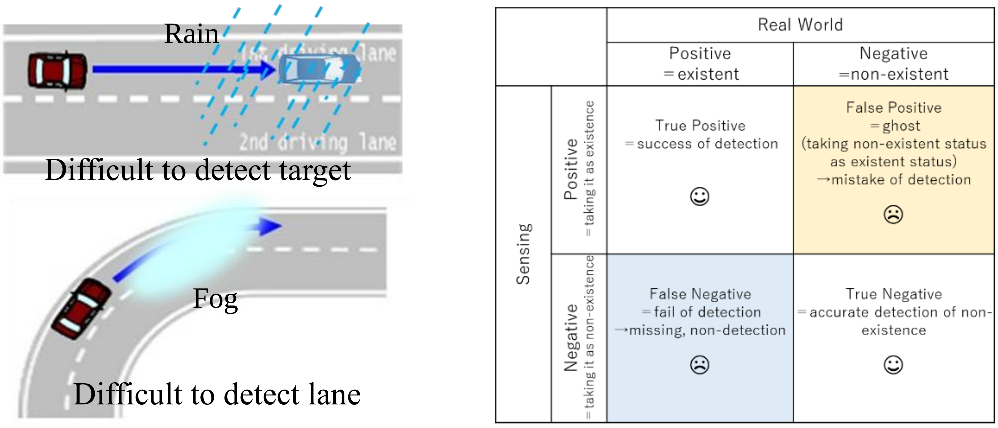
Figure 14. Three Elements of Driving behavior

Determination Method

- Preventable Domain
- Within the preventable domain, the ADS shall achieve collision-avoidance performance equal to or greater than that achievable by a C&C Driver.
- Foreseeable Domain
  Scenarios must be predictable based on physical principles and must take into account:
  ･typical violations by other road users; and
  ･prevailing traffic speeds.
- Evaluation Approach
  Traffic-disturbance scenarios derived through the Physical Principle Approach Process are evaluated in accordance with the above criteria.

3.3.2. Safety Determination Method for Perception Disturbances

A perception disturbance refers to a situation in which the ADS is unable to correctly perceive objects or the surrounding environment (Figure 15-A), or conversely, incorrectly detects objects (Figure 15-B). Such situations arise due to limitations of sensor principles (e.g., camera, LiDAR, radar), weather conditions, surrounding structures, or other external factors.



		Real World	
		Positive ＝existent	Negative ＝non-existent
Sensing	Positive ＝taking it as existence	True Positive ＝success of detection ☺	False Positive ＝ghost (taking non-existent status as existent status) →mistake of detection ☹
	Negative ＝taking it as non-existence	False Negative ＝fail of detection →missing, non-detection ☹	True Negative ＝accurate detection of non-existence ☺

(A)Examples of Environmental Disturbance Factors (B)Perception Outcomes Resulting from Disturbances

Figure 15　Perception Disturbance Factors

Safety-determination flow:

1. Definition of disturbance conditions

- Perception disturbances are classified into the following two types: (Figure 16)
  ･False Negative (underdetection)
  ･False Positive (overdetection)
- Within the ODD, disturbance ranges are defined based on environmental conditions that may reasonably occur, including visibility, brightness, rainfall, road-surface reflections, and backlighting. Disturbance ranges are determined based on:
  1. Legal and regulatory limits
     (e.g., road closure below 50 m visibility, road repair required when step height ≥ 15 cm)
  2. Statistically probable ranges
     derived from environmental data
     (e.g., rainfall intensity, brightness, solar elevation)

2. Determination Method

- The fundamental safety principle for perception disturbances is as follows:
  "Even under traffic-disturbance scenarios, the ADS shall avoid collisions despite the occurrence of perception disturbances."
- Safety evaluation is conducted at the system level, rather than for individual sensors. This includes sensor fusion and downstream processing.
- Even if perception performance partially degrades, the ADS must maintain collision-avoidance capability equal to or greater than that of a C&C Driver at the system level.

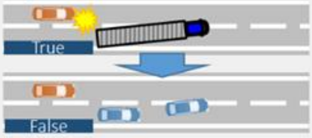
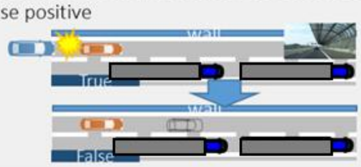
2 kinds of perception target	2 types of perception result with disturbance	
	false negative	false positive
Road object	No collision on traffic disturbance because of false negative 	No collision on traffic disturbance because of false positive 
Lane	No lane departure because of false negative 	No lane departure because of false positive 

Figure 16. Four types of Perception Disturbance situations

3.3.3. Safety Determination Method for Vehicle Dynamics Disturbances

Vehicle-dynamics disturbances often involve situations that are difficult even for human drivers to fully predict. Accordingly,, the safety determination method for vehicle-dynamics disturbances is structured into two layers:
1. Stable driving under preventable conditions
2. Mitigation under unavoidable conditions

Safety-determination flow:

1. Prerequisites

The following prerequisites apply:

- Roads must be designed and maintained in accordance with applicable structural regulations and maintenance standards.
- Vehicles must not be operated when the operator is aware of maintenance deficiencies (e.g., extreme tire wear or insufficient tire pressure).
- Unexpected extreme environments (e.g., flooding or disaster-level storms) are excluded from the evaluation scope.

2. Evaluation procedure

- Quantification of disturbance factors
  Disturbance factors—such as road-surface friction coefficient, road curvature, crosswind, and tire external forces—are quantified as physical inputs.
- Determination of vehicle control limit using adhesion utilization rate (ε)
  ・ε ≤ 75% → Preventable: vehicle dynamics can be controlled
  ・ε > 75% → Unpreventable: vehicle control becomes difficult
- Verification under preventable conditions
  When ε ≤ 75%, the ADS shall maintain lane keeping and stable driving without departing from the lane.
- Mitigation under unavoidable conditions
  When ε exceeds 75%, the ADS must apply:
  ・deceleration to reduce collision impact; and
  ・fail-safe strategies to minimize potential harm.

3. Determination Method

- Operation on limited-access highways (e.g., design speed 100 km/h):

  - Road-surface conditions
    − friction coefficient ≥ 0.3 (locked-wheel μ)
    − road-surface external forces below maintenance thresholds
    (e.g., rutting: 25 mm, step height: 30 mm, pothole: 20 cm)
  - Road geometry:
    − curve radius per road structure regulations (e.g., R = 460 m)
  - Natural phenomena:
    − crosswind within non-regulated range (below 10 m/s)

  Under the combined influence of these factors, the ADS shall maintain stable driving.
  If stable driving cannot be maintained (e.g., crosswind ≥ 5 m/s causing loss of control), such conditions shall be defined as ODD boundaries by the manufacturer.
  Tire conditions shall also be considered. For example, in the case of a slow puncture, the ADS shall detect the condition before the tire rim contacts the road surface.

- Operation on general roads (non-limited-access roads):
  Because traffic regulation is less strict, and speeds are lower:

  - Road-surface conditions:

friction coefficient ≥ 0.3; rutting 30–40 mm, step 40 mm, pothole 20 cm

- Road geometry:
  curve radius in accordance with structural regulations (e.g., R = 120 m for 60 km/h design speed)
- Crosswind:
  vehicle controllability must be maintained up to approx. 20 m/s

- Final Requirement

  Even when vehicle-dynamics disturbances occur, the ADS must maintain collision-avoidance performance equal to or greater than that of a C&C Driver at the system level. Under unavoidable conditions, the ADS must prioritize harm mitigation.

3.4. Classification and Factors of Disturbance Scenarios

This section describes the classification of disturbance scenarios—perception disturbances, traffic disturbances, and vehicle-dynamics disturbances—as well as the factors that give rise to each category.

3.4.1. Traffic Disturbance Scenarios

Traffic-disturbance scenarios are categorized into the following three types (Figure 17)

- General vehicle scenarios
- Motorcycle-specific scenarios
- Traffic vulnerable road users (VRU) scenarios

These categories are generated by systematically analyzing and classifying combinations of road-geometry elements, ego-vehicle behavior, and the positions and behaviors of surrounding traffic participants, together with other relevant components (Figure 18).

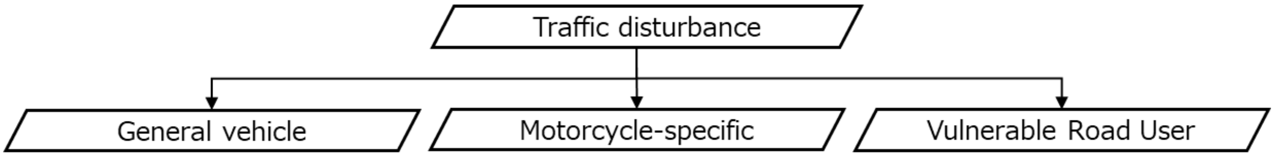


Figure 17. Traffic Disturbance Scenario Classification

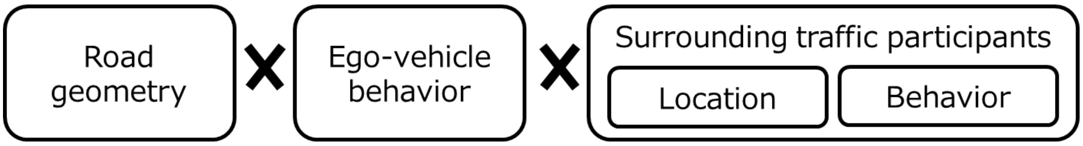


Figure 18. Traffic Disturbance Scenario structure

3.4.1.1. General Vehicle Scenarios

In general-vehicle traffic-disturbance scenarios, the scenario structure is defined by combinations of road geometry, ego-vehicle behavior, and the positions and behaviors of surrounding vehicles.

3.4.1.2. Road-Geometry Classification

Road geometry is defined as follows: (Figure 19)

(a) Non-intersection: a basic straight road segment
(b) Merge section: a section where another lane joins
(c) Branch section: a section where lane diverges
(d) Intersection: a section where two roads cross

These basic units combine to form various road configurations.

On limited-access highways, where intersections generally do not exist, road geometry is grouped into main lane, merge lane, and branch lane.

NOTE: Detailed road-structure parameters are provided in Annex A. Road geometry may influence not only traffic disturbances but also perception disturbances and vehicle-dynamics disturbances.
NOTE: Roundabouts can be represented as combinations of merging and branching. Other configurations—such as parking areas and streetcar (tram) tracks—may also need to be considered. Accordingly, additional annexes are planned for future revisions.

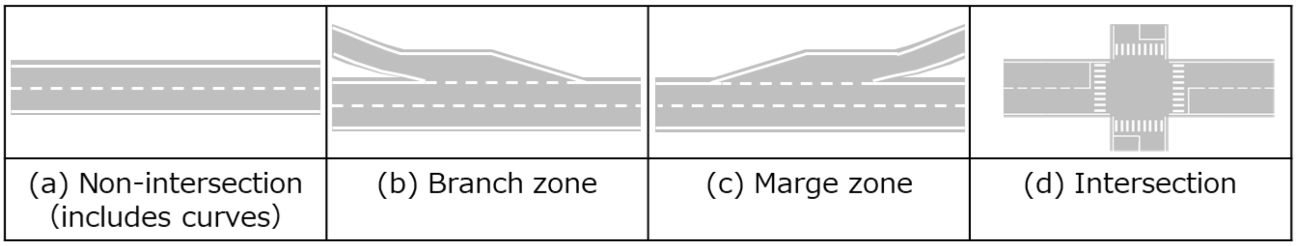

(a) Non-intersection (includes curves) | (b) Branch zone | (c) Marge zone | (d) Intersection

Figure 19. Road-Geometry Classification

3.4.1.3. Ego-Vehicle Behavior Classification

Ego-vehicle behavior is classified into the following categories:

- Going straight (lane keeping)
- Lane change
- Turning (right or left turns)

On a non-intersection road, vehicles either travel straight or change lanes. At intersections, lane changes are not performed; instead, turning maneuvers occur. These behaviors are represented as combinations of road-geometry information (Figure 20).

NOTE: Although U-turns exist in principle, ADS are assumed not to perform ordinary U-turns. When a dedicated U-turn lane exists, it is treated as a merge case.

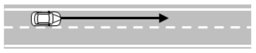
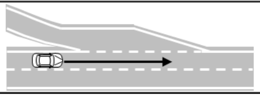
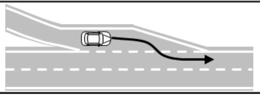
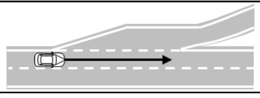
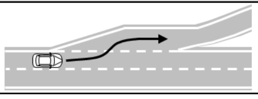
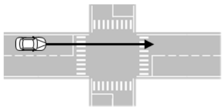
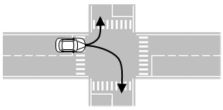
		Ego-vehicle behavior		
		Going straight	Lane change	Turning
Road geometry	non-intersection			
	Merge zone			
	Branch zone			
	Intersection			

Figure 20. Ego-Vehicle Behavior Classification

3.4.1.4. Classification of Positions and Behaviors of Surrounding Vehicles

To construct the scenario structure, the positions of surrounding vehicles are defined relative to the ego vehicle as follows:

- five adjacent positions with potential to intrude into the ego vehicle’s driving path;

- two lateral entry directions in intersections; and
- one oncoming direction (only one side applicable in countries such as Japan).

This results in a total of nine surrounding-vehicle positions (Figure 21).

If the velocity difference between a lead vehicle and the vehicle ahead of it is large, the lead vehicle may perform an abrupt lane change (cut-out) to avoid a collision. To model this situation, the position of the vehicle ahead of the lead vehicle is additionally considered (denoted as “+1”).

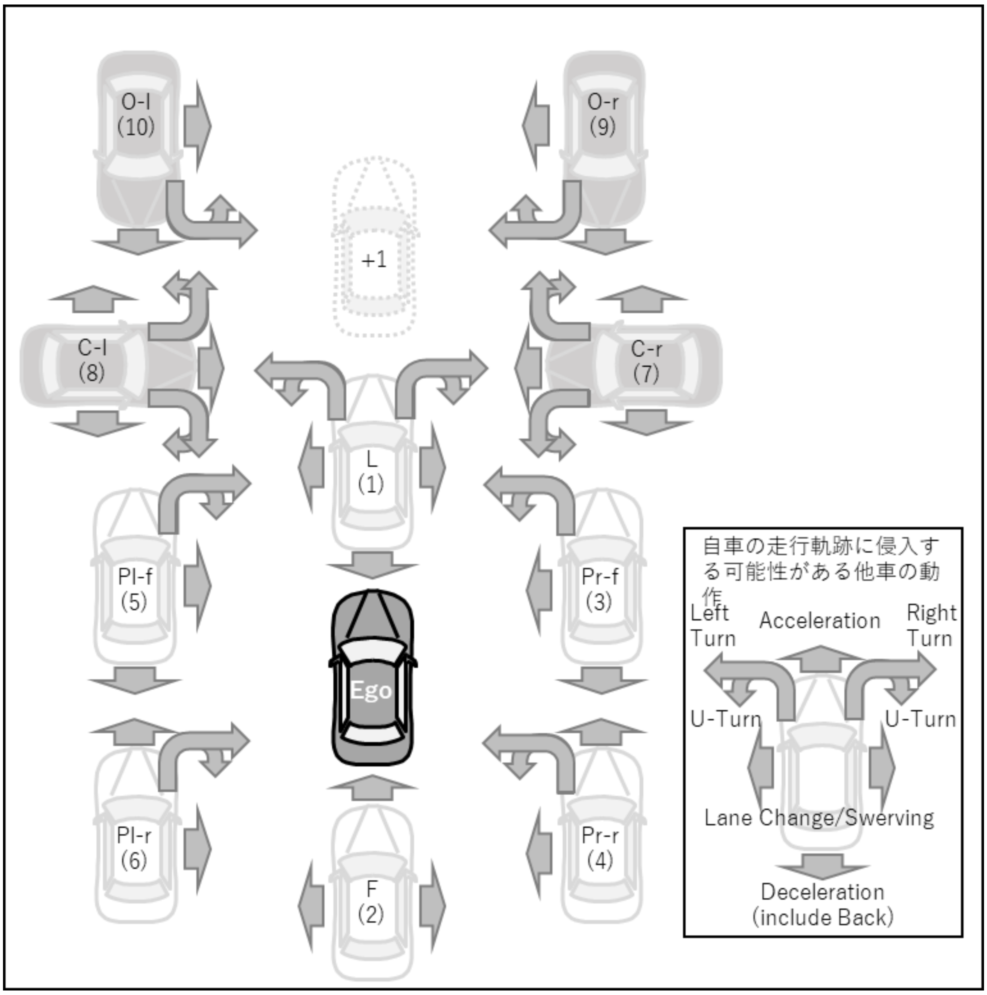


Figure 21. Positions of Surrounding Vehicles

		Surrounding traffic participants behavior							
	Vehicle location	Going straight		Lane change/ swerving			Turning		
		Acceleration	Deceleration	Cut-in	Cut-out	swerving	Right turn	Left turn	U-turn
Surrounding traffic participants location	1. Lead(L)		✓		✓	✓	✓	✓	✓
	2. Following(F)	✓			✓				
	3. Parallel(Pr-f)		✓	✓		✓		✓	✓
	4. Parallel(Pr-r)	✓		✓		✓		✓	✓
	5. Parallel(Pl-f)		✓	✓		✓	✓		✓
	6. Parallel(Pl-r)	✓		✓		✓	✓		✓
	7. Cross(C-r)	✓				✓	✓	✓	✓
	8. Cross(C-l)	✓				✓	✓	✓	✓
	9. Opposite(O-r)	✓				✓	✓		✓
	10. Opposite(O-l)	✓				✓		✓	✓

Figure 22. Surrounding-Vehicle Position and Ego-Vehicle Obstruction Movement Combinations

Surrounding-vehicle behaviors are classified into:

- Straight driving (acceleration or deceleration);
- Lane change (cut-in, cut-out) or swerving (avoidance motion); and
- Turning (right/left turns, or U-turns).

From a safety-evaluation perspective, only combinations of surrounding-vehicle positions and behaviors that may obstruct ego-vehicle motion are analyzed (Figure 22).

3.4.1.5. Resulting Traffic-Disturbance Scenarios

Based on the classifications described above, traffic-disturbance scenarios are structured as combinations of road geometry, ego-vehicle behavior, and the positions and behaviors of surrounding vehicles.

This structure forms a matrix of 58 feasible combinations (Figure 23). Specifically:

- Road geometry is categorized into four types: straight section, merge section, branch section, and intersection.
- Ego-vehicle behavior is categorized into three types: going straight (lane keeping), lane change, and turning (right or left turn).
- Surrounding-vehicle positions and behaviors are categorized into three groups:
    - straight driving (same-direction acceleration/deceleration, crossing, or opposing traffic);
    - lane change (cut-in or cut-out) or swerving; and
    - turning (same-direction or opposing U-turn, right or left turn).

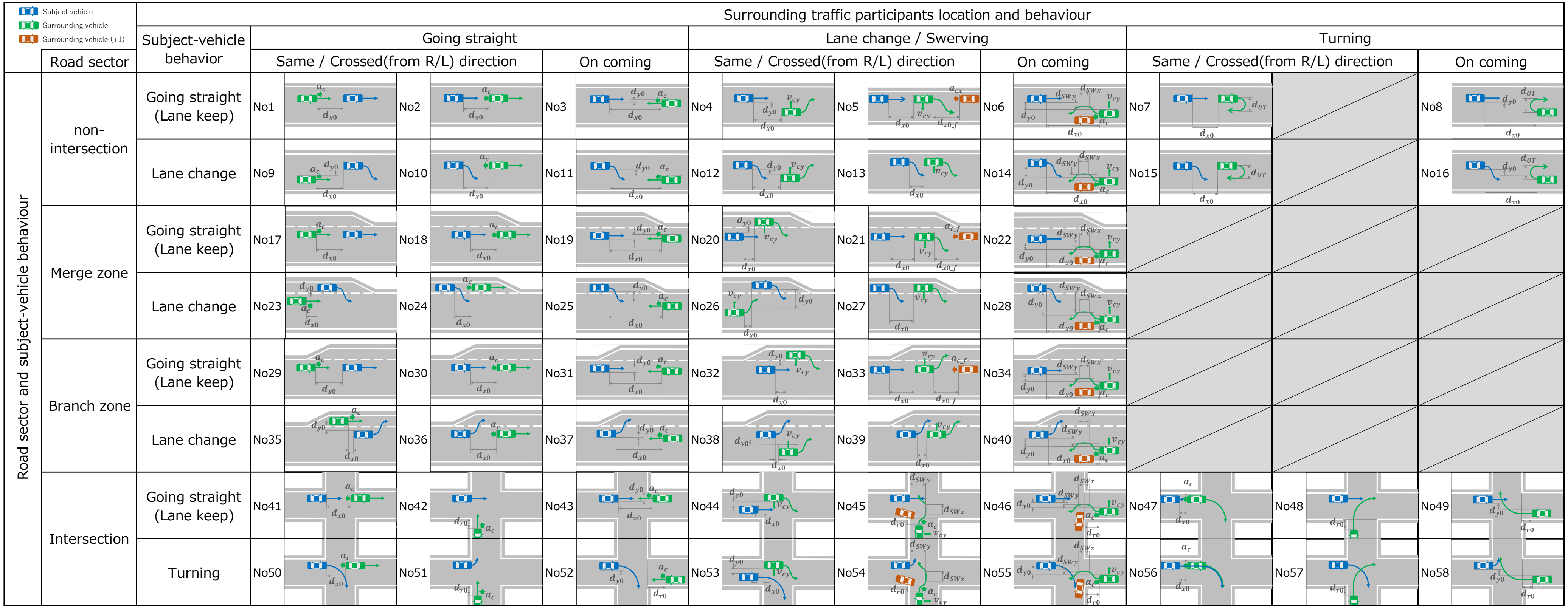
Taken together, these elements form a matrix of 58 combinations corresponding to realizable test scenarios in real traffic environments. The sufficiency of this scenario set—intended to cover hazardous cases that may lead to accidents—can be evaluated by comparison with accident-classification datasets (Annex D).

This matrix provides comprehensive coverage of traffic disturbances involving interactions between two vehicles.

The scenarios shown in Figure 23 represent representative cases. In practice, it is necessary to consider specific combinations of surrounding-vehicle positions and behaviors that may obstruct ego-vehicle motion (Figure 22). At this stage, intrusions from the left and right (such as lane changes) are treated as equivalent behaviors.

As an illustrative example, Figure 24 presents expanded scenarios corresponding to items No. 9, 10, 12, and 13 in Figure 23. In these cases, the road geometry is a non-intersection, the ego vehicle performs a lane change, and the surrounding-vehicle behavior is either straight driving or lane change. Taking item No. 12 as an example, when the ego vehicle performs a lane change, surrounding vehicles may be located ahead of the ego vehicle, behind it, or laterally (e.g., beside the ego vehicle either forward or rearward).

When the number of lanes differs, even the same surrounding-vehicle position may result in different potential conflict paths. Therefore, when considering surrounding-vehicle positions and lane configurations, it is essential to extract combinations of surrounding-vehicle movements that may obstruct the ego vehicle.



			Surrounding traffic participants location and behaviour								
		Subject-vehicle behavior	Going straight			Lane change / Swerving			Turning		
	Road sector		Same / Crossed(from R/L) direction		On coming	Same / Crossed(from R/L) direction		On coming	Same / Crossed(from R/L) direction		On coming
Road sector and subject-vehicle behaviour	non-intersection	Going straight (Lane keep)	No1	No2	No3	No4	No5	No6	No7		No8
		Lane change	No9	No10	No11	No12	No13	No14	No15		No16
	Merge zone	Going straight (Lane keep)	No17	No18	No19	No20	No21	No22			
		Lane change	No23	No24	No25	No26	No27	No28			
	Branch zone	Going straight (Lane keep)	No29	No30	No31	No32	No33	No34			
		Lane change	No35	No36	No37	No38	No39	No40			
	Intersection	Going straight (Lane keep)	No41	No42	No43	No44	No45	No46	No47	No48	No49
		Turning	No50	No51	No52	No53	No54	No55	No56	No57	No58

Figure 23. General-Vehicle Traffic Disturbance Scenarios

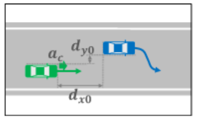
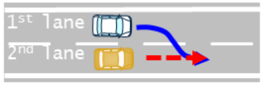
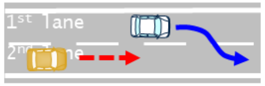
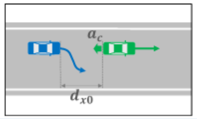
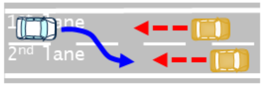
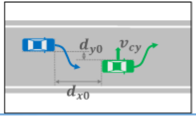
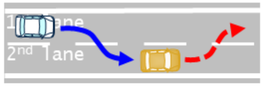
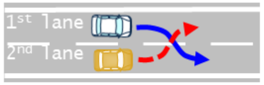
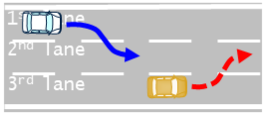
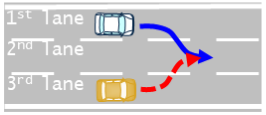
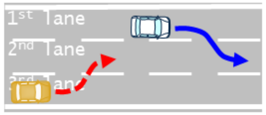
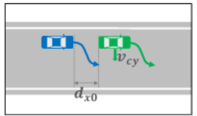
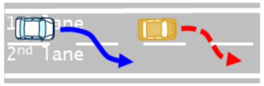
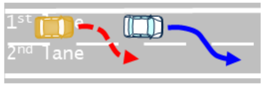
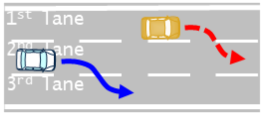
Ego : Other:	Main road 2 lanes 1st lane 2nd lane			Main road 3 lanes 1st lane 2nd lane 3rd lane		
	Forward	Parallel running	Rear	Forward	Parallel running	Rear
No.9 Acceleration 	No trajectory intersects, it doesn’t affect any safety			No trajectory intersects, it doesn’t affect any safety	No trajectory intersects, it doesn’t affect any safety	No trajectory intersects, it doesn’t affect any safety
No.10 Deceleration 	※2 pattern 	No trajectory intersects, it doesn’t affect any safety	No trajectory intersects, it doesn’t affect any safety	No trajectory intersects, it doesn’t affect any safety	No trajectory intersects, it doesn’t affect any safety	No trajectory intersects, it doesn’t affect any safety
No.12 LC in the opposite direction 			No trajectory intersects, it doesn’t affect any safety			
No.13 LC in the same direction 					No trajectory intersects, it doesn’t affect any safety	No trajectory intersects, it doesn’t affect any safety

Figure 24. Example Scenarios Combining Surrounding-Vehicle Positions and Potential Ego-Vehicle Obstruction Movements

3.4.1.6. Scenarios Specific to motorcycle

In principle, the general traffic-disturbance scenario structure (Figure 21, Figure 22) also applies to motorcycles. However, motorcycles exhibit unique characteristics—such as the ability to travel within narrow gaps in the same lane—which require additional positions and behaviors to be considered. These scenarios depend on country-specific traffic laws and road regulations and may therefore occur only in jurisdictions where such regulations apply. Detailed methods and examples are provided in Annex B.

3.4.1.7. Approaches to Complex Traffic-Disturbance Scenarios

Real-world traffic environments involve multiple participants performing diverse maneuvers simultaneously. To address this complexity, the framework decomposes traffic situations into sequences of events.

An example sequence is illustrated in Figure 25:

- a lead vehicle suddenly decelerates (primary event);
- the ego vehicle performs an avoidance maneuver (secondary event); and
- another vehicle may cut into the avoidance area.

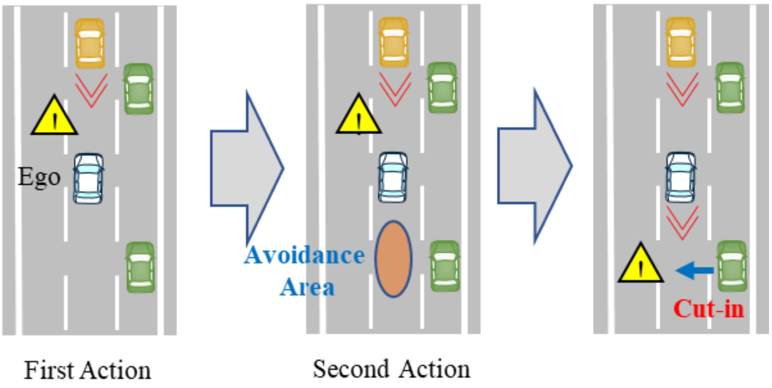


Figure 25 Sequence of Complex Scenarios

By representing traffic disturbances as combinations of sequential behaviors rather than isolated events, it becomes possible to derive scenario sets that more closely reflect real-world situations. Furthermore, by accounting for road-environment characteristics—such as main roads, merge lanes, and intersections—a wide range of traffic-disturbance scenarios can be generated.
For detailed examples and development methods for complex scenarios, refer to Annex C.

3.4.1.8. Traffic-Vulnerable Road User (Pedestrian) Scenarios

Similar to general-vehicle scenarios, traffic-vulnerable road user (pedestrian) scenarios are structured using the traffic-disturbance framework (Figure 18), based on the elements of “road environment,” “ego-vehicle behavior,” and “other traffic participants (position and behavior).” In this context, the “other traffic participants” are pedestrians. Although pedestrian positions and behaviors can vary widely, excessive subdivision would hinder demonstration of completeness. Therefore, pedestrian scenarios are organized using an appropriate level of abstraction.
The resulting Functional Scenario (FS) elements for pedestrian traffic-disturbance scenarios are shown in **Table 2**.

Table 2　Constituent Elements of Functional Scenarios for Pedestrian Traffic-Disturbance Scenarios

Element	Item	Remarks
Road environment	Non - intersection, Intersection	Merge and branch are unnecessary
Ego-vehicle behavior	Non - intersection: go straight, lane change intersection: go straight, turn	Same as general-vehicle scenarios
Other traffic participant (pedestrian) behavior	On driving path, Into driving path	Entering from on-road or off-road

For pedestrian interactions, it is sufficient to consolidate road environments into non-intersection and intersection categories. Ego-vehicle behavior is organized into go straight and lane change on non-intersection roads, and go straight and turn at intersections. Swerving is treated as an avoidance maneuver and is therefore excluded from this structural element. Maneuvers such as entering a parking area on a non-intersection road are treated equivalently to turning at an intersection.

Pedestrian behavior is classified into two types based on its relationship to the ego vehicle's driving path: on driving path and into driving path (Figure 26).

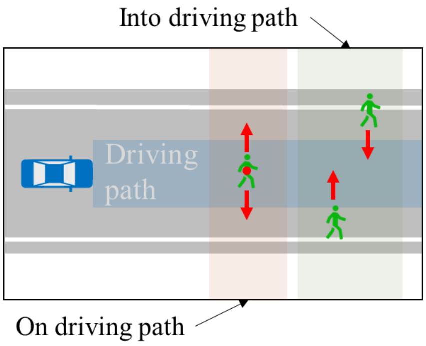


Figure 26　Overview of "On driving path" and "Into driving path"

Here, on driving path refers to situation in which the pedestrian is already located on the ego vehicle's driving path at the start of the scenario. Into driving path refers to situations in which the pedestrian is initially outside the driving path and subsequently enters it. Based on this classification, the pedestrian Functional Scenarios consist of eight scenarios (Figure 27). The corresponding parameters are listed in Table 3.

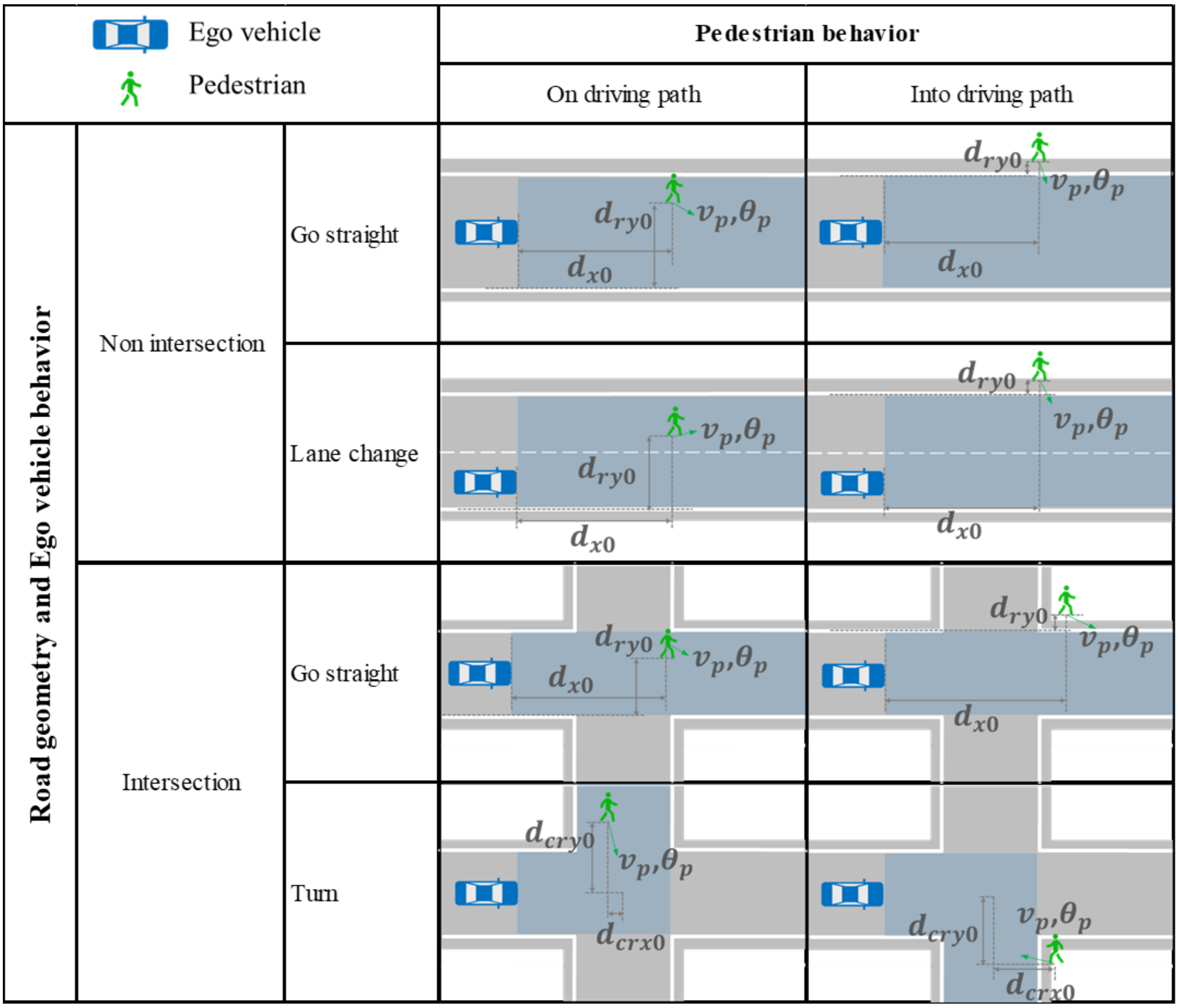


Figure 27 Traffic-Vulnerable Road User (Pedestrian) Disturbance Scenarios

Table 3 Parameters for Pedestrian Traffic-Disturbance Scenarios

Parameter	Unit	Description
v_p	m/s	Pedestrian velocity in the direction of movement
v_v	m/s	Ego vehicle velocity in the direction of movement
d_{x0}	m	Longitudinal distance between the ego vehicle and the pedestrian at the start of interaction
d_{ry0}	m	Lateral distance between the ego vehicle and the pedestrian at the start of interaction
θ_p	rad	Pedestrian movement angle relative to the ego vehicle's initial travel direction (counterclockwise)

Here, the pedestrian behaviors required for defining the Logical Scenario are described.

For on driving path scenarios, pedestrian behavior is grouped into two types:
“move to the left side of the driving path,” and “move to the right side of the driving path.”

A pedestrian remaining stationary outside the driving path does not constitute a critical scenario and is therefore excluded. As with general-vehicle scenarios, the completeness of these pedestrian scenarios has been verified through comparison with real-world accident data (*Annex D*).

3.4.2. Perception-Disturbance Scenarios

Perception-disturbance scenarios include not only perception disturbances themselves, but also obstructed-view scenarios and communication-disturbance scenarios, as shown in Figure 28.

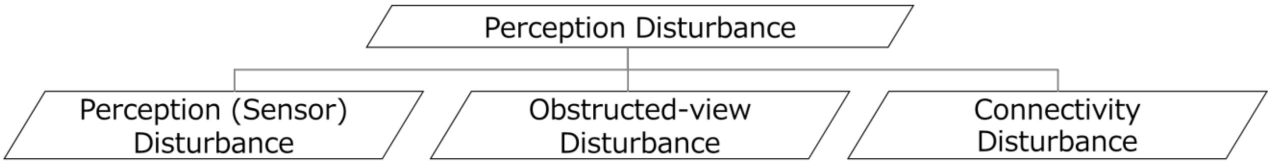


Figure 28. Perception-Disturbance Scenario classification

3.4.2.1. Perception-Disturbance Scenario Generation

Perception-disturbance scenarios are generated based on the factors that cause perception disturbances and the sensing principles of the sensors in which those disturbances occur. Although the disturbance factors themselves are diverse, they can be systematically classified according to their underlying disturbance-generation principles. By selecting representative disturbance factors from each classification group, it becomes possible to derive a scenario set that provides comprehensive coverage of perception disturbances. Furthermore, for each selected disturbance factor, scenarios for evaluating combined perception disturbances can be generated by considering the relevant combinations derived from the disturbance-generation principles (Figure 29).
In this document, perception-disturbance scenarios are described for the following three types: millimeter-wave radar, LiDAR, and camera.
These sensor-specific descriptions enable systematic identification and evaluation of perception disturbances while maintaining traceability to the physical principles underlying each sensing modality.

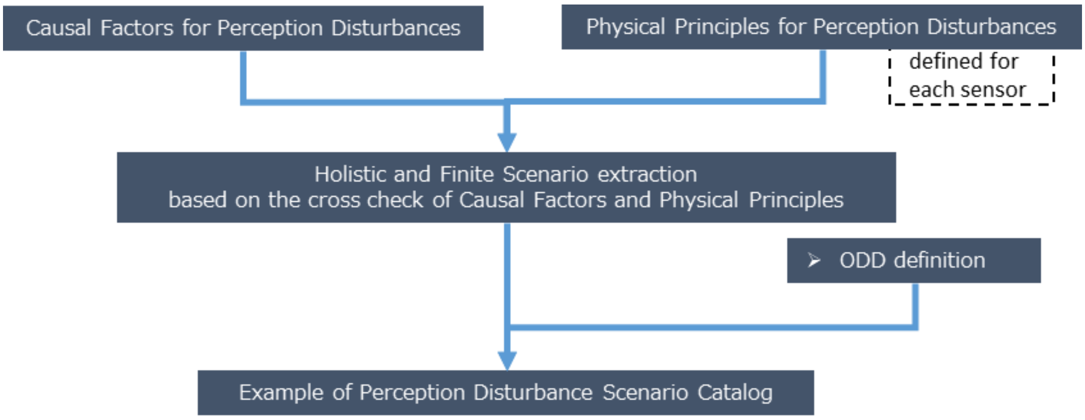


Figure 29. Scenario Derivation Process based on Perception-Disturbance Factors and Sensor Principles

3.4.2.2. Perception-Disturbance Factors

Factors contributing to perception disturbances are first broadly classified, based on their positional relationship to the ego vehicle, into three categories “vehicle/sensor,” “surrounding environment,” and “object to be recognized(target)” (Figure 30). Each category is then decomposed in detail, in a comprehensive and hierarchical manner to form the overall taxonomy of perception-disturbance factors (Figure 31).

Specifically, perception-disturbance factors are progressively broken down from higher-level characteristics—such as structural features, relative position, and object type—into successive layers of increasing detail. This hierarchical decomposition continues until attributes directly relevant to sensor perception are reached, including characteristics such as color, shape, material, and behavior.

This structured classification ensures systematic coverage of perception-disturbance factors while maintaining traceability from high-level categories to sensor-relevant physical attributes.

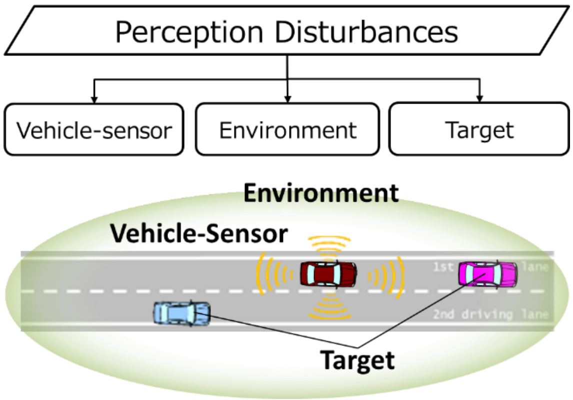


Figure 30. Top-Level Categories of Perception-Disturbance Factors Relative to the Ego vehicle

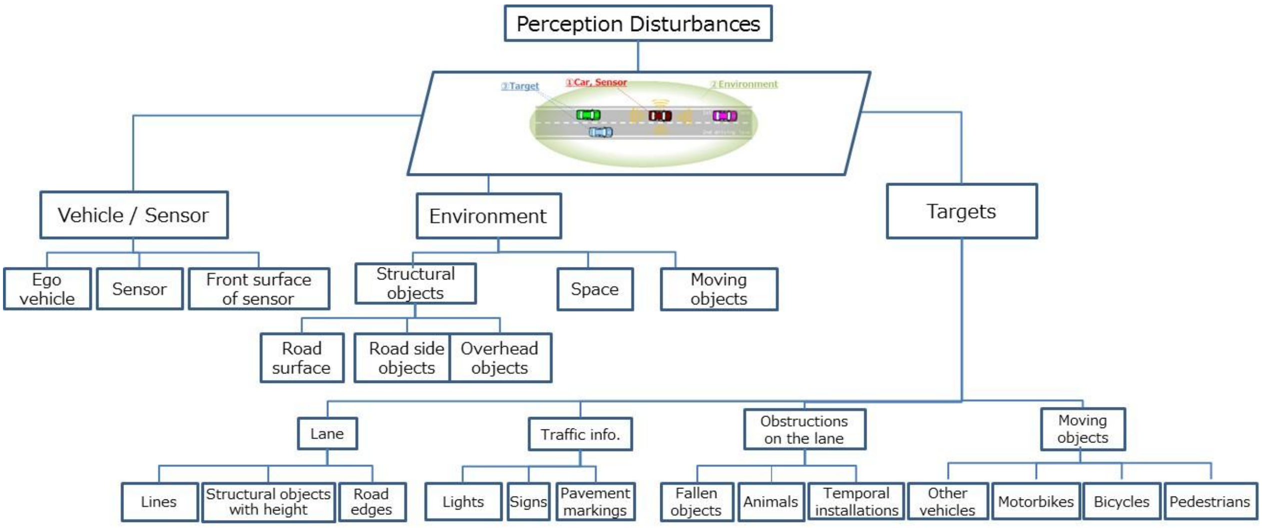


Figure 31. Systematic Classification of Perception-Disturbance Factors

3.4.2.2.1. Perception-Disturbance Factors: Vehicle and Sensors

Perception-disturbance factors classified under the “vehicle/sensor” category originate from characteristics intrinsic to the ego vehicle or its sensing system. These factors are further subdivided according to the location at which the disturbance arises, as illustrated in Figure 32:

(a) Ego vehicle(car)

Factors related to vehicle conditions that may affect sensor posture or orientation, such as vehicle loading, suspension behavior, or body motion.

(b) Sensor

Factors originating from the sensor itself, including installation conditions, alignment accuracy, manufacturing variation, or calibration status.

(c) Sensor front surface

Factors arising at the sensor front surface, such as occlusion or contamination caused by dirt, water droplets, snow, ice, or externally mounted objects.

This subdivision enables clear identification of the physical origin of perception disturbances and supports systematic derivation of evaluation scenarios linked to sensor performance.

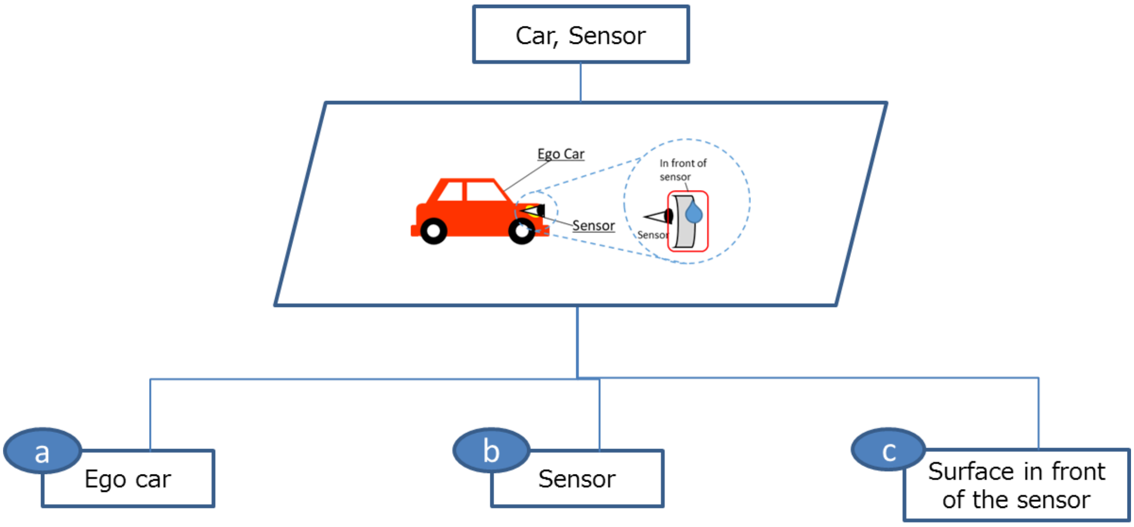
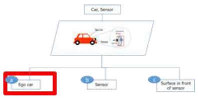


Figure 32. Classification of Vehicle and Sensor Categories

The detailed perception-disturbance factors classified under categories (a), (b), and (c) in Figure 32 are presented in Table 4 through Table 6. For each sensor type, these tables provide a detailed classification of disturbance factors, their effects on perception performance, and the underlying physical principles by which the disturbances are generated.

Table 4 Disturbance factors in category “a. Ego vehicle”

a Ego car



		Millimeter waves	LiDAR	Camera
Influence on sensor principle	Class.	Change of car posture		
	Influence	- Decrease in positioning accuracy which caused by the difference between actual attached position and assumed position that memorized in its sensor. - Changing FOV by changing center axis of Radar. - Misrecognition of road surface as obstacle.	- Misrecognition of road surface as obstacle. note: LiDAR is assumed to be attached to rigid body, so FOV is influenced by posture changing.	- Misrecognition of road surface as obstacle. - Image recognition ability degradation caused by vertical moving of its sensor and ego car.
	Principle	• Undesired signal increasing • Low S/N • Slight shift of axes	• Vehicle posture	• Image shake/flow

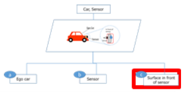
Table 5 Disturbance factors in category “b. Sensor”

b Sensor

		Millimeter waves		LiDAR		Camera	
Influence on sensor principle	Class.	Variation in assembly	Failure of sensor itself	Variation in assembly	Failure of sensor itself	Variation in assembly	Failure of sensor itself
	Influence	- Blind spot. - Decrease in azimuth estimation accuracy which caused by interference direct wave with internal reflected wave. - Decrease in positioning accuracy, which caused by misalignment.	- Decrease in maximum detectable range which caused by receive intensity decreasing. - Change in signal phase and frequency due to change in sensor character.	- Blind spot. - Misalignment in optical axis and attached position.	- Decrease in input and output intensity, which caused by aging degradation.	- Blind spot. - Image recognition ability degradation caused by misalignment.	- Position shift and Color shift in image. - Image recognition ability degradation caused by lens distortion. - Partially information loss due to defective pixels. - Thermal noise and sensitivity variations depend on temperature.
	Principle	• Phase changing • Undesired signal increasing • Low S/N • Slight shift of axes	• Phase changing • Frequency changing • Low S/N	• No signal (partial)	• Signal lowering	• No signal (partial)	• Signal changing • Refraction • No signal (partial) • S/N lowering

Table 6 Disturbance factors in category “c. Sensor Front Surface”

c Surface in front of the sensor



		Millimeter waves		LiDAR		Camera		
Influence on sensor principle	Class.	Sticking objects	Changes in characteristics	Sticking objects	Changes in characteristics	Sticking objects	Changes in characteristics	Reflection on windshield
	Influence	- Decrease in maximum detectable range due to decrease in reception intensity. - Degradation of azimuth estimation accuracy due to interference between reflected wave and direct wave on sticking objects.	- Decrease in maximum recognition range due to decrease in reception intensity. - Degradation of azimuth estimation accuracy due to interference between reflected wave and direct wave to changes in sensor front characteristics.	- maximum detectable range decreases due to received signal strength reducing. - Signal saturation by detecting contamination. - Angle shift due to contamination (oil film, etc.) on the sensor.	- Decrease in received signal strength due to decrease in transmittance. - Signal saturation by detecting cloudiness on surface in front of sensor. - Angle shift due to distortion on the surface in front of sensor.	- Image recognition ability degradation due to lack of an image by objects sticking to windshield. - Image recognition ability degradation due to raindrops and like become noise. - A distant vehicle overlaps with the raindrops, reducing the maximum detectable range.	- Position and color on image are shifted more than design error. - Image recognition ability degradation due to the distortion of windshield.	- False recognition of reflection.
	Principle	• Phase changing • Undesired signal increasing • Low S/N	• Phase changing • Undesired signal increasing • Low S/N	• Signal intensity lowering ~ No signal • Undesired signal increasing • Refraction	• Signal intensity lowering ~ No signal • Undesired signal increasing • Refraction	• No signal (partial) • Low S/N	• Signal changing • Refraction	Low S/N

3.4.2.2.2. Perception-Disturbance Factors: Surrounding Environment

Perception-disturbance factors classified under the “surrounding environment” category are further subdivided, based on the characteristics of objects present around the ego vehicle, into the following three groups:
(d) Surrounding structural objects
(e) Space
(f) Surrounding moving objects
Among these groups, (d) surrounding structures are further classified according to their positional relationship to the ego vehicle into the following subcategories (Figure 33).
(d-1) Road surface
(d-2) Roadside structures(objects)
(d-3) Overhead structures(objects)

This classification enables systematic identification of perception disturbances arising from fixed environmental features located in different spatial relationships to the ego vehicle.

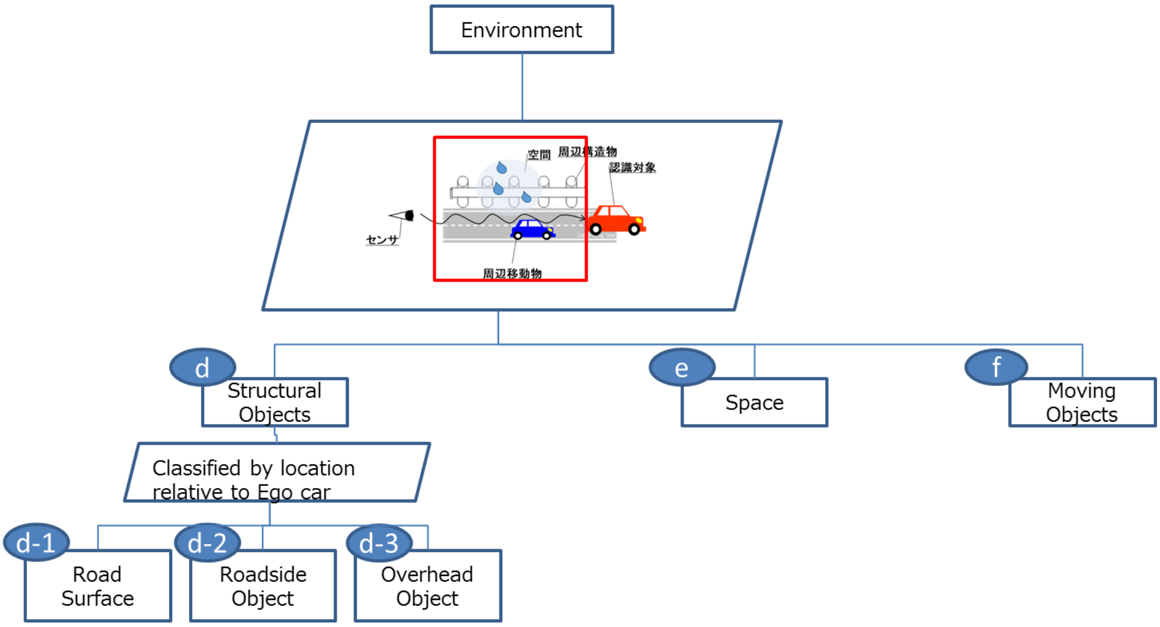
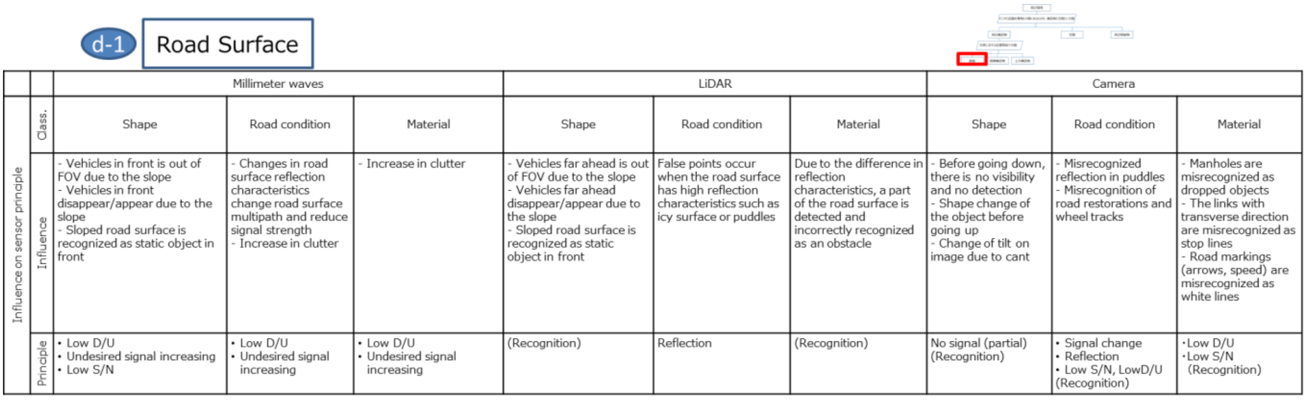


Figure 33. Classification of the Surrounding Environment

The detailed classifications of the perception-disturbance factors categorized as (d-1), (d-2), (d-3), (e), and (f) in Figure 33are presented in Table 7 through Table 11.
For each category, these tables describe the detailed disturbance factors, their impacts on perception performance, and the underlying physical principles by which the disturbances are generated.

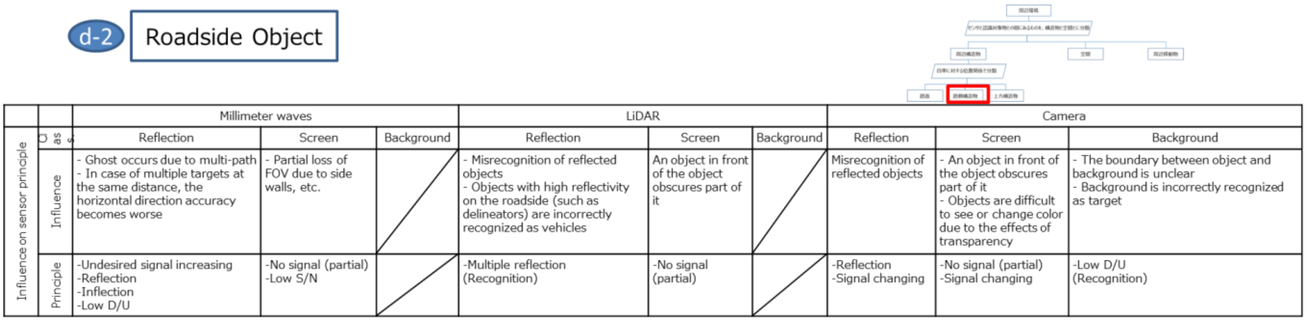
Table 7 Disturbance factors in category “d-1. Road Surface”



d-1 Road Surface

		Millimeter waves			LiDAR			Camera		
Influence on sensor principle	Class.	Shape	Road condition	Material	Shape	Road condition	Material	Shape	Road condition	Material
	Influence	- Vehicles in front is out of FOV due to the slope - Vehicles in front disappear/appear due to the slope - Sloped road surface is recognized as static object in front	- Changes in road surface reflection characteristics change road surface multipath and reduce signal strength - Increase in clutter	- Increase in clutter	- Vehicles far ahead is out of FOV due to the slope - Vehicles far ahead disappear/appear due to the slope - Sloped road surface is recognized as static object in front	False points occur when the road surface has high reflection characteristics such as icy surface or puddles	Due to the difference in reflection characteristics, a part of the road surface is detected and incorrectly recognized as an obstacle	- Before going down, there is no visibility and no detection - Shape change of the object before going up - Change of tilt on image due to cant	- Misrecognized reflection in puddles - Misrecognition of road restorations and wheel tracks	- Manholes are misrecognized as dropped objects - The links with transverse direction are misrecognized as stop lines - Road markings (arrows, speed) are misrecognized as white lines
	Principle	• Low D/U • Undesired signal increasing • Low S/N	• Low D/U • Undesired signal increasing	• Low D/U • Undesired signal increasing	(Recognition)	Reflection	(Recognition)	No signal (partial) (Recognition)	• Signal change • Reflection • Low S/N, LowD/U (Recognition)	·Low D/U ·Low S/N (Recognition)

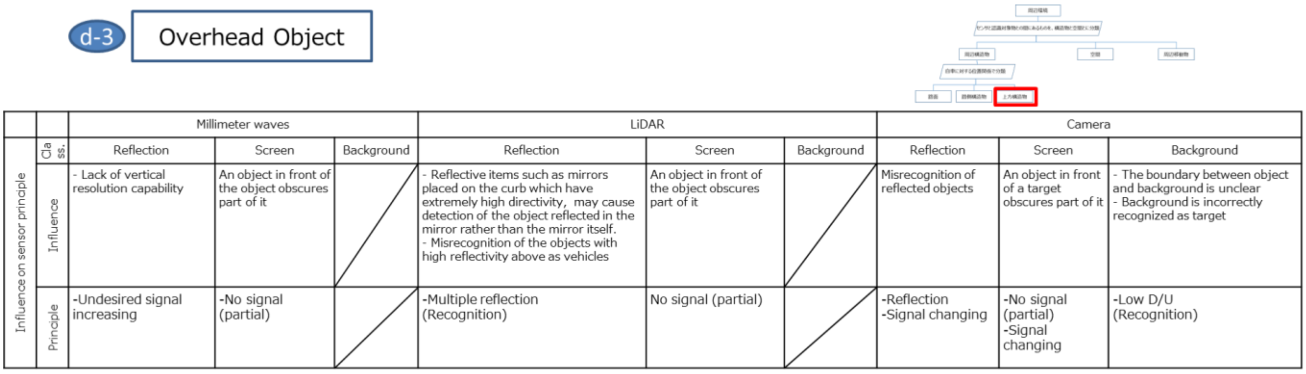
Table 8 Disturbance factors in category “d-2. Roadside Structures”



d-2 Roadside Object

		Millimeter waves			LiDAR			Camera		
Influence on sensor principle	Class	Reflection	Screen	Background	Reflection	Screen	Background	Reflection	Screen	Background
	Influence	- Ghost occurs due to multi-path - In case of multiple targets at the same distance, the horizontal direction accuracy becomes worse	- Partial loss of FOV due to side walls, etc.		- Misrecognition of reflected objects - Objects with high reflectivity on the roadside (such as delineators) are incorrectly recognized as vehicles	An object in front of the object obscures part of it		Misrecognition of reflected objects	- An object in front of the object obscures part of it - Objects are difficult to see or change color due to the effects of transparency	- The boundary between object and background is unclear - Background is incorrectly recognized as target
	Principle	-Undesired signal increasing -Reflection -Inflection -Low D/U	-No signal (partial) -Low S/N		-Multiple reflection (Recognition)	-No signal (partial)		-Reflection -Signal changing	-No signal (partial) -Signal changing	-Low D/U (Recognition)

Table 9 Disturbance factors in category “d-3. Overhead Structures”



d-3 Overhead Object

		Millimeter waves			LiDAR			Camera		
Influence on sensor principle	Class.	Reflection	Screen	Background	Reflection	Screen	Background	Reflection	Screen	Background
	Influence	- Lack of vertical resolution capability	An object in front of the object obscures part of it		- Reflective items such as mirrors placed on the curb which have extremely high directivity, may cause detection of the object reflected in the mirror rather than the mirror itself. - Misrecognition of the objects with high reflectivity above as vehicles	An object in front of the object obscures part of it		Misrecognition of reflected objects	An object in front of a target obscures part of it	- The boundary between object and background is unclear - Background is incorrectly recognized as target
	Principle	-Undesired signal increasing	-No signal (partial)		-Multiple reflection (Recognition)	No signal (partial)		-Reflection -Signal changing	-No signal (partial) -Signal changing	-Low D/U (Recognition)

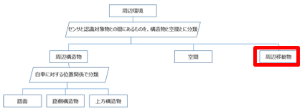
Table 10 Disturbance factors in category “e. Space”

e **Space**

		Millimeter waves		LiDAR		Camera	
	Class.	Spatial obstacles	Radio wave and light in space	Spatial obstacles	Radio wave and light in space	Spatial obstacles	Radio wave and light in space
Influence on sensor principle	Influence	- Due to weaker receiving signal, the max detection distance decreases - Partial or complete loss of FOV due to flying objects - Misrecognition of flying object as target	- Noise floor rising due to radio wave interference - Misrecognition of interference signal as reflection from target	Confirm impact of spatial obstacles caused by weather. Rain is an obstacle in the light path, therefore ranging performance will deteriorate due to reduced reflected light.	- Blocked up shadows due to west sun, backlight, etc. - Noise increase due to increase in background light - Pulse noise by LiDAR of other vehicles	- Objects in short distance are lost because of spatial obstacles as noise. - Target is hidden by obstacles - Misrecognition of flying objects as vehicles or pedestrians - Recognition rate drops due to lower contrast in case of rain or snow.	- In twilight or dusk environment, insufficient light causes recognition ability degradation. - Blown out highlights occur when the light source is strong locally - Blocked up shadows due to west sun, backlight, etc. - Target color changes due to light source color - Target contrast reduces due to light source - Flare and smear caused by strong light source (backlight)
	Principle	-No signal (partial) -Low S/N -Undesired signal increasing	-Low D/U -Undesired signal increasing	-Signal intensity lowering -No signal by obstacle -Signal from other object by reflection or refraction	-Noise such as DC type -Noise such as Pulse type (Recognition)	-No signal (partial) -Signal changing -Low D/U -Low S/N -(Recognition)	Low signal intensity High signal intensity Signal intensity increasing Signal changing Low D/U Low S/N

Table 11 Disturbance factors in category “f. Surrounding Moving Objects”

f **Moving Object**



		Millimeter waves			LiDAR			Camera		
	Class.	Reflection	Screen	Background	Reflection	Screen	Background	Reflection	Screen	Background
Influence on sensor principle	Influence	- Ghost caused by grating, harmonic, phase noise or side lobe - Decrease in accuracy of reflected signal around strong reflection	Blind spot by surrounding vehicles		- False points occur due to surface reflection	Blind spot by surrounding vehicles		Recognition rate reduction depending on paint reflection - Misrecognition due to mirror-finished coating	Blind spot by surrounding vehicles	Recognition rate drops due to protective colour same as surroundings
	Principle	-Grating reflection -High frequency -Low D/U -Undesired signal intensity increasing			-Reflection -Multiple reflection (Reflection)			-Reflection -Signal changing		-Low D/U (recognition)

3.4.2.2.3. Perception-Disturbance Factors: Sensor Perception Targets

Perception-disturbance factors classified under “sensor perception targets” are broadly grouped, according to the type of information to be recognized, into the following four categories (Figure 34).

(g) Lane(Roadway)
(h) Traffic information
(j) On-road obstacles
(k) Moving objects

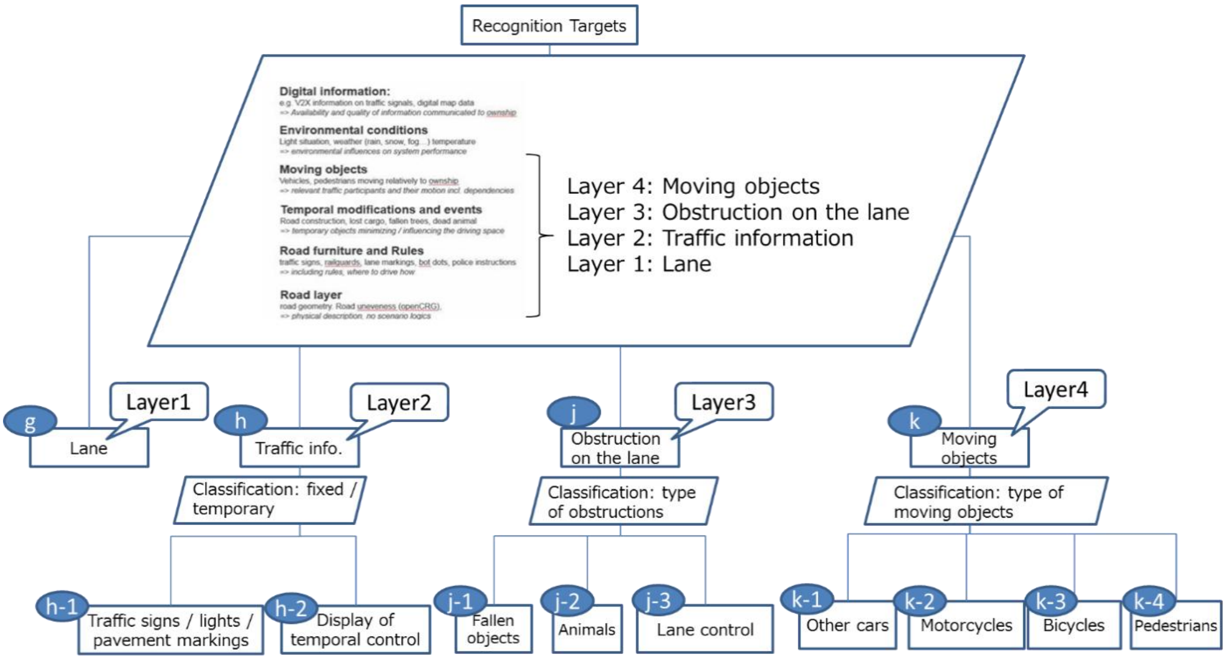


Figure 34. Classification of Sensor Perception Targets

(g) Lane (Roadway)

In Figure 34, the category (g) Lane is classified based on the structures that indicate the presence of a roadway. It is subdivided into the following elements (Figure 35):

(g-1) Lane markings
(g-2) Elevated structures
Road edges

Road edges are further subdivided depending on whether a height difference (step) is present:

(g-3) Road edges without a height difference
(g-4) Road edges with a height difference.

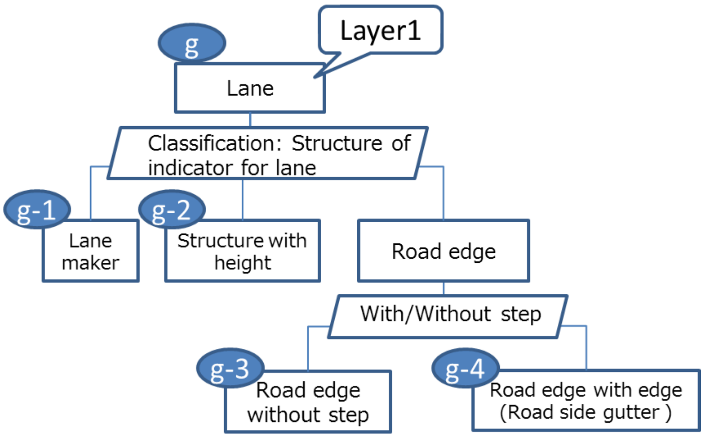


Figure 35. Classification of "g. Roadway"

(h) Traffic Information

In Figure 34, the category (h) Traffic information is classified according to the form in which information is presented to road users. It is subdivided into the following elements (Figure 36):

(h-1) Traffic signals
(h-2) Traffic signs
(h-3) Road-surface markings

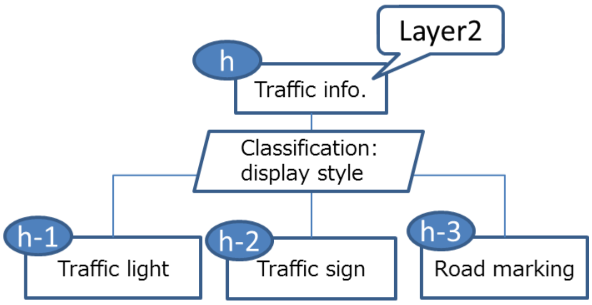


Figure 36. Classification of "h. Traffic Information"

(j) On-Road Obstacles

In Figure 34, the category (j) On-road obstacles is classified based on whether the object is stationary or moving and on the severity of impact in the event of a collision with a vehicle. It is subdivided into the following elements (Figure 37):

(j-1) Fallen objects
(j-2) Animals
(j-3) Installed (fixed) objects

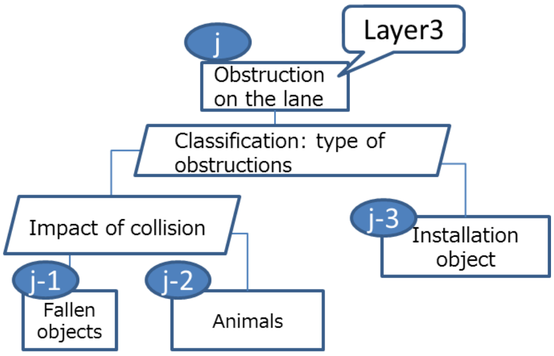


Figure 37. Classification of "j. On-Road Obstacles"

(k) Moving Objects

In Figure 34, the category (k) Moving objects is classified according to the type of traffic participant. It is subdivided into the following elements (Figure 38):

(k-1) Other vehicles
(k-2) Motorcycles
(k-3) Cyclists
(k-4) Pedestrians

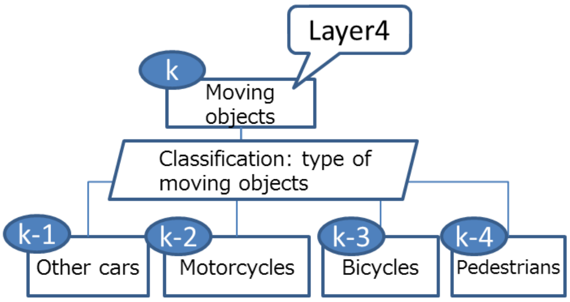


Figure 38. Classification of "k. Moving Objects"

The detailed classifications of the perception-disturbance factors assigned to categories (g-1) through (k-4) are presented in Table 12 through Table 25.
For each category, these tables describe the detailed disturbance factors, their impacts on perception performance, and the underlying physical principles by which the disturbances are generated.

Table 12 Disturbance factors in category "g-1. Lane Markings"

g-1 Lane markers


Including Botts' Dots and Cat's-eye which can be crossed

		Millimeter waves	LiDAR				Camera			
Influence on sensor principle	Class.		Colors/materials	Shapes	Grime/worn	Relative position	Colors/materials	Shapes	Grime/worn	Relative position(*)
	Influence		･Lack of contrast with surrounding pavements ･Unknown reflection intensity	･Unknown shapes (thickness, intervals, appearance, etc.)	･Hidden ･Dirty / worn ･false positive for deleted lines	･shift of positions due to ego-vehicle's movement	･Lack of contrast with surrounding pavements ･Unknown brightness, chroma and color phase	･Unknown shapes (thickness, intervals, appearance, etc.)	･Hidden ･Dirty / worn ･false positive for deleted lines	･Image deletion during driving ･Distortion
	Principle		Recognition process	Recognition process	Low intensity No signal due to masking	Position change of FOV Recognition process	Low D/U (Recognition process)	(Recognition process)	No signal (partial) Low S/N	Blurred image (Recognition process)

Table 13 Disturbance factors in category "g-2. Elevated Structures"

g-2 Structure with height


crash barriers, poles, noise barriers, curbstones, trees, cat's-eyes, etc.

		Millimeter waves				LiDAR				Camera			
Influence on sensor principle	Class.	Colors/materials	Shapes	Grime	Relative position	Colors/materials	Shapes	Grime	Relative position	Colors/materials	Shapes	Grime	Relative position
	Influence	･Lowering of reflection intensity depending on a material	･Lowering or increasing of reflection intensity depending on shape, size and direction	･Lowering of reflection intensity	･Lowering of intensity around the edges of FOV	･Lowering or increasing of reflection intensity depending on a material	･Lowering or increasing of reflection intensity depending on shape, size and direction	･Lowering of reflection intensity	･shift of positions due to ego-vehicle's movement	･Lack of contrast with the background ･Poor perception due to pictures or patterns on the walls	･Poor perception due to unknown shapes	･False positive for grime or patterns as targets	･Image deletion during driving ･Distortion
	Principle	Low S/N	Aliasing Harmonic Large difference of intensity Low D/U Low S/N	Low S/N	Low S/N	Low S intensity High S intensity	Low S intensity High S intensity	Low S intensity	Position change of FOV Recognition process	Low D/U (Recognition process)	Low S/N (Recognition process)	Low S/N	Blurred image (Recognition process)

Table 14 Disturbance factors in category "g-3. Road Edges without Height Difference"

g-3 Road edges without a step


Break of a road, etc.

		Millimeter waves				LiDAR				Camera			
Influence on sensor principle	Class.	Colors/materials	Shapes	Grime	Relative position	Colors/materials	Shapes	Grime	Relative position	Colors/materials	Shapes	Grime	Relative position
	Influence	･Lowering of reflection intensity depending on a material	･Lowering of reflection intensity depending on shape, size and direction	･Lowering of reflection intensity	･Lowering of intensity around the edges of FOV	･False positive for road surface with difference of reflection intensity as road edges	･Lowering of reflection intensity depending on shape, size and direction	･Poor perception due to masking by accumulated snow and fallen leaves	･shift of positions due to ego-vehicle's movement	･False positive for road surface with a different color as road edges	･Unknown road shape out of the lane	･Poor perception due to masking by accumulated snow and fallen leaves	･Image deletion during driving ･Distortion
	Principle	Low S/N	Low S/N	Low S/N	Low S/N	Recognition process	Low S	Low S No signals (partial)	Position change of FOV Recognition process	Low D/U (Recognition process)	Low S/N (Recognition process)	No signals (partial)	Blurred image (Recognition process)

Table 15 Disturbance factors in category “g-4. Road Edges with Height Difference”

g-4 Road edges with a step

Gutters, etc.

		Millimeter waves				LiDAR				Camera			
Influence on sensor principle	Class.	Colors/materials	Shapes	Grime	Relative position	Colors/materials	Shapes	Grime	Relative position	Colors/materials	Shapes	Grime	Relative position
	Influence	・Lowering of reflection intensity depending on a material	・Lowering of reflection intensity depending on shape, size and direction	・Lowering of reflection intensity	・Lowering of intensity around the edges of FOV	・Lowering of reflection intensity depending on a material	・Lowering or increasing of reflection intensity depending on shape, size and direction	・Lowering of reflection intensity	・shift of positions due to ego-vehicle’s movement	・Lack of contrast at the road edge area	・poor detection due to too small gutter width ・Unknown road shapes out of the lane	・Poor perception due to masking by accumulated snow and fallen leaves	・Image deletion during driving ・Distortion
	Principle	Low S/N	Low S/N	Low S/N	Low S/N	Low S	Low S High S	Low S	Position change of FOV Recognition process	Low D/U (Recognition process)	Low D/U (Recognition process)	No signals (partial)	Blurred image (Recognition process)

Table 16 Disturbance factors in category “h-1. Traffic Signals”

h-1 Traffic lights

		Millimeter waves	LiDAR	Camera				
Influence on sensor principle	Class.			Colors/materials	Shapes	Light source	Grime	Relative position
	Influence			・Unknown brightness, chroma and color phase	・Poor perception due to whether portrait of landscape ・Poor perception due to difference of light sizes ・False positives for lights with hoods	・Poor perception due to flicker ・Poor perception due to directional quality of lights	・Poor detection due to masking by snow, etc.	・Miss recognition due to directional quality of lights ・No perception due to FOV ・No perception due to direction and lens distortion ・Recognition of different lights due to direction
	Principle			(Recognition process)	(Recognition process)	Flicker Low S/N	No signal (partial)	Low S/N No signal (partial) (Recognition process)

Table 17 Disturbance factors in category “h-2. Traffic Signs”

h-2 Traffic sign

		Millimeter waves	LiDAR	Camera				
Influence on sensor principle	Class.			Colors/materials	Shapes	Light source	Grime	Relative position
	Influence			・Recognition failure due to insufficient contrast with the surrounding road surface ・Detection / recognition failure due to unexpected brightness / coloring / saturation / hue	・Misrecognition of letters and numbers with similar shapes ・Misrecognition due to different shape of sign for each country	・Electric sign recognition failure due to flicker or lack of partial image	・Misrecognition due to lack of image or image interference with faintness or stains	・Recognition failure due to image flow ・Recognition failure due to shape change with orientation ・Recognize other signs because of their location
	Principle			Low D/U (Recognition process)	(Recognition process)	Flicker	Low S/N	Blurred Image No signal (partial) (Recognition process)

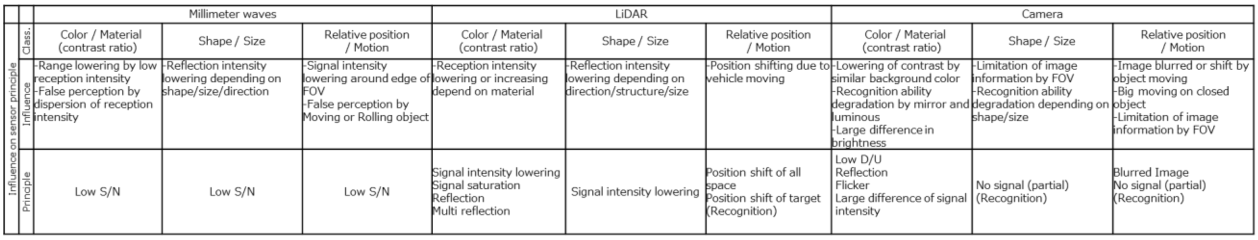
Table 18 Disturbance factors in category “h-3. Road Surface Markings”

h-3 Road marking

		Millimeter waves	LiDAR	Camera			
Influence on sensor principle	Class.			Colors/materials	Shapes	Grime	Relative position
	Influence			・Recognition failure due to insufficient contrast with the surrounding road surface ・Detection / recognition failure due to unexpected brightness / coloring / saturation / hue	・Detection / recognition failure due to unexpected shape of lane (Unknown display, width, space)	・Obstacle objects cannot be imaged and are not recognized ・Misrecognition due to faintness or dirt ・Misrecognition of erased lane	・Recognition failure due to image flow
	Principle			Low D/U (Recognition process)	(Recognition process)	No signal (partial) Low S/N	Blurred Image No signal (partial) (Recognition process)

Table 19 Disturbance factors in category “j-1. Fallen Objects”

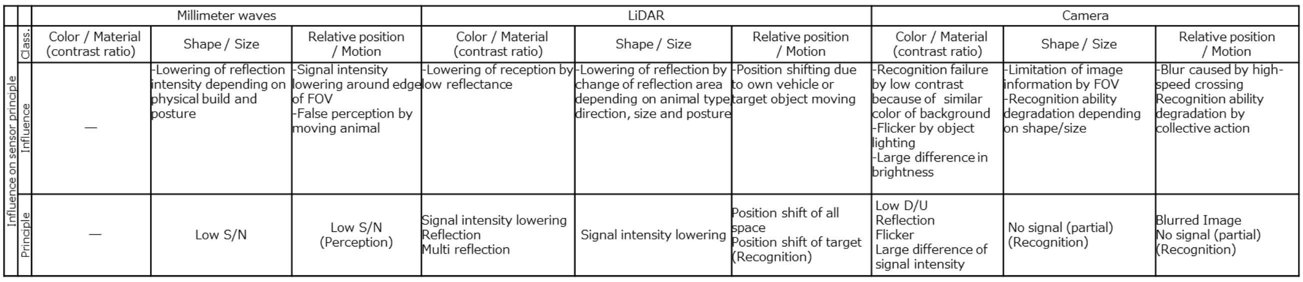
j-1 Fallen objects



		Millimeter waves			LiDAR			Camera		
Influence on sensor principle	Class.	Color / Material (contrast ratio)	Shape / Size	Relative position / Motion	Color / Material (contrast ratio)	Shape / Size	Relative position / Motion	Color / Material (contrast ratio)	Shape / Size	Relative position / Motion
	Influence	-Range lowering by low reception intensity -False perception by dispersion of reception intensity	-Reflection intensity lowering depending on shape/size/direction	-Signal intensity lowering around edge of FOV -False perception by Moving or Rolling object	-Reception intensity lowering or increasing depend on material	-Reflection intensity lowering depending on direction/structure/size	-Position shifting due to vehicle moving	-Lowering of contrast by similar background color -Recognition ability degradation by mirror and luminous -Large difference in brightness	-Limitation of image information by FOV -Recognition ability degradation depending on shape/size	-Image blurred or shift by object moving -Big moving on closed object -Limitation of image information by FOV
	Principle	Low S/N	Low S/N	Low S/N	Signal intensity lowering Signal saturation Reflection Multi reflection	Signal intensity lowering	Position shift of all space Position shift of target (Recognition)	Low D/U Reflection Flicker Large difference of signal intensity	No signal (partial) (Recognition)	Blurred Image No signal (partial) (Recognition)

Table 20 Disturbance factors in category “j-2. Animals”

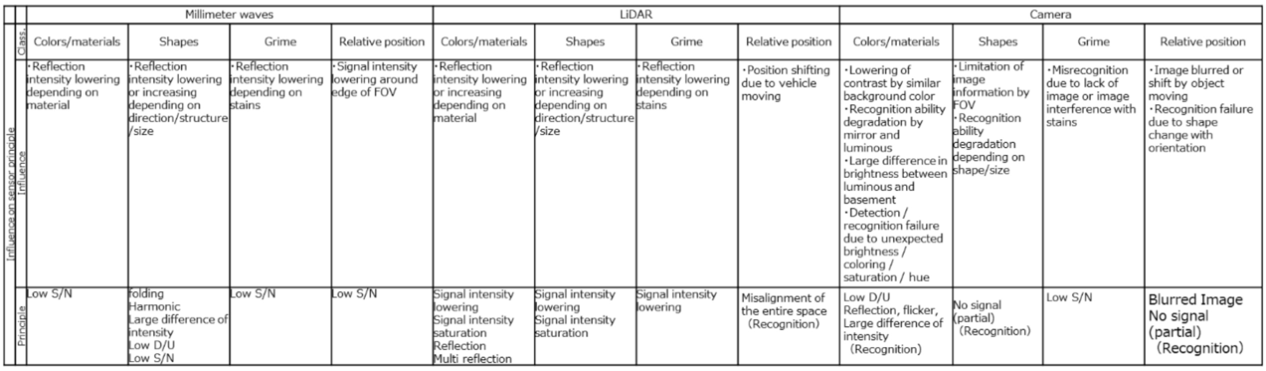
j-2 Animals



		Millimeter waves			LiDAR			Camera		
Influence on sensor principle	Class.	Color / Material (contrast ratio)	Shape / Size	Relative position / Motion	Color / Material (contrast ratio)	Shape / Size	Relative position / Motion	Color / Material (contrast ratio)	Shape / Size	Relative position / Motion
	Influence	—	-Lowering of reflection intensity depending on physical build and posture	-Signal intensity lowering around edge of FOV -False perception by moving animal	-Lowering of reception by low reflectance	-Lowering of reflection by change of reflection area depending on animal type direction, size and posture	-Position shifting due to own vehicle or target object moving	-Recognition failure by low contrast because of similar color of background -Flicker by object lighting -Large difference in brightness	-Limitation of image information by FOV -Recognition ability degradation depending on shape/size	-Blur caused by high-speed crossing Recognition ability degradation by collective action
	Principle	—	Low S/N	Low S/N (Perception)	Signal intensity lowering Reflection Multi reflection	Signal intensity lowering	Position shift of all space Position shift of target (Recognition)	Low D/U Reflection Flicker Large difference of signal intensity	No signal (partial) (Recognition)	Blurred Image No signal (partial) (Recognition)

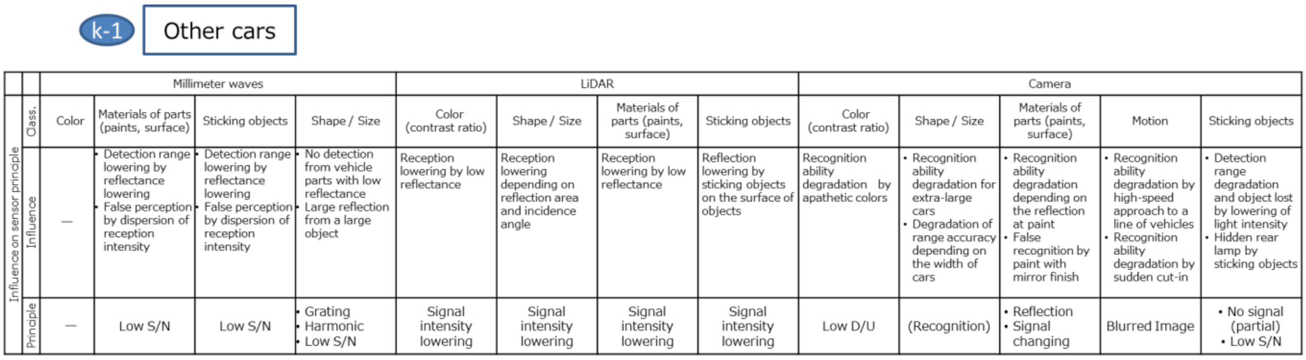
Table 21 Disturbance factors in category “j-3. Installed Objects”

j-3 Installation object



		Millimeter waves				LiDAR				Camera			
Influence on sensor principle	Class.	Colors/materials	Shapes	Grime	Relative position	Colors/materials	Shapes	Grime	Relative position	Colors/materials	Shapes	Grime	Relative position
	Influence	・Reflection intensity lowering depending on material	・Reflection intensity lowering or increasing depending on direction/structure /size	・Reflection intensity lowering depending on stains	・Signal intensity lowering around edge of FOV	・Reflection intensity lowering or increasing depending on material	・Reflection intensity lowering or increasing depending on direction/structure /size	・Reflection intensity lowering depending on stains	・Position shifting due to vehicle moving	・Lowering of contrast by similar background color ・Recognition ability degradation by mirror and luminous ・Large difference in brightness between luminous and basement ・Detection / recognition failure due to unexpected brightness / coloring / saturation / hue	・Limitation of image information by FOV ・Recognition ability degradation depending on shape/size	・Misrecognition due to lack of image or image interference with stains	・Image blurred or shift by object moving ・Recognition failure due to shape change with orientation
	Principle	Low S/N	folding Harmonic Large difference of intensity Low D/U Low S/N	Low S/N	Low S/N	Signal intensity lowering Signal intensity saturation Reflection Multi reflection	Signal intensity lowering Signal intensity saturation	Signal intensity lowering	Misalignment of the entire space (Recognition)	Low D/U Reflection, flicker, Large difference of intensity (Recognition)	No signal (partial) (Recognition)	Low S/N	Blurred Image No signal (partial) (Recognition)

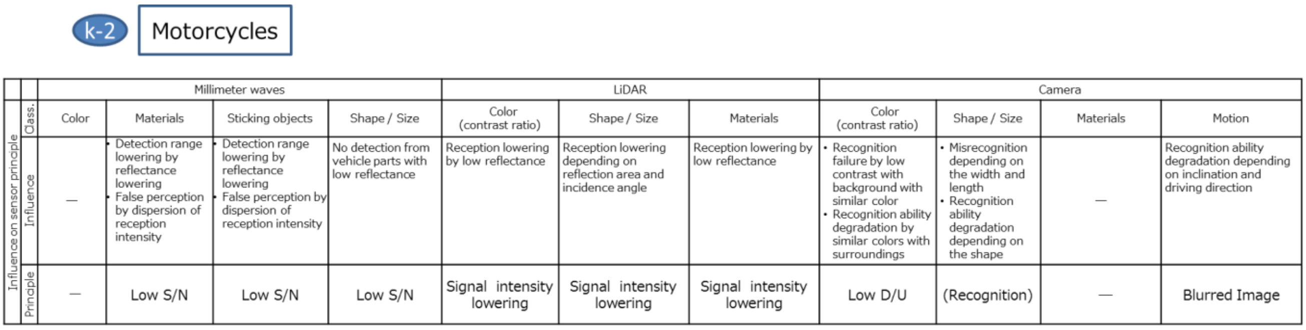
Table 22 Disturbance factors in category “k-1. Other Vehicles”



k-1 Other cars

		Millimeter waves				LiDAR				Camera				
Influence on sensor principle	Class.	Color	Materials of parts (paints, surface)	Sticking objects	Shape / Size	Color (contrast ratio)	Shape / Size	Materials of parts (paints, surface)	Sticking objects	Color (contrast ratio)	Shape / Size	Materials of parts (paints, surface)	Motion	Sticking objects
	Influence	—	• Detection range lowering by reflectance lowering • False perception by dispersion of reception intensity	• Detection range lowering by reflectance lowering • False perception by dispersion of reception intensity	• No detection from vehicle parts with low reflectance • Large reflection from a large object	Reception lowering by low reflectance	Reception lowering depending on reflection area and incidence angle	Reception lowering by low reflectance	Reflection lowering by sticking objects on the surface of objects	Recognition ability degradation by apathetic colors	• Recognition ability degradation for extra-large cars • Degradation of range accuracy depending on the width of cars	• Recognition ability degradation depending on the reflection at paint • False recognition by paint with mirror finish	• Recognition ability degradation by high-speed approach to a line of vehicles • Recognition ability degradation by sudden cut-in	• Detection range degradation and object lost by lowering of light intensity • Hidden rear lamp by sticking objects
	Principle	—	Low S/N	Low S/N	• Grating • Harmonic • Low S/N	Signal intensity lowering	Signal intensity lowering	Signal intensity lowering	Signal intensity lowering	Low D/U	(Recognition)	• Reflection • Signal changing	Blurred Image	• No signal (partial) • Low S/N

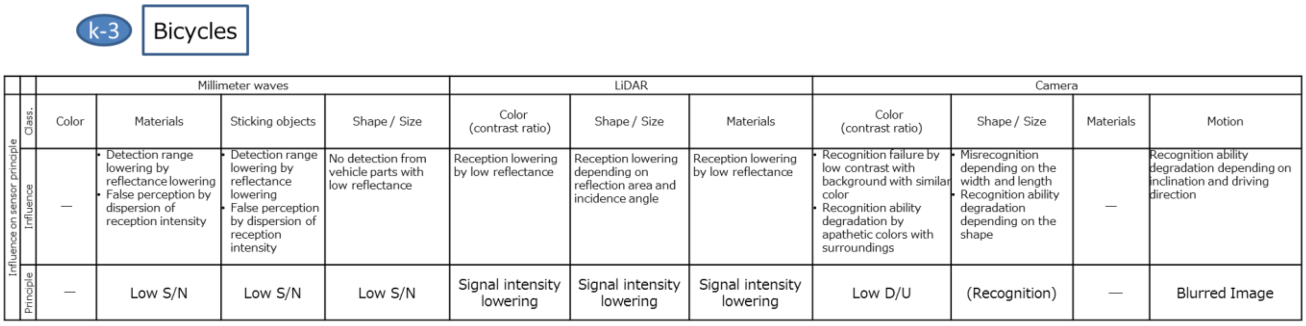
Table 23 Disturbance factors in category “k-2. Motorcycles”



k-2 Motorcycles

		Millimeter waves				LiDAR			Camera			
Influence on sensor principle	Class.	Color	Materials	Sticking objects	Shape / Size	Color (contrast ratio)	Shape / Size	Materials	Color (contrast ratio)	Shape / Size	Materials	Motion
	Influence	—	• Detection range lowering by reflectance lowering • False perception by dispersion of reception intensity	• Detection range lowering by reflectance lowering • False perception by dispersion of reception intensity	No detection from vehicle parts with low reflectance	Reception lowering by low reflectance	Reception lowering depending on reflection area and incidence angle	Reception lowering by low reflectance	• Recognition failure by low contrast with background with similar color • Recognition ability degradation by similar colors with surroundings	• Misrecognition depending on the width and length • Recognition ability degradation depending on the shape	—	Recognition ability degradation depending on inclination and driving direction
	Principle	—	Low S/N	Low S/N	Low S/N	Signal intensity lowering	Signal intensity lowering	Signal intensity lowering	Low D/U	(Recognition)	—	Blurred Image

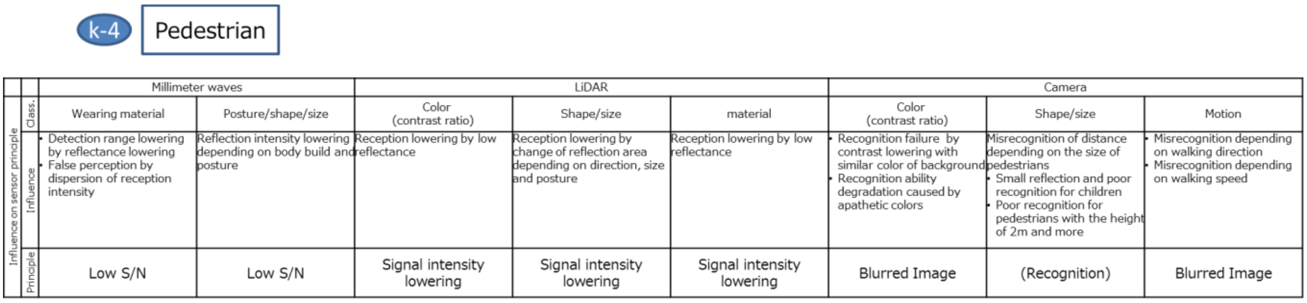
Table 24 Disturbance factors in category “k-3. Cyclist”



k-3 Bicycles

		Millimeter waves				LiDAR			Camera			
Influence on sensor principle	Class.	Color	Materials	Sticking objects	Shape / Size	Color (contrast ratio)	Shape / Size	Materials	Color (contrast ratio)	Shape / Size	Materials	Motion
	Influence	—	• Detection range lowering by reflectance lowering • False perception by dispersion of reception intensity	• Detection range lowering by reflectance lowering • False perception by dispersion of reception intensity	No detection from vehicle parts with low reflectance	Reception lowering by low reflectance	Reception lowering depending on reflection area and incidence angle	Reception lowering by low reflectance	• Recognition failure by low contrast with background with similar color • Recognition ability degradation by apathetic colors with surroundings	• Misrecognition depending on the width and length • Recognition ability degradation depending on the shape	—	Recognition ability degradation depending on inclination and driving direction
	Principle	—	Low S/N	Low S/N	Low S/N	Signal intensity lowering	Signal intensity lowering	Signal intensity lowering	Low D/U	(Recognition)	—	Blurred Image

Table 25 Disturbance factors in category “k-4. Pedestrians”



k-4 Pedestrian

		Millimeter waves		LiDAR			Camera		
Influence on sensor principle	Class.	Wearing material	Posture/shape/size	Color (contrast ratio)	Shape/size	material	Color (contrast ratio)	Shape/size	Motion
	Influence	• Detection range lowering by reflectance lowering • False perception by dispersion of reception intensity	Reflection intensity lowering depending on body build and posture	Reception lowering by low reflectance	Reception lowering by change of reflection area depending on direction, size and posture	Reception lowering by low reflectance	• Recognition failure by contrast lowering with similar color of background • Recognition ability degradation caused by apathetic colors	Misrecognition of distance depending on the size of pedestrians • Small reflection and poor recognition for children • Poor recognition for pedestrians with the height of 2m and more	• Misrecognition depending on walking direction • Misrecognition depending on walking speed
	Principle	Low S/N	Low S/N	Signal intensity lowering	Signal intensity lowering	Signal intensity lowering	Blurred Image	(Recognition)	Blurred Image

3.4.2.3. Principles of Sensor Perception Disturbance Generation

When a sensor recognizes an object, perception disturbances may arise due to the factors described in the previous section. Although the underlying mechanisms of these disturbances differ depending on the sensor type, they can be organized using a common conceptual framework.

In this framework, sensor perception disturbances are classified as follows:
- Disturbances arising in the sensing process,
  such as effects related to sensor orientation or signal acquisition;
- Disturbances arising in the perception-processing stage,
  in which raw sensor signals are processed to extract information; and
- Other disturbances,
  including factors that do not fall directly into the above categories.

Disturbances arising in the perception-processing stage are further classified into:
- disturbances related to the target signal (S) originating from the object to be perceived; and
- disturbances caused by interference with the target signal, such as noise (N) or undesired signals (U).

For each of the target signal S, noise N, and undesired signal U, all relevant disturbance mechanisms affecting the signal are systematically identified and enumerated..

Based on this framework, examples of sensor-specific classifications of disturbance-generation principles are presented below.

- Principles of Perception Disturbance Generation in Millimeter-Wave Radar

  In millimeter-wave radar systems, perception disturbances may arise not only during sensing and perception processing, but also due to the orientation of the sensor itself (Figure 39).

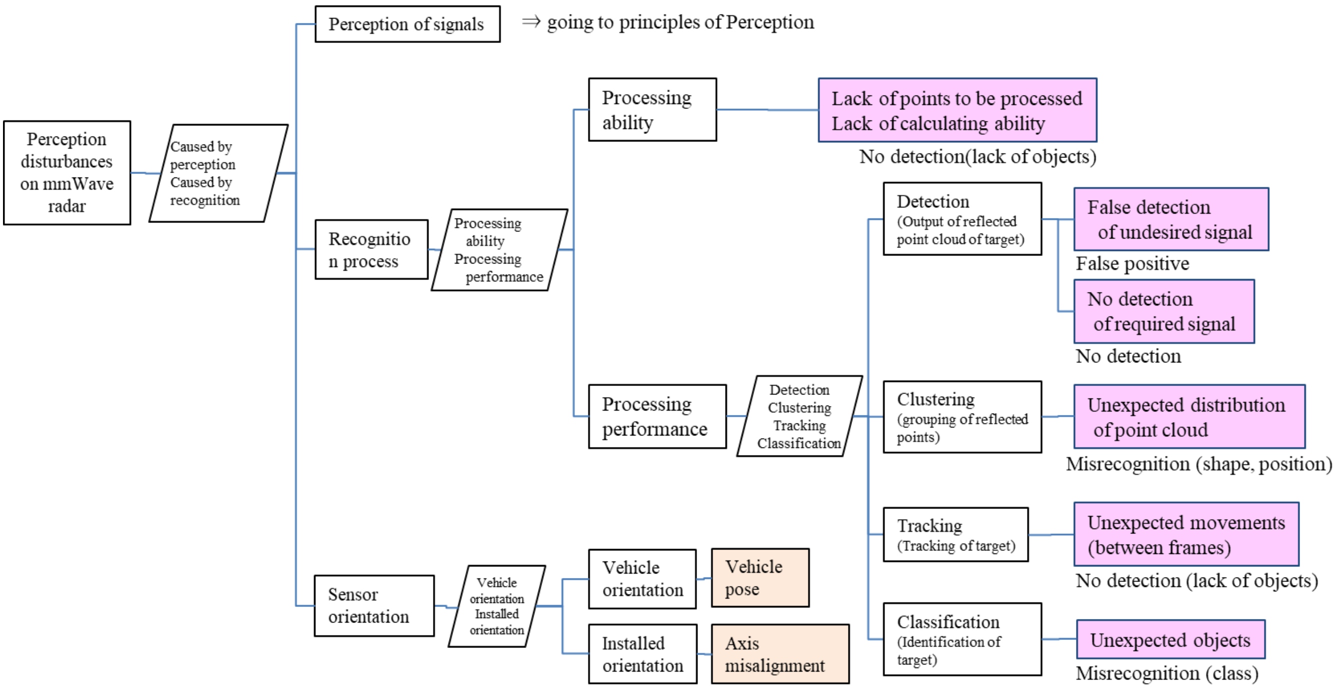


Figure 39. Classification of Perception Disturbances in Millimeter-Wave Radar

In radar perception processing, the physical quantities that characterize the target signal S are frequency, phase, and amplitude (intensity) (Figure 40).

- Frequency: Frequency-related disturbances include abnormalities in the transmitted or received signal frequency caused by sensor hardware characteristics or failures.

- Phase: Phase disturbances occur when the arrival direction of the signal changes or when the signal propagation delay varies. Changes in arrival direction are typically caused by reflection or refraction phenomena.

- Amplitude (intensity): Intensity-related disturbances include partial signal loss, excessively strong signals, large variations in signal strength, and signals that are too weak to be reliably detected.

With respect to noise (N) and undesired signals (U) in the perception-processing stage, potential disturbances include:
- low signal-to-noise ratio (S/N);
- low desired-to-undesired signal ratio (D/U), indicating increased interference; and
- increases in undesired signal components U.

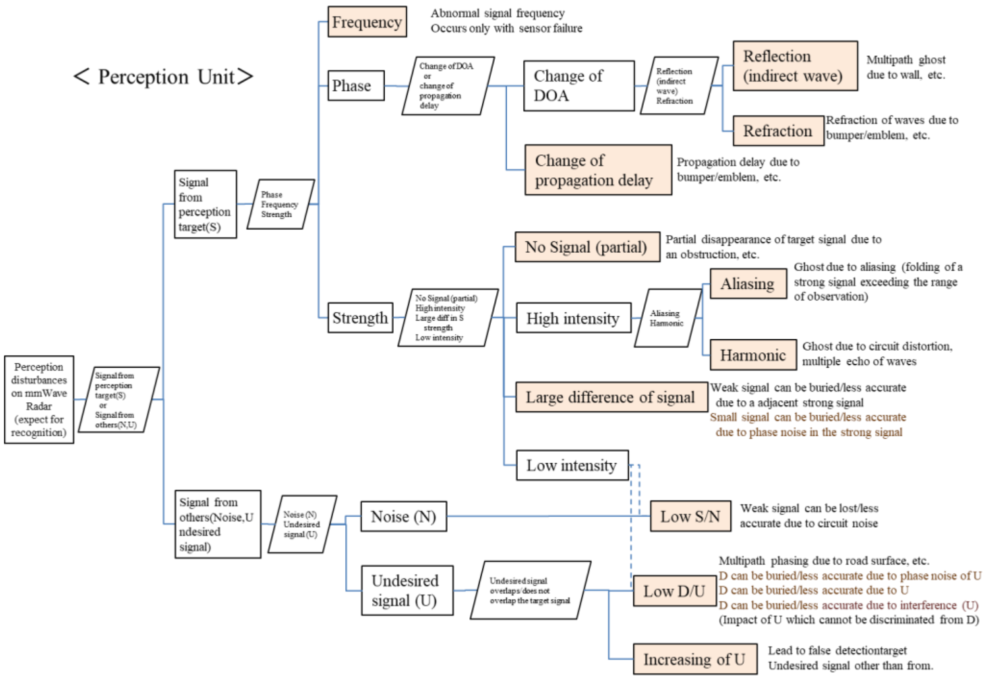


Figure 40. Principles of Disturbance Generation in Millimeter-Wave Radar Perception Processing

- Principles of Perception Disturbance Generation in LiDAR

In LiDAR systems, perception disturbances—similar to those observed in millimeter-wave radar—may arise not only during sensing and perception processing, but also due to the orientation of the sensor itself (Figure 41).

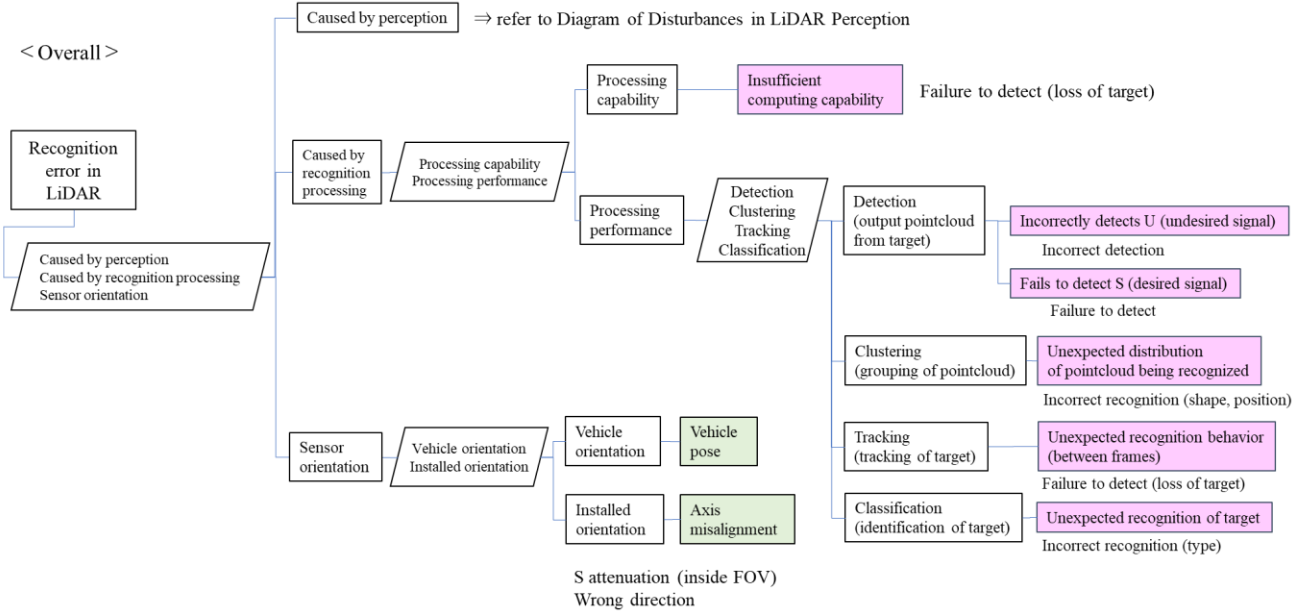


Figure 41. Classification of Perception Disturbances in LiDAR

In LiDAR perception processing, the physical quantities that characterize the target signal S include scan timing, intensity, propagation direction, and velocity.

- Scan timing: Differences in scan timing caused by ego-vehicle motion result in spatial misalignment of the entire scanned area. In contrast, timing differences caused by movement of the target object lead to positional offsets of that object within the point cloud.
- Intensity: Intensity-related disturbances include signal saturation, signal attenuation, and occlusion of the reflected signal.
- Propagation direction: Disturbances in propagation direction arise from reflection or refraction of the emitted laser beam.
- Velocity: Although target velocity affects the time of arrival of reflected signals, it is not treated as a disturbance factor in LiDAR perception.

With respect to noise (N) and undesired signals (U), perception disturbances may include DC-type noise, pulsed noise, and multiple reflections, as well as reflections and refractions from objects other than the intended perception target (Figure 42).

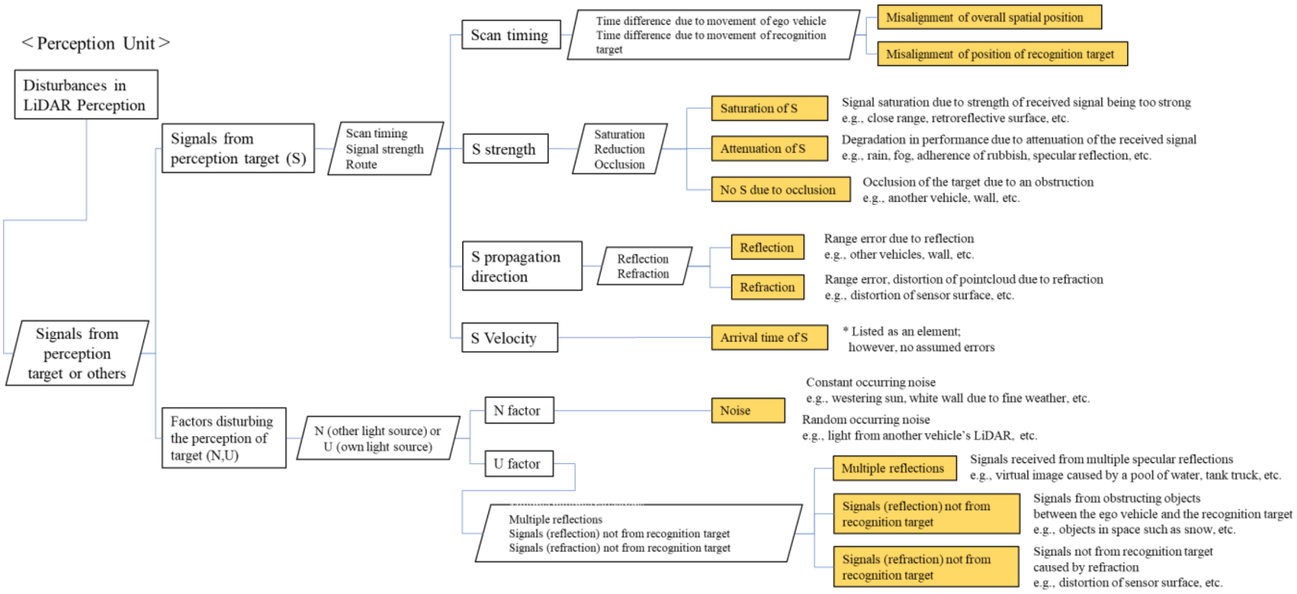
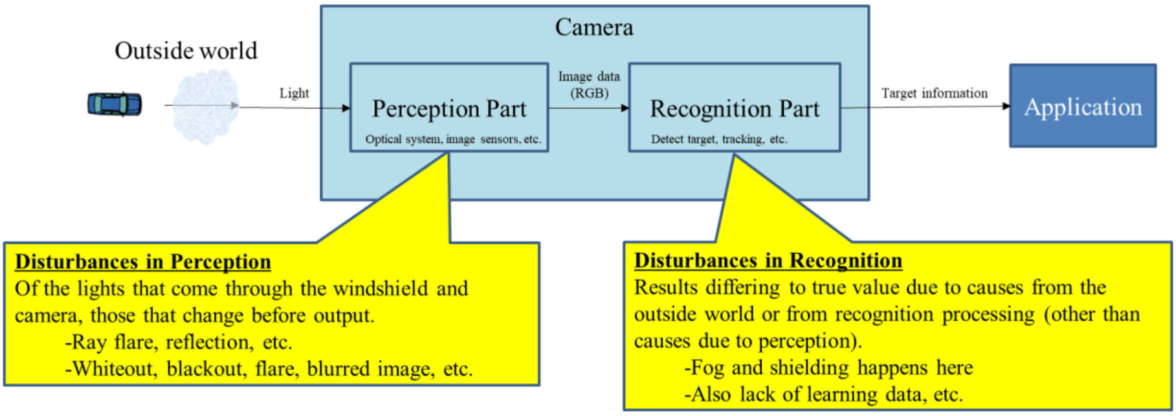


Figure 42. Principles of Disturbance Generation in LiDAR Perception Processing

- Principles of Perception Disturbance Generation in Cameras

In camera-based perception, disturbance mechanisms are classified by focusing on the signal-processing workflow. Phenomena related to the physical properties of light within optical components are categorized under “optical system,” noise-related phenomena are categorized under “image sensor,” and phenomena related to color representation and processing are categorized under “image processing.”
Similarly, disturbances occurring within the image sensor itself are classified according to the sensor-processing stages, namely exposure-time control, charge accumulation, and analog-to-digital (A/D) conversion (Figure 43).



Disturbances in Perception
Of the lights that come through the windshield and camera, those that change before output.
-Ray flare, reflection, etc.
-Whiteout, blackout, flare, blurred image, etc.

Disturbances in Recognition
Results differing to true value due to causes from the outside world or from recognition processing (other than causes due to perception).
-Fog and shielding happens here
-Also lack of learning data, etc.

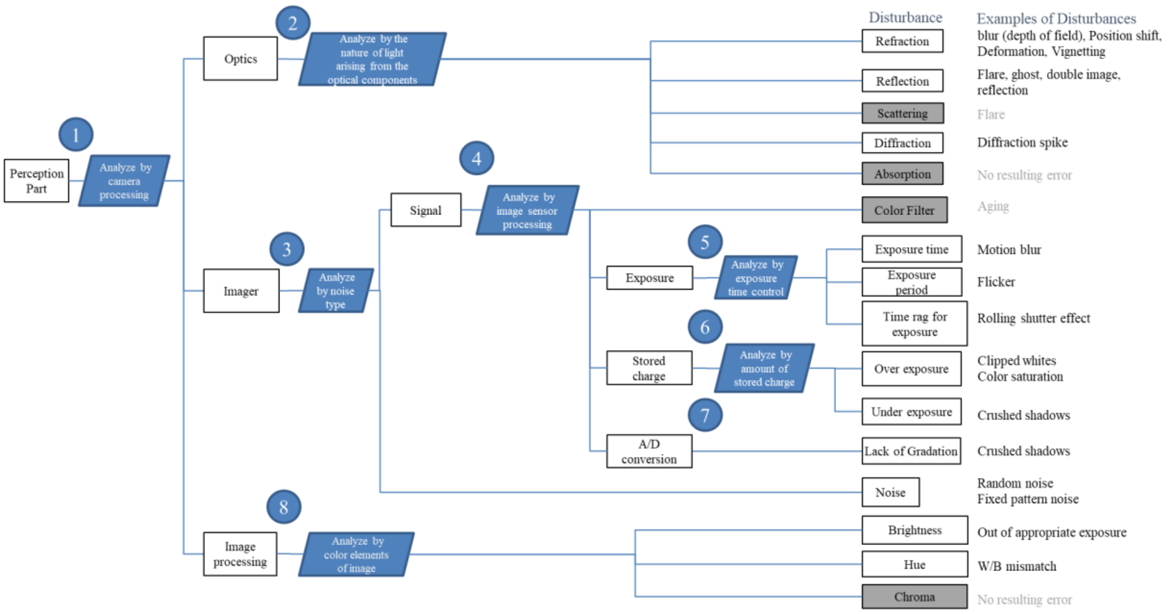


Figure 43. Principles of Disturbance Generation in Camera perception

In addition to sensor-level processing, disturbances in camera-based perception can also be classified by focusing on the perception-processing workflow. From this perspective, disturbances are categorized according to the following processing stages: “feature extraction,” “classification,” “position estimation,” and “tracking” (Figure 44).

This workflow-based classification enables systematic identification of perception disturbances arising at different stages of camera-based perception, from optical input to higher-level interpretation of visual information.

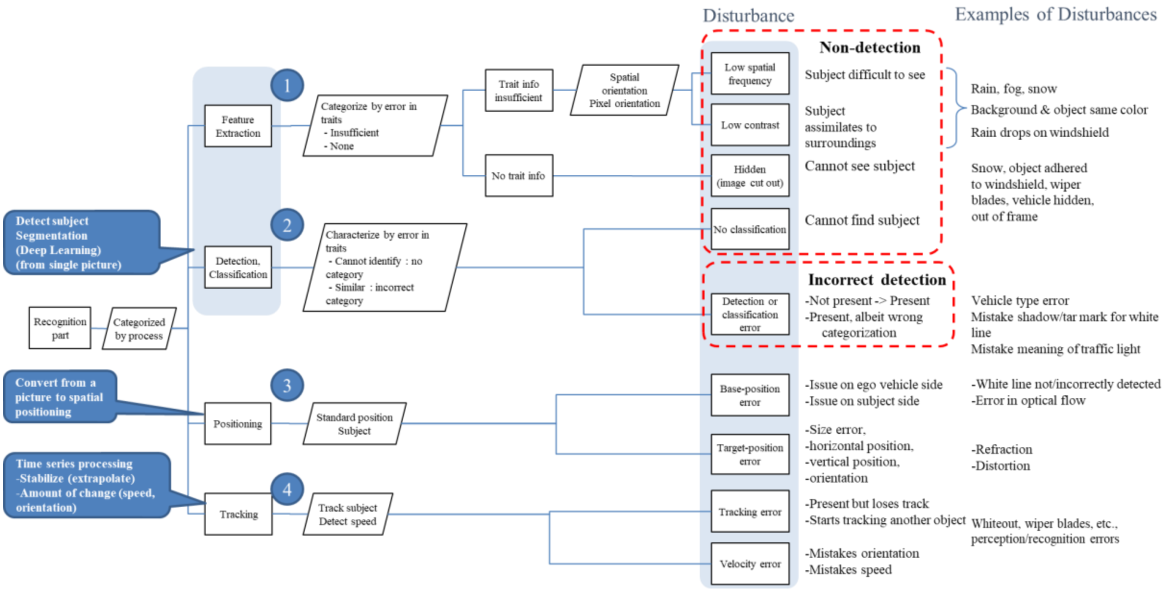


Figure 44. Principles of Disturbance Generation in Camera-Based Perception

3.4.2.4. Scenario Selection Through Cross-Checking of Perception-Disturbance elements and Disturbance-Generation Principle

The relationships between perception-disturbance elements and disturbance-generation principles for each sensor, as described above, can be represented in a matrix form, as shown in Table 26 through Table 30. In these matrices, perception-disturbance elements are arranged along the vertical axis, while disturbance-generation principles are arranged along the horizontal axis. This representation enables identification, for each disturbance-generation principle (i.e., each column), of the corresponding perception-disturbance elements (i.e., rows) that may give rise to that principle. When multiple disturbance elements correspond to the same principle within a given column, they are regarded as interchangeable, as they originate from the same underlying physical mechanism. However, because the parameter ranges associated with these factors may differ, safety evaluation requires selection of disturbance elements whose parameter ranges sufficiently cover the Operational Design Domain (ODD) of the system under evaluation. In this manner, the selected factors are required to represent conditions that are equivalent to or more severe than those expected within the ODD.

When multiple candidate elements are applicable, one or more factors are selected as evaluation targets by additionally considering the reproducibility of the evaluation environment for the corresponding scenarios. Furthermore, depending on the specifications of the ADS under evaluation—such as its defined ODD or the types of objects it is designed to recognize— certain disturbance elements listed along the vertical axis may not be relevant for a given sensor. In such cases, those factors are excluded, and representative scenarios are selected from among the remaining applicable elements.

Table 26 Matrix of Perception-Disturbance Elements and Disturbance-Generation Principles for Millimeter-Wave Radar

Small impact △
Medium impact ○
Great impact ◎

Causal Factors of Perception Disturbances							Perception process																								Recognition process						number of items
							Signal from perception target (S)							Signal from others																	Processing ability	Processing performance					
							Phase			Strength				Noise (N)				Undesired signal (U)														Detection (Output of reflected point cloud of target)		Clustering (grouping of reflected points)	Tracking (tracking of target)	Classification (Identification of target)	
							Change of DOA				High intensity			Low S/N				Low D/U						Increasing of U												
							Reflection (indirect wave)	Refraction	Change of propagation delay	No signal (partial)	Aliasing	Harmonic	Large differnce of signal	Low S/N (change of angle)	Low S/N (attenuation at the sensor surface)	Low S/N (attenuation in space)	Low S/N (low retroreflection)	Low D/U (change of angle)	Low D/U (road surface reflection)	Low D/U (surrounding structures)	Low D/U (floating objects in space)	Low D/U (sensors on other cars)	Low D/U (sensors on ego cars)	Increasing of U (change of angle)	Increasing of U (road surface reflection)	Increasing of U (surrounding structures)	Increasing of U (floating objects in space)	Increasing of U (sensors on other cars)	Increasing of U (sensors on ego cars)	Lack of points to be processed Lack of calculating ability	False detection of undesired signal	No detection of required signal	Unexpected distribution of point cloud	Unexpected movements (between frames)	Unexpected objects	
Classification	Classification of Causal Factors					Variable Parameters / Items	diffuse reflectance, shape, position	refraction range, misalignment, failure of sensor itself	propagation delay range, misalignment, failure of sensor itself	shape, position	retroreflection coefficient, target position, failure of sensor itself	retroreflection coefficient, target position, failure of sensor itself	retroreflection coeffieicent(RCS), 3D shape, target combination, relative position	change of angle, change of vehicle posture, road gradient, misalignment,	transmittivity, range, failure of sensor itseld	attenuation rate in space	retroreflection coeffieicent(RCS), 3D shape, target combination, relative position	change of angle, change of vehicle posture, road gradient, misalignment,	retroreflection coeffieicent, diffuse reflectance	retroreflection coefficient, target position	retroreflection coefficient, attenuation rate in space	type of sensors on other vehicle, position	type of sensors, mounting position, surrounding environment	change of angle, change of vehicle posture, road gradient, misalignment,	retroreflection coeffieicen	retroreflection coefficient, target position	retroreflection coeffieicen	type of sensors on other vehicle, position	type of sensors, mounting position, surrounding environment							
Vehicle motion	Car / Sensor		Ego vehicle	Change of vehicle posture	caused by vehicle situation (	lack of tire pressure, etc.							○				○						○							○	○	false positive, false negative	←	←	8
					caused by vehicle situation (	change of load distribution inside a car							○				○						○							○	○	false positive, false negative	←	←	8
Radar			Sensor	Failure of sensor itself	degradation of sensor surfac	(a level of fault detection failure)		△	△					△	○			△						△							○	○	false positive, false negative	←	←	6
					degradation of sensor itself	(a level of fault detection failure)			△		△	△		△				△						△							○	○	false positive, false negative	←	←	6
					Lowering of electric perfoem	(a level of fault detection failure)					△	△																			○	○	false positive, false negative	←	←	2
Mounted place / status				Variation in assenbly	misalignment (within adjust	(failure of misalignment detection)		○	○					△				△						△							○	○	false positive, false negative	←·○	←	5
					misalignment (out of adjust	(untill detection of misalignment)		◎	◎					○				○						○							○	○	false positive, false negative	←·○	←	5
Front surface of the sensor			Front surface of the sensor	Sticking objects	water x homogeneous										◎																	○	false negative	←	←	1
					water x SPOT (drop)			△	△						◎																○	○	false positive, false negative	←·○	←	3
					ice x even										○																	○	false negative	←	←	1
					ice x SPOT (ice grain)			◎	◎						△																○	○	false positive, false negative	←·○	←	3
					snow x even (ex. after blizard)										◎																	○	false negative	←	←	1
					snow x SPOT (snow grain)			○	○						○																○	○	false positive, false negative	←·○	←	3
					dry clay/dirt x even										○																	○	false negative	←	←	1
					dry clay/dirt x SPOT			△	△						△																○	○	false positive, false negative	←·○	←	3
					wet clay/dirt x even										○																	○	false negative	←	←	1
					wet clay/dirt x SPOT			△	△						△																○	○	false positive, false negative	←·○	←	3
					car washing wax x even										○																	○	false negative	←	←	1
					car washing wax x SPOT			△	△						△																○	○	false positive, false negative	←·○	←	3
					foreign materials (bug, drop	sticking of uneven bugs on the surface		△	△						△																○	○	false positive, false negative	←·○	←	3
				Changes in characteristics	broken surface of the sensor	crack, etc.		△	△						△																○	○	false positive, false negative	←·○	←	3
					broken surface of the sensor	strain		○	○						○																○	○	false positive, false negative	←·○	←	3
					exchange of sensor surface (	(variability after aiming)		△	△						△																○	○	false positive, false negative	←·○	←	3
Propagation of radio wave in space			Space	Spatial obstacles	snow (a few)	lowering of visibility										△					△						△				○	○	false positive, false negative	←	←	3
					snow (a lot / blizard)	bad visibility										○					○						○				○	○	false positive, false negative	←	←	3
					snow (kicked up)	partially low visibility										○					○						○				○	○	false positive, false negative	←	←	3
					rain (a few)	lowering of visibility										△					△						△				○	○	false positive, false negative	←	←	3
					rain (a lot)	bad visibility										○					○						○				○	○	false positive, false negative	←	←	3
					rain (kicked up)	partially low visibility										○					○						○				○	○	false positive, false negative	←	←	3
					sand (a few)	lowering of visibility										△																○	false negative	←	←	1
					sand (a lot)	bad visibility										△																○	false negative	←	←	1
					sand (kicked up)	partially low visibility										○					○						○				○	○	false positive, false negative	←	←	3
					fog (a little)	lowering of visibility										△																○	false negative	←	←	1
					fog (dense)	bad visibility										△																○	false negative	←	←	1
					others	floating of kinds of seeds										△					○						○				○	○	false positive, false negative	←	←	3
					bugs (floating)	swarming over										○					○						○				○	○	false positive, false negative	←	←	3
				Radio wave and light in space	direct x other vehicle	other vehicle → ego vehicle																○						○			○	○	false positive, false negative	←	←	2
					diret x infrastructure	Orbis, etc.																													0
					direct x nature	the sun, etc.																													0
					diffracted wave x ego vehicl	diffraction of other sensors on the ego vehicle																	△						△		○	○	false positive, false negative	←	←	2
Environment / Target	Surrounding environments	Structural objects	Road surface	Shape	rising slope									○				○						○							○	○	false positive, false negative	←·○	←·○	3
					descending slope									○				○						○							○	○	false positive, false negative	←·○	←·○	3
					road with cant									○				○						○							○	○	false positive, false negative	←·○	←·○	3
				Road condition	puddle	difference of reflectance + concave region													○						○						○	○	false positive, false negative	←·○	←·○	2
					iced road	difference of reflectance + less bumps													△						△						○	○	false positive, false negative	←·○	←·○	2
					fixed road	lineally, after fixing of convex region													△						△						○	○	false positive, false negative	←·○	←·○	2
					rut	concave surface pararell to lane markers													○						○						○	○	false positive, false negative	←·○	←·○	2
					accumulated snow	difference of reflectance + a lot bumps													○						○						○	○	false positive, false negative	←·○	←·○	2
				Material	asphalt	default, less bumps													△						△						○	○	false positive, false negative	←·○	←·○	2
					concrete	difference of reflectance, middle level of bumps													△						△						○	○	false positive, false negative	←·○	←·○	2
					ballast	difference of reflectance, a lot of bumps													○						○						○	○	false positive, false negative	←·○	←·○	2
					sand	difference of reflectance, a lot of bumps													○						○						○	○	false positive, false negative	←·○	←·○	2
					thin layer	difference of reflectance,less bumps													△						△						○	○	false positive, false negative	←·○	←·○	2
					stone pavement	difference of reflectance, a lot of bumps													○						○						○	○	false positive, false negative	←·○	←·○	2
					maintainance hole	difference of reflectance, SPOT													◎						◎						○	○	false positive, false negative	←·○	←·○	2
					joint (metal)	difference of reflectance, SPOT													◎						◎						○	○	false positive, false negative	←·○	←·○	2
					joint (asphalt)	difference of reflectance, SPOT													○						○						○	○	false positive, false negative	←·○	←·○	2
			Roadside object	Reflection	crash barrier		○				○	○								○						○				○	○	○	false positive, false negative	←·○	←	5
					building		○				○	○								○						○				○	○	○	false positive, false negative	←·○	←	5
					ridge rail		△				◎	○								◎						◎					○	○	false positive, false negative	←·○	←	5
					road signage board						○	○								○						○					○	○	false positive, false negative	←·○	←	4
					noise barrier		◎				○	○								○						○					○	○	false positive, false negative	←·○	←	5
					rubber pole															△						△					○	○	false positive, false negative	←·○	←	2
					rope															△						△					○	○	false positive, false negative	←·○	←	2
					board		△				○	○								○						○					○	○	false positive, false negative	←·○	←	5
					roadside trees															△						△					○	○	false positive, false negative	←·○	←	2
					low trees															△						△					○	○	false positive, false negative	←·○	←	2
					grass															△						△					○	○	false positive, false negative	←·○	←	2
				Screen	building					◎																						○	false negative	←	←	1
					wall					◎																						○	false negative	←	←	1
					others					◎																						○	false negative	←	←	1
			Overhead object	Reflection	bridge															◎						◎				○	○	○	false positive, false negative	←·○	←·○	2
					tunnel															◎						◎				○	○	○	false positive, false negative	←·○	←·○	2
					building															◎						◎				○	○	○	false positive, false negative	←·○	←·○	2
					road signage board															◎						◎					○	○	false positive, false negative	←·○	←·○	2
					mirror															○						○					○	○	false positive, false negative	←·○	←·○	2
					board															◎						◎					○	○	false positive, false negative	←·○	←·○	2
					traffic light															○						○					○	○	false positive, false negative	←·○	←·○	2
				Screen	traffic light					◎																						○	false negative	←	←	1
					road signage board					◎																						○	false negative	←	←	1
					information board					◎																						○	false negative	←	←	1
		Surrounding moving objects		Reflection			◎				◎	◎								◎						◎					○	○	false positive, false negative	←	←	5
	Recognition targets	Lane	Structure with height	color, material									○				○															○	false negative	←·○	←	2
				shape	large reflection	large signal intensity					○	○	◎																		○	○	false positive, false negative	←·○	←	3
					small reflection	small signal intensity							◎				◎															○	false negative	←·○	←	2
				dirt									△				△															○	false negative	←·○	←	2
				relative position									○				○															○	false negative	←·○	←	2
			Road edge without step	color, material									○				○															○	false negative	←·○	←	2
				Shape									◎				◎															○	false negative	←·○	←	2
				dirt									△				△															○	false negative	←·○	←	2
				relative position									○				○															○	false negative	←·○	←	2
			Road edge with step	color, material									○				○															○	false negative	←·○	←	2
				Shape									◎				◎															○	false negative	←·○	←	2
				dirt									△				△															○	false negative	←·○	←	2
				relative position									○				○															○	false negative	←·○	←	2
		Obstruction on the lane	Fallen objects	color, material									○				○															○	false negative	←·○	←	2
				Shape, size									◎				◎															○	false negative	←·○	←	2
				relative position, motion									○				○															○	false negative	←·○	←·○	2
			Animals	Shape, size									◎				◎															○	false negative	←·○	←·○	2
				relative position, motion									○				○															○	false negative	←·○	←·○	2
			Installation objects	color, material									○				○															○	false negative	←·○	←	2
				Shape, size	large reflection	large signal intensity					○	○	◎																		○	○	false positive, false negative	←·○	←	3
					small reflection	small signal intensity							◎				◎															○	false negative	←·○	←	2
				dirt									△				△															○	false negative	←·○	←	2
				relative position									○				○															○	false negative	←·○	←	2
		Moving objects	Other vehicles	color, material									○				○															○	false negative	←·○	←·○	2
				Shape, size	large reflection	large signal intensity					◎	◎	◎																		○	○	false positive·false negative·○	←·○	←·○	3
					small reflection	small signal intensity							◎				◎															○	false negative	←·○	←·○	2
				Sticking objects									△				△															○	false negative	←·○	←	2
				relative position, motion									○				○															○	false negative	←·○	←	2
			Motorbikes	color, material									○				○															○	false negative	←·○	←	2
				Shape, size									◎				◎															○	false negative	←·○	←·○	2
				Sticking objects									△				△															○	false negative	←·○	←	2
				relative position, motion									○				○															○	false negative	←·○	←·○	2
			Bicycles	color, material									○				○															○	false negative	←·○	←	2
				Shape, size									◎				◎															○	false negative	←·○	←·○	2
				Sticking objects									△				△															○	false negative	←·○	←	2
				relative position, motion									○				○															○	false negative	←·○	←·○	2
			Pedestrians	color, material									○				○															○	false negative	←·○	←	2
				Shape, size									◎				◎															○	false negative	←·○	←·○	2
				relative position, motion									○				○															○	false negative	←·○	←·○	2
number of items							6	13	14	6	12	12	39	8	17	13	36	8	14	19	9	1	1	8	14	19	9	1	1	5	66	118	118	118	118	

Table 27 Perception disturbance elements and generation principle matrix of LiDAR

						Perception Error												Recognition Error						
						Signals from recognition target (S)								Signals not from recognition target (N,U)				Processing capability		Processing performance				
						Scan Timing		S strength			S propagation direction		S Speed	N factor	U factor					Detection		Clustering	Tracking	Classification
						Misalignment of overall spatial position	Misalignment of position of recognition target	Saturation of S	Attenuation of S	No S due to occlusion	Reflection	Refraction	Arrival time of S	Noise	Multiple reflections	Signals not from recognition target (reflection)	Signals not from recognition target (refraction)	Insufficient number of processing points	Insufficient computing capability	Incorrectly detects U (undesired signal)	Fails to detect S (desired signal)	Unexpected distribution of pointcloud being recognized	Unexpected recognition behavior (between frames)	Unexpected recognition of target
Causes of recognition error	vehicle, sensor		Ego vehicle	Change of vehicle pose	due to vehicle condition (semi-permanent)															○	○	misdetected/undetected	←	←
					due to vehicle condition (temporary)															○	○	misdetected/undetected	←・○	←
			Sensor	Variation of installation	axial deviation (inside adjustment range)							△			△	△	△			○	○	misdetected/undetected	←	←
					axial deviation (outside adjustment range)				○	○		△			○	○	△			○	○	misdetected/undetected	←	←
				Failure of sensor itself	degradation of sensor surface				◎												○	undetected	←	←
					degradation of sensor itself (electronic components)				△												○	undetected	←	←
					degradation of electrical performance due to external noise									△						○	○	misdetected/undetected	←	←
			Surface in front of the sensor	Sticking objects	water				◎	◎		◎				○	◎				○	undetected	←	←
					ice				◎	◎		◎				○	◎				○	undetected	←	←
					snow				◎	◎						◎					○	undetected	←	←
					mud / dust				◎	◎						◎					○	undetected	←	←
					car wash wax				△			◎					◎				○	undetected	←	←
					foreign matter(insects, bird droppings) x SPOT				◎	◎						◎					○	undetected	←	←
				changes in characeristics	sensor surface damage (cracks)				◎	△		△				○	△				○	undetected	←	←
					sensor surface damage (distortion)				△			◎				△	◎				○	undetected	←	←
	Environment	Structural objects	Road Surface	Shape	uphill																	○	←	←
					downhill																			
					road cant																	○	←	←
				Road condition	puddle						◎				◎					○		misdetected	←	←
					frozen road						?				?					○		misdetected	←	←
					traces of road repair																	○	←	←
					rut																	○	←	←
					snow cover																	○	←	←
				Material	asphalt																	○	←	←
					concrete																	○	←	←
					gravel																	○	←	←
					sand																	○	←	←
					thin layer pavement																	○	←	←
					cobblestone road																	○	←	←
					manhole																	○	←	←
					road joint (metal joint)																	○	←	←
					road joint (asphalt type joint)																	○	←	←
			Roadside objects	Reflection	curve mirror						◎				◎					○		misdetected	←	←
				Occlusion						◎						◎					○	undetected	←	←
			Overhead objects	Reflection	curve mirror						◎				◎					○		misdetected	←	←
				Occlusion						◎						◎					○	undetected	←	←
			Space	Spatial obstacles	snow				◎	◎						◎				○	○	misdetected/undetected	←	←
					rain				◎	◎						◎				○	○	misdetected/undetected	←	←
					sand				◎	○						○				○	○	misdetected/undetected	←	←
					fog				◎											○	○	misdetected/undetected	←	←
					others / floating in space				◎	△						△				○	○	misdetected/undetected	←	←
					insects / floating in space				◎	△						△				○	○	misdetected/undetected	←	←
				Radiowave and light in space	direct wave x other vehicle									◎						○	○	misdetected/undetected	←	←
					direct wave x infra-structure									◎						○	○	misdetected/undetected	←	←
					direct wave x nature world									◎						○	○	misdetected/undetected	←	←
			Other moving	Reflection							◎				◎					○		misdetected	←	←
Recognition targets	track		Lines	Color / Materials																	○	undetected	←	←
				Shapes																	○	undetected	←	←
				Grime / Thin spot					◎	△											○	undetected	←	←
				Relative position		○															○	undetected	←	←
			Structural objects with height	Color / Materials				△	◎												○	undetected	←	←
				Shapes				△	◎												○	undetected	←	←
				Grime					◎												○	undetected	←	←
				Relative position		○															○	undetected・○	←	←
		Road edges	without a step	Color / Materials																	○	undetected	←	←
				Shapes																	○	undetected	←	←
				Grime					◎	○											○	undetected	←	←
				Relative position		○															○	undetected	←	←
			with a step	Color / Materials					◎												○	undetected	←	←
				Shapes				△	◎												○	undetected	←	←
				Grime					◎												○	undetected	←	←
				Relative position		○															○	undetected・○	←	←
	Obstactions on the lane		Fallen object	Color / Materials				△	◎		△				△					○	○	misdetected/undetected	←	←
				Shape / Size				△	◎												○	undetected	←	←
				Relative position / Motion		○	○															○	←	←
			Animals	Color / Materials					◎												○	undetected	←	←
				Shape / Size					◎												○	undetected	←	←
				Relative position / Motion		○	○															○	←	←
			Temporal installed object	Color / Material				△	◎		△				△					○	○	misdetected/undetected	←	←
				Shape / Size				△	◎												○	undetected	←	←
				Grime					◎												○	undetected	←	←
				Relative position		○																○	←	←
	Moving objects		Other vehicles	Color / Materials				△	◎		△				○					○	○	misdetected/undetected	←	←
				Shape / Size				△	◎												○	undetected	←	←
				Sticking objects					◎												○	undetected	←	←
				Relative position		○	○															○	←	←
			Motor bikes	Color / Materials				△	◎		△				△					○	○	misdetected/undetected	←	←
				Shape / Size				△	◎												○	undetected	←	←
				Sticking objects					◎												○	undetected	←	←
				Relative position		○	○															○	←	←
			Bicycles	Color / Materials				△	◎		△				△					○	○	misdetected/undetected	←	←
				Shape / Size				△	◎												○	undetected	←	←
				Sticking objects					◎												○	undetected	←	←
				Relative position		○	○															○	←	←
			Pedestrians	Color / Materials				△	◎						△					○	○	misdetected/undetected	←	←
				Shape / Size				△	◎												○	undetected	←	←
				Relative position		○	○															○	←	←

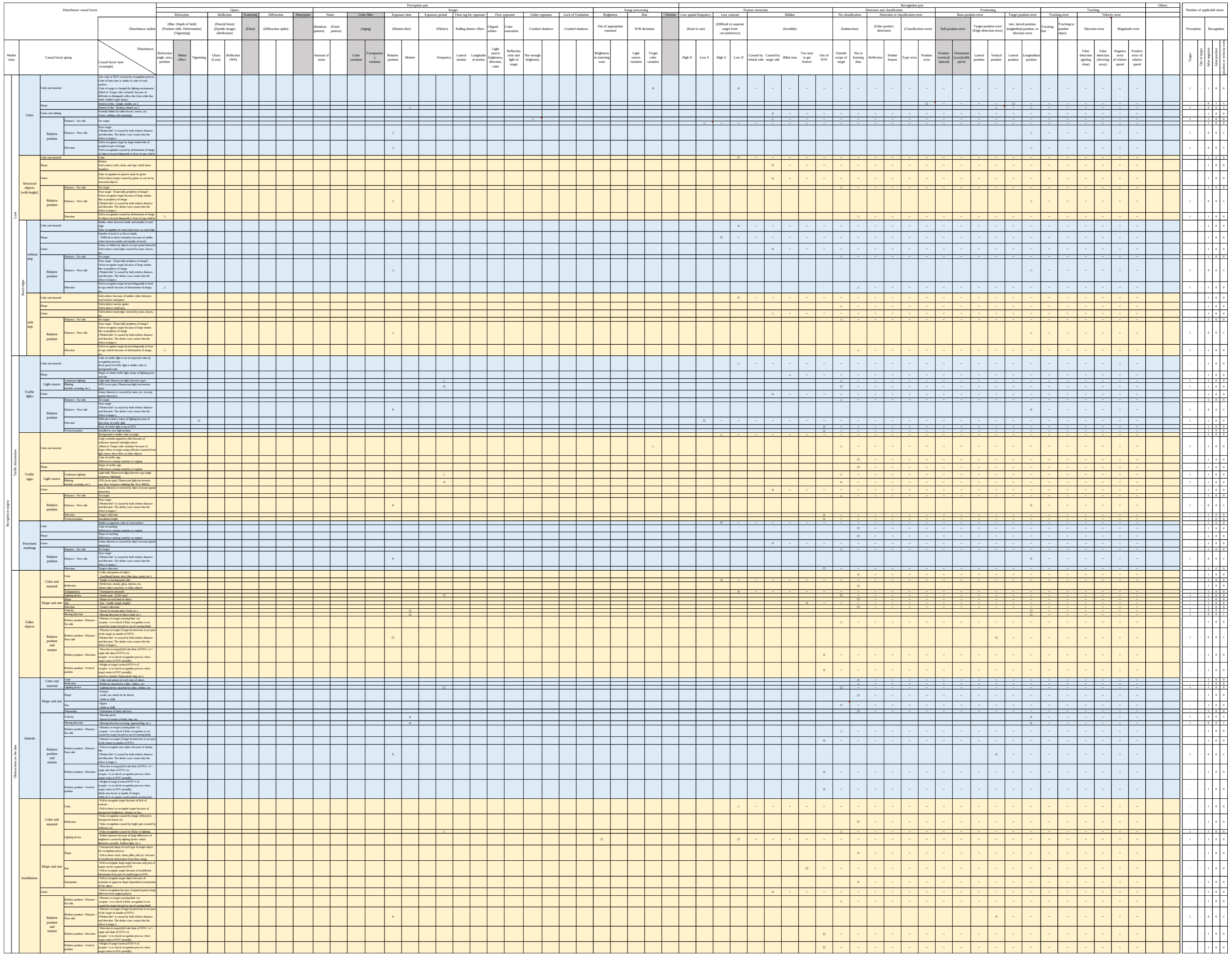
Small impact △
Medium impact ○
Great impact ◎

Table 28 Perception disturbance elements and generation principle matrix of Cameras (Elements: Vehicle/Sensor, Surrounding Environment)

Small effect △
Medium effect ○
Large effect ◎

Model class	Causal factor group				Causal factor item (example)	Number of applicable items: Perception: Target	Perception: Out of target	Recognition: false negative	Recognition: false positive	Recognition: position or velocity error
Ego vehicle and sensors	Ego vehicle		Change of car posture	Sensing - direction - Normal driving	Attitude modification by motion or load（include improper maintenance）	-	-	0	0	3
						-	-	0	0	3
				Sensing - direction - Single vibration	Bump over	-	-	0	0	1
						-	-	0	0	5
				Sensing - direction - Periodic vibration	Using tire chains	-	-	0	0	1
						-	-	0	0	5
				Sensing - direction - Turn a curve	Turning（especially small R like turning at intersection）	1	-	0	0	2
				Sensing - direction - high speed straight ahead	High speed straight ahead（especially with near object on the side of ego vehicle）	1	-	0	0	1
				Ground height -Sensing position	Replacing tires	-	-	0	0	1
	Sensors		Variation	Position - sensing position	Imaging position shift（whole image shift）	-	-	0	0	1
				Direction - sensing direction	Imaging position shift（direction）	-	-	0	0	1
			Sensor itself	Aging-lens transmittance (color change)	Transparency variation of lens（yellow discoloration, etc.）	-	1	0	0	0
				Operating environment- Temperature change- Degradation of CMOS sensor characteristics	Sensor characteristics variation（temperature characteristics, etc.）	1	-	1	0	0
				Operating environment- Temperature change- Degradation of lens characteristics	Lens distortion variation（temperature characteristics, etc.）	-	1	0	0	0
				Pixel Defective - Defective pixels	Small object over defective pixels ⇒Malfunction without fault detection in case of badly defection	-	-	1	0	0
				Lens characteristic - Intra-lens reflection	Degradation of true detection or recognition ratio under reflection caused by very high brightness light source.	1	-	1	0	0
				Lens characteristic - Shading	Degradation of true detection or recognition ratio under dark condition.（Especially periphery of image）	1	-	1	0	0
				Processing capacity limit - Image complexity	Fail to detect or recognize a port of objects because of too many targets.	-	-	1	0	0
				Processing capacity limit - Operating environment	Too many target objects under high temperature	-	-	1	0	0
	Front of sensors		Sticking objects, disturbing objects	Hidden (Image Cut Out) - mud, dust, etc.	Sticking mud, dust, etc.（image loss）	-	-	1	0	0
				Hidden (Image Cut Out) - snow, ice, etc.	Sticking snow, ice, etc.（image loss）	-	-	1	0	0
				Hidden (Image Cut Out) - water, etc.	Sticking water, etc.（image loss）	-	-	1	0	0
				Hidden (Image Cut Out) - insects, bird droppings, etc.	Sticking insects, bird droppings, etc.（image loss）	-	-	1	0	0
				Hidden (Image Cut Out) - Windshield wiper	Wiper operation（image loss）	-	-	1	0	0
				Noise - mud, dust, etc.	Sticking mud, dust, etc.（false detection, false recognition）（as image noise）	-	-	1	0	0
				Noise - snow, ice, etc.	Sticking snow, ice, etc.（false detection, false recognition）（as image noise）	-	-	1	0	0
				Moise - water, etc.	Sticking water, etc.（false detection, false recognition）（as image noise）	-	-	1	0	0
				Noise - insects, bird droppings, etc.	Sticking insects, bird droppings, etc.（false detection, false recognition）（as image noise）	-	-	1	0	0
				Noise - Windscreen wiper	Wiper operation（as noise on recognition target）	-	-	1	0	0
				Refraction	Water drop（Rain drop, etc.）（as transparency object）	1	-	1	0	0
			Characteristics variation	Aging - Transmittance (brightness variation)	Transparency variation of windshield（include effect by stains）	-	1	0	0	0
				Aging - Transmittance (color variation)	Transparency variation of windshield（color spectrum variation）	-	1	0	0	0
				Break - Crack - Noise	Crack on windshield, etc.	-	-	1	0	0
				Break - Crack - Refraction	Curve variation of windshield	1	-	0	0	2
				Product variation - Transmittance (brightness variation)	Transparency variation of whole windshield	-	1	0	0	0
				Product variation - Transmittance (color variation)	Color variation of windshield	-	1	0	0	0
				Product variation - Refraction	Curve variation of windshield	-	1	0	0	0
			Reflection on windshield		Reflected image of dashboard (include objects on dashboard)	1	-	0	1	0
						1	-	1	0	0
Environments	Structural objects	Road surface	Shape	Slope	Variation of position and inclination of road surface as image	-	-	1	0	0
			Road condition	Entire road surface - Noise	Erased road line marker, Wheel track	-	-	0	1	1
					Shadow of guardrail, noise barrier, etc.	-	-	0	1	1
				Entire road surface - Reflection	Road mirage, icy pavement (wide area), water screen（when heavy rain）	-	-	0	1	1
					Road joints（bridge, material change of pavement）	-	-	0	1	1
				Spot on road surface - Reflection	Plash, icy pavement (partially), debris like mirror	-	-	0	1	1
			Material	Entire road surface - Color	Object detection on colored pavement or colored materials of pavement	-	-	1	0	0
				Entire road surface - Particle size	Coarse（stone path） ~ Medium（tiles（pattern）） ~ Fine (asphalt or concrete）	-	-	1	0	0
				Spot on road surface - Installation object	False recognition caused by manhole cap, etc.	-	-	0	1	1
				Spot on road surface - Painted sign	False recognition as painted sign on road surface, etc.	-	-	0	1	1
		Road side objects	Reflection	Mirror surface	Reflected image on traffic roadside mirror, etc.	-	-	0	1	1
				Non-mirror surface	False recognition as different object like sign on road side	-	-	0	1	1
			Hidden (Image Cut Out)	Non-transparent material	Image cut out by roadside trees, buildings, roadside signs, etc.	-	-	1	0	0
				Transparent material	Box created by transparency materials (telephone box, bus station, etc.)	-	-	0	1	1
			Back-ground	Color	Major background color (by buildings, signs, trees, etc.) is analogous to detection or recognition target.	-	-	1	0	0
				Shape	Interference shape of recognition target with shape of background objects. False recognition of background object as person or obstruction	-	-	0	1	1
		Overhead objects	Reflection	Mirror surface	N/A	27	3	0	0	0
				Non-mirror surface	False recognition of overhead object	-	-	0	1	1
			Hidden (Image Cut	Non-transparent material	Branches and trees of tall tree. Bridge	-	-	1	0	0
				Transparent material	N/A	27	3	0	0	0
			Back-ground	Color	Overhead sign（Major color）	-	-	1	0	0
				Shape	Interference shape of recognition target with shape of overhead sign. False recognition of object placed on down slope ahead of road	-	-	0	1	1
	Space		Spatial obstacles	Reflection - Mirror surface	N/A	27	3	0	0	0
				Reflection - Non-mirror surface	False recognition of reflective floating objects (like ice, aluminum foil) as obstacle object. False recognition of patterns on smoke caused by lighting condition	-	-	0	1	1
				Hidden (Image Cut Out) - Non-transparency（rain, snow, etc.）	Rain, snow, or fog before recognition target	-	-	1	0	0
				Hidden (Image Cut Out) - Non-transparency（sandstoms, petals blizzard, etc.）	Sandstorms or petals blizzard before recognition target	-	-	1	0	0
				Hidden (Image Cut Out) - Non-transparency（large flying objects）	Large flying object before recognition target	-	-	1	0	0
				Hidden (Image Cut Out) - Transparency	Flying transparent plastic bag	-	-	0	1	1
				Background - Color	Snow or fog (as background of recognition target)	-	-	1	0	0
				Background - Shape	Distribution profile of snow or fog	-	-	0	1	0
			Radio wave and light	Visible - Light source (point) - Color	Street lamp, sun's light, headlight of ego vehicle	-	-	0	1	0
				Visible - Light source (point) - Forward light	Street lamp, sun's light, headlight of ego vehicle ⇒ no effect	27	3	0	0	0
				Visible - Light source (point) - Backlight	Late afternoon sun headlight from oncoming vehicle	1	-	1	0	0
				Visible - Light source (point) - Reflected light	Reflected image on surface of like water from street light, sun's light, headlight from oncoming vehicle, etc.	-	-	0	1	1
				Visible - Light source (environment) - Color	Scattering light or ego vehicle's headlight with biased spectrum (visible)	1	-	1	0	0
				Visible - Light source (environment) - brightness (bright)	Strong scattering light（visible）, Wildfire, under the searing sun	1	-	1	0	0
				Visible - Light source (environment) - brightness (dark)	Weak scattering light（visible） Ego vehicle's headlight	1	-	1	0	0
				Visible - Light source (environment) - brightness (bright + dark)	Strong scattering light（visible）and shadow（searing sun and shady area, etc.）	1	-	1	0	0
				Invisible - Disturbance light source (point)	Infrared light projector, sun's light	-	-	0	1	1
				Invisible - Disturbance light source (environment)	Scattering light（near-infrared light）	-	-	1	0	0
	Moving objects		Reflection	Mirror surface	False recognition of reflected image on specular surface of vehicle (like tank truck)	-	-	0	1	1
				Non-mirror surface	False recognition of reflected image of like light on polished body	-	-	0	1	1
			Hidden (Image Cut Out)	Non-transparent material	Parked vehicle, Roadside tree, Incoming flying object	-	-	1	0	0
				Transparent material	Transparent object（like glass case on loading platform）	-	-	0	1	1
			Back-ground	Color	False recognition because of similar target color to background color	-	-	1	0	0
				Shape	Interference shape of recognition target with background. (Impossible to separate recognition target from background because of the shape)	-	-	0	1	2

Table 29 Perception disturbance elements and generation principle matrix of Cameras (Elements: Roadway, Traffic information, On-Road obstacles)



Small effect △
Medium effect ○
Large effect ◎

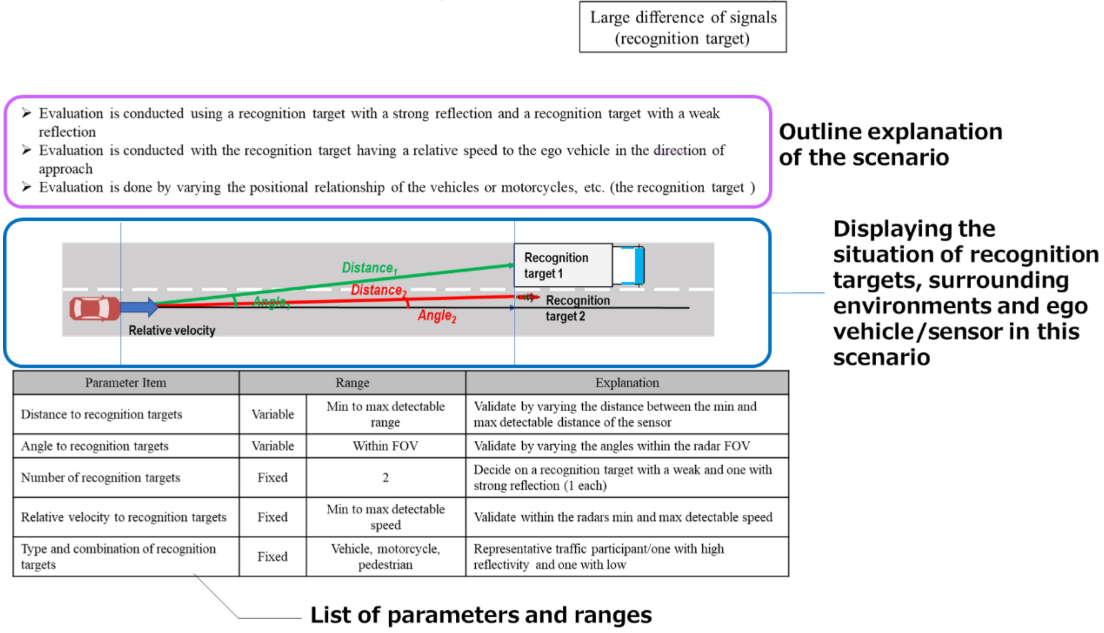
Table 30 Perception disturbance elements and generation principle matrix of Cameras (Elements: Moving objects)

Small effect △
Medium effect ○
Large effect ◎

Disturbance causal factor						Perception part																														Recognition part																											Others		Number of applicable items				
						Optics									Imager																Image processing					Feature extraction									Detection and classification						Positioning						Tracking												
						Refraction			Reflection		Scattering	Diffraction		Absorption	Noise		Color filter		Exposure time		Exposure period		Time rag for exposure		Over exposure		Under exposure		Lack of Gradation		Brightness		Hue		Chroma	Low spatial frequency		Low contrast		Hidden					No classification		Detection or classification error				Base-position error				Target position error		Tracking error		Velocity error										
					Disturbance outline	(Blur: Depth of field) (Position shift, Deformation) (Vignetting)			(Flare)(Ghost) (Double image) (Reflection)		(Flare)	(Diffraction spike)			(Random pattern)	(Fixed pattern)	(Aging)		(Motion blur)		(Flicker)		Rolling shutter effect		Clipped whites	Color saturation	Crushed shadows		Crushed shadows		Out of appropriate exposure		W/B deviation			(Hard to see)		(Difficult to separate target from circumference)		(Invisible)					(Indetection)		(False positive detection)		(Classification error)		Self-position error		Target-position error (Edge detection error)		size, lateral position, longitudinal position, or direction error		Tracking lost	Tracking to another object	Direction error		Magnitude error				Perception		Recognition		
Model class			Causal factor group		Disturbance / Causal factor item (example)	Refraction angle, area, position	Minor effect	Vignetting	Ghost (Lens)	Reflection (WS)					Amount of noise		Color variation	Transparency variation	Relative position	Motion		Frequency	Lateral motion	Longitudinal motion	Light source brightness, direction, color	Reflection ratio and light of target	Not enough brightness				Brightness in metering zone		Light source variation	Target color variation		High N	Low S	High U	Low D	Caused by vehicle side	Caused by target side	Blind area	Too near to get feature	Out of FOV	Outside scope of target	Not in learning data	Reflection	Similar feature	Type error	Position error	Position (vertical) (lateral)	Orientation (yaw)(roll)(pitch)	Lateral position	Vertical position	Lateral position	Longitudinal position			False detection (getting close)	False detection (drawing away)	Negative error of relative speed	Positive error of relative speed			Target	Out of target	false negative	false positive	position or velocity error
Recognition targets	Moving object	Other vehicles	Color and material	Color	Base color of vehicle (need to consider plural base colors)																																		○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Reflection	Reflection on glossy body of vehicle					○																																					○	-	-	-	-	-	-	-	○	-	-	-	-	-	-	-			1	-	0	1	1
			Shape and size	Shape	Unexpected shape of vehicle type (sedan, station wagon, hatchback, truck, bus, trailer, special-purpose vehicle, etc.) False recognition of load, which has flag, etc., out of vehicle (Fail to recognize the load as part of vehicle)																																									◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Size	Fail to recognize target vehicle because of target's part outside of FOV (not only relative location, but also large size of target vehicle)																																							◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
					Unexpected vehicle size (compact, usual, truck or bus (various size))																																									◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Orientation	Orientation of target vehicle against ego vehicle																																									◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
			Materials of each part (Paints and surface property)	Color	Fail to recognize target because of parts color																																		△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Reflection	Degradation of recognition caused by reflected image on mirror of ego vehicle Fail to recognition because of partial brightness area caused by reflector or mirror																				△																					△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
				Transparency	Transparent part of target vehicle (Fail to recognize transparent load like transparent board, etc.)																																		△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Lighting device	Headlight, stoplight, etc. (especially LED type)																				○												○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
					Turn signal																																									△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
			Relative position and motion	Velocity	Speed of target vehicle (stop ~ high speed)															○																										○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
				Moving direction	Orientation of target vehicle against ego vehicle (same direction, opposite direction, crossing direction, etc.) ("Motion blur" effect becomes large when relative lateral position of target changes rapidly, for example ego vehicle turns)															○																										○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
				Relative position - Distance - Far side	・Distance to target (sensing limit +α) (require +α to check if false recognition is not caused by target located at out of sensing limit)																																								△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Relative position - Distance - Near side	・Distance to target (Target located near to set part of the target to outside of FOV) ("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)														○																																					○	-	-	-	-	-	-	-	-			1	-	0	0	1
				Relative position - Direction	・Direction to target((left side limit of FOV) +α～(right side limit of FOV)+α) (require +α to check recognition process when target exists in FOV partially)																																							○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
			Sticking objects	Color	Base color of sticking object																																					△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Shape	Various shapes of sticking objects																																					△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Area	Area of sticking objects																																					◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Reflection	Reflection from sticking object (no reflective object (general object) ~ reflective object (mirror, metals, or reflector))																																									△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Transparency	Transparent colored sticker, etc.																																△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
		Motor bikes	Color and material	Color	・Color variation of motorcycles, color of each part ・Color and pattern of rider's clothes ・Color of helmet ・Similar color to background																																				○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Reflection	・Reflector, mirror, wheel																																									○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Transparency	・Transparent board (windshield, etc.)																																		△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Lighting device	・headlight, stoplight, etc. (especially LED type)																				○												○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
					・Turn signal, etc.																	△																							△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
			Shape and size	Shape	・Tandem motorcycle, motorcycle with side car ・Shape of helmet ・Posture																																									◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Size	・Width and length																																									△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Orientation	・Orientation of motorcycle body																																									◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
			Relative position and motion	Velocity	・Moving speed, wheel rotation															○																										○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
				Moving direction	・Moving direction															○																										○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
				Relative position - Distance - Far side	・Distance to target (sensing limit +α) (require +α to check if false recognition is not caused by target located at out of sensing limit)																																								△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Relative position - Distance - Near side	・Distance to target (Target located near to set part of the target to outside of FOV) ("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)														○																																					○	-	-	-	-	-	-	-	-			1	-	0	0	1
				Relative position - Direction	・Direction to target((left side limit of FOV) +α～(right side limit of FOV)+α) (require +α to check recognition process when target exists in FOV partially)																																							◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Tilt angle	・Tilt angle of motorcycle body																																									○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
		Bicycles	Shape and size	Color	・Color variation of bicycles, color of each part ・Color of helmet, Color of rider's hair ・Color and pattern of rider's clothes ・Similar color to background																																				○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Reflection	・Reflector, wheel																																									△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Transparency	・Transparent raincoat																																		△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Lighting device	・Headlight																	○																							○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
			Shape and size	Shape	・Type of bicycle																																									○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Size	・Width and length																																									◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Orientation	・Orientation of bicycle body																																									◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
			Relative position and motion	Velocity	・Moving speed, wheel rotation															○																										○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
				Moving direction	・Moving direction															○																										○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
				Relative position - Distance - Far side	・Distance to target (sensing limit +α) (require +α to check if false recognition is not caused by target located at out of sensing limit)																																								△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Relative position - Distance - Near side	・Distance to target (Target located near to set part of the target to outside of FOV)("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)														○																																					○	-	-	-	-	-	-	-	-			1	-	0	0	1
				Relative position - Direction	・Direction to target((left side limit of FOV) +α～(right side limit of FOV)+α) (require +α to check recognition process when target exists in FOV partially)																																							◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Tilt angle	・Tilt angle of bicycle body																																									○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
		Pedestrians	Color and material	Color	・Color of hair ・Color and patterns of clothes and baggage																																									◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
					・Similar color to background																																	◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Reflection	・Reflector																																									△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Transparency	・Transparent umbrella, raincoat																																									△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Lighting device	・flash-light (include blinking type)																	○																							○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
			Shape and size	Shape	・Shape depended on clothes and baggage ・Orientation ・Posture (walk, run, stand, sit, lie down) ・Adult, child																																									◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Size	・Figure ・Adult, child																																								◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Orientation	・Orientation of body																																																												-	-	0	0	0
			Relative position and motion	Velocity	・Moving speed, motion of arms and legs															○																										○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	-	1	0	0
				Moving direction	・Moving direction																																								△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Relative position - Distance - Far side	・Distance to target (sensing limit +α) (require +α to check if false recognition is not caused by target located at out of sensing limit)																																								△	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0
				Relative position - Distance - Near side	・Distance to target (Target located near to set part of the target to outside of FOV)("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)														○																																					○	-	-	-	-	-	-	-	-			1	-	0	0	1
				Relative position - Direction	・Direction to target((left side limit of FOV) +α～(right side limit of FOV)+α) (require +α to check recognition process when target exists in FOV partially)																																							◎	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	1	0	0

As an illustrative example, one of the scenarios selected using the approach described above is shown in Figure 45. Each scenario illustration shall include the following elements. Detailed requirements are provided in *Annex E*.

- an overview description of the scenario;
- visual representations of the perception targets, the surrounding environment, and the states of the ego vehicle and sensors; and
- a list of relevant parameter items together with their defined ranges.



Large difference of signals (recognition target)

- Evaluation is conducted using a recognition target with a strong reflection and a recognition target with a weak reflection
- Evaluation is conducted with the recognition target having a relative speed to the ego vehicle in the direction of approach
- Evaluation is done by varying the positional relationship of the vehicles or motorcycles, etc. (the recognition target)

Outline explanation of the scenario

Displaying the situation of recognition targets, surrounding environments and ego vehicle/sensor in this scenario

Parameter Item	Range		Explanation
Distance to recognition targets	Variable	Min to max detectable range	Validate by varying the distance between the min and max detectable distance of the sensor
Angle to recognition targets	Variable	Within FOV	Validate by varying the angles within the radar FOV
Number of recognition targets	Fixed	2	Decide on a recognition target with a weak and one with strong reflection (1 each)
Relative velocity to recognition targets	Fixed	Min to max detectable speed	Validate within the radars min and max detectable speed
Type and combination of recognition targets	Fixed	Vehicle, motorcycle, pedestrian	Representative traffic participant/one with high reflectivity and one with low

List of parameters and ranges

Figure 45. Example of an Illustration for a Perception-Disturbance Evaluation Scenario

3.4.2.5. Combined Evaluation of Perception Disturbances

Perception disturbances may occur simultaneously when multiple disturbance factors act on a single sensor. When the effects of these factors mutually amplify their impact on perception performance, it becomes necessary to evaluate perception performance using combined disturbance scenarios. Whether such mutual amplification occurs is determined based on the disturbance-generation principles. As described in the preceding section, this determination is performed by examining the corresponding columns in the disturbance-factor–principle matrices and assessing the principles associated with each disturbance factor. If this assessment indicates that the underlying disturbance-generation principles either attenuate each other's effects or do not interact, the corresponding combinations are excluded from combined-disturbance evaluation. Only combinations for which amplification effects may reasonably occur are selected for combined evaluation (Figure 46).

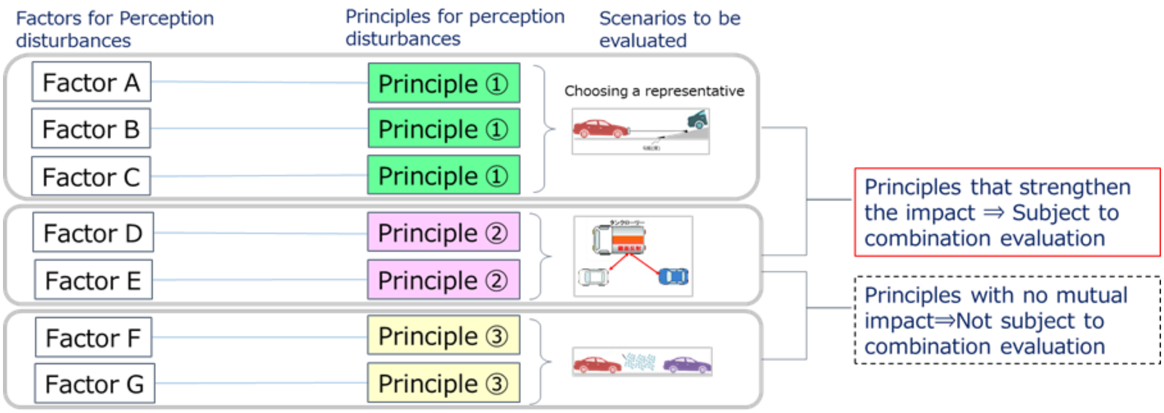


Figure 46. Disturbance-Generation Principles Subject to Combined Evaluation

3.4.2.6. Evaluation of Perception Disturbances in Multi-Sensor Automated Driving Systems

ADS generally employ sensor-fusion architectures that integrate information from multiple sensors. When evaluating perception performance at the system level, a consolidated scenario set is constructed by aggregating the individual evaluation scenarios selected for each sensor through the processes described above, in accordance with the system's specific sensor configuration. System-level perception evaluation is then performed under each applicable disturbance condition using this integrated set of scenarios. This approach enables assessment of perception robustness while accounting for the interactions among multiple sensors and sensor-fusion logic.

3.4.2.7. Obstructed-View Scenarios

The traffic-disturbance scenario structure described in Section 3.4.1.1 assumes that surrounding vehicles are always detectable. In actual traffic environments, however, surrounding vehicles or road structures may temporarily occlude other vehicles, resulting in obstructed-view conditions. Safety-relevant scenarios arising from such occlusion phenomena therefore need to be systematically identified and incorporated into the safety analysis.

In this chapter, the term "obstructed-view" does not refer to areas typically associated with driver blind spots caused by mirrors, vehicle pillars, or similar features. Instead, it refers specifically to situations in which the line of sight is physically obstructed by other vehicles or road structures, thereby causing occlusion of recognition targets at the sensor level.

Obstructed-view scenarios are classified into the following three subcategories (Figure 47):

- obstructions caused by surrounding vehicles;
- obstructions caused by road structures; and
- obstructions caused by road gradients.

This classification provides a structured basis for analyzing safety risks associated with temporary loss of visibility and resulting occlusion effects due to physical obstructions.

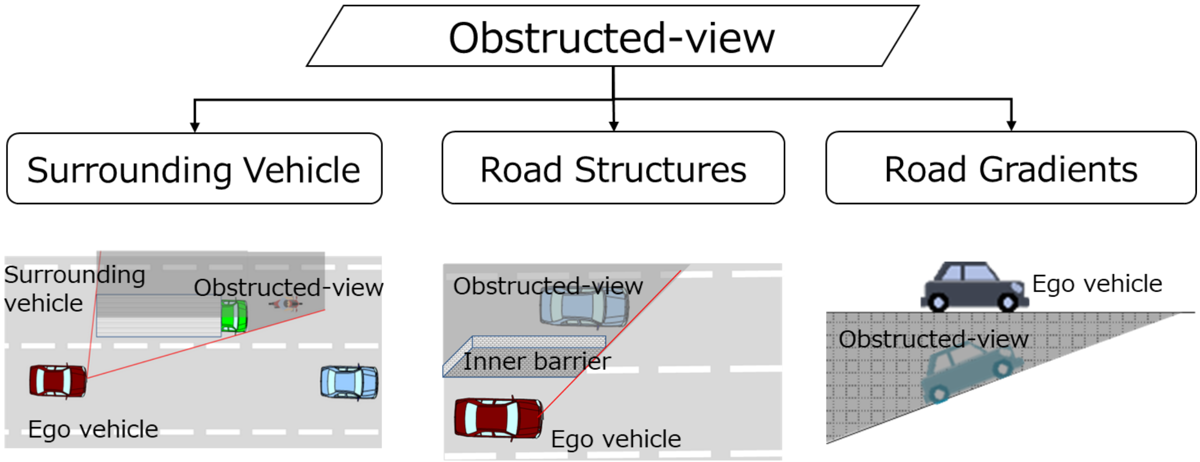


Figure 47. Classification of Perception Disturbance Related to Obstructed-Views

3.4.2.8. Obstructed-View Scenarios Caused by Surrounding Vehicles

To structure obstructed-view scenarios caused by surrounding vehicles, eight surrounding-vehicle positions are defined around the ego vehicle, and sixteen additional positional definitions are introduced in their vicinity (Figure 48). Each surrounding vehicle may generate obstructed-view not only for the vehicle immediately behind it, but may also occlude other surrounding vehicles. This is particularly significant when both the ego vehicle and surrounding vehicles are traveling on a curved road, where obstructed-view regions and the corresponding occlusion relationships between vehicles—change dynamically. In addition, on general roads, obstructed view conditions may also be created by oncoming vehicles. Accordingly, surrounding vehicles considered in obstructed-view scenarios may be traveling either in the same direction as the ego vehicle or in the opposite direction.

To clarify these dynamic phenomena, the obstructed-view positions generated by surrounding vehicles are explained using the examples shown in Figure 49 through Figure 51. Figure 49 illustrates obstructed-view positions arising from the combination of road curvature and the position of a surrounding vehicle located within the same lane as the ego vehicle. Figure 50 and Figure 51 similarly illustrate obstructed-view conditions conditions—and the resulting vehicle-to-vehicle occlusion—caused by surrounding vehicles positioned laterally and diagonally relative to the ego vehicle, respectively.

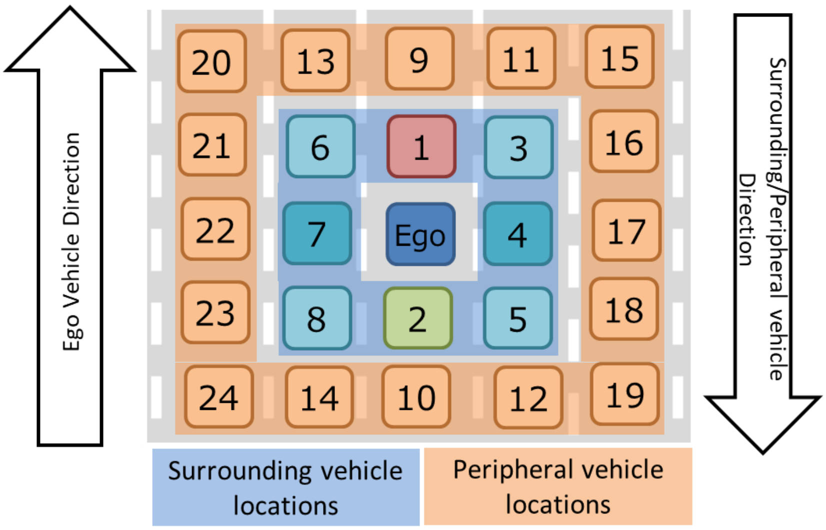


Figure 48. Applicable Surrounding-Vehicle Positions for Defining Obstructed-View Scenarios

Obstructed-View Positions Generated by a Surrounding Vehicle at Position 1

Figure 49 illustrates the obstructed-view positions generated by a surrounding vehicle located at Position 1. For clarity, a large vehicle is used in the illustration. On a straight road, the large vehicle generates an obstructed-view position only at Position 9. However, when both the ego vehicle and the large vehicle travel through a right-hand curve, the relative orientation of the large vehicle with respect to the ego vehicle changes, resulting in obstructed views at Positions 6, 9, 13, 20, and 21. On a left-hand curve, vehicles at Positions 3, 9, 11, 15, and 16 may become occluded by the large vehicle.

As a result, a total of nine obstructed-view positions—3, 6, 9, 11, 13, 15, 16, 20, and 21—are identified as potential sources of hazardous situations due to vehicle-to-vehicle occlusion. Among these, some obstructed-view positions exhibit inclusion relationships. For example, in a right-hand curve, a lane-change maneuver associated with obstructed-view Position 20 corresponds to movement into obstructed-view Position 13. Because Position 13 is closer to the ego vehicle, it represents a more critical condition with shorter available reaction time. Therefore, by evaluating safety for Position 13, the hazardous maneuver associated with Position 20 is inherently covered.

Applying the same reasoning, obstructed-view Positions 15, 16, and 21 are also excluded. Consequently, the obstructed-view positions considered in safety analysis for a surrounding vehicle located at Position 1 are reduced to five positions: 3, 6, 9, 11, and 13, as summarized in the simplified diagram shown in Figure 49.

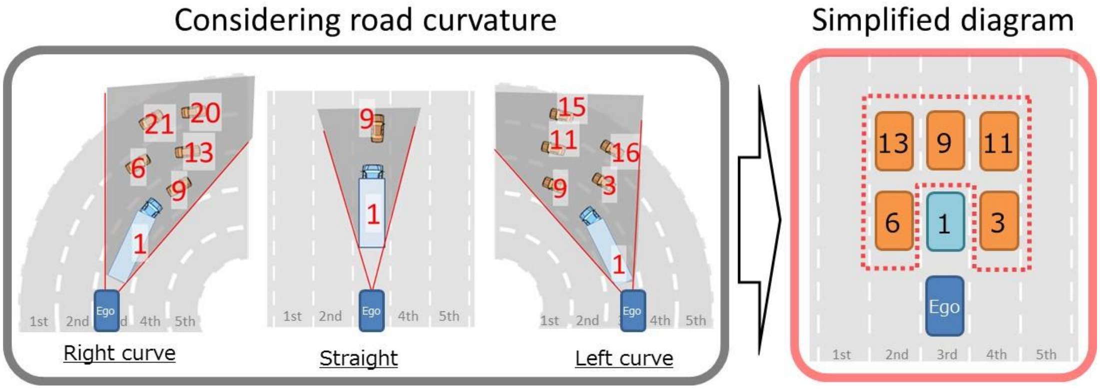


Figure 49. Obstructed-View Positions Resulting from a Surrounding Vehicle at Forward Position 1

Obstructed-View Positions Generated by a Surrounding Vehicle at Position 4

Figure 50 illustrates the obstructed-view positions generated by a large surrounding vehicle located at Position 4. On a straight road, this vehicle may generate obstructed-view positions at Positions 3, 5, 16, 17, and 18. When both vehicles travel through a right-hand curve, the number of obstructed-view positions increases to eleven: Positions 1, 2, 3, 5, 6, 8, 16, 17, 18, 21, and 23. On a left-hand curve, vehicles at Positions 16, 17, and 18 may become occluded by the large vehicle.

As in the previous case, obstructed-view positions are reduced based on the principle of evaluating the most critical scenarios. For example, a lane change by a vehicle at Position 6 into the adjacent right lane results in a situation equivalent to Position 1. Therefore, evaluating Position 1 also covers maneuvers originating from Position 6. The same logic applies to lane changes from Positions 21, 8, and 23.

In addition, deceleration of a vehicle at Position 6 is less critical than simultaneous lane changes by the ego vehicle and a vehicle at Position 1 into the left adjacent lane, and is therefore substituted by the latter scenario. Similarly, acceleration of a vehicle at Position 8 is less critical than simultaneous lane changes by the ego vehicle and a vehicle at Position 2.

Furthermore, cut-in scenarios involving vehicles at Positions 16, 17, and 18 are excluded because the surrounding vehicle at Position 4 prevents the ego vehicle from changing lanes, thereby eliminating the associated vehicle-to-vehicle occlusion risk. As a result, the obstructed-view positions considered in safety analysis for a surrounding vehicle at Position 4 are reduced to Positions 1, 2, 3, and 5, as shown in Figure 50.

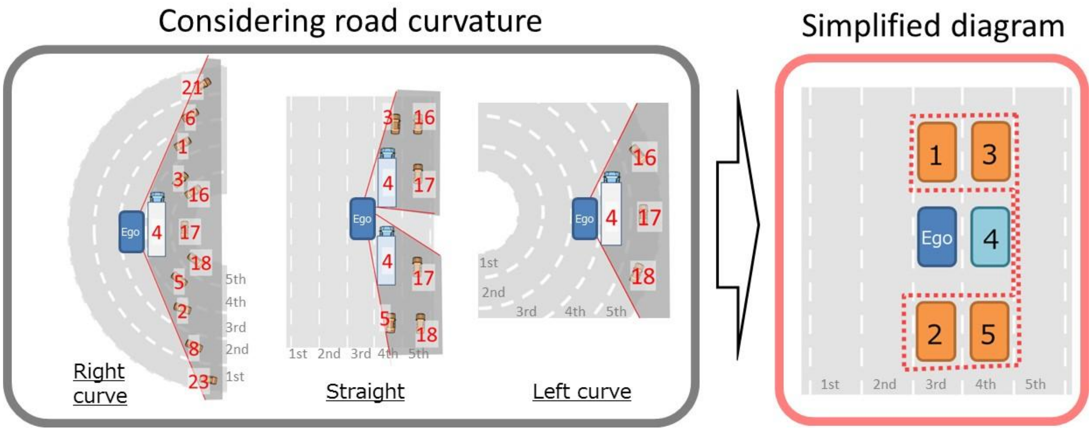


Figure 50. Obstructed-View Positions Resulting from a Surrounding Vehicle at Side Position 4

Obstructed-View Positions Generated by a Surrounding Vehicle at Position 3

Figure 51 illustrates the obstructed-view positions generated by a large surrounding vehicle located at Position 3, which is diagonally positioned relative to the ego vehicle. On a straight road, obstructed-view positions may occur at Positions 11, 15, and 16. On a right-hand curve, the number of obstructed-view positions increases to Positions 1, 6, 9, 11, 13, 15, 16, 20, and 21, while on a left-hand curve, vehicles at Positions 15 and 16 may become occluded by the large vehicle.

As in the previous cases, cut-in scenarios involving Positions 6, 13, 20, and 21 are replaced by more critical scenarios involving Positions 9 and 11. Similarly, deceleration scenarios at Positions 6 and 13 are substituted by scenarios in which the ego vehicle and a vehicle at Position 9 perform simultaneous lane changes. Consequently, the obstructed-view positions considered in safety analysis for a surrounding vehicle at Position 3 are reduced to Positions 1, 9, 11, 15, and 16, as summarized in Figure 52. These positions represent the critical configurations in which vehicle-to-vehicle occlusion may affect collision-avoidance behavior.

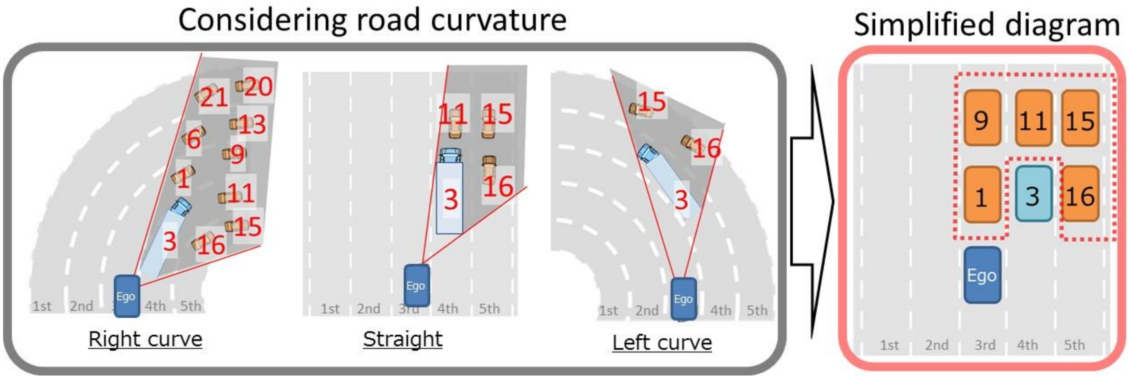


Figure 51. Obstructed-view positions induced by a surrounding vehicle at Position 3

Consolidation of Surrounding-Vehicle-Induced Obstructed-View Positions

By applying principles of analogy and symmetry to the three cases illustrated in Figure 49 through Figure 51, all obstructed-view positions that must be considered in safety analysis can be consolidated into a single representation (Figure 52). While the preceding discussion assumes that the ego vehicle and surrounding vehicles travel in the same direction, evaluation of general-road scenarios additionally requires consideration of occlusion caused by oncoming vehicles, which may generate analogous obstructed-view conditions.

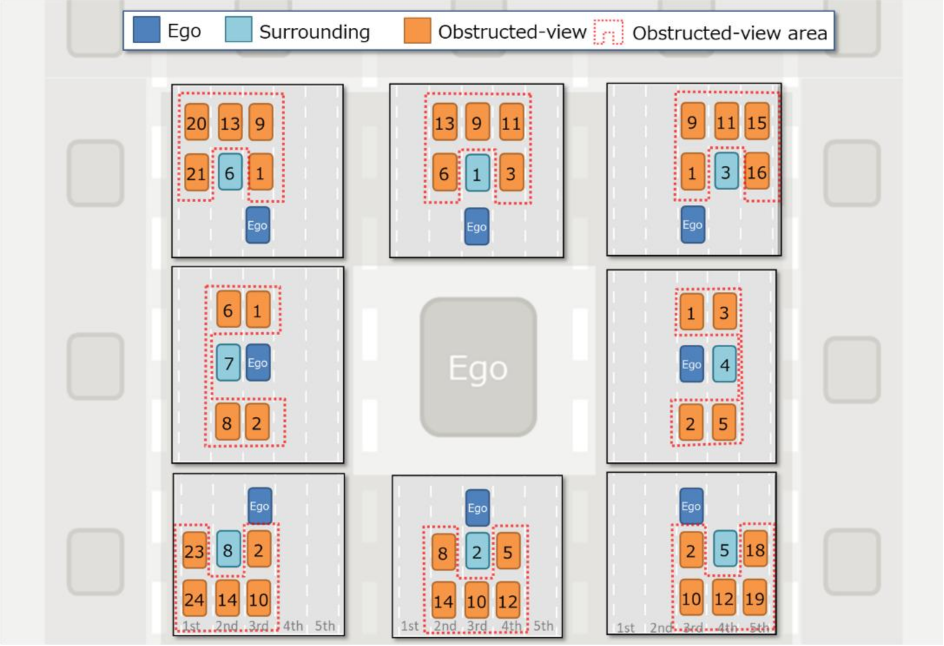


Figure 52. Complete set of Surrounding-Vehicle-Induced Obstructed-View Positions for Safety Analysis

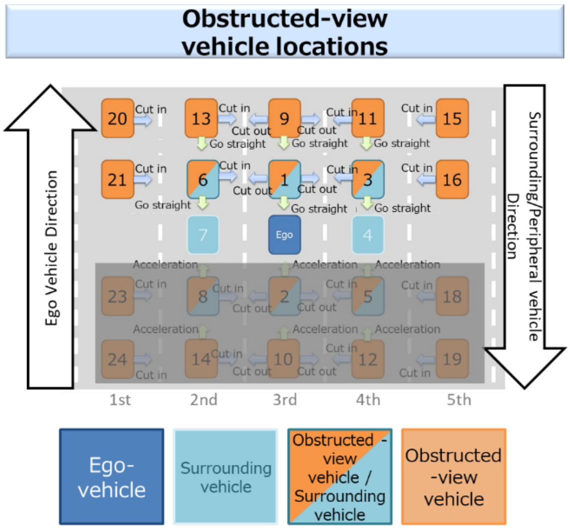
Movements of Obstructed-view Vehicles

The possible movements of vehicles located within obstructed-view regions (i.e., regions in which vehicles may be occluded) are classified into:

- straight driving (acceleration or deceleration); and
- lane change (cut-in, cut-out) or swerving.

To reduce the number of combinations requiring evaluation, safety analysis focuses on movements of obstructed-view vehicles that may obstruct the behavior of the ego vehicle (Figure 53). For example, deceleration maneuvers by vehicles located in obstructed-view positions behind the ego vehicle (Positions 2, 5, 8, 10, 12, 14, 18, 19, 23, and 24) are excluded because they do not pose a hazard to the ego vehicle. The same exclusions apply to oncoming vehicles.

In addition, synchronized motion between the ego vehicle and an obstructed-view vehicle does not create a hazardous situation. In Figure 53, circles indicate combinations of obstructed-view vehicle positions and movements that may obstruct the ego vehicle and therefore require safety evaluation.



Obstructed-view vehicle locations and motions

Obstructed-view vehicle location	Obstructed-view vehicle's motion	
	Go straight (Accel. Decel.)	Lane change /Swerving
1	○	○
3 (6)		○
9	○	
11 (13)	○	○
15 (20)		○
16 (21)		○

Figure 53. Obstructed-View Vehicle Positions (Left) and Combinations of Positions and Movements that May Obstruct the Ego Vehicle (Right)

Obstructed-View Conditions at Intersections

At intersections, the locations where obstructed-view conditions occur depend not only on whether the ego vehicle is traveling straight or turning, but also on whether surrounding vehicles are traveling in the same direction or in the oncoming direction. Figure 54 illustrates the positional relationships among the ego vehicle and surrounding vehicles under these conditions. When general roads are considered, scenario construction must explicitly account for occlusion caused by oncoming vehicles, in addition to occlusion generated by same-direction traffic.

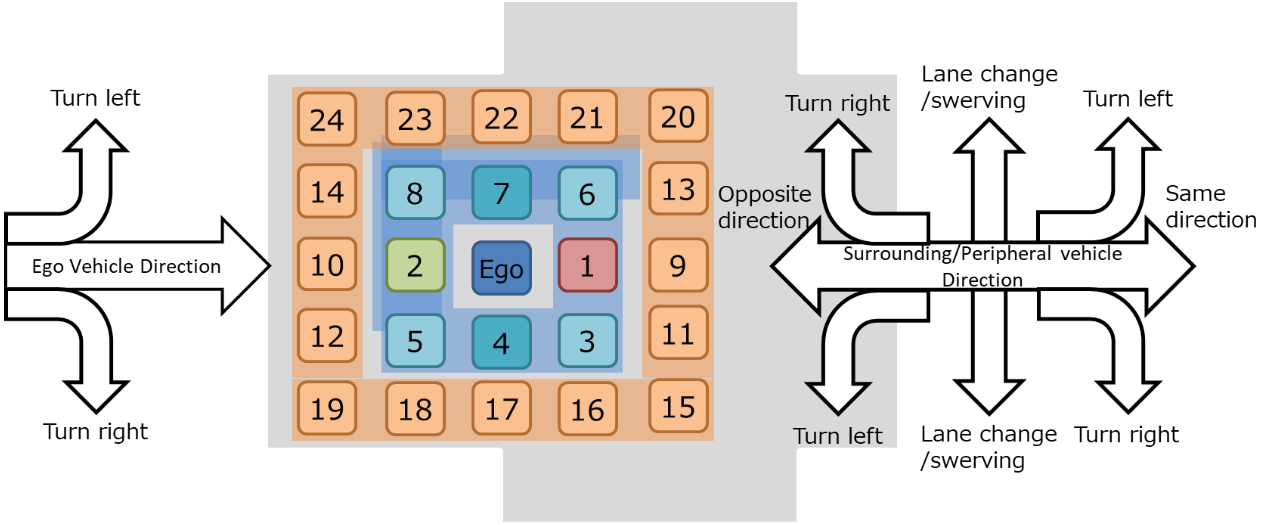


Figure 54. Positions of the Ego Vehicle and Surrounding Vehicles at an Intersection

Considering the possible vehicle behaviors at intersections, the arrangement of surrounding vehicles is equivalent to that shown in Figure 52. Figure 55 presents the results of assigning possible behaviors to surrounding vehicles in these arrangements and determining whether such behaviors can generate obstructed-view conditions and resulting vehicle-to-vehicle occlusion. Owing to left–right symmetry, only one side is illustrated.

Obstructed vehicle position	Surrounding vehicle behavior								
	Peripheral Lane keep			Peripheral Lane change/Swerving			Peripheral Turning		
	Obstructed vehicle behavior								
	Same	Crossed From L/R	On coming	Same	Crossed	On coming	Same	Crossed	On coming
1	○	○	○	○	○	○	○	○	○
3 (6)	○	○		○	○	○	○	○	○
9	○	○	○	○	○	○	○	○	○
11 (13)	○	○	○	○	○	○	○	○	○
15 (20)		○		○	○	○		○	
16 (21)		○		○	○	○		○	
17 (22)		○			○			○	

Figure 55. Arrangement of Surrounding Vehicles and their Behaviors at Intersections

3.4.2.9. Obstructed-View Scenarios Caused by Road Structures

Obstructed-view scenarios caused by road structures are defined by combining the positional relationships of roadway structures with the relative movements of the ego vehicle and the potentially occluded vehicle.

In general, such obstructing elements are located within the roadway structure and are classified, according to the type and position of the structure, into inner barriers and outer walls (Figure 56).

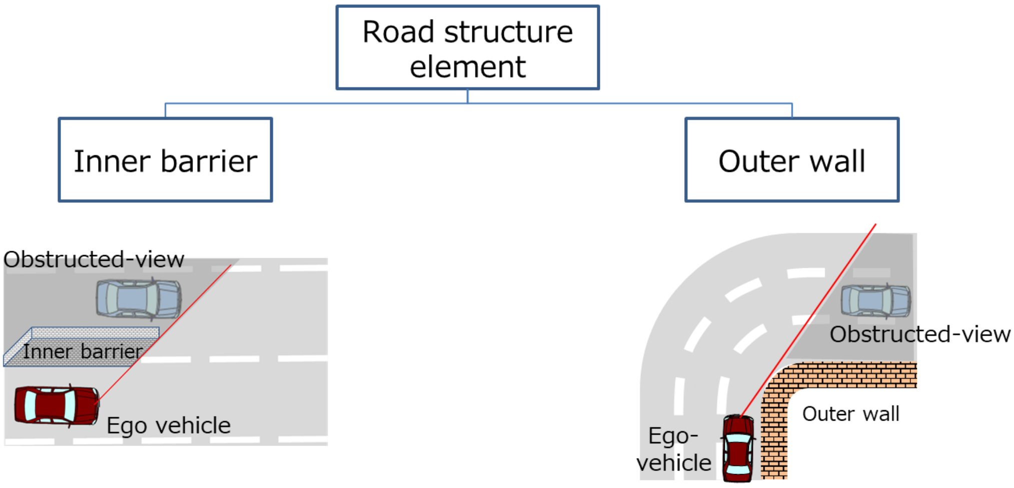


Figure 56. Classification of Obstructed-View Scenarios Caused by Road Structures

3.4.2.9.1. Obstructed-View Scenarios Caused by Inner Barriers

Figure 57 illustrates obstructed-view scenarios caused by inner barriers. When the ego vehicle is positioned upstream of the structure, a vehicle located behind the structure (Vehicle ①) becomes occluded by the structure and is therefore regarded as a obstructed-view vehicle.

A similar situation arises when the ego vehicle is positioned alongside the middle of the structure. In this case, vehicles located behind the structure (Vehicle ③) and ahead of the structure (Vehicle ④) may become occluded. Vehicles located at the lateral midpoint of the structure are considered not to affect safety, because the presence of the structure prevents those vehicles from moving closer to the ego vehicle’s lane.

In contrast, when a obstructed-view vehicle is positioned diagonally behind the ego vehicle (Vehicle ②), a safety concern arises. In such cases, the vehicle may suddenly appear immediately after the end of the structure, creating a potentially hazardous situation due to sudden loss and reappearance following structural occlusion.

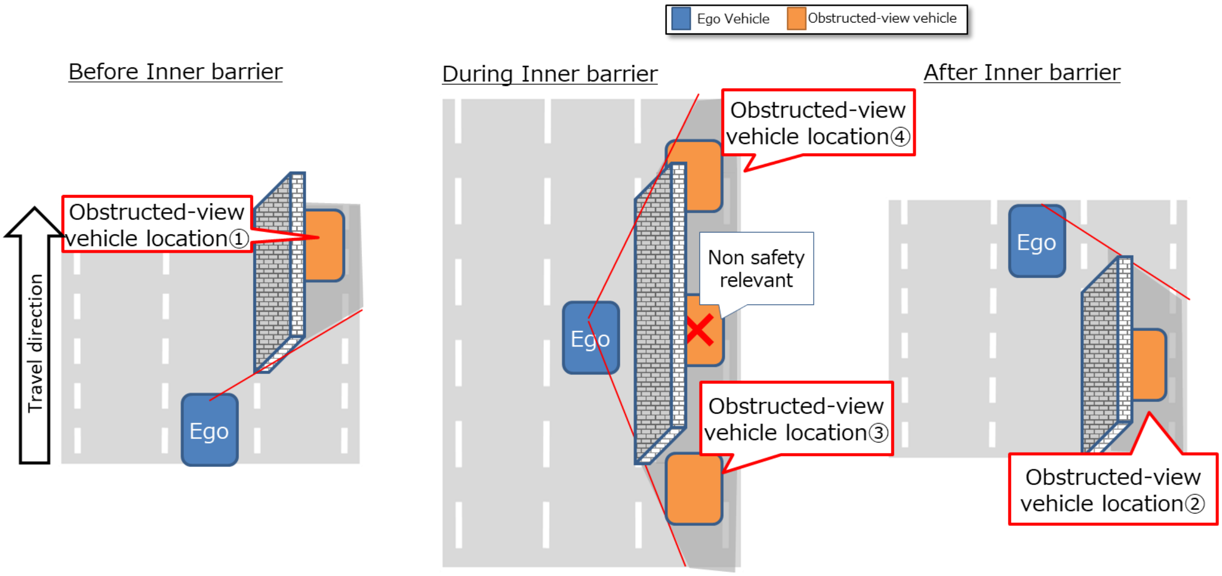


Figure 57. Definition of Obstructed-View Conditions and Structural Occlusion Caused by Internal Barriers

Figure 58 presents a matrix summarizing perception-limit scenarios associated with obstructed-views caused by inner barriers. In this matrix, the four obstructed-view regions described above—represented by blue rectangles indicating the ego vehicle and dark gray regions indicating obstructed-view vehicles—are combined with the possible maneuvers that obstructed-view vehicles may perform.

The considered maneuvers include straight driving and lane change; the same classifications apply to oncoming vehicles. This combination yields a total of 16 possible scenarios, although not all are safety-relevant. Based on safety relevance, nine obstructed-view scenarios associated with inner barriers—indicated by circles in Figure 58—are selected and incorporated into the safety analysis.

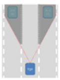
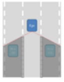
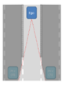
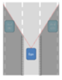
Inner barrier related Obstructed-view pattern	Obstructed-view vehicle's movement			
	Same direction		On coming	
	Obstructed-view vehicle's behavior			
	Go straight	Lane changing /swerving/turning	Go straight	Lane changing /swerving/turning
1 	○ Deceleration	X	○	○ Swerving, turning
2 	○ Acceleration	○ Cut-in	X	X
3 	X	○ Cut-in	X	X
4 	X	○ Cut-in, turning	○	○ Swerving, turning

Figure 58. Perception-Limit Scenarios related to Obstructed-Views Caused by Internal Barriers

3.4.2.9.2. Obstructed-View Scenarios Caused by Outer Walls

As illustrated in Figure 59, when the ego vehicle travels along the outer edge of a roadway where wall-like structures are present, vehicles located on curves or at intersections may become occluded by the outer walls, resulting in obstructed-view conditions. Depending on road curvature or intersection geometry, such outer walls may cause vehicles both ahead of and behind the ego vehicle to become structurally occluded, thereby forming obstructed-view regions.

Similar obstructed-view conditions also occur on general roads, in the same manner as on controlled-access roads. The primary differences are the greater variety of intersection geometries and the potential presence of oncoming traffic. When evaluating obstructed-view scenarios caused by outer walls, it is therefore necessary to consider:

- whether structural occlusion is present;
- the behaviors of vehicles located within obstructed-view regions; and
- the resulting potential for collision due to delayed visibility or sudden reappearance following occlusion.

The obstructed-view scenarios requiring evaluation under these conditions are summarized in Figure 60.

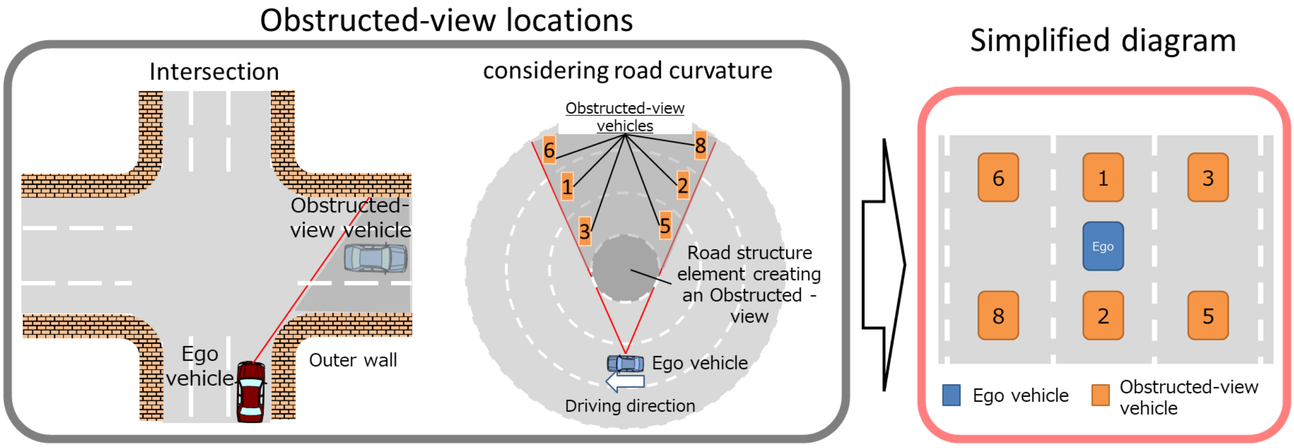


Figure 59. Conceptual Illustration of Structural Occlusion Generated by Outer Road Barriers

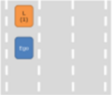
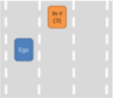
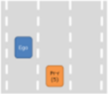
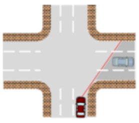
Outer barrier related Obstructed-view pattern	Ego vehicle behavior	Obstructed-view vehicle's movement			
		Same direction		On coming	
		Obstructed-view vehicle's behavior			
		Go straight /crossing	Lane changing /swerving/turning	Go straight /crossing	Lane changing /swerving/turning
1 	Going straight	○ Deceleration	○ Deceleration	○	○ Swerving, turning
	Lane change	X	○ Cut-out	○	○
2 	Going straight	○ Acceleration	○ Cut-out	X	X
	Lane change	X	○ Acceleration	X	X
3 	Going straight	○ Deceleration	○ Cut-in	○	○ Swerving, turning
	Lane change	○ Deceleration	○ Cut-in	○	○
4 	Going straight	○ Acceleration	○ Cut-in	X	X
	Lane change	○ Acceleration	○ Acceleration	X	X
5 	Going straight	○ crossing	○ Turning to same ego direction	○	○ Turning against ego direction
	Turning	○	X	○	○ Turning to intersecting direction

Figure 60. Perception-Limit Scenarios Related to Obstructed-View Conditions Caused by Outer Walls

3.4.2.10. Obstructed-View Scenarios Caused by Road Gradients

Obstructed-view scenarios related to road gradients are defined based on the geometric characteristics of the roadway gradient and the traffic patterns of the ego vehicle and the potentially occluded vehicle. Obstructed-view conditions caused by road gradients arise from vertical height differences along the same roadway, which reduce the available sight distance and may cause structural occlusion of vehicles beyond a crest or slope transition. These gradient-related conditions are classified into two types: longitudinal gradients and parallel gradients, as shown in Figure 61.

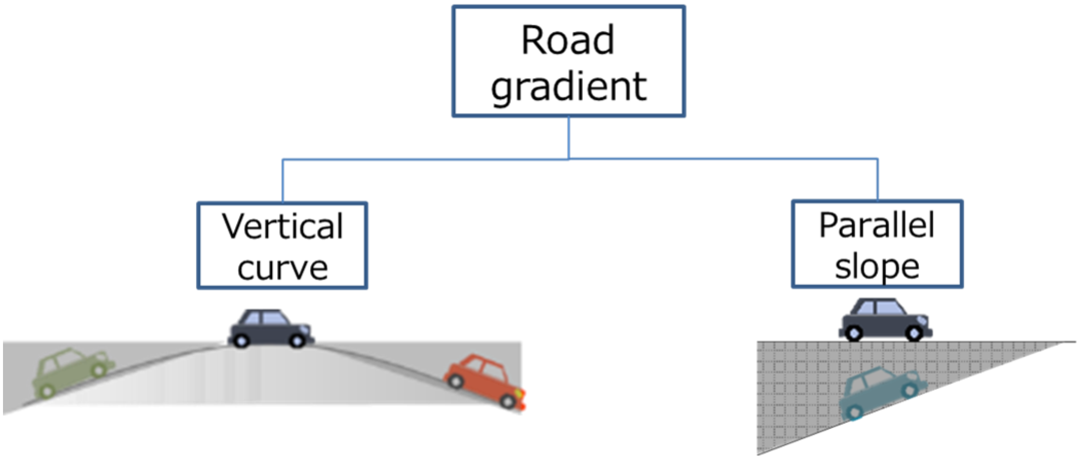


Figure 61. Classification of Obstructed-view Scenarios Caused by Road Gradients

3.4.2.10.1. Longitudinal-Gradient Scenarios

A longitudinal gradient (Figure 62) is a roadway configuration in which obstructed-view regions may arise both ahead of and behind the ego vehicle. When the roadway includes a convex crest or similar vertical profile change, vehicles located beyond the crest may become occluded by the road surface itself, resulting in temporary loss of visibility until the ego vehicle reaches a sufficient elevation. Because a longitudinal gradient reduces the ego vehicle's effective sight distance, certain combinations of surrounding-vehicles positions and movements—specifically Positions 1, 2, 3, 5, 6, and 8—together with the ego vehicle's own motion, can create potentially hazardous traffic situations due to delayed detection following gradient-induced occlusion.

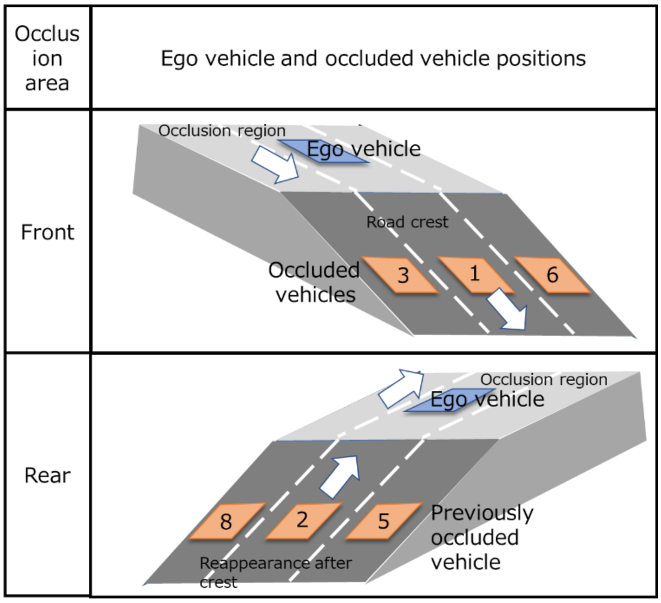
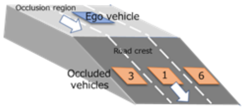
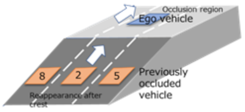
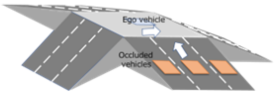
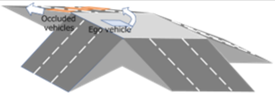


Figure 62. Conceptual Illustration of Structural Occlusion Generated by Longitudinal Gradients

illustrates the perception-limit scenarios that must be evaluated under longitudinal-gradient conditions. These scenarios are defined by considering:

- the presence or absence of structural occlusion;
- the movements of the vehicles involved; and
- the resulting potential for collision following reappearance from occlusion.

This evaluation takes into account both the longitudinal relationship between the ego vehicle and the vehicle located within the obstructed-view region and, where applicable, the lateral relationship between vehicles at intersections.

Classification of Obstructed-View Scenarios	Surrounding Vehicle Traveling Direction	
	Same direction	On coming
1 	○ Cut-in, Deceleration	○
2 	○ Cut-in, Acceleration	X
3 	○	○
4 	X Turning toward the occluded vehicle	X

○ = Applicable, X = Not applicable

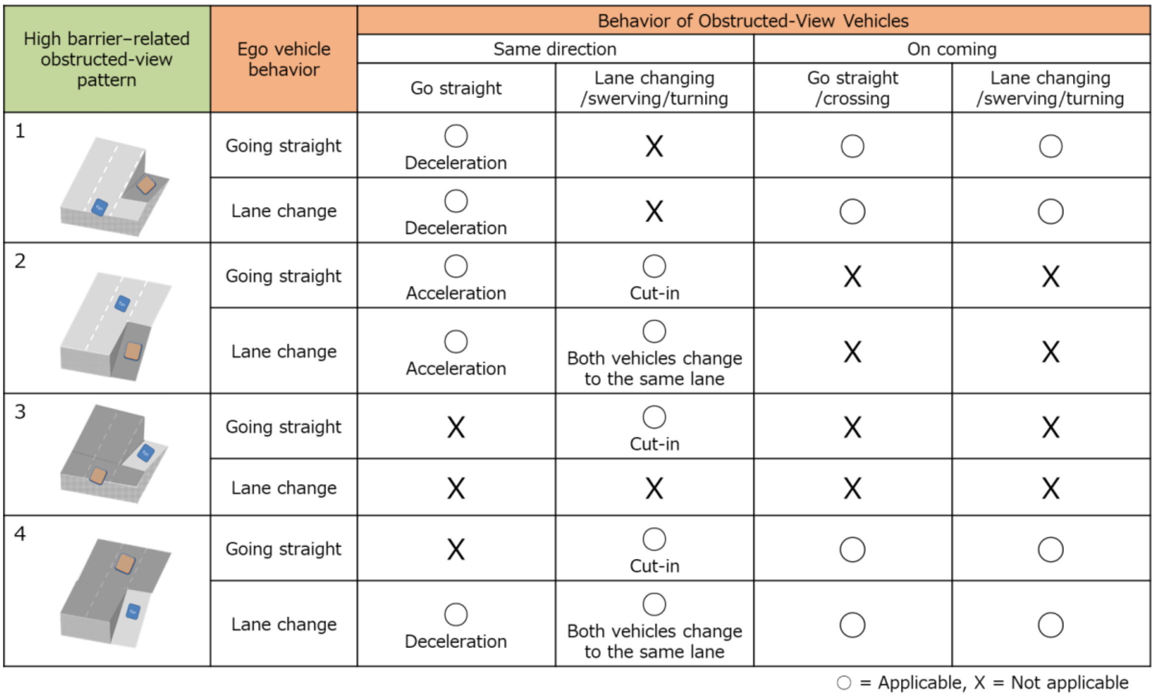
Figure 63. Perception-Limit Scenarios related to Obstructed-Views Conditions Caused by Longitudinal Road Gradients

3.4.2.10.2. Parallel-Gradient Scenarios

Obstructed-view conditions may arise when elevation differences occur between adjacent lanes due to slope-like gradients, such as those commonly found at merge and branch sections. Under such configurations, relative height differences between lanes may cause structural occlusion of vehicles in the adjacent lane, resulting in temporary perception limitations.

In these scenarios, evaluation patterns are defined by considering:
- the presence or absence of structural occlusion;
- the movements of the vehicles involved; and
- the resulting potential for collision following reappearance from occlusion.

These patterns are determined based on the road geometry and the travel directions of both the ego vehicle and the vehicle located within the obstructed-view region. The resulting perception-limit scenarios are illustrated in Figure 64.



High barrier-related obstructed-view pattern	Ego vehicle behavior	Behavior of Obstructed-View Vehicles			
		Same direction		On coming	
		Go straight	Lane changing /swerving/turning	Go straight /crossing	Lane changing /swerving/turning
1	Going straight	○ Deceleration	X	○	○
	Lane change	○ Deceleration	X	○	○
2	Going straight	○ Acceleration	○ Cut-in	X	X
	Lane change	○ Acceleration	○ Both vehicles change to the same lane	X	X
3	Going straight	X	○ Cut-in	X	X
	Lane change	X	X	X	X
4	Going straight	X	○ Cut-in	○	○
	Lane change	○ Deceleration	○ Both vehicles change to the same lane	○	○

○ = Applicable, X = Not applicable

Figure 64. Perception-Limit Scenarios related to Obstructed-View Conditions Caused by Parallel Road Gradients

3.4.2.11. Connectivity Disturbance Scenarios

A connectivity disturbance scenario refers to a situation in which the ADS's ability to perceive its surroundings is degraded due to instability in connectivity or degradation of information transmission. Such disturbances arise from factors related to sensors, the surrounding environment, or communication devices. Unlike sensor-based perception disturbances, connectivity disturbances inherently depend on communication infrastructures such as digital maps and Vehicle-to-Everything(V2X) communication. For this reason, disturbance factors related to connectivity must be classified and evaluated in a systematic manner. Accordingly, connectivity disturbance scenarios are defined by considering characteristics unique to connectivity across the following three categories: sensor, environment, and transmitter (Figure 65).

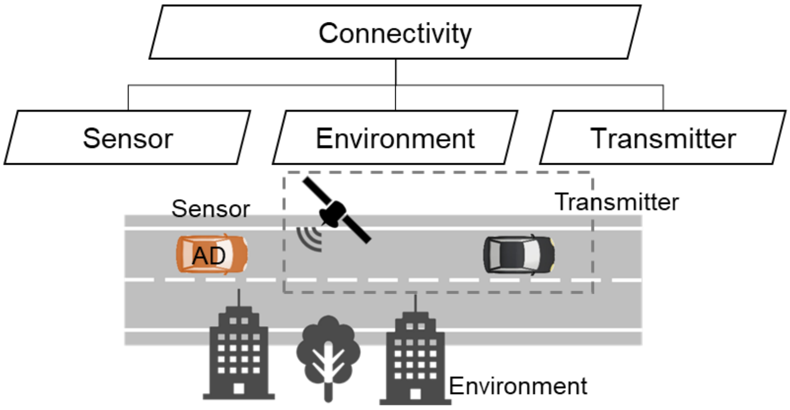


Figure 65. Classification of Perception Limits related to Connectivity Disturbances

3.4.2.12. Sensor Classification

As illustrated in Figure 66, sensor-related connectivity disturbances are classified into digital-map-related factors and V2X-related factors. Digital maps are used to support and implement functions essential to ADS operation, such as vehicle localization and navigation. When integrated with onboard perception sensors, digital maps also contribute to enhancing the overall reliability of the perception system by providing prior knowledge of road geometry and traffic infrastructure. In contrast, V2X is a communication mechanism that enables a vehicle to exchange information with other vehicles, roadside infrastructure, pedestrians, servers, and other entities. A key advantage of V2X lies in its ability to provide advance information about the surrounding environment, which is particularly valuable under adverse weather conditions or in complex traffic environments.

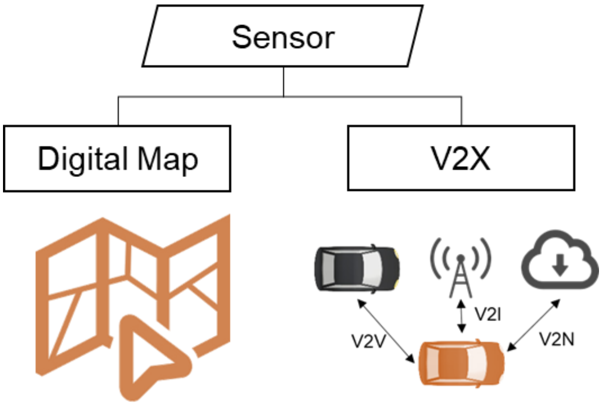


Figure 66. Classification of Perception Limits related to Sensor Connectivity Disturbances

A digital-map–related connectivity disturbance refers to situation in which map data cannot be correctly obtained or utilized. Such deficiencies may arise from deficiencies in map-related algorithms or from inappropriate timing of data acquisition. Typical examples include cases in which temporary lane closures or changes in road curvature are not reflected in the map data, resulting in the use of outdated information.
In addition, malfunctions or inconsistencies in sensor-fusion processing may affect both digital-map and V2X functionalities. In such cases, the digital map, V2X information, and onboard perception sensors may provide mutually inconsistent information, leading to further degradation of system-level perception.

3.4.2.13. Environmental Classification

As shown in Figure 67, environment-related connectivity disturbances are classified into static entities, spatial entities, and dynamic entities. These entities may interfere with communication or positioning signals and, as a result, may generate obstructed views or degrade the transmission of digital-map or V2X information.

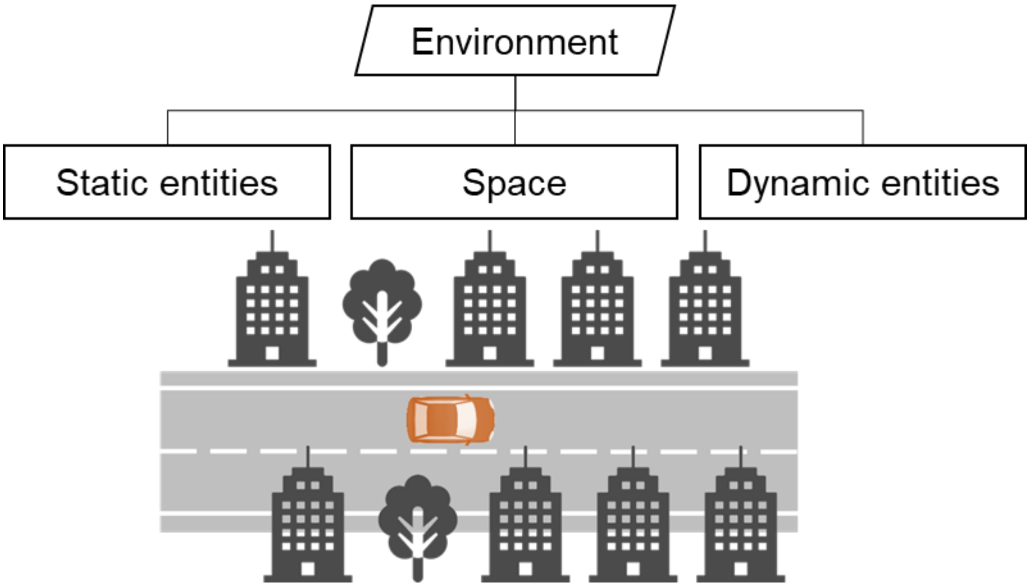


Figure 67. Classification of Perception Limits related to Environmental Connectivity Disturbances

- Static Entities: Fixed objects such as roadside structures (e.g., buildings, trees, tunnels), objects beneath elevated structures (e.g., overpasses), and underground structures (e.g., parking facilities).
- Spatial Entities: Environmental conditions that interfere with communication connectivity, including signal interference and signal attenuation caused by rain, fog, or similar phenomena.
- Dynamic Entities: Factors arising from moving objects in the surrounding environment, including other vehicles, motorcycles, pedestrians, and similar road users.

3.4.2.14. Transmitter Classification

As illustrated in Figure 68, transmitter-related connectivity disturbances are classified according to the type of transmitting entity, including other vehicles, infrastructure, pedestrians, servers, and satellites. Errors or malfunctions in transmitters may cause V2X messages to become unavailable or reduce their reliability. In addition, errors related to satellite systems may result in loss, degradation, or misinterpretation of Global Navigation Satellite System (GNSS) signals.

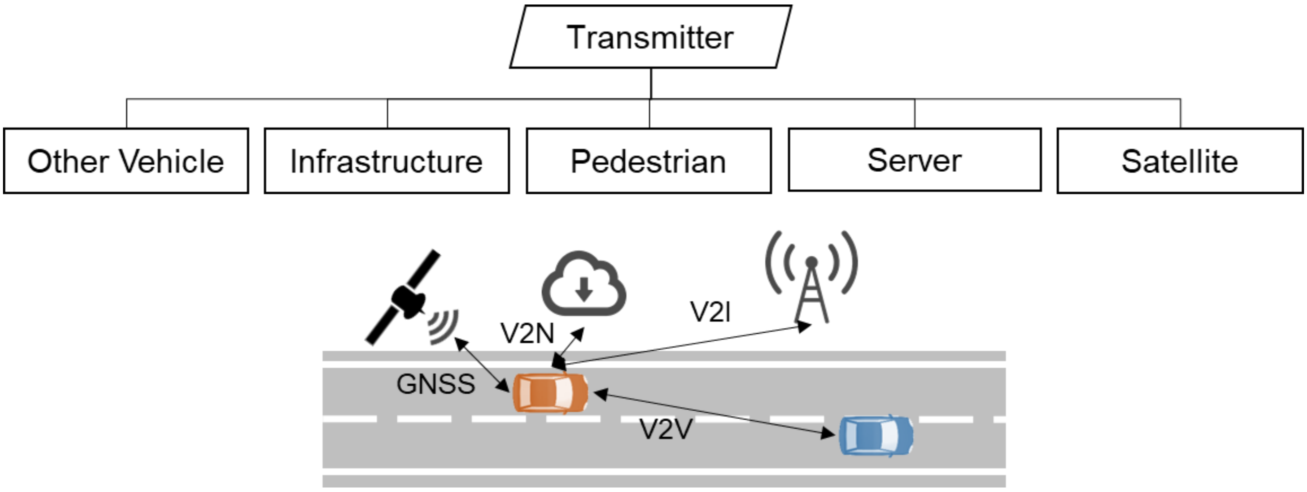


Figure 68. Classification of Perception Limits related to Transmitter Connectivity Disturbances

3.4.3. Vehicle-Dynamics Disturbance Scenarios

This section describes the framework and criteria for vehicle-dynamics disturbance scenarios used to assure the safety of ADS. A safe state under vehicle-dynamics disturbances is defined as a condition in which no accident occurs, even if vehicle motion changes due to sudden disturbances. The effects of such disturbances on vehicle motion can be broadly classified into two types.

The first type consists of factors in which external forces act directly on the vehicle body, affecting motion in the lateral, longitudinal, and yaw directions. The second type consists of factors in which tire-generated forces fluctuate, affecting vehicle motion in the lateral, longitudinal, vertical, and yaw directions (Figure 69).

These two types of inputs form the basis for classifying vehicle-dynamics disturbance scenarios into:

- body-input disturbances; and
- tire-input disturbances (Figure 70).

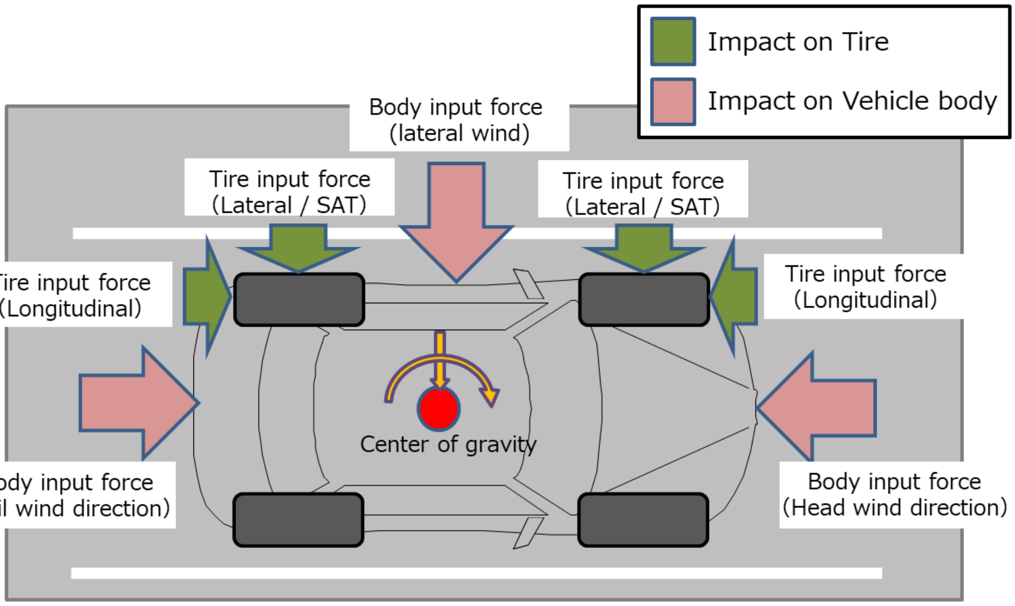


Figure 69. External Physical Forces Considered in Defining Vehicle-Dynamics Disturbance Scenarios

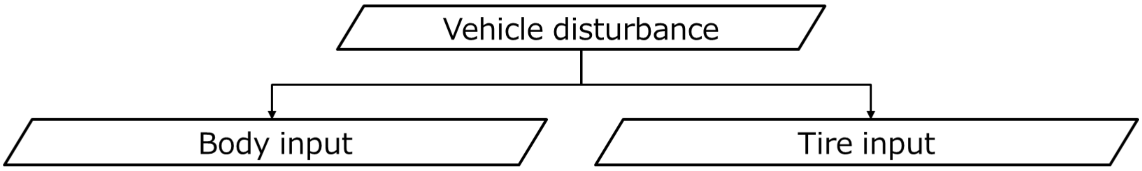


Figure 70. Systematic Structure of Vehicle-Dynamics Disturbance Scenarios

3.4.3.1. Classification of Body-Input Disturbances

Factors that affect the vehicle body are classified into road geometry and natural phenomena (Figure 71). Road geometry factors includes superelevation on curved sections, longitudinal gradients, and road curvature. Natural phenomena include crosswinds, tailwinds, and headwinds, and headwinds that occur under natural conditions. All of these factors act directly on the vehicle body and influence vehicle motion in the lateral, longitudinal, and yaw directions.

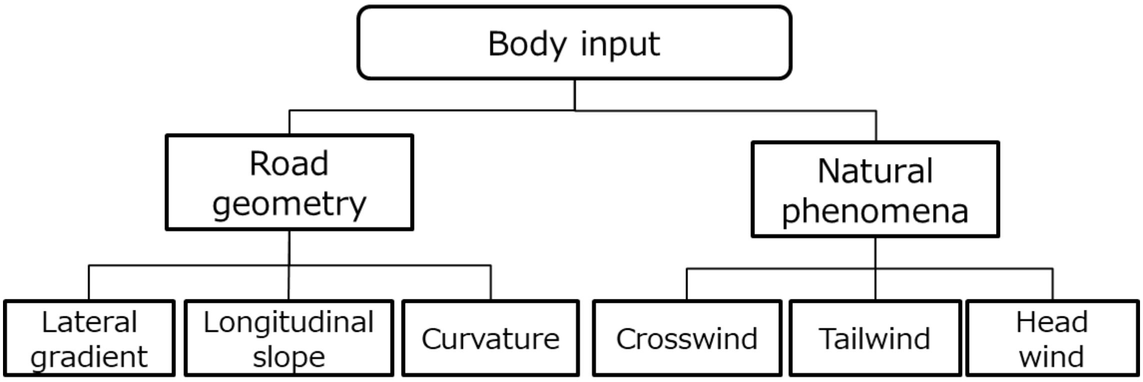


Figure 71. Systematic Structure of Body-Input Disturbance Scenarios

3.4.3.1.1. Road geometry

The direction and magnitude of gravitational force acting on the vehicle body vary depending on road geometry, such as curvature and road-surface inclination. For example, on curved sections, superelevation introduces a lateral component of gravitational force, which may increase the risk of lane departure.
In addition, on uphill gradients, forces act rearward on the vehicle, while on downhill gradients, forces act forward. These longitudinal force components may induce velocity fluctuations and, as a consequence, increase the risk of collisions with other vehicles(Figure 72).

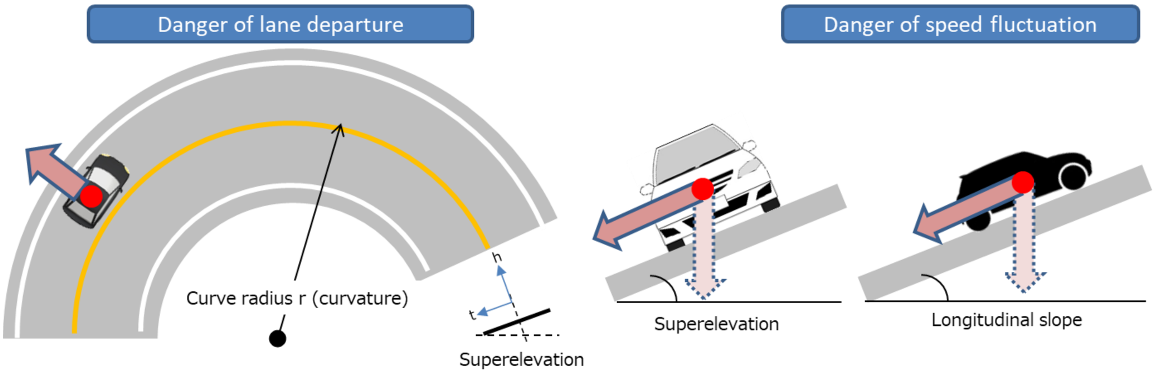


Figure 72. Classification of Road Geometry

3.4.3.1.2. Natural phenomena

When lateral or longitudinal forces are applied to the vehicle body by naturally occurring gusts or strong winds, the vehicle may be displaced from its intended trajectory. Such disturbances can result in lane departure or velocity fluctuations and may consequently increase the risk of collisions with other vehicles (Figure 73).

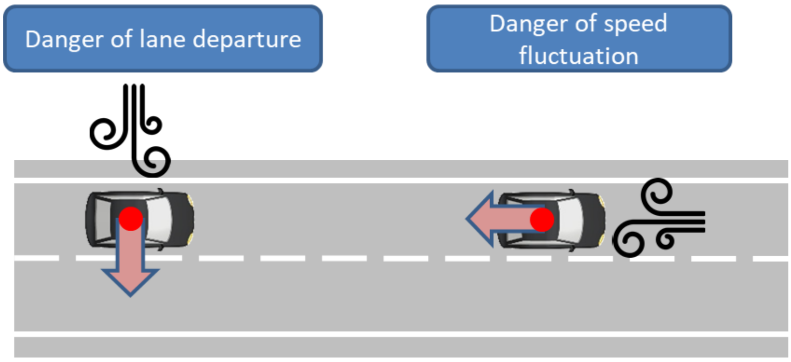


Figure 73. Classification of Natural Phenomena

3.4.3.2. Classification on Tire-Input Disturbances

Factors that affect the tires are classified into road-surface conditions and tire conditions (Figure 74).
Road-surface conditions refer to changes in the road surface that directly influence tires behavior. For example, variations in the friction coefficient between the road surface and the tires—caused by uneven surfaces, wet conditions, or contaminants—may reduce available grip and adversely affect vehicle stability.
Tire conditions refer to factors such as punctures, blowouts, and tire wear, which can significantly alter tire characteristics and degrade force generation. Such conditions may lead to vehicle instability and loss of controllability.
All of these tire-related factors can induce hazardous vehicle behavior if not appropriately managed.

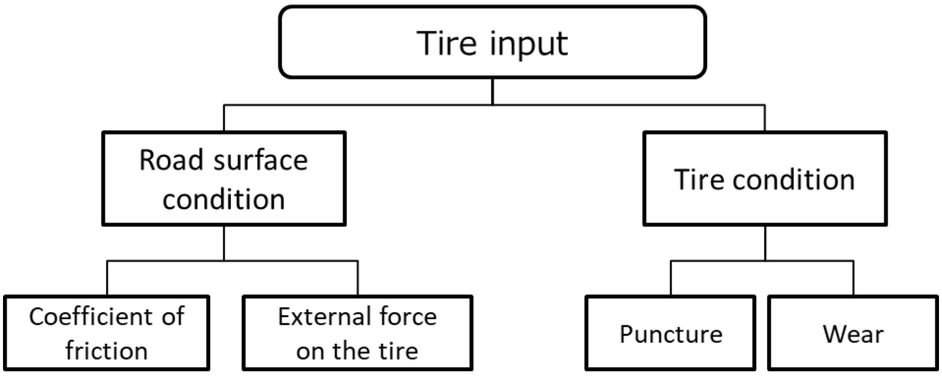


Figure 74. Systematic Structure of Tire-Input Disturbance Scenarios

3.4.3.2.1. Road-Surface Conditions

Depending on the road-surface geometry, variations in tire inputs and changes in the road–tire friction coefficient (μ) can cause fluctuations in tire forces, thereby affecting vehicle behavior. For example, external forces induced by road-surface irregularities or reductions in friction caused by rain may alter the vehicle's traveling direction and, in some cases, lead to lane departure or velocity fluctuations, increasing the risk of collisions with other vehicles. Accordingly, road-surface conditions are classified into the following two categories (Figure 75):

- friction coefficient, and
- external forces.

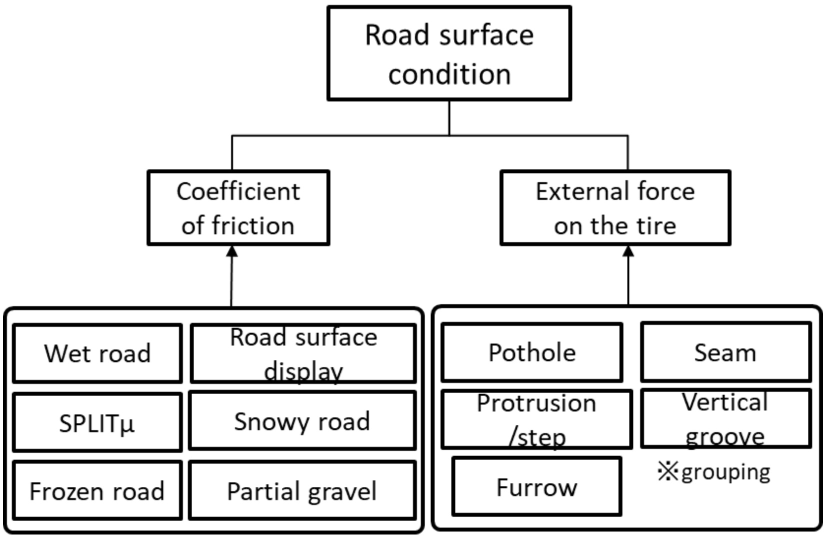


Figure 75. Classification of Road Surface Conditions

Road-surface factors that affect the friction coefficient between the tire and the road include wet roads, icy roads, snow-covered roads, and localized gravel. For example, when a vehicle suddenly transitions from a dry road surface to a wet road surface, the friction coefficient decreases, which may adversely affect vehicle stability (Figure 76, upper left). In contrast, external forces related to the road surface arise from features such as potholes, protrusions, and grooves. When a vehicle traverses a road step or protrusion, a force is rapidly applied to the tire in an obliquely upward direction (Figure 76, upper right), causing a change in the vehicle's traveling direction. Such changes may result in deviation from the planned trajectory and increase the risk of collision.

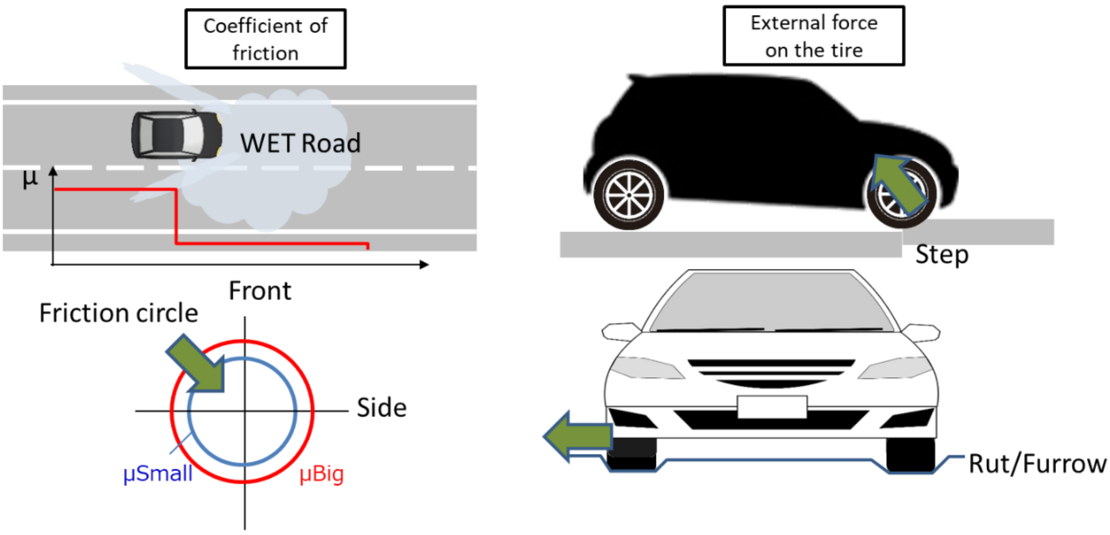


Figure 76. Vehicle-Dynamics Disturbances related to Road-Surface Conditions Caused by Changes in Friction Coefficient (Left) and External Forces Acting on Tires (Right)

3.4.3.2.2. Tier Conditions

Tire conditions refer to factors in which changes in tire characteristics affect vehicle behavior. Tire force generation may be reduced due to tire wear, punctures, or blowouts (Figure 77). As a result, lane departure or vehicle velocity fluctuations may occur, potentially increasing the risk of collisions with other vehicles.

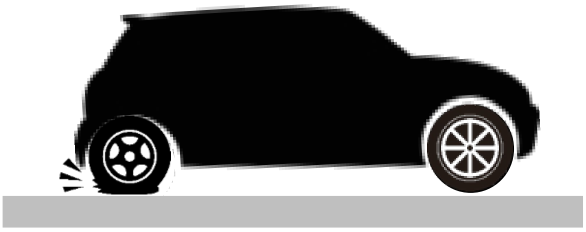


Figure 77. Vehicle-Dynamics Disturbances related to Tire Conditions Caused by a Blowout

3.4.3.3. Safety Approach for Foreseeable Vehicle-Dynamics Disturbance

Before describing the technical safety approach for foreseeable vehicle-dynamics disturbances, this section first outlines two general prerequisite conditions that form the basis for subsequent safety determination.

Prerequisite Conditions

Before defining the technical safety approach for foreseeable vehicle-dynamics disturbances, the following two prerequisite conditions are established. These conditions represent commonly accepted assumptions regarding the operating environment and the responsibilities of the ADS operator and form the basis for subsequent safety determination.

Prerequisite 1: Common Assumptions Regarding Road Design, Maintenance, and Environmental Conditions

The first prerequisite concerns commonly accepted assumptions related to the design, maintenance, and environmental conditions of road infrastructure. Roads are assumed to be designed, constructed, and continuously maintained by responsible public or private authorities in accordance with applicable laws, engineering standards, and accepted safety practices.

In many countries, road-structure regulations are established to ensure that roads can be safely used by all licensed drivers, regardless of age or skill level. For example, in Japan, road-design standards specify minimum curve radius such that lateral acceleration does not exceed 0.11 G on wet road surfaces at a design velocity of 100 km/h. If this requirement cannot be satisfied, the design speed is reduced accordingly.

In addition, road administrators are expected to promptly identify and address hazardous conditions, such as reduced friction due to ice or road-surface degradation caused by cracks, uplift, or potholes. With respect to natural environmental conditions, authorities are expected to define the range within which safe driving is possible and to impose speed restrictions or road closures during extreme events, such as disaster-level storms.

Drivers are required to comply with such measures, and Automated Driving Systems are subject to the same principle. Conditions in which road-design, maintenance, or environmental assumptions are not satisfied are therefore classified as unpreventable within the ADS safety assurance framework.

Prerequisite 2: Responsibility of the ADS Operator

The second prerequisite concerns commonly accepted assumptions regarding the responsibility of the ADS operator. While the ADS assumes responsibility for the DDT during automated operation, the operator remains responsible for ensuring that the vehicle is in a condition suitable for safe operation prior to activation of the system.

Specifically, the operator is responsible for refraining from operating the ADS when aware of maintenance deficiencies, including, but not limited to:

- excessive tire wear below legally required inspection standards;
- tire pressure lower than values recommended by the tire manufacturer;
- failure to address a punctured tire; and
- operating conditions that prevent the vehicle from delivering its original performance, such as the use of a temporary spare tire, studless tires, or tire chains.

If the ADS is activated under such conditions, collision avoidance may no longer be feasible. Accordingly, scenarios arising from these conditions are treated as unpreventable within the scope of vehicle-dynamics disturbance evaluation.

3.4.3.3.1. Engineering Safety Approach to Vehicle-Dynamics Disturbances

Based on the prerequisite conditions defined in the previous section, this section describes the engineering safety approach for addressing foreseeable vehicle-dynamics disturbances.

The fundamental concept of this approach is to clearly distinguish between conditions under which vehicle motion can be controlled and conditions under which vehicle control becomes difficult or impossible. Accordingly, the safety approach is structured around two complementary objectives:

- collision avoidance under conditions that are both foreseeable and preventable; and
- harm mitigation under conditions that are foreseeable but unpreventable.

When vehicle behavior is affected by vehicle-dynamics disturbances that remain within the preventable range, the ADS is required to maintain stable control and continue driving without interruption. In contrast, when disturbances exceed the preventable range and lead to unpreventable conditions, the ADS is required to apply a best-effort strategy to minimize the consequences of a potential collision.

Figure 78 illustrates this safety concept. In the upper example, an ADS encounters a sudden reduction in road friction on a wet surface but remains within the preventable range and is able to maintain stable vehicle control. In the lower example, an ADS equipped with summer tires encounters an icy road surface, resulting in a severe reduction in friction and entry into an unpreventable condition, in which only mitigation measures—such as maximum deceleration—can be applied.

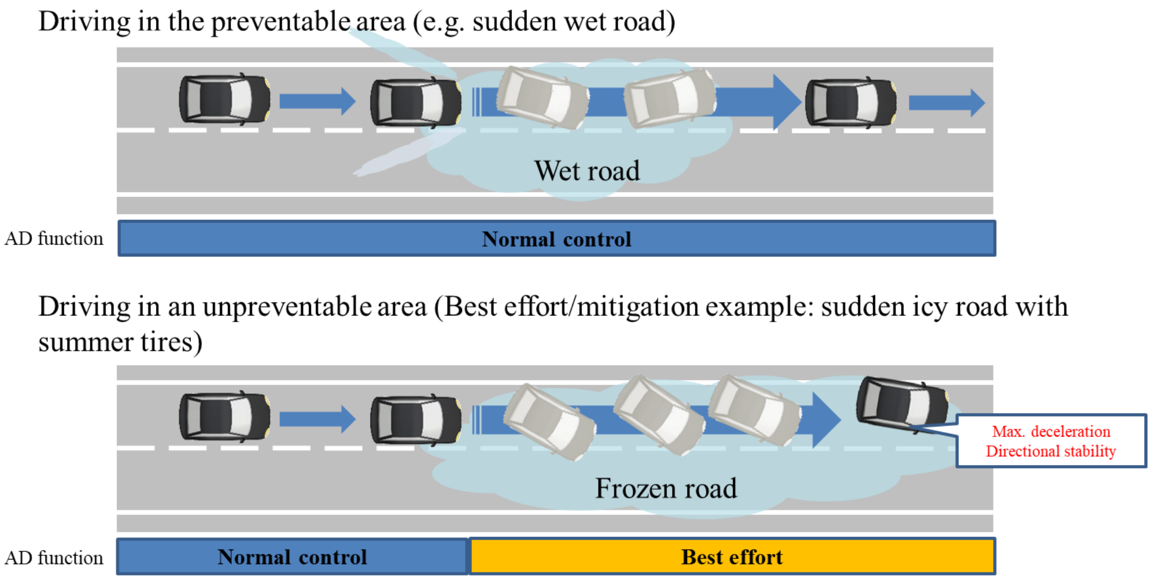


Figure 78. Safety Approach to Vehicle-Dynamics Disturbances under Preventable (Upper) and Unpreventable (Lower) Conditions

Thus, the safety approach is formalized by defining the relationship between vehicle motion principles and controllability using two engineering metrics:

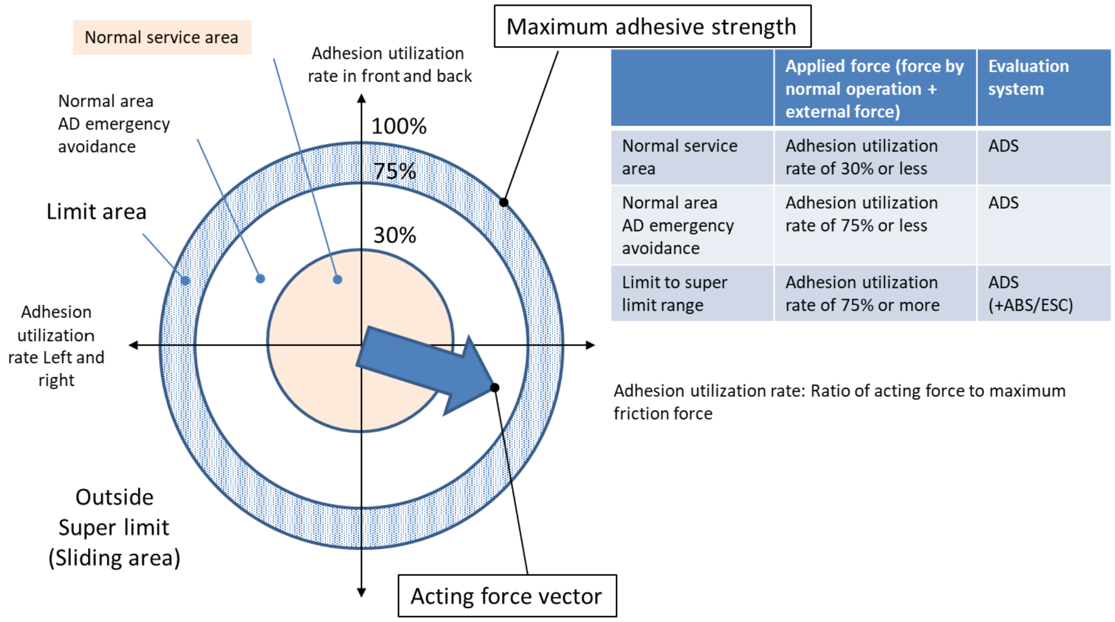
1. Forces acting on the vehicle, representing the combined effects of driving inputs and external disturbances (e.g., road geometry, wind, road-surface conditions, and tire conditions); and
2. Adhesion utilization rate (ε), which represents the proportion of available tire–road friction being utilized.

Figure 79 conceptually illustrates how the vehicle operating domain into regions based on the adhesion utilization rate ε:

- Normal operation region (ε ≤ 30%), corresponding to typical driving conditions;
- Emergency-avoidance region (30% < ε ≤ 75%), corresponding to conditions in which the ADS performs emergency avoidance maneuvers;
- Limit region (75% < ε ≤ 100%), representing boundary conditions in which vehicle control systems such as ABS are activated; and
- Over-limit region (ε > 100%), in which tire grip is lost.

When the combined forces acting on the vehicle remain within ε ≤ 75%, vehicle motion is physically controllable, and collision-avoidance strategies can be applied. When ε exceeds 75%, vehicle control becomes increasingly difficult, and the ADS shall prioritize collision-mitigation strategies.

Through this structured distinction between preventable and unpreventable conditions, the engineering safety approach provides a clear and physically grounded basis for safety determination under vehicle-dynamics disturbances.



	Applied force (force by normal operation + external force)	Evaluation system
Normal service area	Adhesion utilization rate of 30% or less	ADS
Normal area AD emergency avoidance	Adhesion utilization rate of 75% or less	ADS
Limit to super limit range	Adhesion utilization rate of 75% or more	ADS (+ABS/ESC)

Adhesion utilization rate: Ratio of acting force to maximum friction force

Figure 79. Conceptual Diagram of Vehicle Forces and Adhesion Utilization Rate Defining the Safety Approach to Vehicle-Dynamics Disturbances

3.4.3.4. Controllable Range of Vehicle Dynamics

Vehicle-dynamics disturbances can dynamically change the forces acting on a vehicle and may cause transition into regions in which maintaining stable vehicle control becomes difficult. The controllable range of vehicle dynamics is therefore defined by the relationship between the forces acting on the vehicle and the available tire–road friction. Figure 80 illustrates the controllable region and the region in which vehicle control becomes difficult, using the acting force and the road-tire friction coefficient as representative axes.

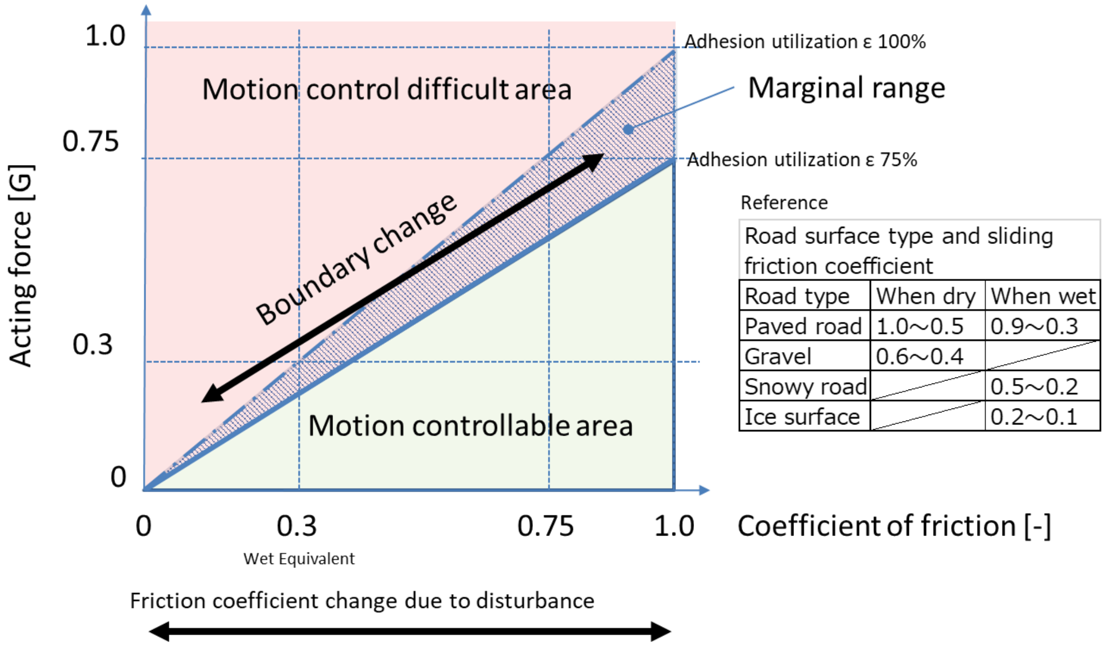
The sliding friction coefficient of paved roads generally falls within the following ranges:

- Dry conditions: 0.5–1.0
- Wet conditions: 0.3–0.9
- Icy conditions: 0.1–0.2

To ensure that the forces induced by vehicle-dynamics disturbances remain within the controllable region, AD vehicles shall be designed to implement appropriate motion-control strategies and shall verify their performance through testing. This controllable operating region is represented by the green triangular area shown in Figure 80.

NOTE:

The sliding friction coefficient generally refers to the value under locked-wheel conditions. Experimental studies (e.g., *Müller et al. Development of a Real-Time Friction Estimation Procedure, 2017*) reports that the sliding friction coefficient during rainy driving conditions is approximately 0.6.



Road surface type and sliding friction coefficient

Road type	When dry	When wet
Paved road	1.0～0.5	0.9～0.3
Gravel	0.6～0.4	
Snowy road		0.5～0.2
Ice surface		0.2～0.1

Figure 80. Controllable Range of Vehicle Dynamics

3.4.3.4.1. Controllability under Road-Geometry–Induced Body-Input disturbances

Among road-geometry-related factors, the curve radius represents the most critical condition affecting vehicle controllability. Road-structure regulations specify minimum curve radii to ensure stable driving on curved road sections. These minimum values are defined by considering not only the balance between centrifugal force and road–tire friction, but also occupant comfort and acceptable lateral acceleration.

Under Japanese road-structure regulations, for a design speed of 100 km/h, the minimum curve radius is specified as 460 m (or 380 m under provisional conditions). The relationship among vehicle velocity, curve radius, superelevation, and the friction coefficient required to prevent lateral sliding is expressed by the following equation:

$$Z = \frac{G}{g}\frac{v^2}{R} \quad \cdot\cdot\cdot \text{(Equation 1)}$$

where:

Z: centrifugal force (N)
v: vehicle velocity (m/s)
g: acceleration due to gravity (= 9.81 m/s²)
G: total vehicle weight (N)
F: friction coefficient between the road surface and the tire against lateral slip
i: road superelevation (= tan α)
R: curve radius (m)

The condition under which lateral sliding does not occur is given by:

$$Z\cos\alpha - G\sin\alpha \leqq f(Z\sin\alpha + G\cos\alpha) \quad \cdot\cdot\cdot \text{(Equation 2)}$$

By substituting Equation (1) into Equation (2) and rearranging, the following expression is obtained:

$$R \geq \frac{V^2}{127(i+f)} \quad \cdot\cdot\cdot \text{(Equation 3)}$$

The friction coefficient f, corresponding to lateral acceleration, is expressed as:

$$f = \frac{V^2}{R*127} - i \quad \cdot\cdot\cdot \text{(Equation 4)}$$

For example, when the design speed is 100 km/h, the superelevation is 6%, and the curve radius is 463 m, the resulting friction coefficient is f = 0.11. In other words, Japanese controlled-access highways are designed such that vehicles can travel at a lateral acceleration of 0.11 G at a speed of 100 km/h.

For road geometries that do not satisfy this condition—for example, when available adhesion is reduced due to rainfall or terrain effects—the posted speed limit must be reduced accordingly. Therefore, on controlled-access highways in Japan, normal operation assumes adhesion corresponding to a maximum lateral acceleration of 0.11 G.

Figure 81 illustrates this maximum disturbance value due to road geometry (0.11 G) as a reference line. For instance, on a dry road surface with a friction coefficient of 0.75, the remaining available force margin is 0.45 G (0.56 G − 0.11 G), whereas on a wet road surface, the remaining margin is reduced to 0.12 G. Accordingly, when evaluating vehicle-dynamics disturbances, road geometry shall always be taken into account, and the combined forces generated by road geometry and other disturbance factors shall remain within the controllable region of vehicle motion.

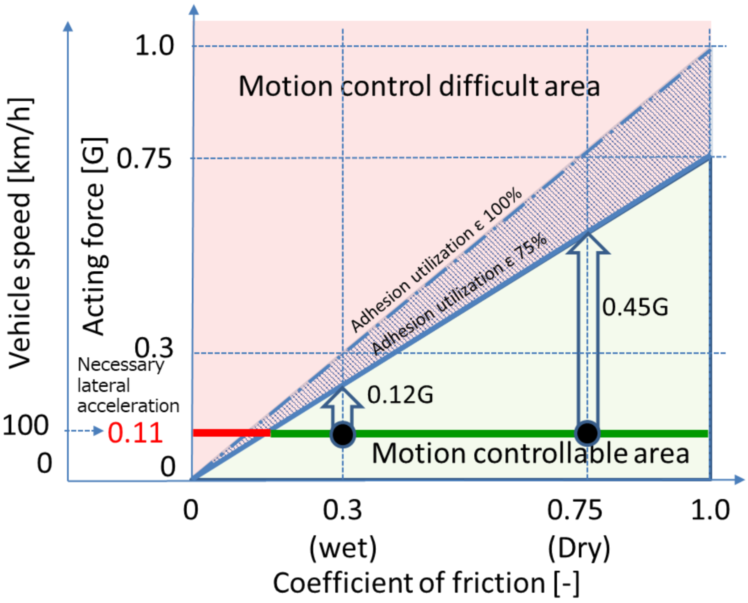


Figure 81. Relationship between the Friction Coefficient and Acting Forces with Respect to Road Geometry

Vehicle-dynamics disturbance factors do not necessarily occur in isolation. Accordingly, it is necessary to consider situation in which multiple disturbance factors act simultaneously. In real-world environments, for example, vehicle traveling through a curve during rainfall may also be subjected to a crosswinds.

Road-surface conditions─such as dry, wet, or snow-covered roads─can be represented in terms of the road-tire friction coefficient. In contrast, road geometry, natural phenomena (e.g., crosswinds), and external forces acting on the tires (e.g., road-surface irregularities) can be represented as acting forces. In addition, a tire puncture can be modeled as a condition in which the adhesion utilization rate cannot reach 100% (Figure 82).

Therefore, vehicle-dynamics disturbances shall be evaluated not as individual factors, but as combinations of multiple factors.

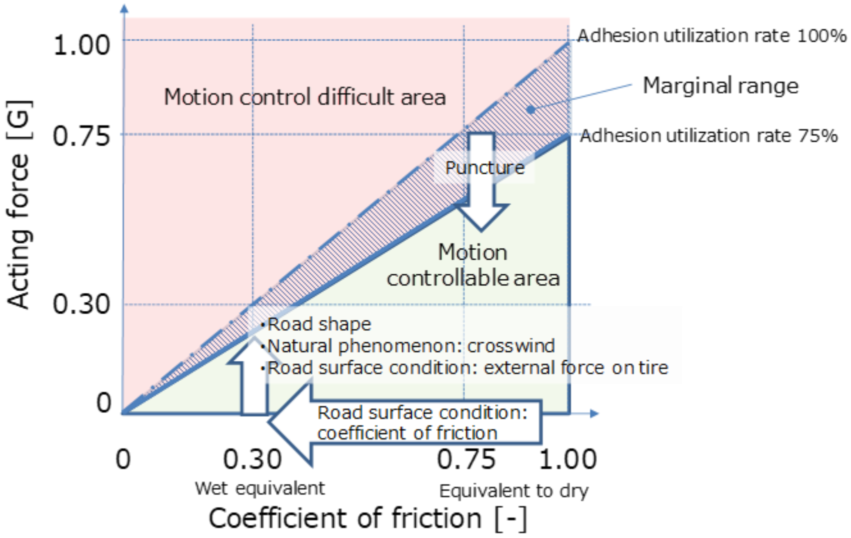
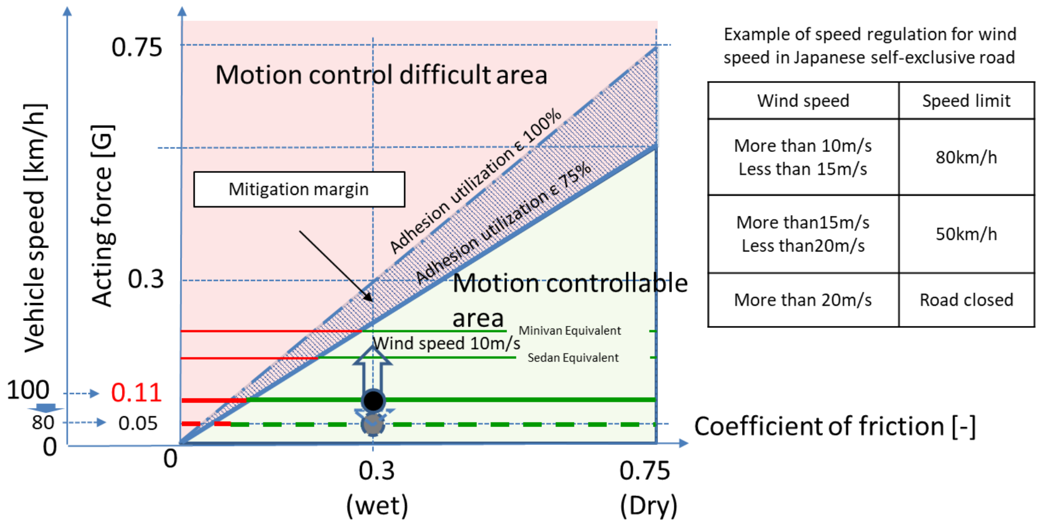


Figure 82. Combinations and Relationships of Factors in Vehicle-Dynamics Disturbances

3.4.3.4.2. Controllability under Natural-Phenomenon–Induced Body-Input Disturbances

Natural phenomena, such as wind, introduce external forces that act directly on the vehicle body and therefore constitute body-input disturbances. These disturbances are treated as additional acting forces and are superimposed on the forces required for normal driving, including those arising from road geometry.
Among natural phenomena, crosswinds represent the most critical disturbance affecting vehicle controllability. The magnitude of the acting force generated by crosswinds depends on factors such as wind speed, vehicle shape, and vehicle size. As illustrated in Figure 83, the acting force induced by a given crosswind speed differs significantly between vehicle classes, for example between sedan-class vehicles and minivan-class vehicles.

At higher wind speeds, the combined acting force may cause the adhesion utilization rate to exceed the controllable range. For instance, at a wind speed of approximately 20 m/s, even a sedan-class vehicle may enter a region in which the adhesion utilization rate exceeds 75%, corresponding to a condition in which vehicle control becomes difficult and mitigation measures are required.
On controlled-access highways in Japan, however, speed regulations are imposed when wind speeds exceed approximately 10 m/s. These regulations reduce the vehicle speed and, consequently, the acting force required due to road geometry. As a result, stable driving can be maintained even under wind conditions exceeding 10 m/s.
Accordingly, for controlled-access highways in Japan, a wind speed of less than 10 m/s, under which driving at a design speed of 100 km/h is permitted, is defined as the boundary condition for controllability with respect to wind-induced disturbances.



Example of speed regulation for wind speed in Japanese self-exclusive road

Wind speed	Speed limit
More than 10m/s Less than 15m/s	80km/h
More than15m/s Less than20m/s	50km/h
More than 20m/s	Road closed

Figure 83. Relationship between Friction Coefficient and Acting Forces with Respect to Natural Phenomena (Crosswinds)

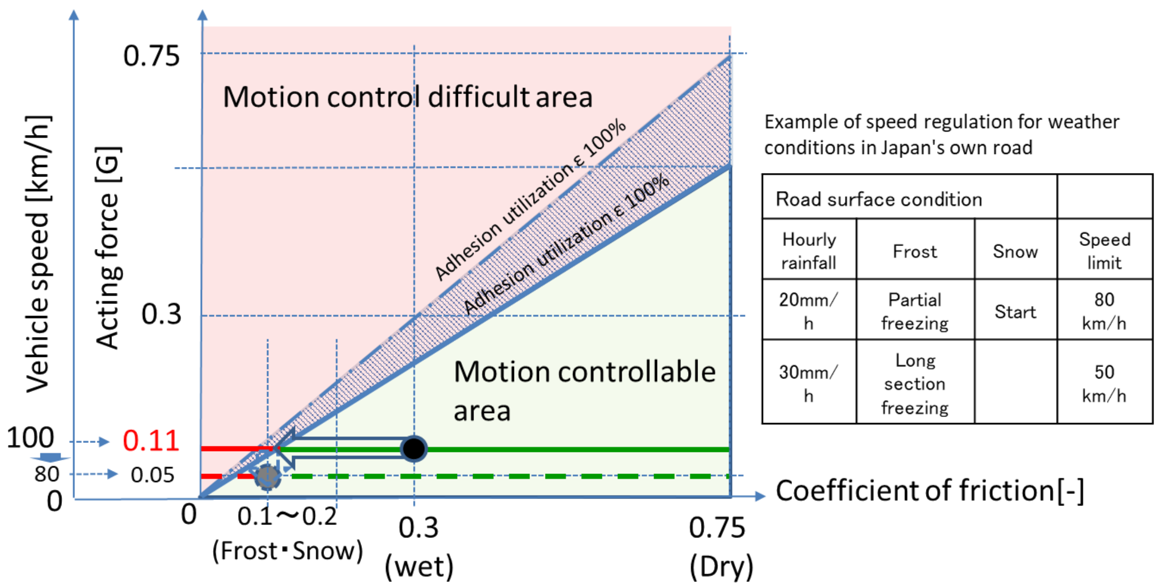
3.4.3.4.3. Controllability under Road-Surface–Condition–Induced Tire-Input Disturbances

Road-surface conditions directly affect tire–road interaction and therefore constitute tire-input disturbances. Variations in road-surface conditions influence the available friction coefficient and the external forces acting on the tires, thereby affecting vehicle controllability.

On controlled-access highways in Japan, speed regulations are imposed according to meteorological conditions. Accordingly, road-surface conditions under which no speed restriction is applied are regarded as the boundary conditions for safe operation. For a design speed of 100 km/h, rainfall of less than approximately 20 mm/h does not lead to hydroplaning, and a locked-wheel friction coefficient of $\mu \geq 0.3$ can be defined as the boundary value for controllable operation.
When rainfall intensity exceeds this level, hydroplaning may occur and the friction coefficient can decrease significantly. Similarly, on icy or snow-covered road surfaces, the friction coefficient may decrease to 0.2 or lower. When such low-friction conditions are combined with other disturbances—such as crosswinds described in the previous section—the vehicle may transition into a region in which stable control can no longer be maintained.
Accordingly, under typical operating conditions with standard tires, a friction coefficient of $\mu = 0.3$, corresponding to wet road conditions, is defined as the lower boundary for controllable vehicle dynamics (Figure 84).

In addition to changes in friction coefficient, external forces acting on the tires due to road-surface irregularities—such as deep steps, potholes, or similar defects—may disturb vehicle motion. Road administrators are responsible for maintaining safe road conditions and define target values for maintenance and repair decisions. When these target values are satisfied, it is assumed that ordinary drivers can operate vehicles safely.

Therefore, boundary conditions for tire-related external forces are also defined based on these maintenance target values and, similar to wind-induced forces, are treated as acting forces in the evaluation of vehicle-dynamics disturbances.



Road surface condition			
Hourly rainfall	Frost	Snow	Speed limit
20mm/h	Partial freezing	Start	80 km/h
30mm/h	Long section freezing		50 km/h

Figure 84. Relationship between Friction Coefficient and Acting Forces with Respect to Road Surface Conditions

Table 31 Target Criteria for Maintenance and Repair Decisions

Item / Road type	Furrow [mm]	Step[mm]		Coefficient of friction	Vertical unevenness[mm]	Crack rate [%]	Pothole diameter [cm]
		bridge	drain				
Motorway	25	20	30	0.25	8m profile 90(Pr) 3m profile 3.5(σ)	20	20
Urban（Heavy traffic）	30～40	30	40	0.25	3m profile	30～40	20
Urban（Low traffic）	40	30	---	---	---	40～50	20

References: Japan Road Association(Road maintenance and repair guideline)

3.4.3.4.4. Controllability under Tire-Condition–Induced Tire-Input Disturbances

Tire-condition-induced disturbances arise when changes in tire characteristics directly affect tire force generation and, consequently, vehicle controllability. Typical examples include tire wear, punctures, and blowouts, which can significantly reduce the available tire–road adhesion.

A tire puncture occurring during driving can be modeled as a condition in which the maximum achievable adhesion utilization rate is reduced, rather than as an increase in acting forces. According to experimental studies (e.g., *SAE, Tandy et al., 2013*), even when a single tire is punctured, vehicle controllability can be maintained up to approximately 0.6 G, provided that the tire rim does not contact the road surface. This corresponds to a reduction of the effective adhesion utilization rate to approximately 60%.

Although a reduction in adhesion of this magnitude does not immediately result in a loss of control, it is essential that the tire condition be detected promptly by the driver or the Automated Driving System (ADS). The ADS is therefore required to identify such tire-condition disturbances and initiate appropriate measures—such as controlled deceleration and transition to a safe stop—before a complete loss of tire integrity occurs (e.g., rim contact or blowout).

Accordingly, tire-condition-induced disturbances are treated as foreseeable but potentially unpreventable beyond a certain point. Safety determination in such cases focuses not on continued collision avoidance at the limit of control, but on timely detection and mitigation of consequences.

4. Scenario Database

4.1. Three Layers of Scenario Abstraction

The Functional Scenario defines the highest-level qualitative structure of scenarios. It enables comprehensive scenario safety evaluation by systematically organizing scenarios into three categories—perception disturbance, traffic disturbance, and vehicle-dynamics disturbance—based on the three elements of driving behavior: perception, decision, and operation.

The Logical Scenario extends the Functional Scenario by introducing quantitative parameter ranges. For example, in traffic-disturbance scenarios, a data-driven approach can be applied in which vehicle trajectories are extracted from traffic-flow data and traffic-related parameters—such as relative velocity or cut-in velocity—are defined using statistical distributions. In this context, traffic-flow data include sources such as traffic-monitoring and observation data, driving data, accident databases, and map and road data.

The Concrete Scenario represents a specific evaluation condition under which an actual assessment is conducted. Such scenarios can be derived, for example, from safety-determination boundaries that distinguish between safe and unsafe states (see Section3.1.1.2).

4.2. Concept of the Scenario Database

This section describes the concept of a scenario database that links the three layers of scenario abstraction described above to the development process.

Figure 85 illustrates the conceptual process for the development and application of data-driven AD safety scenarios. In order to satisfy the safety criteria specified by regulatory authorities, the three layers─Functional Scenarios, Logical Scenarios, and Concrete Scenarios─are used to define, in a rational and transparent manner, the ranges of conditions that are reasonably foreseeable and preventable.

At this stage, it is desirable that each scenario be objectively defined based on real-world data. Accordingly, the primary purpose of the scenario database is to provide:

- Logical Scenarios that represent reasonably foreseeable conditions; and
- Concrete Scenarios derived from preventable boundaries.

Detailed methods for defining reasonably foreseeable Logical Scenarios and preventable Concrete Scenarios are described in subsequent sections.

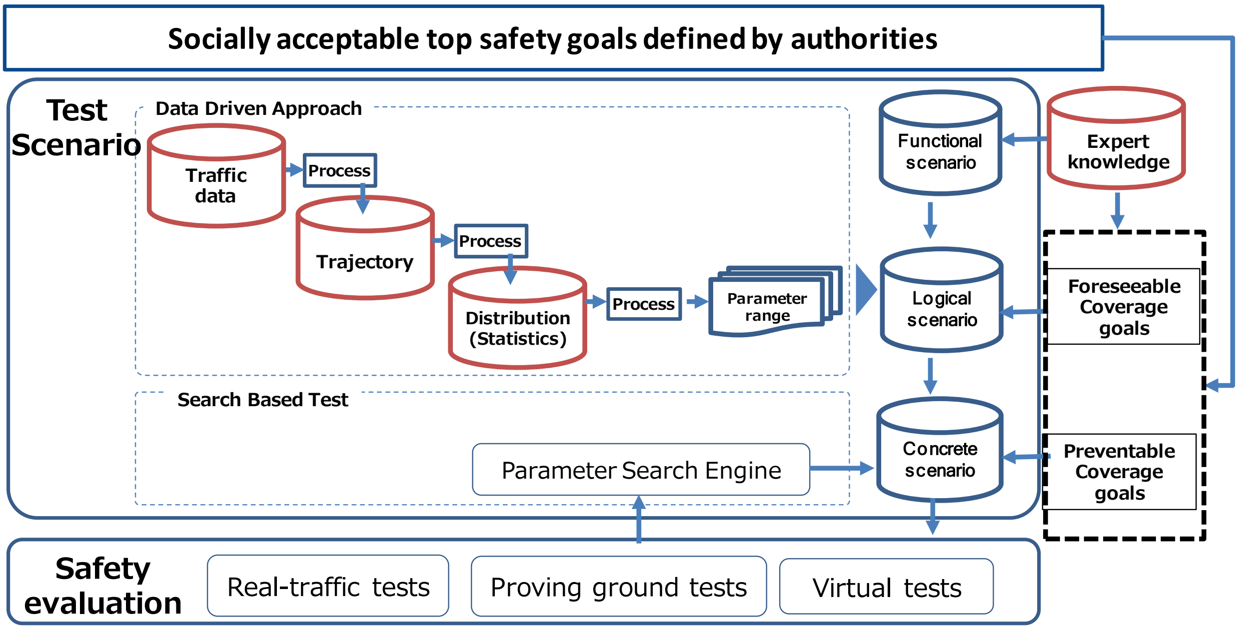


Figure 85. Development and Application Process of Data-Driven AD safety scenarios

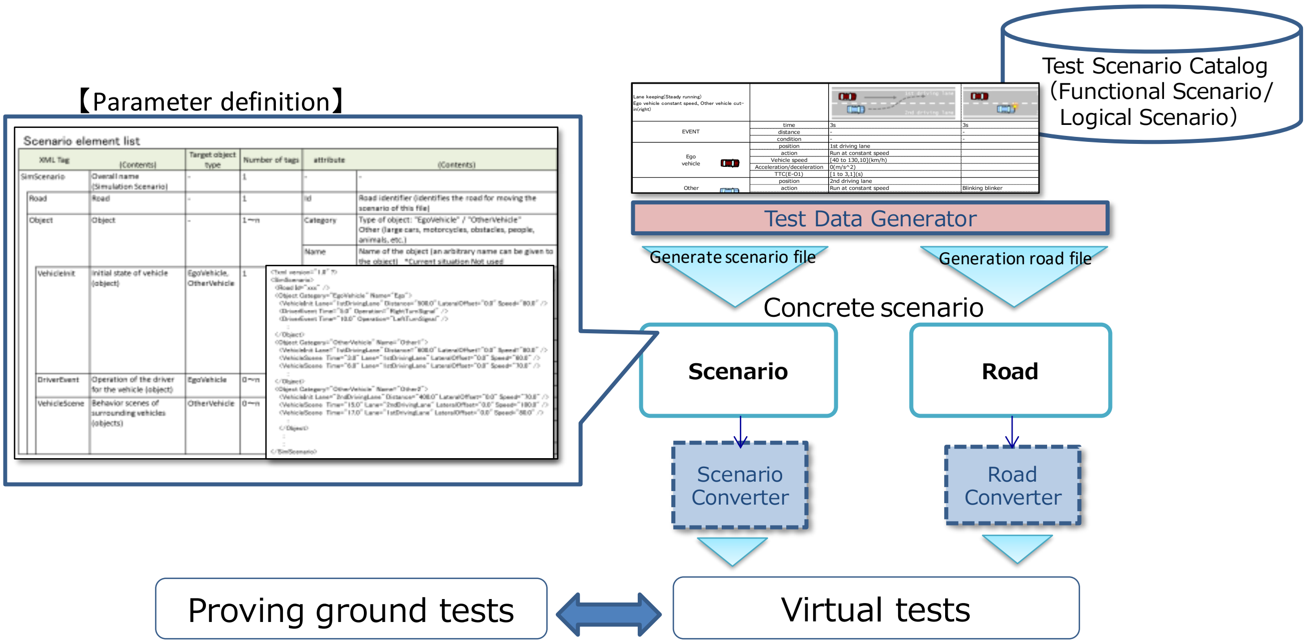
4.3. Information Flow Scheme for AD safety Evaluation based on Standardized Scenarios

Figure 86 illustrates the information-flow scheme used to generate concrete test scenarios from a scenario catalog and to output these scenarios in a standardized format for AD safety evaluation.

In this scheme, standardized scenarios are used as a common interface between the scenario database and various evaluation environments. A test-data generator converts scenario information—such as vehicle behavior and road geometry—stored in the scenario catalog into test-scenario files. These files are then transformed, via appropriate converters, into formats compatible with different simulation and testing environments.

By adopting a standardized data format with sufficient generality, the information-flow scheme enables AD safety evaluation to be conducted independently of specific simulation tools or commercial software products. This tool-independent structure enhances reproducibility, transparency, and reusability of safety-evaluation scenarios across different development projects and organizations.

Furthermore, the standardized information-flow scheme supports consistent application of scenarios across virtual simulation, hardware-in-the-loop testing, and physical vehicle testing, thereby contributing to comprehensive and efficient safety evaluation.



Scenario element list

XML Tag	(Contents)	Target object type	Number of tags	attribute	(Contents)
SimScenario	Overall name (Simulation Scenario)	-	1	-	-
Road	Road	-	1	Id	Road identifier (identifies the road for moving the scenario of this file)
Object	Object	-	1~n	Category	Type of object: "EgoVehicle" / "OtherVehicle" Other (large cars, motorcycles, obstacles, people, animals, etc.)
				Name	Name of the object (an arbitrary name can be given to the object) *Current situation Not used
VehicleInit	Initial state of vehicle (object)	EgoVehicle, OtherVehicle	1		
DriverEvent	Operation of the driver for the vehicle (object)	EgoVehicle	0~n		
VehicleScene	Behavior scenes of surrounding vehicles (objects)	OtherVehicle	0~n		

Figure 86. Information-Flow Scheme for AD Safety Evaluation based on Standardized Scenarios

4.4. Interface specifications for the test scenario database

Figure 87 illustrates the overall structure of the scenario database and its interfaces. The scenario database takes real-world traffic data as input and outputs scenario data required for safety evaluation. To support this functionality, clearly defined input and output interfaces are required. In addition, the results of safety evaluation conducted using the output scenario data are fed back into the scenario database to support continuous improvement.

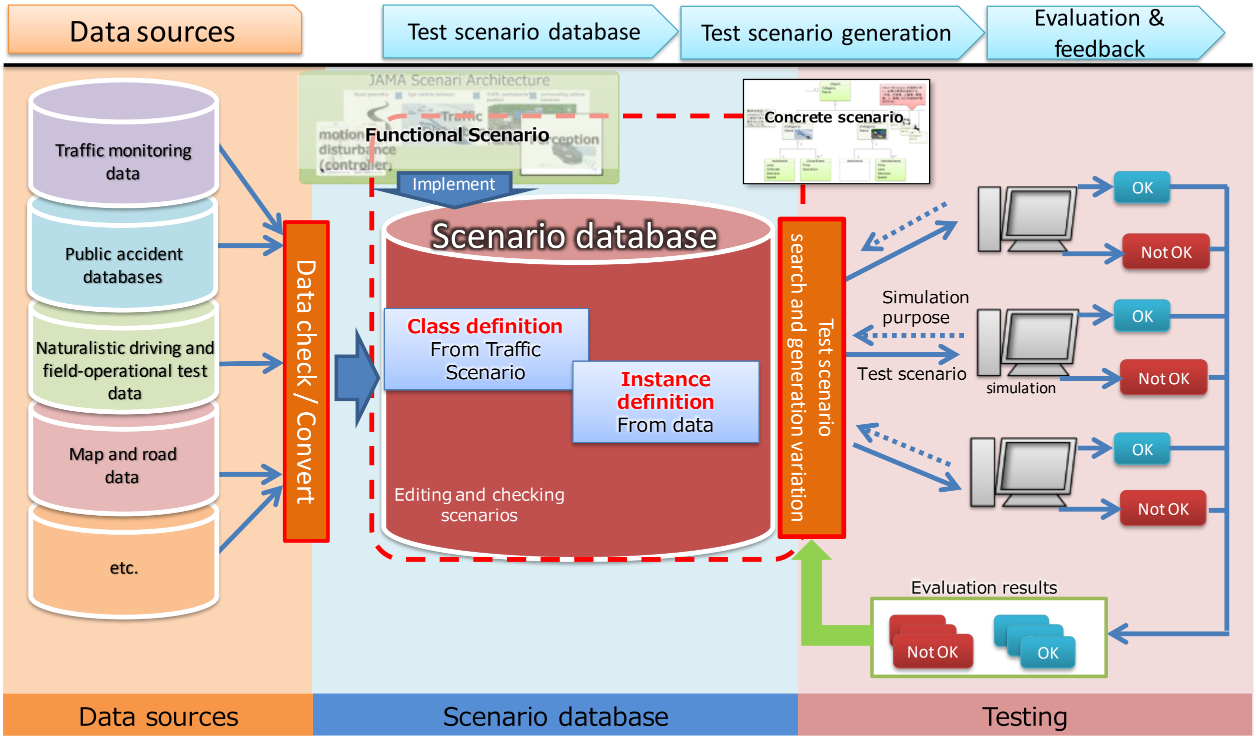


Figure 87. Scheme and Interfaces of the Scenario Database

Real-world traffic dat include a wide variety of sources, such as traffic-monitoring data, accident data, field-test data, and map and road data. To incorporate these heterogeneous data sources into the scenario database, relevant information must be extracted and converted into appropriate formats. This process corresponds to the data checking and conversion step shown in .

Once the data have been ingested into a common database, scenarios are generated in accordance with standardized methodologies. To enable effective use of the generated scenarios in safety evaluation, the scenario database provides interfaces that support:

- scenario search,
- scenario generation and variation, and
- scenario export.

These interfaces allow users to efficiently retrieve, configure, and apply scenarios across different evaluation environments. Furthermore, by feeding evaluation results back into the scenario database, the framework supports refinement of scenario definitions and continuous enhancement of scenario coverage and quality.

5. Details of the Reasonably Foreseeable Range

5.1. Overview of Reasonably Foreseeable Logical Scenarios Based on Real-World Traffic Data

Methods for defining Logical Scenarios include approaches based on traffic laws and international standards, as well as approaches based on various types of traffic data. This section describes a method for quantitatively defining the reasonably foreseeable range using real-world traffic data.

Assuming that situations encountered by automated vehicles are categorized into Functional Scenarios, as shown in Figure 23 and Figure 27, reasonably foreseeable Logical Scenarios can be quantified by defining representative parameters for each scenario and determining their applicable ranges. Figure 88 illustrates the process up to the definition of reasonably foreseeable Logical Scenarios.

First, real-world traffic-environment data are collected using probe vehicles and fixed-point cameras. Vehicle trajectory data are then transformed into a coordinate system aligned with the road geometry—specifically, the longitudinal direction (direction of travel) and the lateral direction (perpendicular to the identified travel)—and stored in a database. From this database, the relevant Functional Scenarios are identified, and the representative parameters defined for each scenario are extracted.

Next, occurrence probability distributions of the extracted parameters are estimated. When correlations exist among parameters, multidimensional probability distributions are derived to capture those dependencies. For parameters that are mutually independent, individual probability distributions are derived. The product of these occurrence probabilities is then used to estimate the probability of occurrence for arbitrary combinations of parameters.

Based on these estimated occurrence probabilities, parameter combinations whose probabilities exceed a threshold—defined based on considerations such as social acceptability—are regarded as reasonably foreseeable.

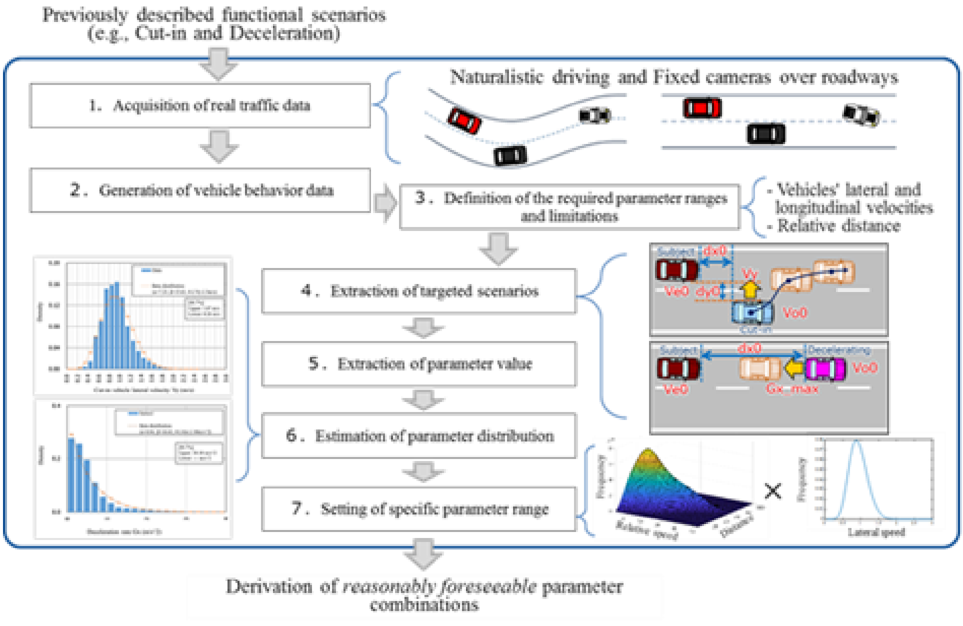


Figure 88 Process of Logical Scenario Definition

5.2. Definition of a Logical Scenario for a Cut-In Scenario (No. 4) on Domestic Controlled-Access Highways

Using a scenario in which another vehicle cuts in front of an automated driving vehicle as a representative example, this section describes the process for defining a reasonably foreseeable Logical Scenario.

For the cut-in scenario, representative parameters are defined as shown in Figure 89 and Table 32. Time-series data corresponding to cut-in events are extracted when all of the following conditions are satisfied:

1) The longitudinal velocity of the other vehicle is lower than that of the ego vehicle.
2) The longitudinal inter-vehicle distance is within 100 m.
3）The lateral velocity of the other vehicle increases (or decreases) monotonically from 0 m/s in one direction and subsequently returns to 0 m/s.
4）During condition (3), the other vehicle moves from the lane adjacent to the ego vehicle into the lane in which the ego vehicle is traveling.
5）No other vehicles are present between the ego vehicle and the other vehicle.

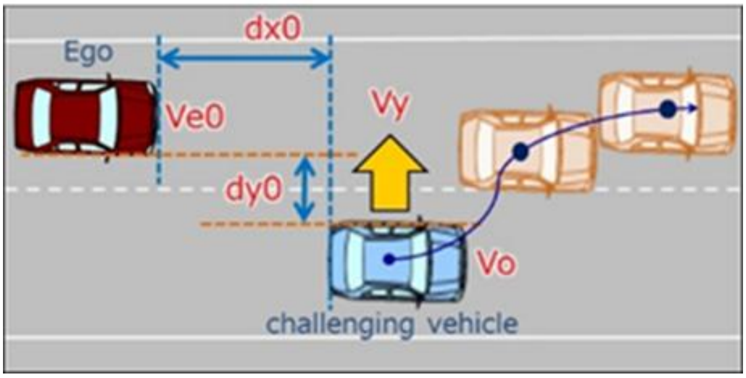


Figure 89 Parameters of the Cut-In Scenario (No. 4)

Table 32 Parameters of the Cut-In Scenario (No. 4)

Parameter Name	Variable	Unit	Remarks
Ego-vehicle longitudinal velocity	Ve0	km/h	Value extracted at the start of the scenario
Other-vehicle longitudinal velocity	Vo0	km/h	Value extracted at the start of the scenario
Relative velocity	Ve0 − Vo0	km/h	Value extracted at the start of the scenario
Longitudinal inter-vehicle distance	dx0	m	Value extracted at the start of the scenario
Other-vehicle lateral velocity	Vy	m/s	Maximum value extracted

Based on the conditions described in the Remarks column of Table 32, scalar parameter values are derived from the extracted time-series scenario data. The distributions of each parameter, as well as correlations among parameters, are then analyzed (Figure 90).

The analysis shows that the upper bound of the relative velocity depends on the ego-vehicle velocity. Similarly, a correlation is observed between relative velocity and longitudinal inter-vehicle distance. In contrast, the lateral velocity of the other vehicle exhibits weak correlation with the other parameters and can therefore be treated as statistically independent.

Taking these observations into account, the occurrence frequency of parameter combinations for cut-in events can be estimated, as illustrated in Figure 91. his is achieved by deriving a multidimensional frequency distribution of relative velocity and longitudinal inter-vehicle distance and then combining it with the frequency distribution of the other vehicle’s lateral velocity.

From the resulting frequency distribution, reasonably foreseeable parameter ranges for the cut-in scenario are defined.

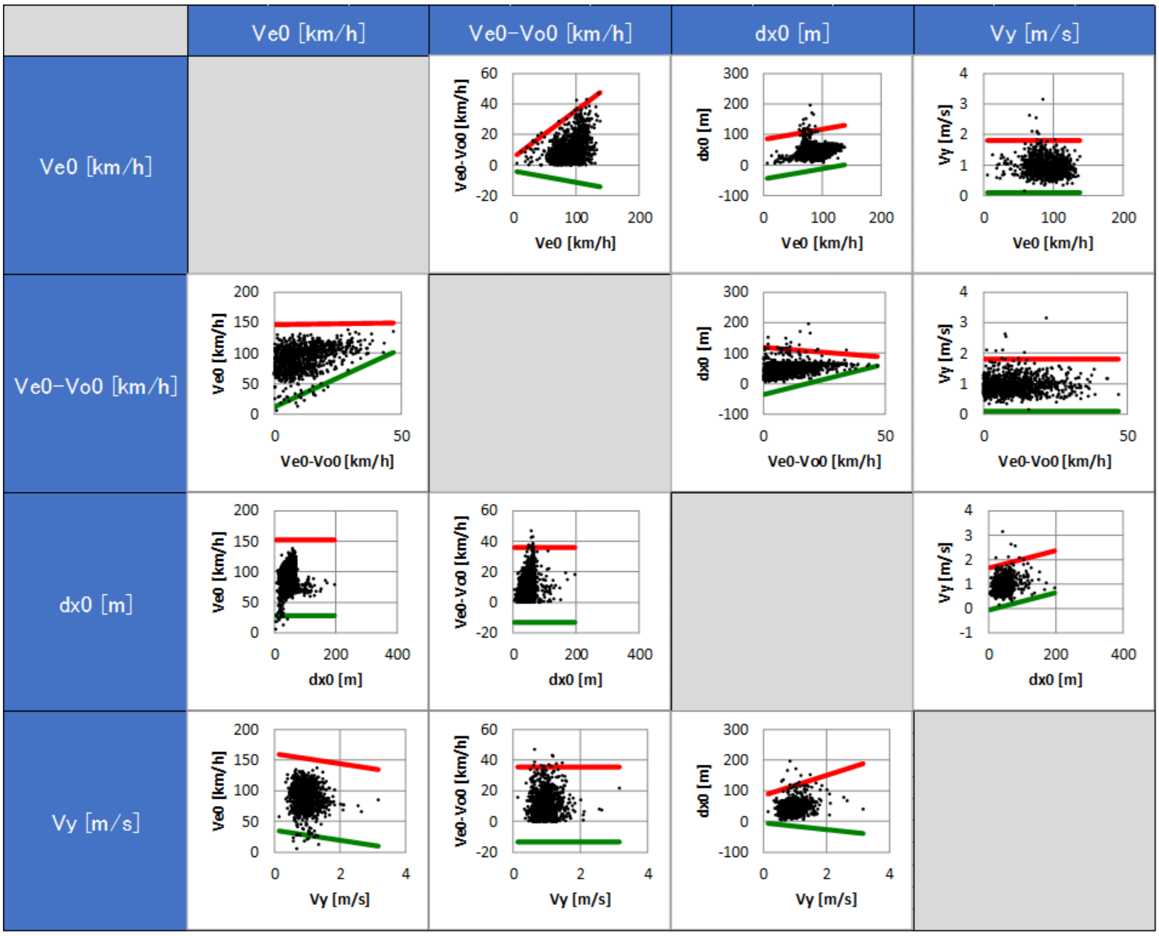
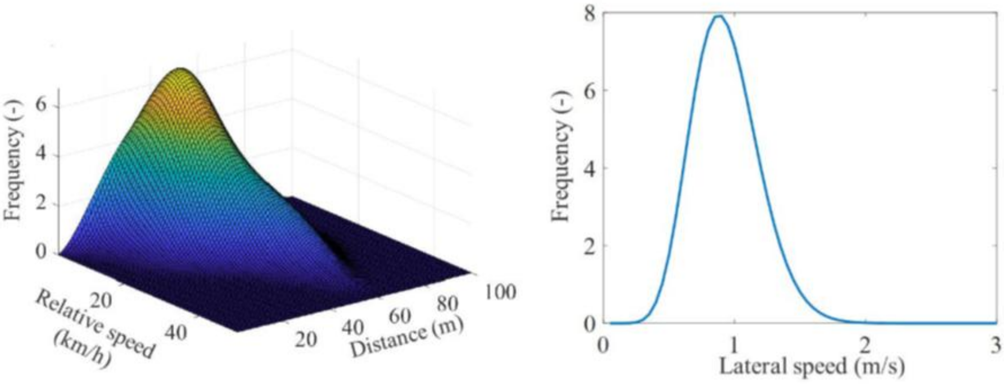


Figure 90 Correlation Analysis among Parameters of the Cut-In Scenario



(a) Multidimensional frequency distribution of speed and inter-vehicle distance

(b) Frequency distribution of other-vehicle relative lateral speed

Figure 91 Frequency Distribution of Cut-In Scenario Parameters

(Source: *Nakamura et al., 2022, Defining Reasonably Foreseeable Parameter Ranges Using Real-World Traffic Data for Scenario-Based Safety Assessment of Automated Vehicles*)

6. Details of the Safety Determination Method (Preventable)

This chapter presents the conceptual basis for defining the performance of a Competent and Careful (C&C) human driver, as introduced in the traffic-disturbance safety determination method described in Section 3.3.1. It also provides concrete examples of how such performance is defined based on quantitative evidence derived from experimental data.

6.1. Conceptual Approach to Defining a C&C Driver

6.1.1. Safety Requirements According to the Role of an Automated Driving Vehicle

In traffic-disturbance scenarios expressed as combinations of elements such as ego vehicle behavior, safety requirements vary depending on the relative relationships between the ego vehicle and other traffic participants. For example, in a scenario in which the ego vehicle is lane keeping on a main lane and another vehicle performs a cuts in maneuver, the primary requirement is to avoid a collision. If collision avoidance is not feasible, the ego vehicle is required to minimize the severity of the resulting collision to the greatest extent possible.

In contrast, in a scenario in which the ego vehicle performs a lane change in front of a following vehicle that is lane keeping on the main lane, the safety requirements differ. In such cases, the ego vehicle is required not only to avoid a collision with the following vehicle, but also to avoid impeding the progress of that vehicle. If such interference cannot be avoided, the ego vehicle is required to abort the lane-change maneuver.

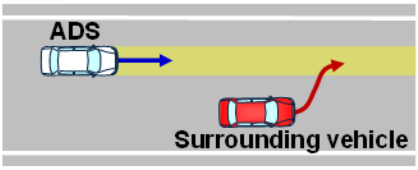
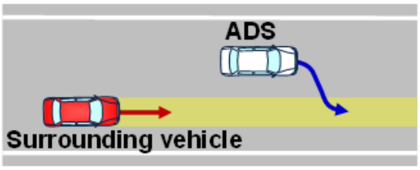
Because safety requirements differ depending on the role assumed by the automated driving vehicle, Kusano et al. (2023) describe this distinction using the two roles summarized in Table 33:

- Responder: the role in which the automated driving vehicle reacts to a situation in which another traffic participant creates a collision risk; and
- Initiator: the role in which the automated driving vehicle must ensure that it does not create a collision risk for other traffic participants.

In scenarios where the automated driving vehicle acts as a Responder, it is necessary to define driver performance that is superior in perception, decision-making, and operation with respect to collision-risk avoidance. In contrast, in scenarios where the automated driving vehicle acts as an Initiator, it is necessary to clarify the relative conditions under which other drivers would perceive their progress as being impeded and to define sufficient safety margins—such as relative distance or time gaps—to prevent such interference.

Accordingly, because automated driving vehicles may assume two distinct roles, the safety determination method shall be applied in accordance with the role of the automated driving vehicle in the scenario under evaluation.

Table 33 Safety Requirements Depending on the Role of the Automated Driving Vehicle

	Responder role ◀ Role inversion	▶ Initiator role
Scenario	No.1  	No.7 
Safety requirement	- Strive to achieve utmost effort for collision avoidance or damage mitigation while surpassing the performance of human driver	- To temporarily withhold lane change to prevent collisions and avoid obstructing the rear vehicle - To complete the lane change appropriately
Research subject	Quantification of **a competent and careful driver behavior**	Quantification about **the subjective experience of the rear vehicle driver's feelings**

6.1.2. Types of Collision-Risk Avoidance Measures

In road traffic, the primary means of avoiding collision risks are braking and steering. Depending on the situation, it may be appropriate to apply these measures either individually or in combination.

Although steering-based avoidance can be effective even in situations that exceed the physical limits of braking-based avoidance, steering maneuvers may introduce new collision risks to surrounding traffic participants. Such secondary risks must therefore be carefully considered.

Accordingly, in this document, the Competent and Careful (C&C) Driver in the Responder role is defined under the assumption that approaching collision risks to the ego vehicle are addressed primarily through braking maneuvers. This assumption provides a conservative and socially acceptable basis for defining preventable boundaries in traffic-disturbance scenarios.

6.1.3. Decomposition of the Components of the Collision-Avoidance Process Performed by a Driver

When focusing on collision-risk avoidance through braking, the driver’s behavior can be decomposed into the fundamental driving-behavior elements shown in Figure 92. In studies of human reaction time, the processing sequence leading to an externally observable response to a stimulus is commonly divided into three stages:

1. Perception of the stimulus;
2. Judgment and response selection; and
3. Motor execution of the response.

When these stages are applied to automobile driving, the process in which the driver becomes aware of a collision risk and determines that braking-based avoidance is required corresponds to the Risk Perception Situation (A). The process in which, after deciding to apply braking, the driver releases the accelerator pedal, moves the foot to the brake pedal, and initiates braking corresponds to the Delay in Time (B). Finally, the process in which vehicle deceleration is generated in accordance with brake-pedal input corresponds to the Deceleration Degree and Maximum G-Force (C).

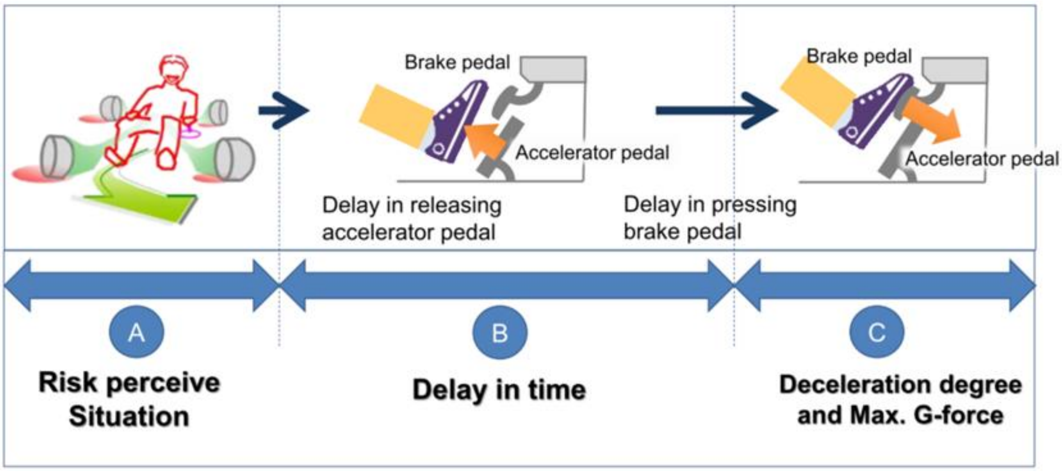


Figure 92 Basic Process of Driver Collision-Risk Avoidance Using Braking

Human reaction time is generally classified according to task complexity into Simple Reaction Time (SRT), Choice Reaction Time (CRT), and Discriminative Reaction Time (DRT).

In traffic-disturbance scenarios where another vehicle cuts in from an adjacent lane in front of the ego vehicle, the driver must discriminate whether the other vehicle's lateral motion represents normal lane-keeping behavior or a continuous lateral movement indicative of a cut-in maneuver. Accordingly, such scenarios require consideration of the discrimination process by which the driver determines whether a cut-in is occurring.

The braking-related collision-avoidance process for a cut-in scenario is illustrated in Figure 93. In this context, the driver is assumed to judge that a cut-in is occurring once the lateral displacement of the other vehicle exceeds the range associated with normal lane keeping. The time required to make this determination is defined as the hazard judgment time.

Following hazard judgment, the driver releases the accelerator pedal, transitions to the brake pedal, and applies braking input. After the brake application, deceleration is generated in the vehicle body.

In this scenario, the automated driving vehicle assumes the role of a Responder. Accordingly, the C&C Driver model used for safety evaluation is defined using parameters that represent superior performance in each of the above processes. Here, superior refers to performance characteristics that are more effective for collision avoidance, such as shorter reaction times and higher brake-pedal application rates.

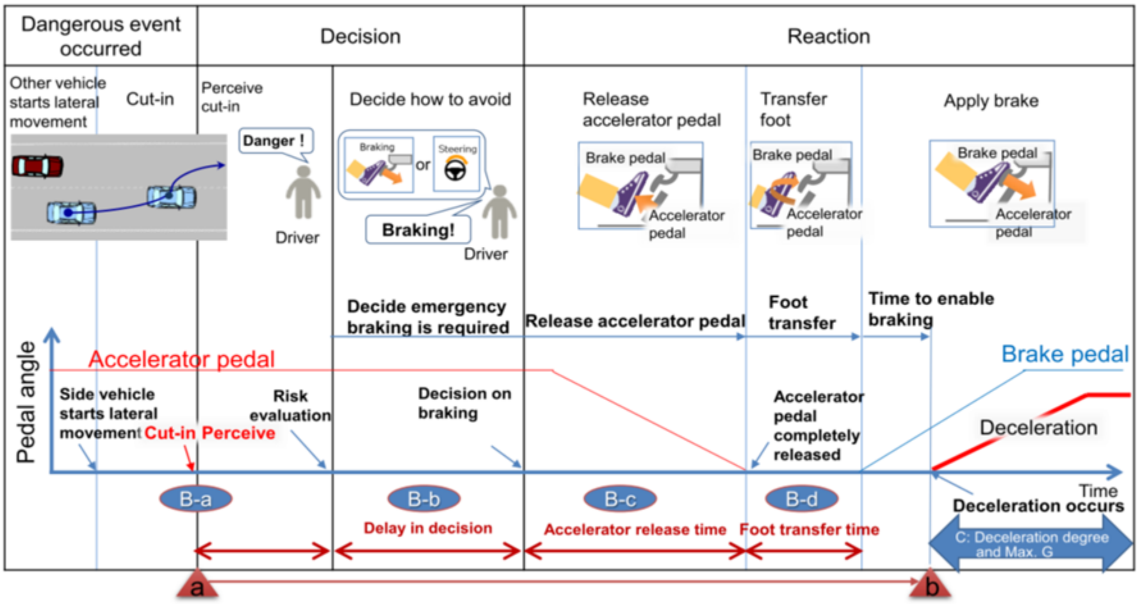


Figure 93 Driver Braking-based Collision-Avoidance Process in a Cut-In Scenario

6.2. Method for Defining the Performance of a C&C Driver

This section describes the method for defining the performance of a Competent and Careful (C&C) human driver, which serves as the reference benchmark for determining preventability in traffic-disturbance scenarios.

6.2.1. Performance When the Automated Driving Vehicle Acts as a Responder

As described in the preceding sections, when an automated driving vehicle assumes the role of a Responder, the primary avoidance maneuver is assumed to be braking. Under this assumption, preventability is determined by defining the performance of the C&C driver's braking operation, independent of the specific type of traffic disturbance (i.e., the positions and behaviors of surrounding traffic participants).

To determine preventability, it is necessary to quantify the elements of driving behavior involved in braking-based collision avoidance. However, it is not practical to individually quantify all driving-behavior elements for every possible scenario. Therefore, driver-performance elements are classified into general (generic) elements and scenario-specific elements, which are then quantified separately.

General Driver-Performance Elements

Examples of general elements include:

- the delay time from the moment the C&C driver perceives a hazard to the generation of physical deceleration force;
- the time required to reach maximum deceleration after brake application, and
- the maximum achievable deceleration.

Scenario-Specific Driver-Performance Elements

Examples of scenario-specific elements include:

- the time required to judge whether the lateral movement of a vehicle traveling in an adjacent lane represents normal lane keeping or a lane-change maneuver.

Definition of Delay Time from Hazard Perception to Deceleration

The delay time from hazard perception by a C&C Driver to the generation of deceleration force is defined as 0.75 seconds. This value is based on the delay time commonly applied in Japan by the National Police Agency and in traffic-accident court cases as the standard “delay time from judging a hazard to initiating brake application.”

NOTE：A police-related reference at: *https://www.pref.niigata.lg.jp/uploaded/attachment/325068.pdf*
For comparison, the WHO/GRSP publication *Speed Management: A Road Safety Manual for Decision-Makers and Practitioners (2008)* adopts a value of 1 second.

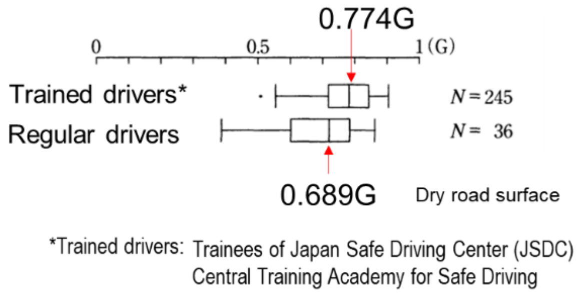
Definition of Maximum Deceleration

The maximum deceleration is defined as 0.774 G, based on experimental data obtained in Japan, as shown in Figure 94 (*Makishita et al., 2001*). In this study, brake-operation data under assumed emergency conditions were collected through full-scale vehicle tests involving 67 ordinary drivers and 183 drivers who had received safe-driving skills training.

The results indicate that:
- ordinary drivers achieved a maximum deceleration of 0.689 G under emergency conditions; and
- drivers with safe-driving skills training achieved a maximum deceleration of 0.774 G.

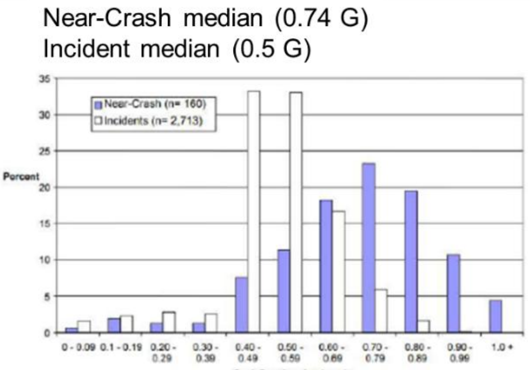
Accordingly, the higher-level performance exhibited by drivers with safe-driving skills training was adopted as the reference value for defining the Competent and Careful driver state..

In addition, data from a study conducted by NHTSA (2007) investigating drivers’ maximum deceleration during traffic accidents (Figure 95) reported 0.74 G as the most frequent observed value. Taken together, these findings indicate that a maximum deceleration of 0.774 G represents an appropriate and reasonable value for the C&C driver model.



(Makisita et al., 2001)

Figure 94. Examples of Studies on Emergency Braking Characteristics (Max. deceleration)



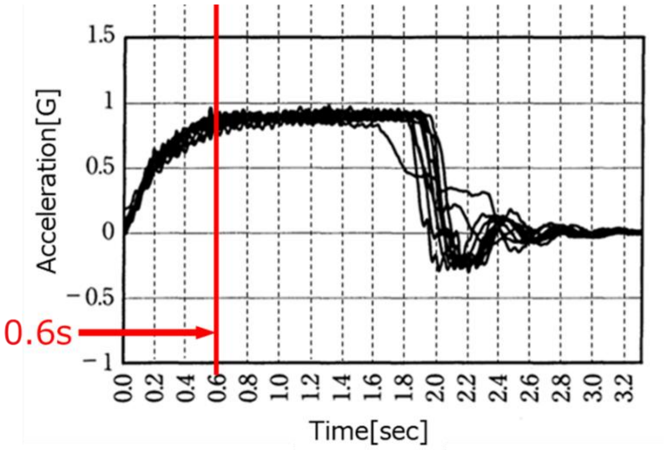
(NHTSA, 2007)

Figure95. Maximum Deceleration Induced by Lead-Vehicle Deceleration

Definition of Time to Reach Maximum Deceleration

Figure 96 shows the deceleration waveform during emergency braking performed by drivers who had received safe-driving skills training. This waveform illustrates the process from brake application to attainment of maximum deceleration, followed by a phase in which deceleration is maintained at an approximately constant level.

Analysis of this waveform indicates that the time required for a C&C driver to reach maximum deceleration converges to approximately 0.6 seconds. Accordingly, this value is adopted as the definition of the time required to reach maximum deceleration.



(Makisita et al. , 2001)

Figure 96. Examples of Emergency Braking Characteristics (Time to Maximum Deceleration)

Braking-Force Model of the C&C Driver

Figure 97 illustrates the driving-behavior elements that constitute the braking operation of a C&C Driver. Figure 98 presents the corresponding braking-force model.

In Figure 98:

- the model on the left represents the process by which braking force is generated through the driver's braking operation; and
- the model on the right represents the functional model of an Advanced Emergency Braking (AEB) system, reflecting the improvement in avoidance performance achieved through braking assistance.

By integrating these two models, a composite braking-force model is defined in which the braking operation executed by a competent and careful driver—based on the driver's own judgment—is augmented by braking assistance provided by the AEB system.

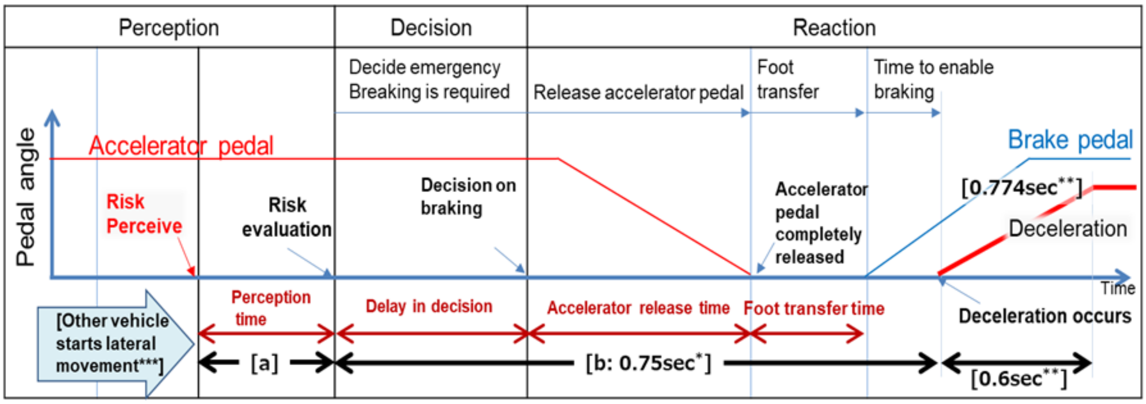


Figure 97 Flow of the Braking Operation in the C&C Driver Model

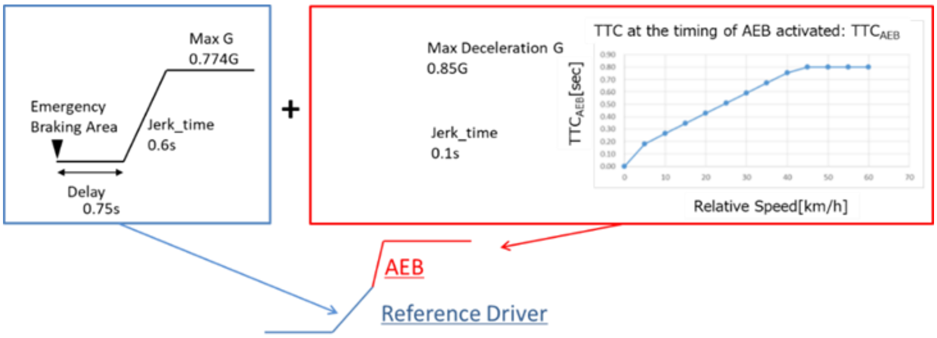


Figure 98　Brake Force Model in the C&C Driver Model

6.2.2. Performance When the Automated Driving Vehicle Acts as an Initiator

When an automated driving vehicle assumes the role of an Initiator, it enters the path of other vehicles through maneuvers such as lane changes or turning maneuvers. In such cases, the ego vehicle is required not only to avoid collisions, but also to avoid impeding the progress of other vehicles.

Article 2, Paragraph 22 of Chapter 1 (General Provisions) of Japan's Road Traffic Act, which aims to prevent hazards on roads and ensure both safety and smooth traffic flow, defines impeding the progress as follows:

"Impeding the progress refers to continuing or initiating movement when there is a risk that another vehicle, upon continuing or initiating its movement, would be required to suddenly change its velocity or direction in order to prevent danger."

Accordingly, to avoid impeding the progress of other vehicles under the Road Traffic Act, it is necessary to define safety requirements such that other vehicles are not required to suddenly change their velocity or direction as a result of the automated driving vehicle's maneuver.
The perception of whether progress is impeded vary depending on the scenario. As illustrated in Figure 99, i in a lane-change scenario, it is expected that, at the moment when the ego vehicle completes the lane change, a sufficient margin is secured such that the following driver does not perceive the maneuver as impeding.
Similarly, as illustrated in Figure 100, in a right-turn scenario, it is expected that a sufficient margin is secured during the interval between the time when the rear end of the ego vehicle clears the intersection area and the time when the front end of the oncoming vehicle reaches that area, such that the oncoming driver does not perceive the maneuver as impeding.
These scenario-dependent margins form the basis for defining the performance requirements of a Competent and Careful (C&C) driver when the automated driving vehicle acts as an Initiator.

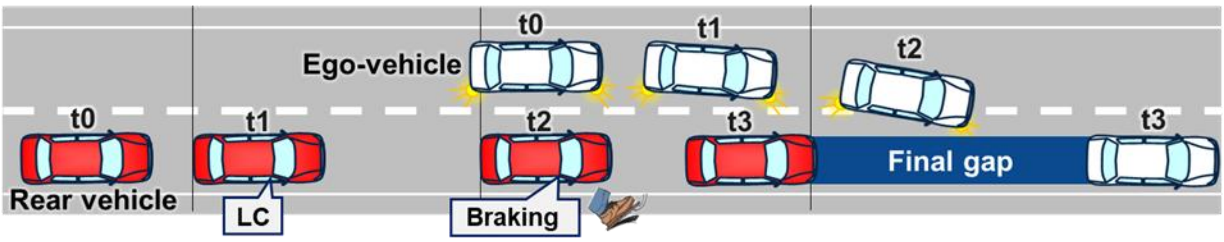


Figure 99　Concept of Progress-Impeding Consideration in a Lane-Change Scenario by the Ego Vehicle

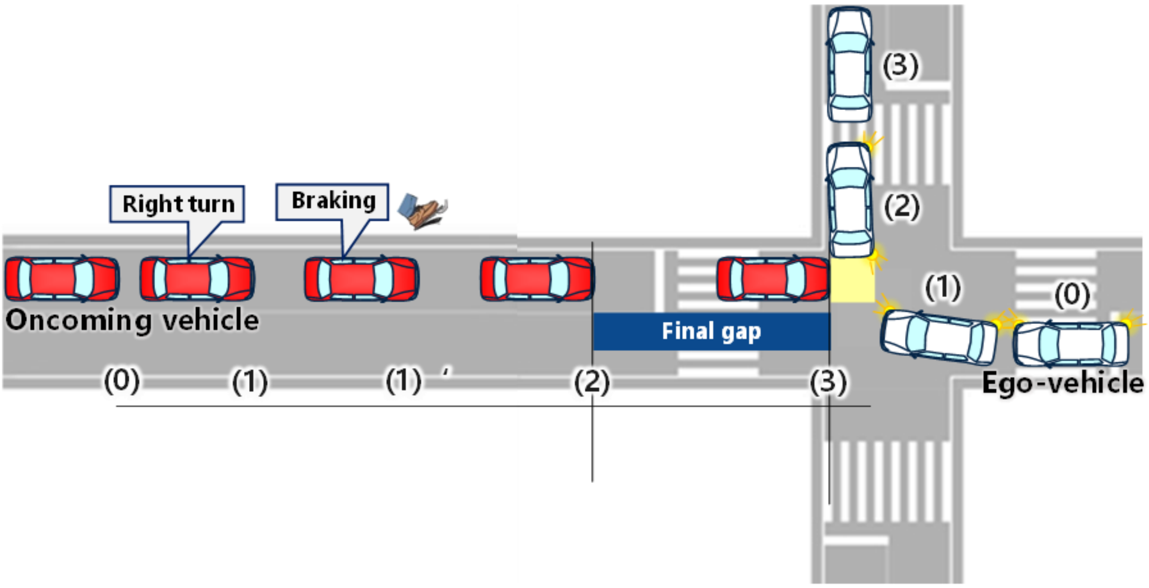


Figure 100 Concept of Progress-Impeding Consideration in a Right-Turn Scenario by the Ego Vehicle

(Source: *Kitajima et al., 2025, Defining Preventable Boundaries in Automated Driving Systems: A Driver Behavior Model for Scenario-Based Assessments*)

6.3. Concrete Examples of a C&C Driver for Verifying Responder Safety Requirements

This section presents concrete examples of how the performance of a Competent and Careful (C&C) human driver is defined and applied for verifying safety requirements when the automated driving vehicle acts as a Responder.

6.3.1. Cut-In Scenario

A cut-in scenario refers to a situation in which a vehicle traveling in a lane adjacent to the ego vehicle merges into the space in front of the ego vehicle. Figure 101 provides a schematic illustration of the boundary conditions up to the point at which a C&C driver judges the situation to be hazardous when another vehicle cuts in front of the ego vehicle. Because the time required to judge a situation as hazardous constitutes a scenario-specific element in cut-in scenarios, it is necessary to investigate this element through experiments using driving simulators or equivalent experimental methods.

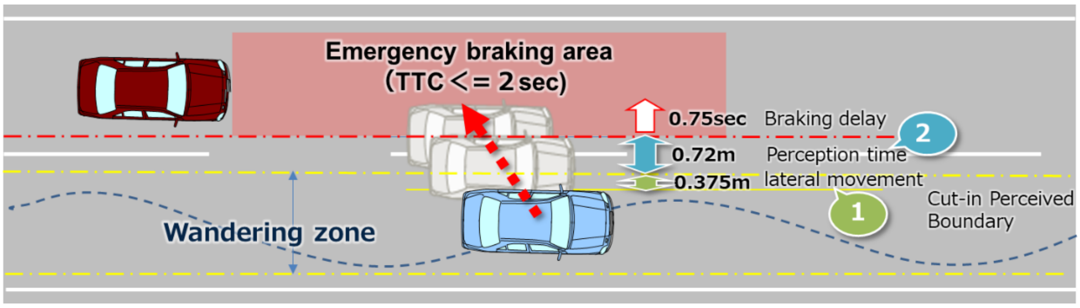


Figure 101 Conditions for Cut-In Judgment and Hazard-Decision Boundary

Boundary Condition for Cut-In Judgment
The boundary condition for judging that a vehicle traveling in an adjacent lane is performing a cut-in maneuver is defined in terms of the lateral displacement distance (weaving amplitude) of the other vehicle.

In real traffic environments, vehicles maintaining their lanes inevitably exhibit a certain degree of lateral weaving. Within the range of lateral displacement associated with normal lane keeping, it is unlikely that a

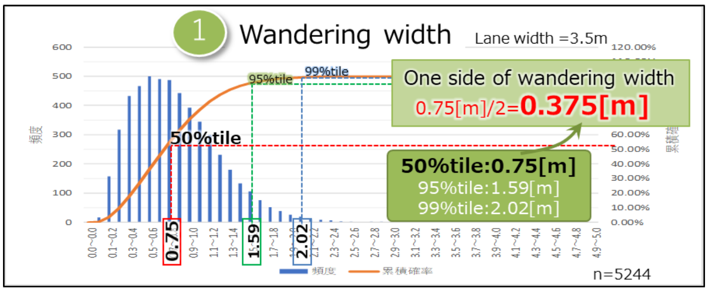
driver would judge the vehicle to be executing a cut-in maneuver. Accordingly, the boundary condition for cut-in judgment is defined based on the statistical distribution of lateral displacement distances of lane-keeping vehicles derived from real-world traffic observation data (Figure 102).
Analysis of this data shows that the 50th percentile value of the in-lane weaving amplitude of surrounding lane-keeping vehicles is 0.75 m, which corresponds to ±0.375 m on one side. Drivers are therefore assumed to judge lateral movements within ±0.375 m as normal lane keeping, whereas continuous lateral movement exceeding 0.375 m is judged as a cut-in maneuver.

Definition of the Hazard-Judgment Boundary (Lateral Direction)

After a driver judges that another vehicle is performing a cut-in maneuver, the boundary condition for recognizing the situation as hazardous and deciding to apply emergency braking—referred to as the hazard-judgment boundary—can be defined.
This boundary is determined by multiplying:

- the maximum lateral velocity of the cut-in vehicle derived from real-world traffic observation data; and
- the time required to judge the situation as hazardous, derived from driving-simulator experiments.

Figure 103 shows the distribution of the maximum lateral velocity of other vehicles during cut-in maneuvers, obtained from real-world traffic observation data. Based on this distribution, the maximum lateral velocity during cut-in events is defined as 1.8 m/s.



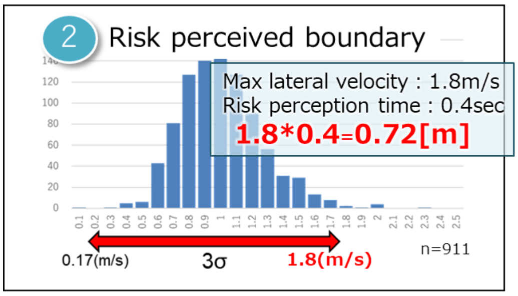


Figure 102 Statistical Values of Observed Real-World data for Wandering Width

Figure 103 Statistical Values of Observed Real-World Data for Maximum Lateral Velocity

Determination of Hazard-Judgment Time

To determine the time required to judge a situation as hazardous, experiments were conducted using a driving simulator. The experimental assumptions and conditions are summarized in Figure 104.

Parameter	Value
Lane width	3.5 m
Ego-vehicle target velocity V_e	100 km/h
Platoon velocity traveling in parallel forward V_o	70 km/h
Max. lateral velocity of cut-in vehicle V_{oL}	1.8 m/s
TTC at cut-in start	3.0 s

Figure 104 Prerequisite Conditions for the Driving Simulator Test

The experiment measured driver responses—including reaction time and avoidance behavior—to cut-in events by other vehicles for 20 ordinary drivers (Table 34). Each driver participated in two trials. The time required to judge the situation as hazardous was derived by comparing the average values obtained in the first and second trials.

Table 34 Attributes of the Experimental Participants

Group	No. of participants	Description	Composition of participants
Expert Driver	11	Having 5 years or more driving experience on regular basis, drives on highway at least once a month	- 6 Males, 5 Females - Avg. age: 38.7
Beginner Driver	9	Having 5 years or less driving experience on regular basis, drives on highway not more than once a year	- 6 Males, 3 Females - Avg. age: 23.1

The experimental results are shown in Figure 105. The time from the onset of the cut-in maneuver to the point at which the driver judged the situation to be hazardous was approximately 0.8s in the first trial and approximately 0.4 s in the second and subsequent trials.

These results indicate that, during the first trial, the driver requires time both to identify that a cut-in is occurring and to judge the situation as hazardous. In contrast, during the second and subsequent trials, drivers are already attentive to potential cut-in events, and therefore the time required for cut-in identification is no longer necessary. Nevertheless, even under attentive driving conditions, a certain amount of time is still required to judge a situation as hazardous, as illustrated in Figure 106. Accordingly, the hazard-judgment time is defined as 0.4 seconds.

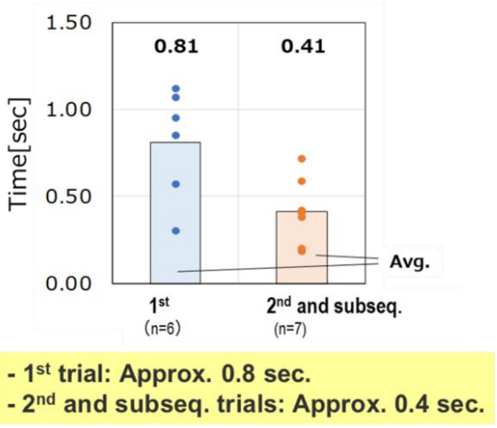


Figure 105 Results of the Driving Simulator Test

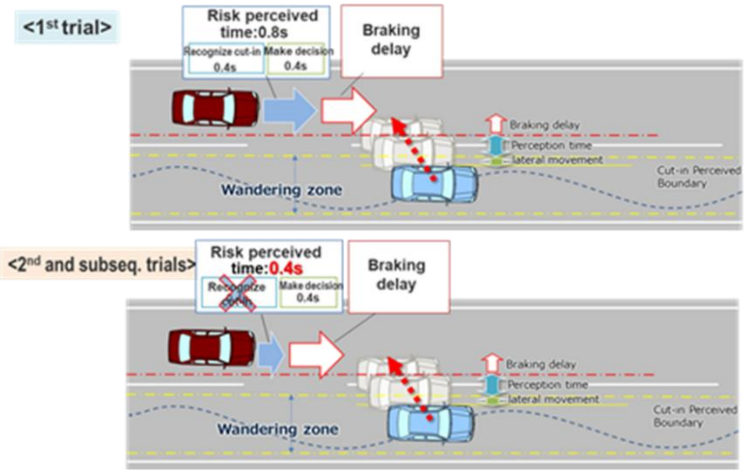


Figure 106 Relationship between Cut-In Identification Time and Hazard Judgment Time

Definition of the Hazard-Judgment Boundary

Based on the above analysis, the hazard-judgment boundary in the lateral direction is defined as the product of the maximum lateral velocity and the hazard-judgment time:

$$1.8 \times 0.4 = 0.72 \text{ m}$$

Accordingly, 0.72 m is defined as the hazard-judgment boundary in the lateral direction.

When the cut-in judgment conditions and the hazard-judgment boundary are applied to the braking-process diagram shown in Figure 97, the resulting C&C driver model representation for the cut-in scenario is obtained, as shown in Figure 107.

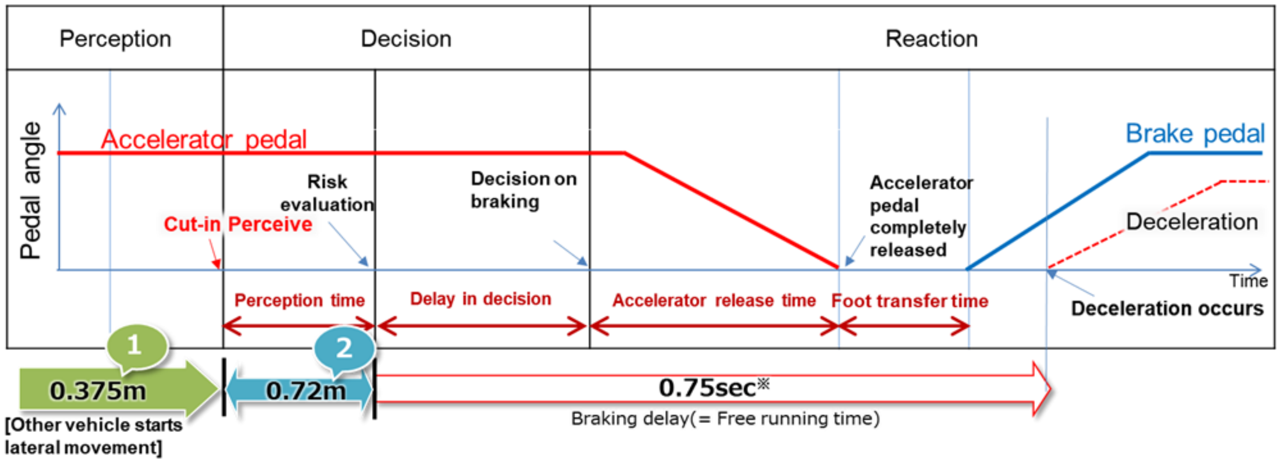


Figure 107 Competent and Careful Human Driver Model（Cut In）

Longitudinal Hazard-Judgment Boundary
With respect to the longitudinal direction, the UN Regulation (UNR) collision-warning guidelines define the boundary at which emergency action is required as Time to Collision (TTC) = 2.0 s(Figure 108).
Based on this guideline, the longitudinal hazard-judgment boundary for the cut-in scenario is defined as TTC = 2.0 s.

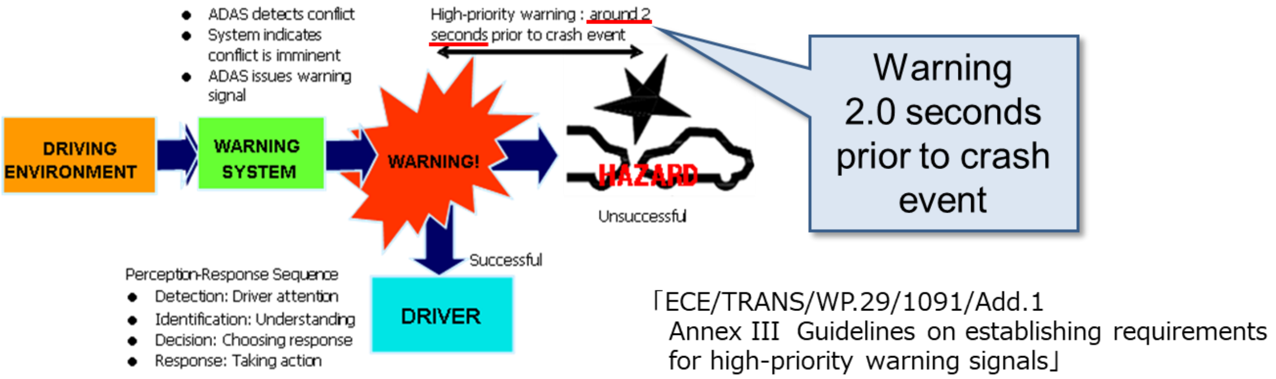


Figure 108 UNR Collision Warning Guidelines (Referenced)

6.3.2. Cut-Out Scenario

A cut-out scenario refers to a situation in which a lead vehicle being followed by the ego vehicle suddenly changes lanes into an adjacent lane. This maneuver may cause a slow-moving or stopped vehicle—for example, due to a breakdown or the tail end of congestion—to suddenly appear in front of the ego vehicle.
Figure 109 presents a schematic diagram illustrating the boundary conditions up to the point at which a C&C driver judges the situation to be hazardous when the lead vehicle performs a cut-out maneuver.

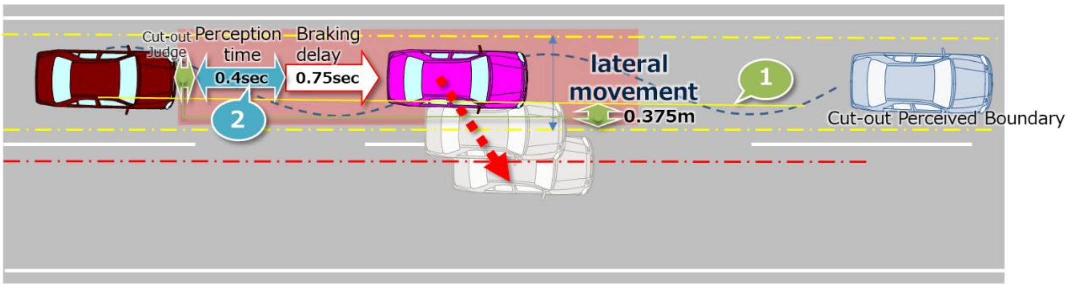


Figure 109 Cut-Out Judgment Conditions and Hazard-Judgment Boundary

The boundary condition for judging that a lead vehicle is performing a cut-out is defined, in the same manner as for the cut-in scenario, in terms of the lateral displacement distance (wandering width) of the lead vehicle. Because both cut-in and cut-out are lane-change maneuvers, the same judgment boundary—derived from the distribution of lateral wandering width obtained from real-world traffic observation data (Figure 102) —is applied. After the cut-out maneuver is judged, the time required for driver to recognize the vehicle that appears ahead and to judge the situation as hazardous is defined as 0.4 seconds, based on the experimental results described in Figure 105 and 106.

When the cut-out judgment condition and the hazard-judgment condition are applied to the braking-process diagram shown in Figure 97, the resulting C&C driver model representation for the cut-out scenario is obtained, as shown in Figure 110.

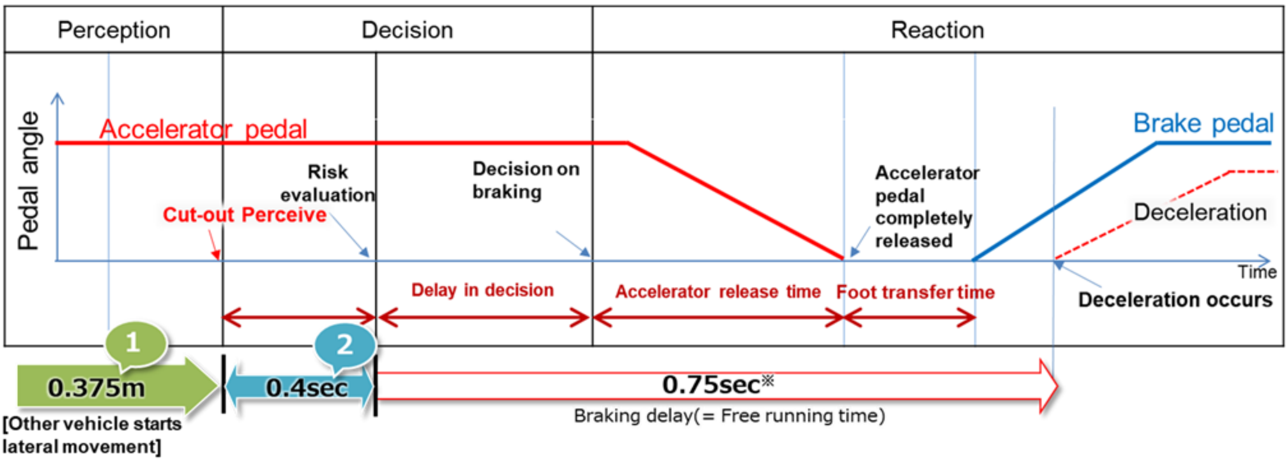


Figure 110 Competent and Careful Human Driver Model（Cut Out）

6.3.3. Deceleration Scenario

A deceleration scenario assumes a situation in which a lead vehicle being followed by the ego vehicle suddenly performs hard deceleration , as illustrated Figure 111. In the previously described cut-in and cut-out scenarios, it was necessary to define conditions related to the lane-change behavior of surrounding vehicles. In contrast, the deceleration scenario involves only longitudinal behavior. Accordingly, it is sufficient to define the time required to judge the lead vehicle’s deceleration as hazardous.

Consistent with the previous scenarios, the hazard-judgment time applicable to the deceleration scenario is defined as 0.4 seconds.

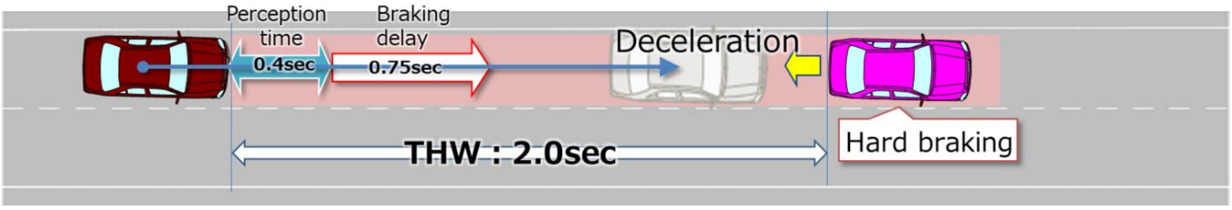


Figure 111 Hazard-Judgment Boundary in the Deceleration Scenario

When the hazard-judgment conditions for the deceleration scenario is applied to the braking-process diagram shown in Figure 97, the resulting C&C driver model representation is obtained, as shown in Figure 112.

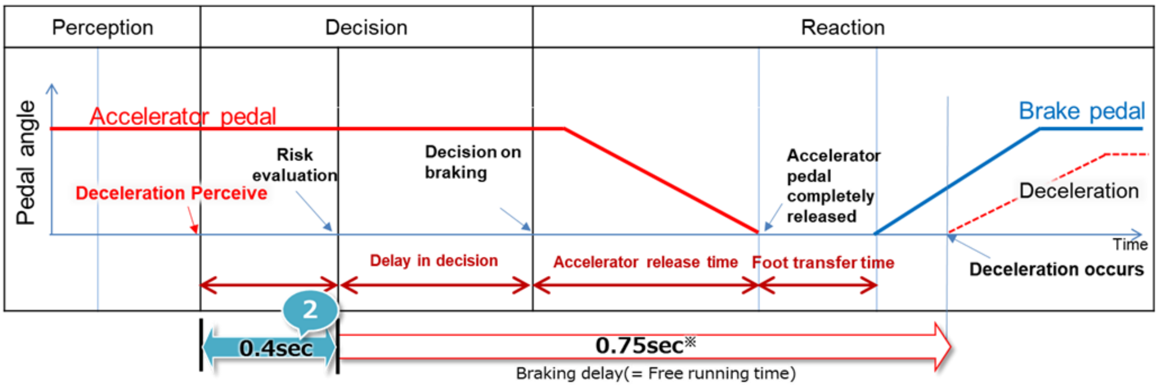


Figure 112 Competent and Careful Human Driver Model（Deceleration）

6.3.4. Parameter Definitions for Deriving Criteria

Table 35 lists the parameters required for deriving safety criteria related to traffic-disturbances. Evaluation scenarios are generated based on combinations of road geometry, ego-vehicle behavior, and the positions and behaviors of surrounding traffic participants.

Each parameter item used in the evaluation scenarios is defined with a specific numerical range. Within these ranges, Pass/Fail boundaries are derived based on the Competent and Careful (C&C) driver model.

Table 35 Traffic-Disturbance Parameter Items

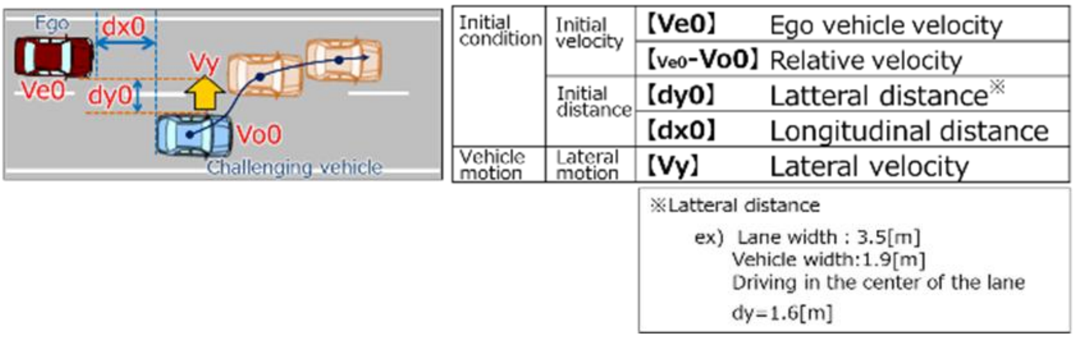
Operating conditions	Roadway	**#of lanes** = number of parallel and adjacent lanes in the same direction of travel **Lane Width** = width of each lane
Initial condition	Initial velocity	**Ve0** = ego vehicle velocity
		Vo0 = velocity of the leading vehicle in the same or adjacent lane
		Vf0 = velocity of vehicle in front of the leading vehicle
	Initial distance	**dx0** = longitudinal distance between the front end of the ego vehicle and the rear end of the leading vehicle
		dy0 = lateral distance between the outside edge of ego vehicle and the outside edge of the leading vehicle
		dy0_f = lateral distance between the outside edge of leading vehicle and the outside edge of the vehicle in front of the leading vehicle
		dx0_f = longitudinal distance between the front end of leading vehicle and the rear end of vehicle in front
		dfy = width of the vehicle in front of leading vehicle
		doy = width of the leading vehicle
		dox = length of the leading vehicle
Vehicle motion	Lateral motion	**Vy** = lateral velocity of the leading vehicle
	Deceleration	**Gx_max** = maximum deceleration of the leading vehicle (G)
		dG/dt = deceleration rate (jerk) of the leading vehicle

6.4. Calculation of Preventability Boundaries Using a C&C Driver

This section describes the calculation of preventable boundaries for each traffic-disturbance scenario using the defined C&C driver model. As described above, preventable boundaries are derived through numerical calculations based on the C&C driver model. The parameter ranges used for boundary derivation are defined such that all relevant combinations of parameters are covered, within the maximum vehicle-velocity range permitted for the automated driving system.

6.4.1. Results of Deriving Preventable Boundaries for the Cut-In Scenario

Safety criteria for the cut-in scenario are derived for each combination of ego-vehicle velocity and relative velocity with respect to the cut-in vehicle. Within the parameter ranges indicated by the green area in Figure 114, collisions with the cut-in vehicle are not acceptable and therefore must be avoided.



Initial condition	Initial velocity	【Ve0】	Ego vehicle velocity
		【Ve0-Vo0】	Relative velocity
	Initial distance	【dy0】	Latteral distance※
		【dx0】	Longitudinal distance
Vehicle motion	Lateral motion	【Vy】	Lateral velocity

※Latteral distance

ex) Lane width : 3.5[m]
Vehicle width:1.9[m]
Driving in the center of the lane
dy=1.6[m]

Figure 113 Parameter Concept Diagram for the Cut-In Scenario

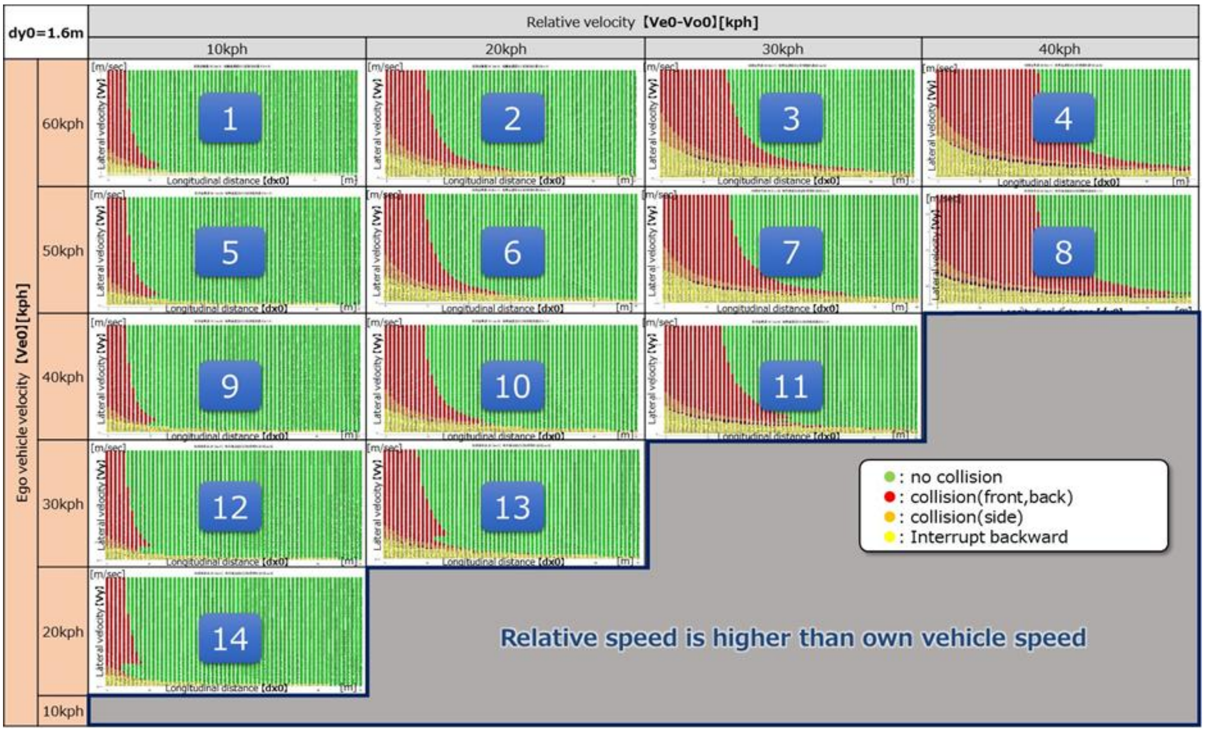
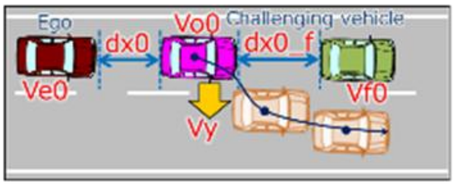


Figure 114 Results of Preventability Boundary Derivation in the Cut-In Scenario

6.4.2. Results of Deriving Preventable Boundaries for the Cut-Out Scenario

The safety criteria for the cut-out scenario requires that collisions be avoidable with all decelerating or stopped vehicles that appear ahead after the lead vehicle performs a cut-out maneuver. In deriving this criteria, the previously defined C&C driver model is applied under the assumption that the ego vehicle follows the lead vehicle at a Time Headway (THW) of 2.0 seconds. The value THW = 2.0 s is adopted with reference to laws and guidance in various countries (reference: *Express Highway Research Foundation of Japan, 2015*).



Initial condition	Initial velocity	【Ve0】	Ego vehicle velocity
		【Vo0】	Leading vehicle velocity
		【Vf0】	Vehicle in front of leading vehicle
	Initial distance	【dx0】	Longitudinal distance※
		【dx0_f】	Front of lead distance
Vehicle motion	Lateral motion	【Vy】	Lateral velocity

※ Follow the leading vehicle in THW=2sec
Vo0 = Ve0(Same speed as the leading vehicle)
Vf0 = 0 (stop vehicle)

Figure 115 Parameter Concept Diagram for the Cut-Out Scenario

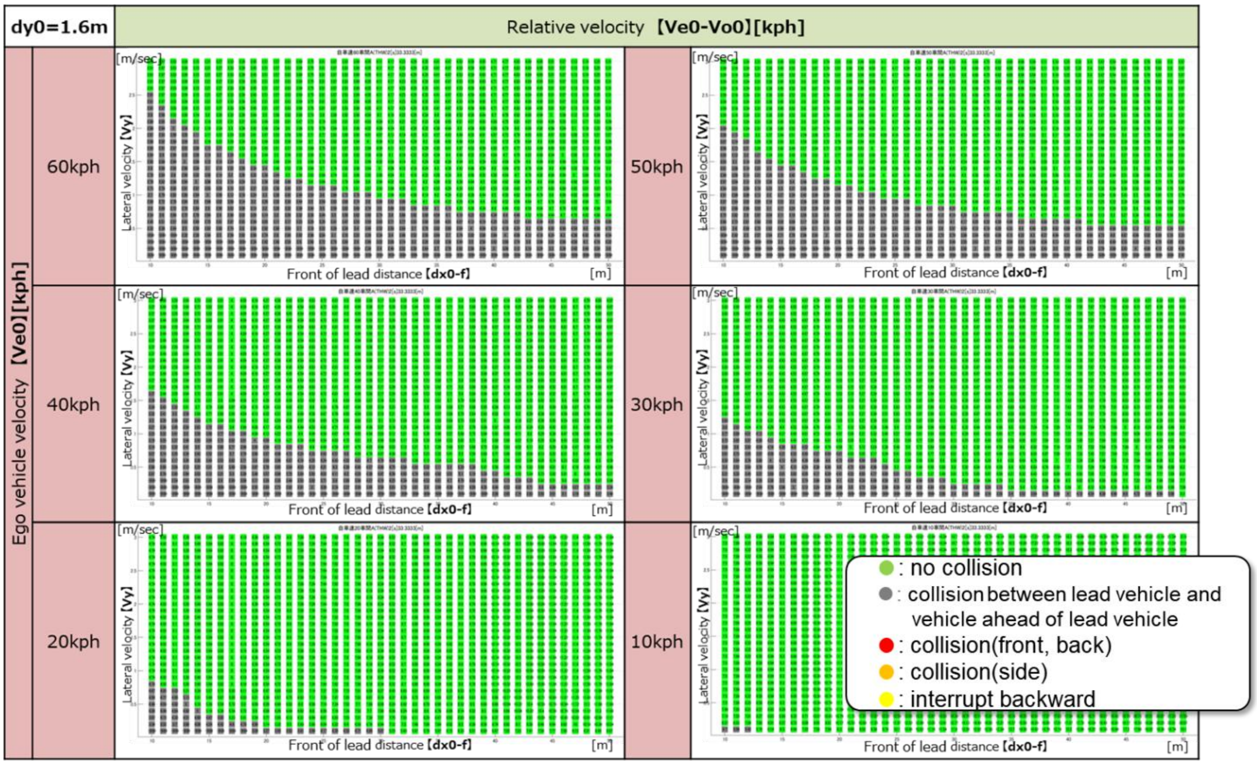
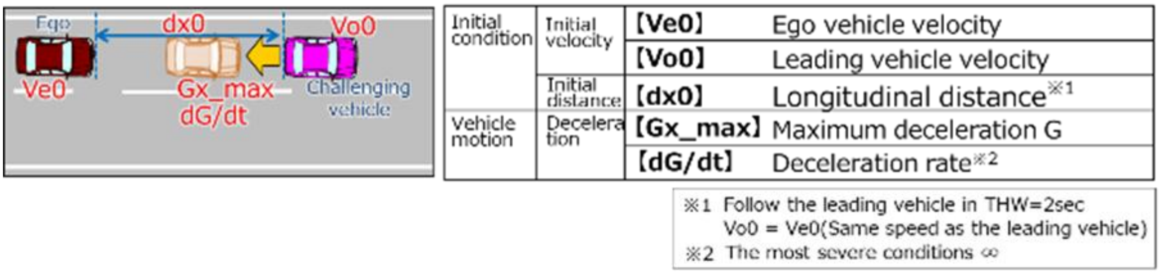


Figure 116 Results of Preventability Boundary Derivation in the Cut-Out Scenario

6.4.3. Results of Deriving Preventable Boundaries for the Deceleration Scenario

The safety criterion for the deceleration scenario requires that collisions be avoidable with a lead vehicle undergoing hard deceleration of −1.0 G or greater, as well as with a stopped vehicle ahead. As in the cut-out scenario, preventable boundaries are derived using the C&C driver model under the assumption that the ego vehicle follows the lead vehicle at a Time Headway (THW) of 2.0 seconds, based on applicable laws and international guidance.



Initial condition	Initial velocity	【Ve0】	Ego vehicle velocity
		【Vo0】	Leading vehicle velocity
	Initial distance	【dx0】	Longitudinal distance※1
Vehicle motion	Deceleration	【Gx_max】	Maximum deceleration G
		【dG/dt】	Deceleration rate※2

※1 Follow the leading vehicle in THW=2sec
Vo0 = Ve0(Same speed as the leading vehicle)
※2 The most severe conditions ∞

Figure 117 Parameter Concept Diagram for the Deceleration Scenario

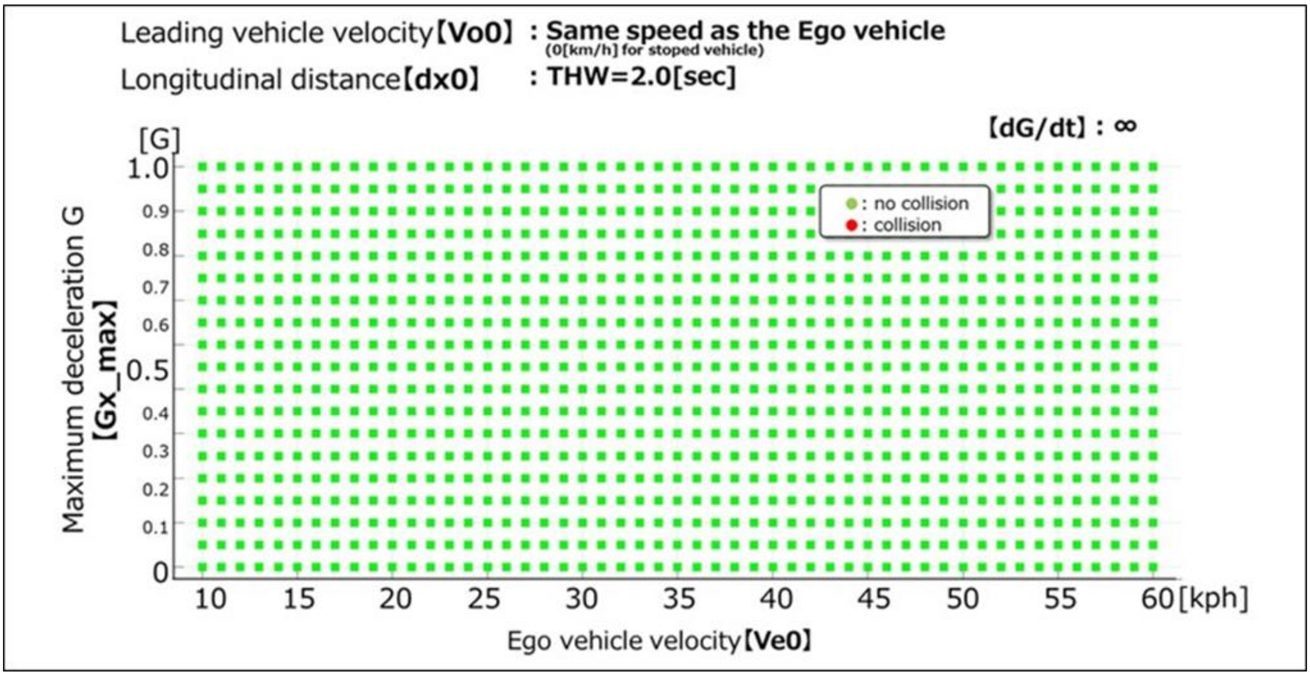


Figure 118 Results of Preventability Boundary Derivation in the Deceleration Scenario

NOTE: No preventable boundary appears in Figure 118 under conditions of 60 km/h or lower , indicating that collisions are avoidable within the defined parameter range at these velocity.

List of committee members

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Deputy Chief of Sectional Committee, Evaluation Scenario WG Leader: Koichiro Ozawa, Honda Motor Co., Ltd.

Deputy Chief of Sectional Committee, Driving Behavior Acceptability WG Leader: Kohji Ishiwata, Nissan Motor Co., Ltd.

Committee member: Atsushi Ohshiba, Hino Motors Ltd.

Committee member: Shinji Tsunoda, SUBARU CORPORATION

Committee member: Shinichiro Kono, Isuzu Motors Limited

Committee member: Shinya Kyusaka, Mazda Motor Corporation

Committee member: Yumi Kubota, Nissan Motor Co., Ltd

Committee member: Fumihiko Takekoshi, Suzuki Motor Corporation

Committee member: Yasuhiro Furukawa, Mitsubishi Motors Corporation

Committee member: Katsuya Yashiro, UD Trucks Corporation

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Advisor member: Hiroki Nakamura, Japan Automobile Research Institute

Advisor member: Tomoyoshi Murata, Japan Automobile Research Institute

Annex A Road Geometry

This annex presents a tree-structured representation of road-geometry elements extracted from road-structure definitions, together with the correspondence between road-configuration elements and their associated parameter items. Definitions of these parameter items are provided in Table A-1.

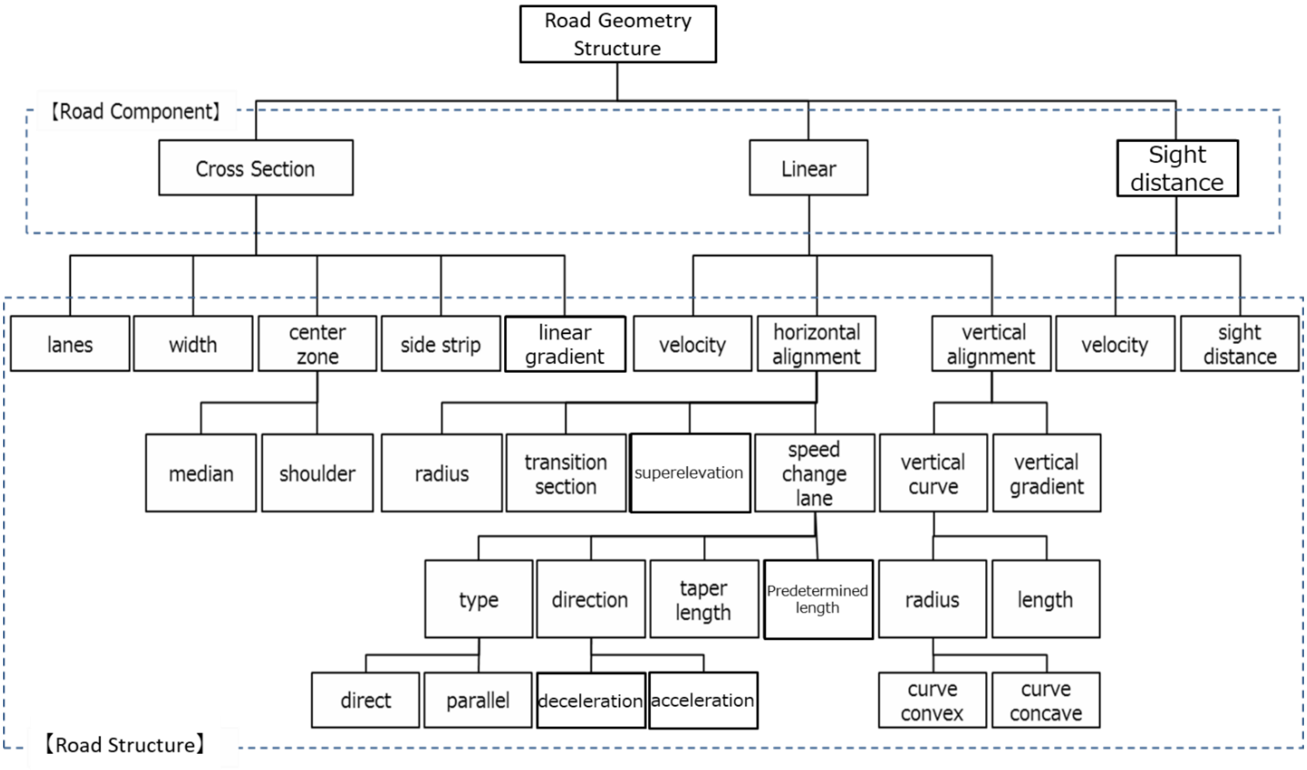


Figure A- 1. Road Geometry Structure Elements based on Road-Structure Regulations (Cross Section, Linear, and Sight Distance) and Their Associated Parameter Items

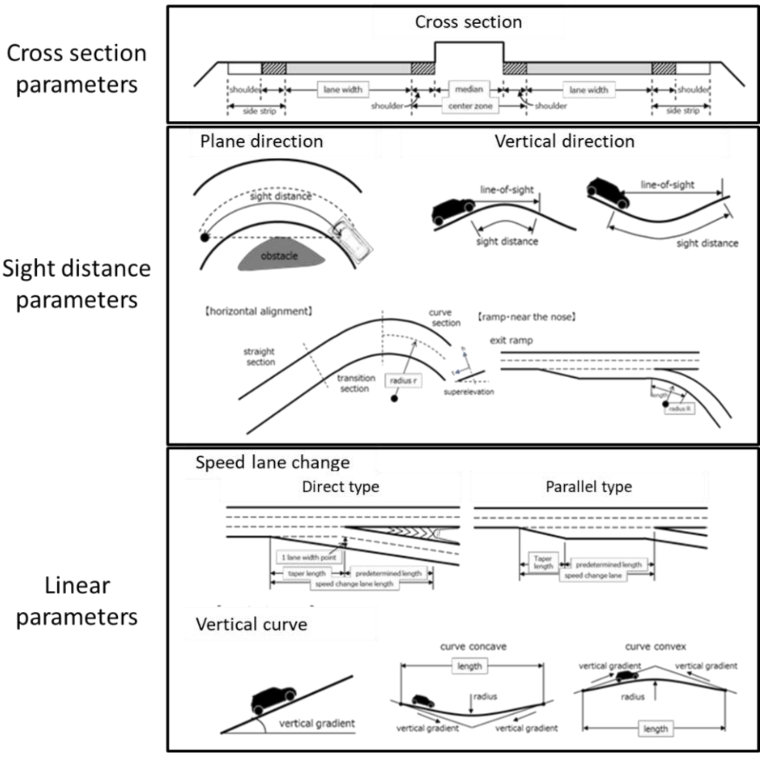
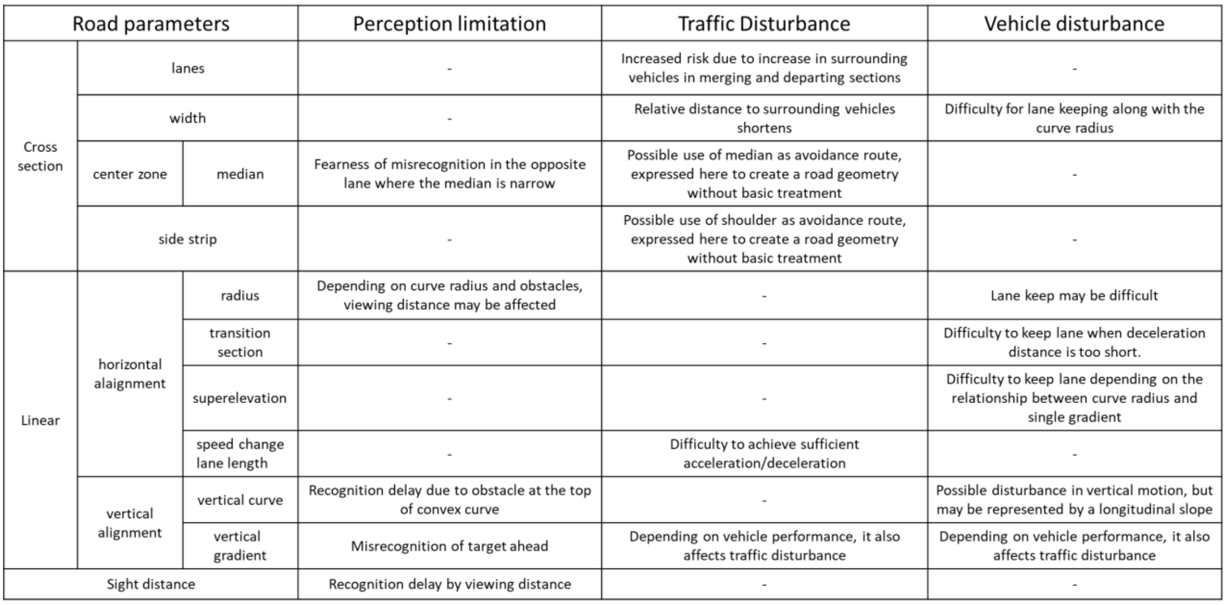


Figure A- 2. Examples of Cross-Section, Sight-Distance, and Straight-Road Parameters Based on the Japanese Road Structure Ordinance

Road-geometry parameters were examined for each scenario category—perception disturbances, traffic disturbances, and vehicle-dynamics disturbances. For example, in traffic-disturbance scenarios, an increase in the number of surrounding vehicles may require an increase in the number of lanes. However, such changes are not necessarily relevant to perception-disturbances or vehicle-dynamics disturbances scenarios. Accordingly, Table A- 1 summarizes the road-geometry parameters used for scenario development for each scenario category.

Table A- 1. Road-Geometry Parameters for Scenario Development by Vehicle-Control Category



Road parameters			Perception limitation	Traffic Disturbance	Vehicle disturbance
Cross section	lanes		-	Increased risk due to increase in surrounding vehicles in merging and departing sections	-
	width		-	Relative distance to surrounding vehicles shortens	Difficulty for lane keeping along with the curve radius
	center zone	median	Fearness of misrecognition in the opposite lane where the median is narrow	Possible use of median as avoidance route, expressed here to create a road geometry without basic treatment	-
	side strip		-	Possible use of shoulder as avoidance route, expressed here to create a road geometry without basic treatment	-
Linear	horizontal alaignment	radius	Depending on curve radius and obstacles, viewing distance may be affected	-	Lane keep may be difficult
		transition section	-	-	Difficulty to keep lane when deceleration distance is too short.
		superelevation	-	-	Difficulty to keep lane depending on the relationship between curve radius and single gradient
		speed change lane length	-	Difficulty to achieve sufficient acceleration/deceleration	-
	vertical alignment	vertical curve	Recognition delay due to obstacle at the top of convex curve	-	Possible disturbance in vertical motion, but may be represented by a longitudinal slope
		vertical gradient	Misrecognition of target ahead	Depending on vehicle performance, it also affects traffic disturbance	Depending on vehicle performance, it also affects traffic disturbance
Sight distance			Recognition delay by viewing distance	-	-

Scenario-Category-Specific Road-Geometry Parameters
Based on the above considerations, the principal road-geometry parameters handled in each scenario category are as follows:

- Perception-disturbance scenarios
  Parameters such as central medians, curve radius, longitudinal alignment, and sight distance.
- Traffic-disturbance scenarios
  Parameters such as number of lanes, lane width, acceleration/deceleration lanes, and longitudinal gradient.
- Vehicle-dynamics disturbance scenarios
  Parameters such as road width, curve radius, non-regulated sections, superelevation, and longitudinal alignment.

With respect to road-geometry parameters used in test scenarios, the number of required test cases can be reduced by fixing parameters that do not affect safety and defining ranges only for safety-relevant parameters.

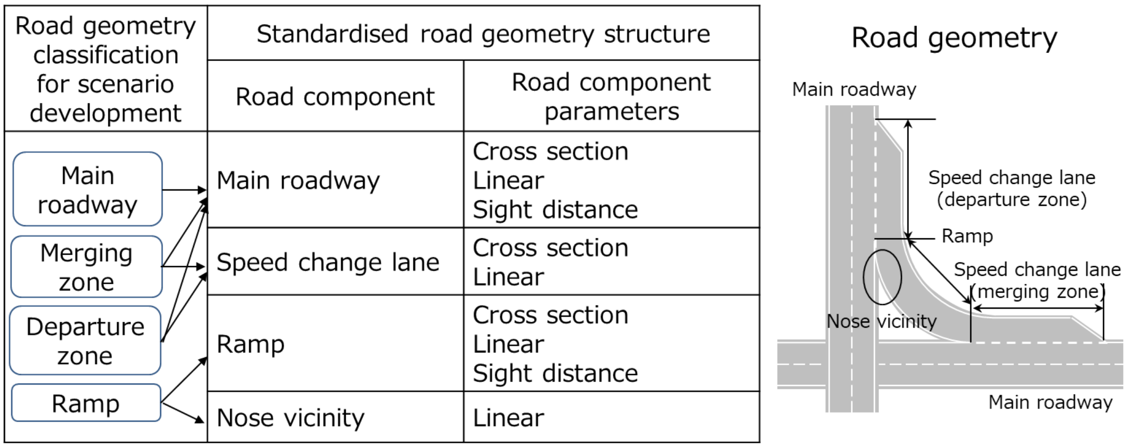
A.1. Road-Geometry Components

Based on the definition of the driving environment, road geometry is classified into main lanes, merge lanes, diverging lanes, and ramps. In addition, the road-geometry classification used for scenario development consists of four elements: main lane, velocity-change lane, rampway, and nose vicinity (Figure A- 3).

Under the Road Structure Ordinance (RSO), road-structure parameters are defined for each component in this document (see Section 3.4). This basic classification enables a clear correspondence between the road-geometry categories used for scenario development and the standardized road-geometry components used in road construction in Japan. Examples of standardized components include main roads, velocity-change lanes, ramps, and nose-vicinity areas.

Furthermore, the Road Structure Ordinance defines relationships between each road-geometry component and safety-critical road parameters, such as cross-section, alignment, and sight distance.

> Note: Although the road-geometry components and associated parameters described in this document are defined in accordance with Japanese road-engineering standards, most road-design standards in other countries are based on similar principles. This facilitates application of the proposed methodology to other countries and regions.



Road geometry classification for scenario development	Standardised road geometry structure	
	Road component	Road component parameters
Main roadway Merging zone Departure zone Ramp	Main roadway	Cross section Linear Sight distance
	Speed change lane	Cross section Linear
	Ramp	Cross section Linear Sight distance
	Nose vicinity	Linear

Figure A- 3. Relationship between Road-Geometry Classification for Scenario Development, Standardized Road-Geometry Components, and Safety-relevant parameters

A.2. Basic Road-Geometry Parameters

To determine the basic road-geometry parameters used in the road-structure model (for Japan, see Table A- 2), key parameters are set to the most severe values applicable to each scenario, as shown in the rightmost column of Table A- 2. These parameters are specified with upper and lower bounds and may vary depending on the scenario.

Table A- 2. Road-Parameter List Derived from the RSO and Baseline Road-Geometry Parameters based on the Japanese RSO

Road parameters				Reference values	Most Demanding values	
Cross section	Number of lanes			1, 2, 3, 4	3	
	Width (m)			3.25, 3.5, 3.7	3.25	
	Center zone	Median (m)		1.25, 1.5, 2, 2.25, 3, 4.5	1.25	
		Shoulder (m)		0.25, 0.5, 0.75	0.25	
	Side strip (m)			1.25, 1.75, 2.5	1.25	
	Linear gradient (%)			2, 2.5	2.5	
Linear	Velocity (km/h)			120, 100	120	100
	Horizontal alignment	Curve section	Radius (m)	570, 380	570	380
			Transition section (m)	100, 85	100	85
			Superelevation (%)	6, 8, 10	10	
		Speed change lane	Type	direct, parallel	Direct	Parallel
			Direction	deceleration, acceleration	Deceleration	Acceleration
			Taper length (m)	70, 60	70	60
			Pre-determined length (m)	210, 110	110	220
	Vertical Alignment	Vertical Curve	Radius curve convex (m)	11000, 6500	11000	6500
			Radius curve concave (m)	4000, 3000	4000	3000
			Length (m)	100, 85	100	85
		Vertical gradient (%)		5, 6	5	6
Sight distance	Velocity (km/h)			120, 100	120	100
	Sight distance (m)			210, 160	210	160

A.3. Update Based on Real-World Environmental Data

Actual road geometries may not always strictly comply with legal requirements due to various constraints, such as terrain or urban-density limitations. Such deviations are often treated as provisional measures and may persist over extended periods. Because road conditions can change over time, it is therefore necessary to reflect actual severe conditions observed in real-world environments when defining scenarios.

Table A- 3. Examples of Severe Conditions in Real-World Environments

Situation description	Critical Parameter	Disturbance type
Complicated highway interchange	Short merge and departure lanes	Traffic disturbance
Pronounced curve	Reduced curve radius (limited field of view) High lateral acceleration	Preception distrubance Vehicle disturbance
Absence of central zone	Central zone width (non-regulated)	Perception disturbance
Narrow tunnel dividing wall at merge	Reflection shoulder width (non-regulated)	Perception disturbance
Separators to prevent from driving in the wrong direction	Merge point separators	Perception disturbance

A.4. Updating Road-Geometry Parameters Using Real-World Map Data

This section describes the procedure for definition key road-geometry parameters using real-world map data. Although road-geometry parameters are initially derived from national road-structure ordinances, not all parameters are equally critical for safety evaluation. For example, an increase in the number of lanes may increase the number of surrounding vehicles and affect traffic-disturbance scenarios, but it does not necessarily affect perception-disturbance or vehicle-dynamics disturbance scenarios. Accordingly, the selection of road-geometry parameters depends on the scenario category.

- Perception-disturbance scenarios
  Separation zones, curve radius, curve length, longitudinal alignment, and sight distance.
- Traffic-disturbance scenarios
  Number of lanes, lane width, acceleration/deceleration lanes, and longitudinal gradient.
- Vehicle-dynamics disturbance scenarios
  Lane width, curve radius, transition sections, superelevation, and longitudinal gradient. .

Note : By fixing parameters that do not affect safety and defining only critical parameters as road-geometry parameters for test scenarios, the number of required test cases can be significantly reduced.

To determine road-geometry parameters, the most severe values were initially assigned to key parameters in accordance with Table A- 2, based on the Japanese Road Structure Ordinance. However, actual road topography may deviate from ordinance values for various reasons—for example, in densely populated urban areas where construction space is limited, merge lanes may be shorter than specified.

Accordingly, baseline road-geometry parameter values defined by the Road Structure Ordinance must be updated using actual severe road-geometry conditions. To achieve this, dynamic map data are incorporated into the parameter-definition process.

For example, an analysis of controlled-access highways in the Tokyo area under the conditions of “statutory speed of 100 km/h” and “minimum curve radius less than 100 m” is shown in Figure A- 4 (left). The results (blue points shown on the right side of Figure A- 4) indicate that many locations satisfy these conditions. This finding demonstrates that, in order to accurately reflect actual road-geometry conditions in the Tokyo region, the baseline curve-radius parameter defined in Table A- 2 must be updated from 380 m to less than 100 m.

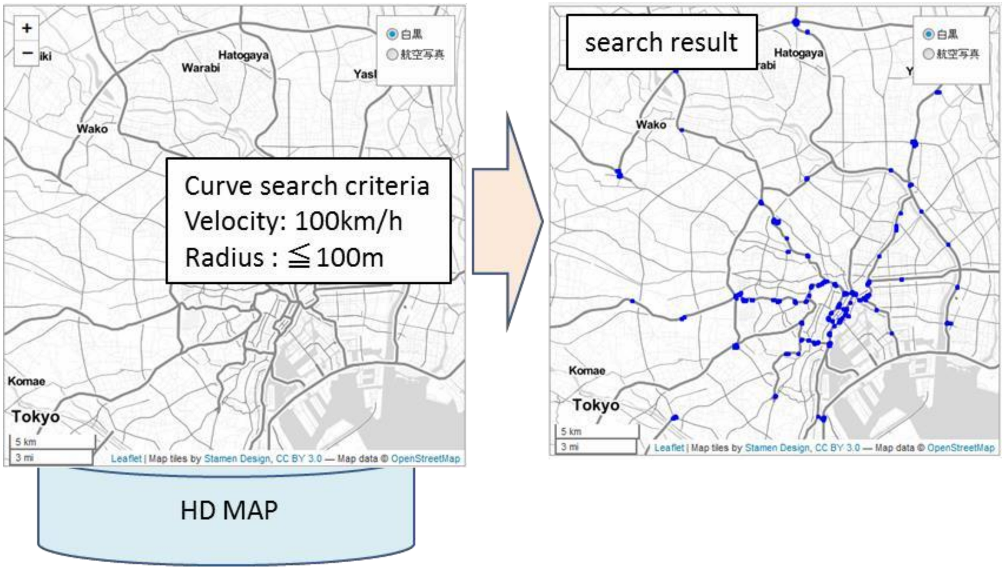


Figure A- 4. Data Extraction Using Dynamic Maps

Annex B Motorcycle-Specific Traffic-Disturbance Scenarios

In a manner analogous to the systematization process described for general traffic-disturbance scenarios, this annex proposes a methodology for structuring motorcycle-specific traffic-disturbance scenarios. These scenarios are defined as combinations of road geometry, ego-vehicle behavior, and the positions and behaviors of surrounding motorcycles (Figure B- 1).

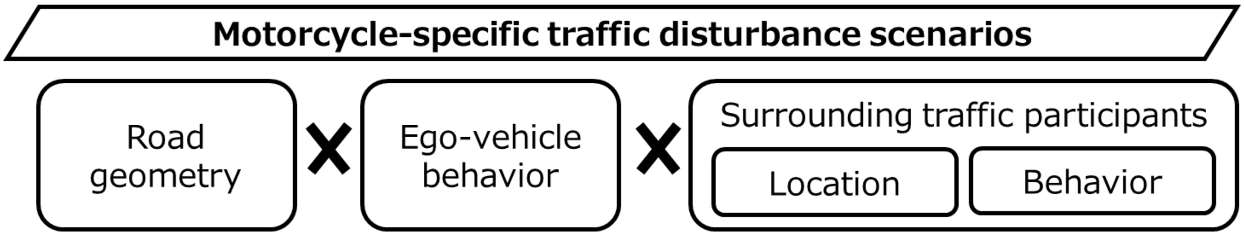


Figure B- 1. Conceptual Structural Diagram of Motorcycle-Specific Traffic-Disturbance Scenarios

B.1. Classification of Positions and Behaviors Specific to Surrounding Motorcycles

In traffic-disturbance scenario for general vehicles, the positions of surrounding vehicles are defined in eight directions around the ego vehicle. For motorcycle-specific scenarios, two additional positions—specific to motorcycles—are defined to account for behaviors unique to two-wheeled vehicles.

As shown on the left side of Figure B- 2, the motorcycle-specific positions [L] and [R] are located on he left and right sides of the ego vehicle within the same lane. These positions reflect the ability of motorcycles to travel within narrow lateral spaces that are not typically accessible to four-wheeled vehicles.

A motorcycle may move into position [L] or [R] through the following behaviors, as illustrated in the center of Figure B- 2.
(a) decelerating from the forward position (Position 1);
(b) accelerating from the rearward position (Position 2); or
(c) changing lanes from positions 3, 4, 5, 6, 7, or 8 surrounding the ego vehicle.
Furthermore, as shown on the right side of Figure B-2, a motorcycle located at position [L] or [R] may subsequently perform the following behaviors:
(d) approaching laterally toward the ego vehicle;
(e) advancing to a forward position;
(f) moving back to a rearward position; or
(g) traveling side by side with the ego vehicle.

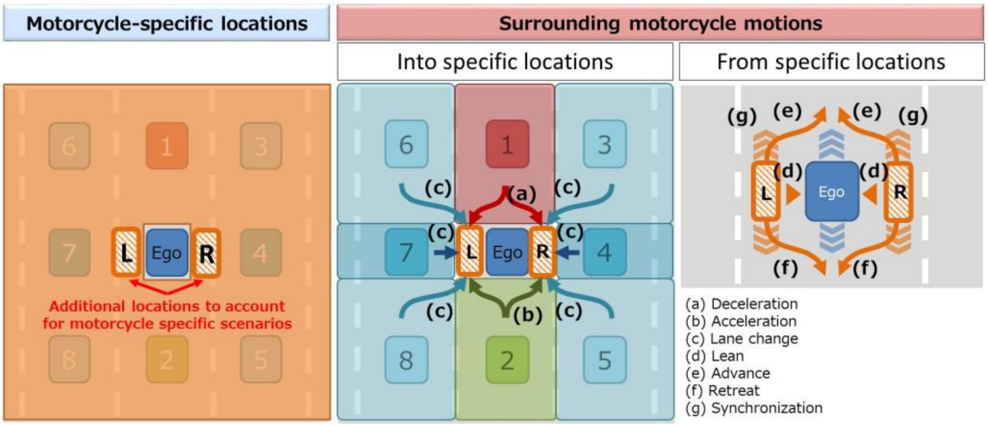


Figure B- 2. Motorcycle-Specific Positions and Behaviors that may Obstruct the Motion of the Ego vehicle

Motorcycles-specific traffic-disturbance scenarios can be evaluated using the same fundamental framework applied to general-vehicle scenarios (see Figure 23). However, it is essential to explicitly consider the motorcycle-specific positions [L] and [R] and their associated behaviors in order to accurately represent interactions between automated driving vehicles and motorcycles.

Annex C Approach to Complex Traffic-Disturbance Scenarios

In real traffic environments, multiple traffic participants may perform numerous actions at different times. This annex examines scenarios involving multiple traffic participants based on the previously developed concept of traffic-disturbance scenarios.

C.1. Concept of Avoidance motion Scenarios

When surrounding vehicles suddenly perform hazardous maneuvers, the ego vehicle must execute appropriate actions to avoid them. Such hazards situations may arise both when the ego vehicle is lane keeping and when it is changing lanes. The latter case represents a situation in which a surrounding vehicle located in the target lane attempts to enter the same space as the ego vehicle.

The actions taken by the ego vehicle to avoid such hazardous situations are referred to as avoidance motions. These motions correspond to secondary actions performed by the ego vehicle in response to a primary hazardous event. Accordingly, avoidance-motion scenarios are intended to evaluate the safety of these secondary behaviors executed by the ego vehicle.

C.2. Traffic-Disturbance Scenarios

To analyze scenarios that arise from actions taken to avoid hazardous movements of surrounding vehicles, a stepwise sequence is defined. This sequence begins with either:

- a hazardous approach of a surrounding vehicle toward the ego vehicle while the ego vehicle is lane keeping; or
- a sudden approach of a surrounding vehicle when the ego vehicle attempts to change lanes.

This initial event serves as the starting point for the ego vehicle’s avoidance motion (Figure C- 1).

Before executing an avoidance motion, the ego vehicle must determine the region in which such a maneuver can be safely performed. This region is referred to as the evasion area.

For example, when a lead vehicle suddenly decelerates and the situation becomes potentially hazardous (an evasion trigger), the ego vehicle must determine whether the area immediately behind it is available (i.e., whether an evasion area exists) and then perform deceleration as an avoidance motion. However, when determining available evasion-area options, the ego vehicle must also consider the possibility of cut-in vehicles intruding into the same area.

By taking these factors into account—together with the road environment being traveled (e.g., main lanes or merge lanes)—a wide range of traffic-disturbance scenarios can be generated.

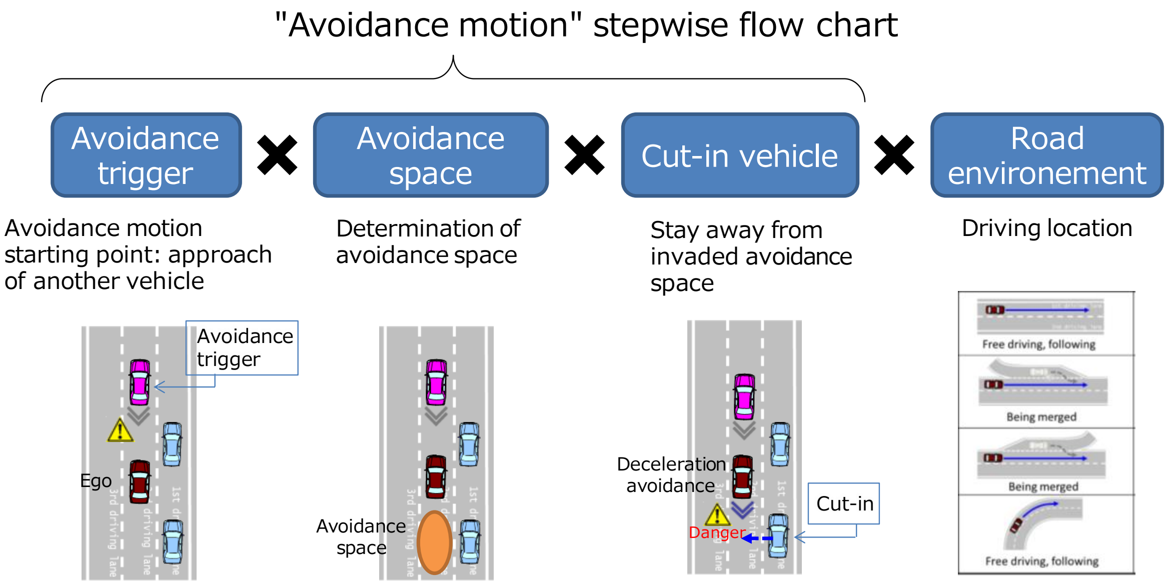


Figure C- 1. Process from the Initiation to the Completion of an Avoidance Motion

C.2.1. Avoidance Trigger

Figure C- 2 illustrates representative driving situations of the ego vehicle in avoidance-motion scenarios, focusing on the events that serve as avoidance triggers.

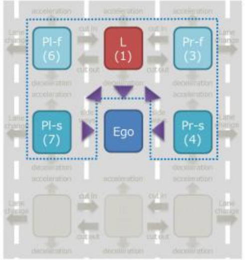
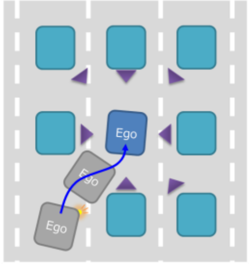
Ego-vehicle motion	Avoidance trigger types	Pattern diagram
Lane keep	a)Approach from the front and sides Deceleration of the lead vehicle, cut-in by the lead side vehicles. ※Approach from the back (rear-end collision) is not considered.	a)Approach from the front and sides 
Lane change	c)Approach to the lane change destination Cut-ins from directions other than that of the ego-vehicle ※Consideration of lane change to the left isn't necessary because of symmetry	b) Approach to the lane change destination 

Figure C- 2. Driving Situations of the Ego Vehicle in Avoidance-Motion Scenarios

C.2.2. Avoidance Area

The avoidance area is defined as the region in which the ego vehicle can execute an avoidance motion. When the approach of a surrounding vehicle that serves as an avoidance trigger begins, the ego vehicle must determine the location of the available avoidance area. For safety reasons, the avoidance area is defined as not being in the direction from which the trigger vehicle is approaching. Figure C- 3 highlights the avoidance areas for both lane-keeping scenarios and lane-change scenarios.

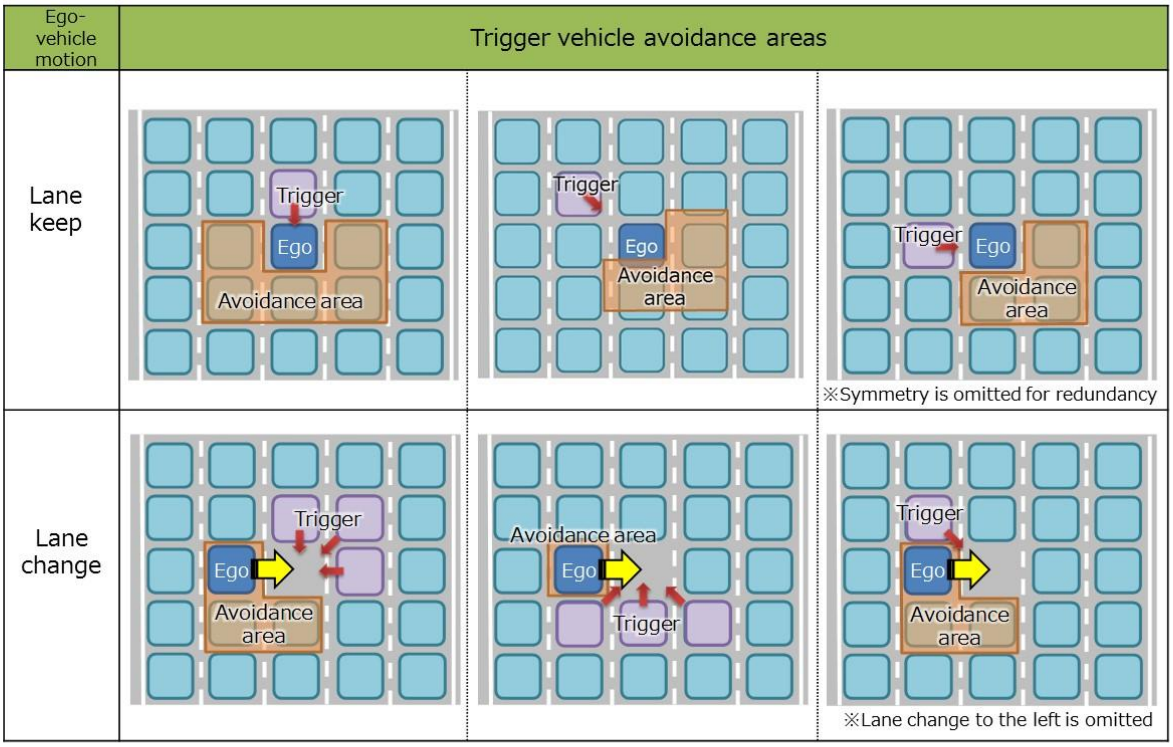


Figure C- 3. Avoidance Areas for Each Trigger Vehicle in Lane-Keeping (upper) and Lane-Change (lower) scenarios

In the lane-keeping case (upper half of Figure C- 3), the trigger vehicle may approach from:
- the forward position of the ego vehicle [L(1)];
- forward-lateral positions [Pl-f (6), Pl-f (3)]; or
- lateral positions [Pl-s (7), Pl-s (4)].

The areas shown in orange represent the corresponding avoidance areas (left–right symmetric cases are omitted).

In the lane-change case (lower half of Figure C- 3), surrounding vehicles located around the target lane of the ego vehicle's lane change may serve as trigger vehicles. The areas highlighted in red represent the corresponding avoidance areas.

After identifying the avoidance area, it is necessary to determine the patterns of vehicle presence within that area. For example, when deceleration of a lead vehicle serves as the trigger, the number of possible combinations of vehicle presence within each cell of the avoidance area is $2^5 = 32$, as illustrated in Figure C- 4.

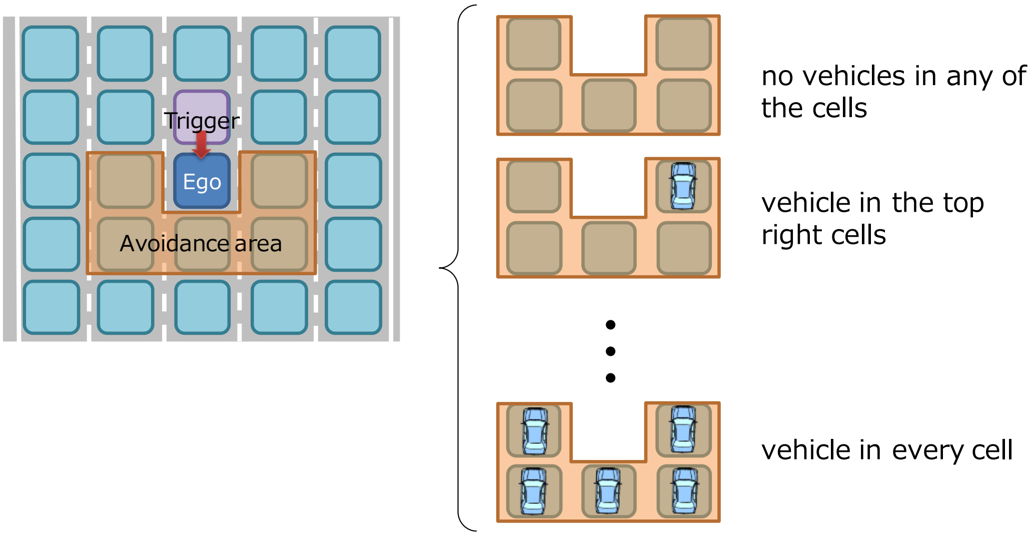


Figure C- 4. Patterns of Vehicle Presence in Each Cell within the Avoidance Area

C.2.3. Vehicles Cut-in to the Avoidance Area

In addition to vehicles already present within the avoidance area, it is necessary to identify vehicles that may cut in to the avoidance area from adjacent spaces. The range within which such vehicles may cut in is shown in Figure C- 5.

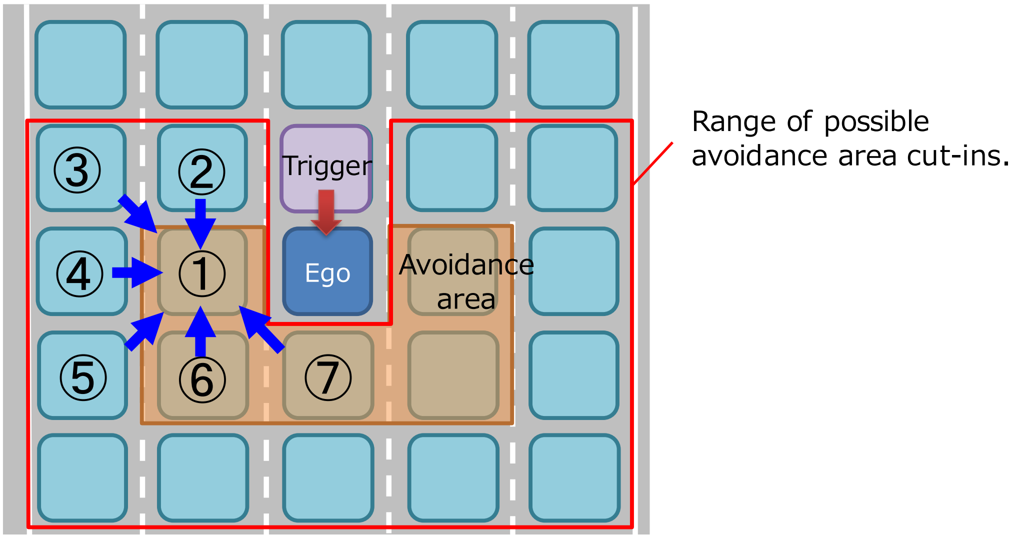


Figure C- 5. Range within which Vehicles can Cut-In to the Avoidance Area

In Figure C- 5, the area highlighted in orange represents the avoidance area. Considering a case in which the ego vehicle moves into Cell ① to avoid the trigger vehicle, it is necessary to take into account potential cut-in vehicles originating from:

- surrounding positions ⑥ and ⑦ within the avoidance area; and
- adjacent positions ②, ③, ④, and ⑤ outside the avoidance area.

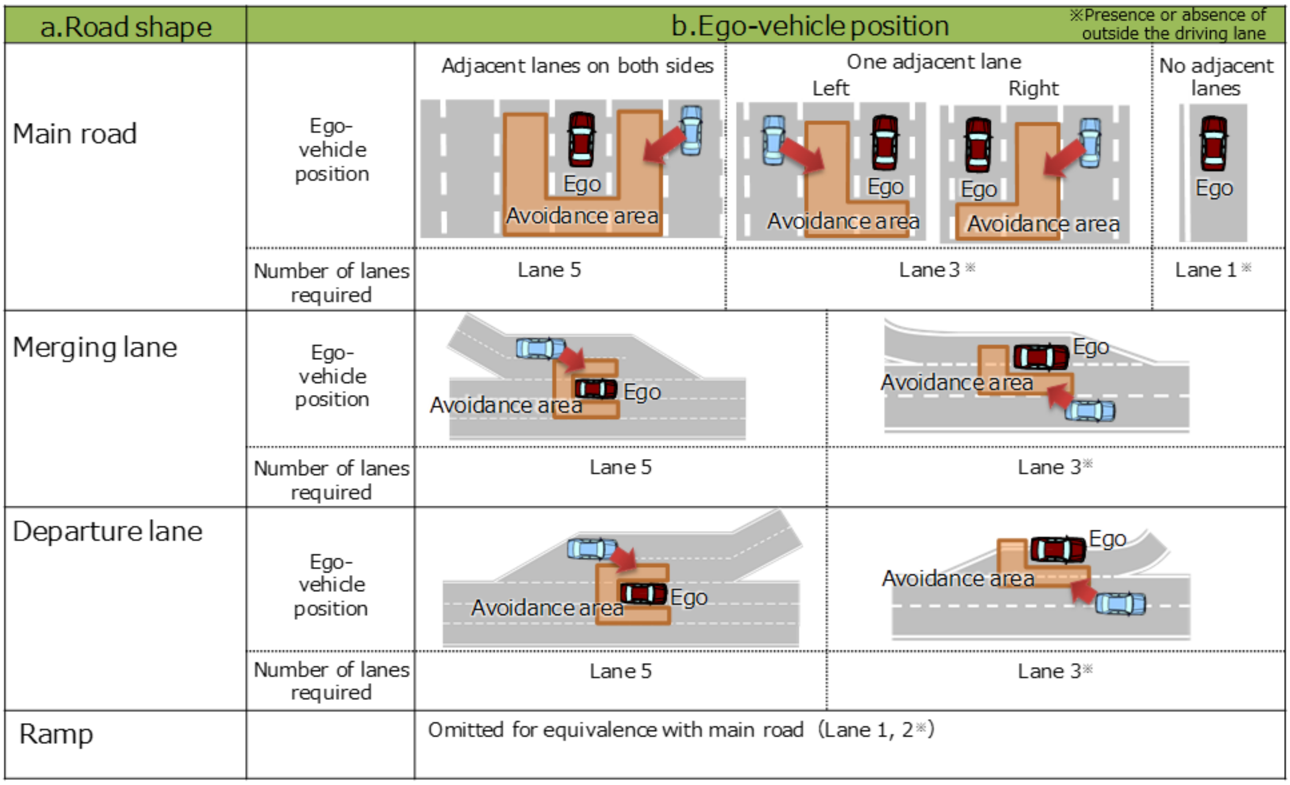
C.2.4. Road Environment

The road environment is defined as the combination of road geometry and the position of the ego vehicle, which together influence the feasibility and safety of avoidance motions.

Road geometry is classified into four categories:

- main lane,
- merge lane,
- diverging lane, and
- ramp.

The position of the ego vehicle is defined based on the shape of the avoidance area and the number of lanes associated with each road-geometry category.



a.Road shape	b.Ego-vehicle position ※Presence or absence of outside the driving lane				
Main road		Adjacent lanes on both sides	One adjacent lane Left	One adjacent lane Right	No adjacent lanes
	Ego-vehicle position	Ego Avoidance area	Ego Avoidance area	Ego Avoidance area	Ego
	Number of lanes required	Lane 5	Lane 3※		Lane 1※
Merging lane	Ego-vehicle position	Avoidance area Ego		Ego Avoidance area	
	Number of lanes required	Lane 5		Lane 3※	
Departure lane	Ego-vehicle position	Avoidance area Ego		Ego Avoidance area	
	Number of lanes required	Lane 5		Lane 3※	
Ramp		Omitted for equivalence with main road（Lane 1, 2※）			

Figure C- 6. Classification of Road Environments in Avoidance-Motion Scenarios

Annex D　Verification of the Coverage of the Traffic-Disturbance Scenario Framework Based on Accident Data

This annex explains how the coverage of the traffic-disturbance scenario framework is verified using accident data. Three representative examples are presented to demonstrate the applicability and limitations of the proposed framework.

D.1. German In-Depth Accident Study (GIDAS) Data

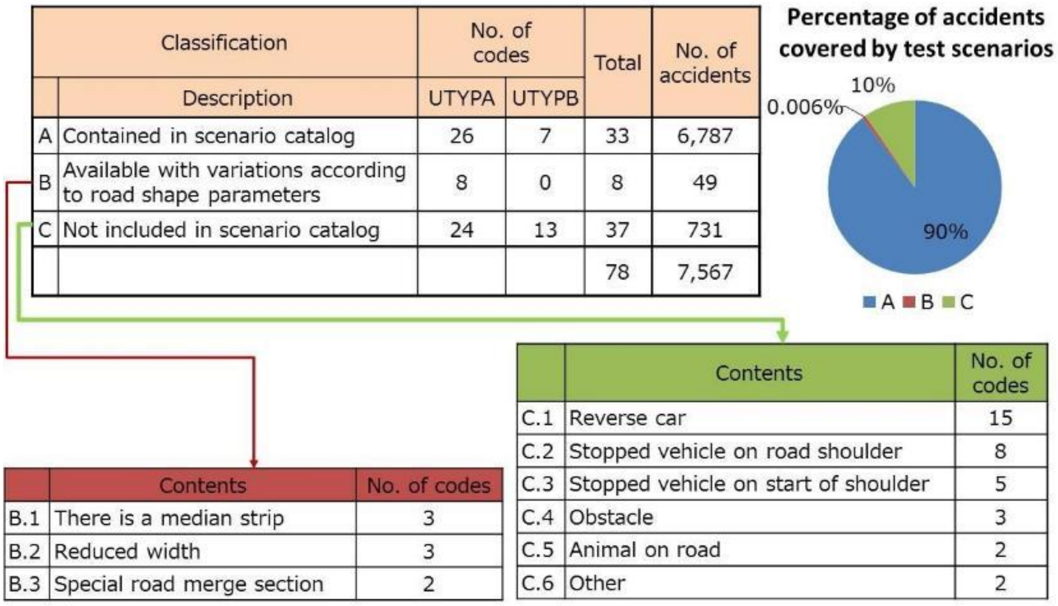
The coverage of the traffic-disturbance scenario framework can be evaluated by examining whether accident cases reported in the German In-Depth Accident Study (GIDAS) database (*Otte, Krettek, Brunner, & Zwipp, 2003*) are appropriately represented within the framework. As a prerequisite for this evaluation, it is assumed that the GIDAS accident classification system adequately represents all reasonably foreseeable scenarios in the German traffic environment. GIDAS classifies traffic accidents based on predefined rules related to accident characteristics.

To conduct the verification, correspondence relationships were established between the GIDAS accident classification codes and the traffic-disturbance scenario framework, and a comparative analysis was performed. The table shown in the upper-left portion of Figure D- 1 summarizes the number of GIDAS accident codes classified through this mapping. Categories A, B, and C together represent 78 types of codes and 7,567 accidents occurring on controlled-access highways in the analyzed dataset.

The results indicate that:

- 33 types of codes, corresponding to 6,787 accidents, can be analyzed within the traffic-disturbance scenario framework.
  This corresponds to approximately 90% of accidents on controlled-access highways in Germany.
- Category B includes 8 types of codes and 49 accidents (approximately 0.006% of all controlled-access highway accidents) related to road characteristics not covered by the current scenario matrix.

The road-geometry data used to construct the scenario list are based on the Japanese Road Structure Ordinance (Japan Road Association, 2004). As a result, certain characteristics specific to German controlled-access highways may not be sufficiently represented. To cover the remaining 8 code types in Category B, it would therefore be necessary to extend the scenario framework by incorporating road characteristics specific to Germany.



Classification		No. of codes		Total	No. of accidents
	Description	UTYPA	UTYPB		
A	Contained in scenario catalog	26	7	33	6,787
B	Available with variations according to road shape parameters	8	0	8	49
C	Not included in scenario catalog	24	13	37	731
				78	7,567

	Contents	No. of codes
B.1	There is a median strip	3
B.2	Reduced width	3
B.3	Special road merge section	2

	Contents	No. of codes
C.1	Reverse car	15
C.2	Stopped vehicle on road shoulder	8
C.3	Stopped vehicle on start of shoulder	5
C.4	Obstacle	3
C.5	Animal on road	2
C.6	Other	2

Figure D- 1. Scenario Database and Number of Accident Cases (by Road Type and Driving Situation)

Category C includes 37 types of codes and 731 accidents, representing approximately 10% of the total dataset, that are not covered by the proposed safety methodology.

Further analysis reveals that:

- Three subcategories (C1–C3), comprising 28 code types, are related to illegal driving behaviors, such as wrong-way driving on controlled-access highways and illegal parking on the shoulder.
- The remaining seven code types (C4–C6) are associated with road obstacles, animals suddenly entering the roadway, and other uncertain or unpredictable factors.

Many accidents in Category C represent cases that are difficult to prevent using conventional Automated Driving Systems (ADS). Preventing such accidents requires not only technical countermeasures, but also institutional and societal approaches, such as stricter enforcement of traffic regulations and improvements in operational rules.

These results indicate that, while the traffic-disturbance scenario framework covers the majority of major accident scenarios, accidents caused by illegal behaviors or highly uncertain factors require additional consideration through both scenario-framework extensions and non-technical countermeasures.

D.2. Pre-Crash Scenario Typology for Crash Avoidance Research (NHTSA)

The NHTSA Pre-Crash Scenario Typology for Crash Avoidance Research defines a set of pre-crash scenario categories for crash-avoidance studies based on the NHTSA General Estimates System (GES) crash database (*Najm, Smith, & Yanagisawa, 2007*). This typology describes vehicle motion, vehicle dynamics, and critical events occurring immediately prior to a collision.

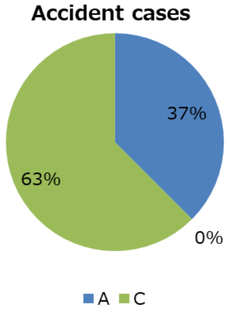
By applying a methodology similar to that used for the GIDAS data, it is possible to compare the NHTSA pre-crash scenario typology with the traffic-disturbance scenario framework developed in this document.

The NHTSA typology consists of 37 pre-crash scenario categories, of which 16 categories correspond to accidents occurring on controlled-access highways. Comparison of these categories with the scenario database constructed under the proposed framework confirms that:

- 6 of the 16 categories are covered by the traffic-disturbance scenario framework; and
- the remaining 10 categories primarily involve illegal behaviors or unpreventable events.

These findings suggest that achieving complete coverage of pre-crash scenarios would require the introduction of complementary approaches beyond vehicle-engineering measures alone.

Classification		number of codes
	Description	
A	Contained in scenario catalog	6
B	Available with variations according to road shape parameters	-
C	Not included in scenario catalog	10
D	Urban road specific (intersection, railway crossing, pedestrian ...)	15
E	Independent accident (due to recognition / vehicle disturbance)	-
-	Driver misuse, vehicle disturbance	5
-	Other	1
		37



	Contents	number
C.1	Reverse car	2
C.2	Shoulder stop vehicle available	-
C.3	Start of road shoulder stop vehicle	2
C.4	Obstacle	4
C.5	Animal on road	2
C.6	Other	-

Figure D- 2. Comparison between the Traffic Disturbance Scenario Database and NHTSA Pre-Crash Categories

D.3. Institute for Traffic Accident Research and Data Analysis (ITARDA) Data

The Institute for Traffic Accident Research and Data Analysis (ITARDA) (https://www.itarda.or.jp/) is a public-interest foundation that systematically compiles and maintains a comprehensive database of traffic accidents occurring in Japan. In this study, 633,639 traffic accident records that occurred between 2018 and 2019, provided by ITARDA, were analyzed. The aggregation conditions applied to the dataset are summarized in Table D- 1. By comparing these accident data with the traffic-disturbance scenarios for general vehicles (Figure 23), the coverage of the proposed scenario framework can be quantitatively verified.

Table D- 1 Aggregation Conditions for ITARDA Accident Data

Item	ITARDA data classification	Aggregation method / rationale
Accident type	"Pedestrian vs. Vehicle", "Vehicle vs. Vehicle", "Single Vehicle", "Train"	Because the scenario framework targets interaction scenes involving vehicles, the analysis is limited to vehicle-to-vehicle accidents.
Accident severity	"Fatal", "Serious Injury", "Minor Injury"	As the objective is coverage verification, all personal-injury accidents are included.
Road geometry	"Intersection", "Near Intersection", "Non-intersection Road", "Railroad Crossing", "General Traffic Area"	In ITARDA data, merge/diverge sections cannot be explicitly distinguished and are therefore included in non-intersection road categories. "General traffic area" is excluded. "Near intersection", "Non-intersection road", and "Railroad crossing" are mapped to non-intersection (including merge/diverge) in the Functional Scenario framework. However, among non-intersection cases, accidents are reclassified as intersections if either vehicle performs a right/left turn or if vehicles approach from crossing directions.
Party type	"Passenger Car", "Truck", "Special Vehicle", "Motorcycle", "Streetcar", "Train", "Light Vehicle", "Pedestrian", "Property", "No Counterparty", "Excluded Party"	For analysis, the ego vehicle and other vehicle in the scenario framework are mapped to the first and second parties in ITARDA data. The ego vehicle is defined as "Passenger Car" (excluding minicars) and "Truck". The other vehicle includes "Passenger Car", "Truck", "Special Vehicle", "Motorcycle", "Streetcar", "Train", and "Light Vehicle".
Action type	"Start", "Go Straight", "Overtaking (Passing)", "Lane Change", "Left Turn", "Right Turn", "U-turn", "Reverse", "Crossing", "Weaving", "Sudden Stop", "Stop", "Parking", "Other", "Excluded Party"	Actions are mapped to Functional Scenario behaviors "Going straight", "Lane change / Swerving", and "Turning" (see Table D-2).
Travel direction of parties	"Vehicle on Road Standard", "Vehicle Off-Road Standard"	Based on travel direction , the approach of the other vehicle relative to the ego vehicle is classified as Same, Crossed (from right/left), or Oncoming.

NOTE: Among vehicle-to-vehicle accidents , the analysis assumes that an Automated Driving (AD) vehicle can substitute for passenger cars and trucks. Accordingly, for accidents in which either vehicle could plausibly be replaced by an AD vehicle (e.g., a right-turn versus straight-through collision at an intersection), cases in which the AD vehicle is substituted for both parties are included. As a result, the number of analyzed scenarios exceeds the number of actual accidents, because multiple AD-vehicle substitution cases are derived from a single real-world accident.

Table D- 2 Correspondence between Functional Scenarios Behaviors and Accident-Data Classifications

Behavior in Functional Scenarios	Accident-data Classification※1
Going straight	“Start”, “Go straight”, “Crossing※2”, “Sudden stop”, “Stop”, “Parking”
Lane change / Swerving	“Overtaking (Passing)”, “Lane change※3”, “Weaving”
Turning	“Left turn”, “Right turn”, “Crossing※2”
Other	“Other”, “Excluded party”

※1 Accident-data classifications are based on ITARDA definitions.

※2 “Crossing” is classified depending on the specific scenario context.

※3 “Lane change” includes path-change maneuvers as defined in the accident database.

D.4. Coverage Verification Results

D.4.1. Coverage of Traffic-Disturbance Scenarios for General Vehicles

Using ITARDA data, accident scenes were classified in accordance with the structure of the traffic-disturbance scenario framework. The results of analyzing occurrence tendencies for each scenario are summarized in Table D- 3.
In the scenario framework, road geometry is classified into Non-intersection, Merge, Branch, and Intersection. However, because ITARDA data do not distinguish merge and branch sections, these are aggregated into the Intersection category for this analysis.

With respect to the approach direction of the other vehicle:

- Same: the other vehicle travels in the same direction as the ego vehicle;
- Crossed (from R/L): the other vehicle approaches from a crossing direction;
- Oncoming: the other vehicle approaches from the opposite direction.

In Table D- 3, green cells indicate accident scenes covered by the scenario framework, while red cells indicate scenes for which detailed information is unavailable.

As a result of the analysis:

- the number of accident scenes in green cells was 1,004,752; and
- the number of accident scenes in red cells was 1,128.

If the coverage rate is defined as the ratio of accident scenes covered by the scenario framework (green cells) to all accident scenes that an AD vehicle may encounter (green + red cells), it is confirmed that 99.89% of accident scenes are covered by the scenario framework (Table D- 4).

These results indicate that the traffic-disturbance scenario framework provides near-complete coverage of vehicle-to-vehicle accident scenes represented in the ITARDA dataset.

Table D- 3 Results of Comparison with ITARDA Accident Data for Traffic-Disturbance Scenarios of General Vehicles

			Surrounding vehicle behavior and coming direction											
			Going straight			Lane Change/Swerving			Turning			Other		
			Same	Crossed	On coming	Same	Crossed	On coming	Same	Crossed	On coming	Same	Crossed	On coming
Road structure and Subject vehicle behavior	Non-intersection	Going straight	481K	-	29K	10K	-	2K	829	-	239	463	-	177
		Lane Change	14K	-	2K	646	-	30	8	-	0	26	-	2
	Intersection	Going straight	44K	215K	3K	1K	430	89	11K	28K	16K	117	214	29
		Turning	41K	49K	47K	1K	192	89	2K	3K	1K	29	43	36

Table D- 4 Coverage Results based on ITARDA Accident Data

Item	Value
Number of accident scenes covered by Functional Scenarios (green cells)	1,004,307 cases
Accident scenes with insufficient detail (red cells)	1,136 cases
Coverage rate [green / (green + red)]	99.89%

D.4.2. Coverage of Traffic-Disturbance Scenarios for Traffic-Vulnerable Users (Cyclist)

Traffic-disturbance scenarios for traffic-vulnerable users (Cyclist) have a structure equivalent to that of traffic-disturbance scenarios for general vehicles. Accordingly, the same comparison methodology was applied to cyclist accident data.

The comparison results are shown in Table D- 5. As a result of the analysis:

- the number of accident scenes covered by the scenario framework (green cells) is 129,312; and
- the number of accident scenes with insufficient detail (red cells) is 200.

Using the same definition of coverage as in Section D.4.1, the coverage rate for cyclist traffic-disturbance scenarios is confirmed to be 99.85%, as summarized in Table D- 6.

These results demonstrate that the scenario framework also provides very high coverage of cyclist-related accident scenes.

Table D- 5 Results of Comparison with ITARDA Accident Data for Traffic-Disturbance Scenarios involving Cyclist

			Surrounding behavior and cyclist coming direction											
			Going straight			Lane Change/Swerving			Turning			Other		
			Same	Crossed	On coming	Same	Crossed	On coming	Same	Crossed	On coming	Same	Crossed	On coming
Road structure and Subject vehicle behavior	Non-intersection	Going straight	6,493	-	2,151	718	-	93	6	-	1	52	-	25
		Lane Change	326	-	40	31	-	6	0	-	0	1	-	2
	Intersection	Going straight	1334	56,872	761	138	160	20	1,326	4,026	299	15	69	5
		Turning	19,554	16,437	17,076	38	23	10	390	871	112	10	14	9

Table D- 6 Coverage Results for Cyclist Traffic-Disturbance Scenarios

Item	Value
Number of accident scenes covered by Functional Scenarios (green cells)	129,312 cases
Accident scenes with insufficient detail (red cells)	200 cases
Coverage rate [green / (green + red)]	99.85%

D.4.3. Coverage of Traffic-Disturbance Scenarios for Traffic-Vulnerable Users (Pedestrians)

For traffic-vulnerable users (pedestrians), coverage was verified by establishing correspondence between pedestrian accident patterns in the following datasets and the pedestrian traffic-disturbance scenarios defined in Figure 27:

- ITARDA(Japan)
- IGLAD (Initiative for the Global Harmonization of Accident Data: https://iglad.org)
- DCA (Definitions for Classifying Accident, Australia)

Table D- 7 Results of comparison with each accident pattern in Pedestrian Traffic-Disturbance Scenarios

			Pedestrian behavior					
			ITALDA		IGLAD		DCA	
			On driving path	Into driving path	On driving path	Into driving path	On driving path	Into driving path
Road structure and Subject vehicle behavior	Non-intersection	Going straight	8	22	5	15	3	4
		Lane Change	—	—	6	—	—	—
	Intersection	Going straight	2	11	—	27	—	1
		Turning	1	9	—	12	—	1

NOTE: The numerical values indicate the number of accident patterns that can be covered by pedestrian scenarios.

The comparison results are summarized in . The numerical values in the table indicate the number of accident patterns that can be mapped to the pedestrian traffic-disturbance scenarios.

The comparison shows that:

- In the ITARDA dataset, two accident patterns were found that do not correspond to the pedestrian traffic-disturbance scenarios. These cases involve collisions between pedestrians and vehicles moving in reverse. However, all such accidents occurred outside public roads, for example in parking areas. Therefore, it can be concluded that all pedestrian scenarios required for safety evaluation of automated driving vehicles on public roads are covered.
- Across the reference datasets (ITARDA, IGLAD, and DCA), some categories show few or no corresponding cases. This is attributed to differences in classification granularity among the datasets rather than to deficiencies in the scenario framework.

For example, in ITARDA accident patterns, ego-vehicle behavior distinguishes between going straight and turning, whereas lane change is not defined as an independent category. As a result, accidents involving lane changes may be included within the going-straight category.

In the IGLAD dataset, six accident patterns involving lane changes were identified. However, these cases are primarily classified as accidents occurring after avoidance of a forward obstacle and are therefore grouped under going-straight or turning maneuvers of the ego vehicle. Similarly, the absence of cases corresponding to on driving path at intersections in the IGLAD and DCA datasets is presumed to result from such cases being classified as non-intersection (straight-road) accidents.

Because definitions of ego-vehicle behavior differ across accident-pattern datasets, it is difficult to establish a strict one-to-one correspondence. Nevertheless, since all reference accident patterns are encompassed within the pedestrian traffic-disturbance scenarios, it can be concluded that the proposed scenario framework provides sufficient and comprehensive coverage of pedestrian-related accident patterns.

Annex E Principle Models and Evaluation Scenarios for Perception Disturbances

As described in Section 3.4.2.1, deriving principle-based perception-disturbance scenarios requires an understand of principle models of each sensor and the definition of the types and ranges of parameters that constitute those models.
Accordingly, this annex presents, for each sensor—millimeter-wave radar, LiDAR, and camera—the following elements:

- the applicable principle models;
- the types and ranges of parameters that characterize those models; and
- representative evaluation scenarios derived from the models.

The representative examples include not only scenarios related to high-frequency physical phenomena, but also scenarios of concern in verification experiments conducted on dedicated test routes, such as pedestrian intrusions, raindrops, and water puddles on the road surface.

E.1. Process for Describing Principle Models and Deriving Evaluation Scenarios

Principle models and evaluation scenarios for perception disturbances are derived using the following systematic procedure:

1. Describe the perception disturbances phenomena, clarify their characteristics, and identify the corresponding phenomenon parameters.
2. Construct a physical model (i.e., a principle model) capable of describing the above phenomena and identify the associated principle parameters.
3. Enumerate disturbance factors that affect variations in the principle parameters and identity the associated principle parameters.
4. Determine the feasible ranges of values for each disturbance-factor parameter.
5. Represent perception disturbance as variations in disturbance-factor parameters and combine them with traffic-disturbance scenarios to define evaluation scenarios for perception disturbances.

For disturbance factors used in evaluation scenarios, if multiple factors can be described using the same principle model, any representative factor may be selected. However, it is required that the ranges of the selected disturbance-factor parameters sufficiently cover the system’s ODD.

An example illustrating the relationships among phenomenon parameters, principle parameters, disturbance factors, and disturbance-factor parameters derived through this process is shown in Figure E- 1.

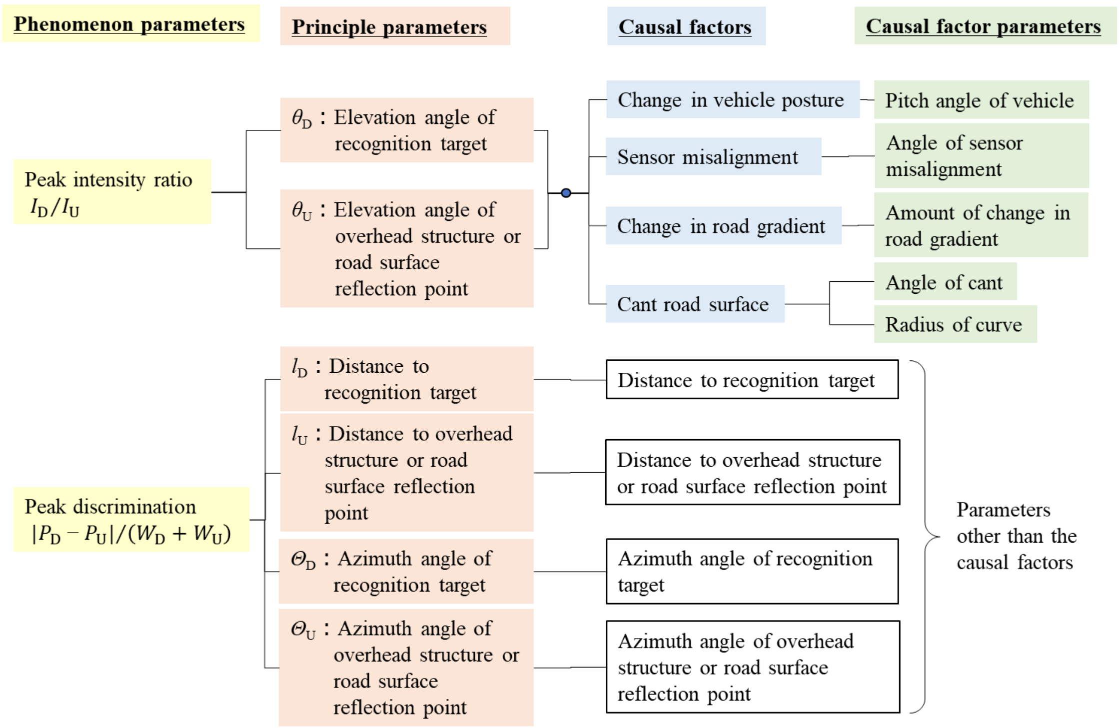


Figure E- 1 : Example of Relationships among Phenomenon Parameters, Principle Parameters, Disturbance Factors, and Disturbance-Factor Parameters for Perception Disturbances

In the following sections, example descriptions of principle models and evaluation scenarios for perception disturbances are presented for each sensor type. Among the evaluation scenarios, those in which the ego-vehicle speed is set to the maximum vehicle velocity within the ODD are described by selecting conditions under which the time to collision with the perception target becomes minimal, from the perspective of safety evaluation.

E.2. Principle Models and Evaluation Scenarios for Millimeter-Wave Radar

For millimeter-wave radar, principle models and representative evaluation scenarios are described for the following five perception-disturbance generation mechanisms:

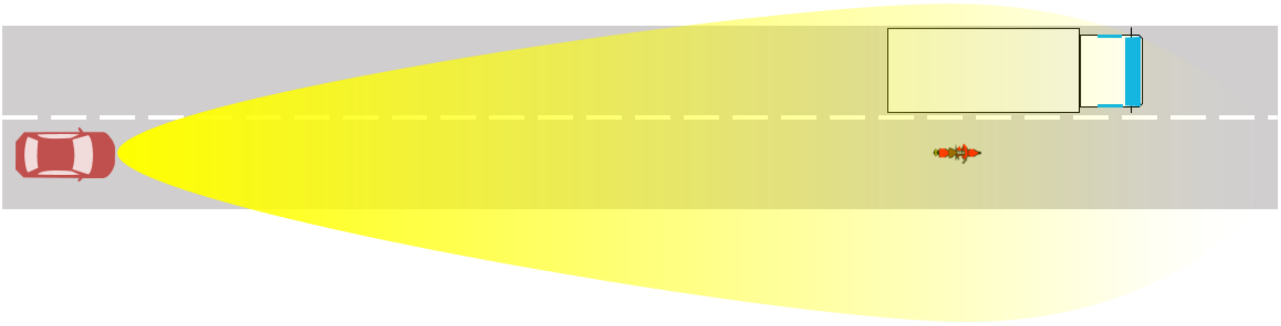
- Large difference in target signal (S) intensity (recognition target)
- Low D/U caused by road-surface multipath
- Low D/U caused by azimuth/elevation-angle variation
- Low S/N caused by vehicle orientation
- Low D/U caused by structures

E.2.1. [Millimeter-Wave Radar] Large Difference in Target Signal (S) Intensity (Recognition Target)

E.2.1.1. Phenomenon and Principle

E.2.1.1.1. **Phenomenon**

When pedestrians, motorcycles, or other objects with relatively low radar reflection intensity travel alongside large vehicles—such as trucks—that generate strong radar reflections, the received signal from the large vehicle becomes dominant. As a result, signals reflected from pedestrians or motorcycles are masked by the stronger signal from the large vehicle. Consequently, the radar sensor may fail to detect these smaller objects, leading to false negatives (missed detections).



Phenomenon Parameters

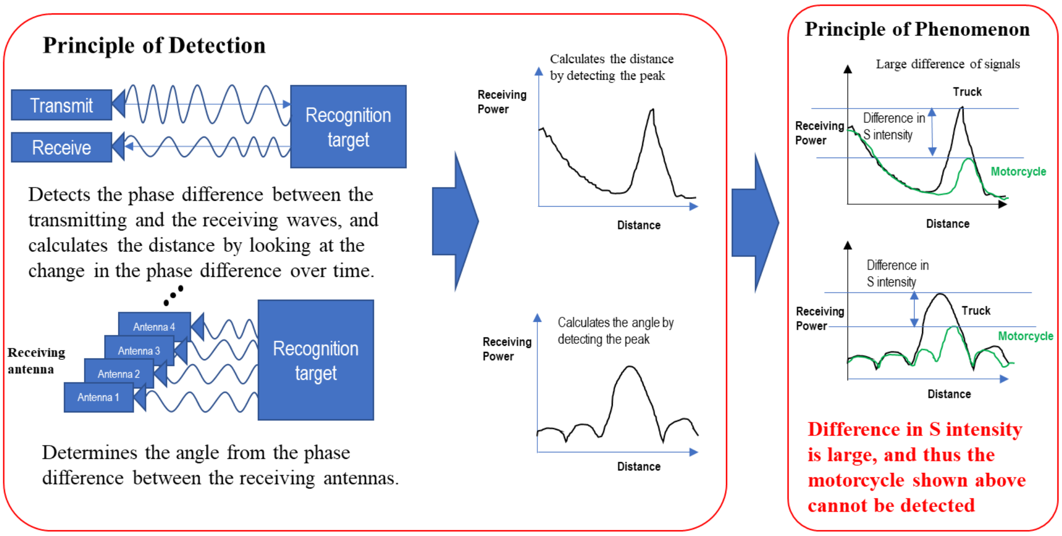
Reflected Point Cloud

Region	Degree/amount	Duration
Full area of the recognition target	Completely unobtainable	Cannot be obtained for a continuous period of time

E.2.1.1.2. **Principle**

When there is a large difference in radar reflection intensity between target objects, signals with lower reflection intensity may be masked by signals with higher reflection intensity. As a result, recognition targets with weaker reflections cannot be reliably detected.

As illustrated on the left side of the figure, the transmitted radar signal is radiated by multiple antennas, and reflected waves from multiple targets—such as a large vehicle and a motorcycle—return to the receiving unit. As shown on the right side of the figure, this effect appears in both range detection (upper) and angle detection (lower). In these processes, the strong reflection component from the large vehicle forms the dominant peak in the received signal. In contrast, the weaker reflection from the motorcycle is suppressed and appears near the noise floor, making it difficult or impossible to distinguish from noise.

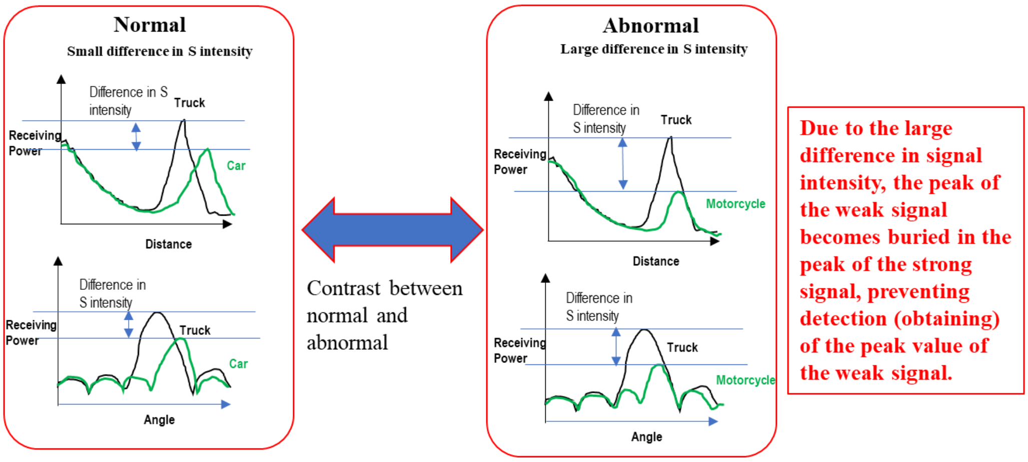


Detects the phase difference between the transmitting and the receiving waves, and calculates the distance by looking at the change in the phase difference over time.

Determines the angle from the phase difference between the receiving antennas.

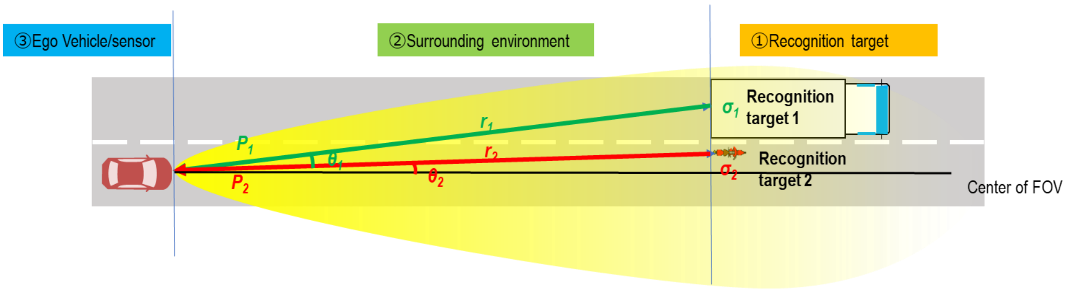
Difference in S intensity is large, and thus the motorcycle shown above cannot be detected

When comparing normal conditions with t conditions under which a perception disturbance occurs, the received signal characteristics change as illustrated in the figure below. Under normal conditions, individual reflection peaks corresponding to each target can be separated. Under disturbed conditions, however, the weak target signal is obscured by the strong reflection component, resulting in a false-negative detection of the weaker target.



Due to the large difference in signal intensity, the peak of the weak signal becomes buried in the peak of the strong signal, preventing detection (obtaining) of the peak value of the weak signal.

E.2.1.1.3. Principle Model



The intensity of the target signal S corresponds to the power of the reflected radar signal. Accordingly, the principle model focuses on a formulation that describes the reflected-signal power.

The power of the reflected wave from a recognition target n is expressed as follows:

$$P_n = \frac{\lambda^2\{G(\theta_n)\}^2 P_t}{(4\pi)^3 {r_n}^4}\sigma_n$$

P_t: Transmitted signal power
P_n : Power of the reflected signal from recognition target n
λ: Wavelength of the electromagnetic wave
G (θ): Antenna gain as a function of angle θ
σn: Radar cross section (RCS) of recognition target n

NOTE: When multiple recognition targets (n) are present, the indices of P, r, and σ are replaced with the corresponding recognition-target index.

When two recognition targets are present, the powers of the reflected waves are given, respectively, by:

$$P_1 = \frac{\lambda^2\{G(\theta_1)\}^2 P_t}{(4\pi)^3 r_1^4}\sigma_1 \qquad P_2 = \frac{\lambda^2\{G(\theta_2)\}^2 P_t}{(4\pi)^3 r_2^4}\sigma_2$$

$$\sigma = \lim_{r\to\infty} 4\pi r^2 \left|\frac{E_s(\vartheta,\varphi)}{E_i}\right|^2$$

On the other hand, the radar cross section (RCS) , denoted by σ of a recognition target can be expressed as the product of its projected area, reflectivity, and the directivity of the scattered waves.
The projected area refers to the effective area of the reflecting surface of the recognition target and depends on factors such as the shape, orientation, size, and relative position of the target with respect to the radar.
The reflectivity depends on the dielectric constant of the target material and the angle of incidence of the radar wave. The dielectric constant is a material-dependent parameter that characterizes the electromagnetic properties of the target.

For the case of vertical polarization, the reflectivity can be expressed as follows:

$$R_p = \frac{\left|\varepsilon_2 \cos\psi_0 - \sqrt{\varepsilon_1(\varepsilon_2 - \varepsilon_1 \sin^2\psi_0)}\right|^2}{\left|\varepsilon_2 \cos\psi_0 + \sqrt{\varepsilon_1(\varepsilon_2 - \varepsilon_1 \sin^2\psi_0)}\right|^2}$$

R_p : Reflectivity for horizontal polarization
R_s : Reflectivity for vertical polarization
ε_1 : Dielectric constant of air
ε_2 : Dielectric constant of the reflecting object

For the case of horizontal polarization , the reflectivity can be expressed as follows:

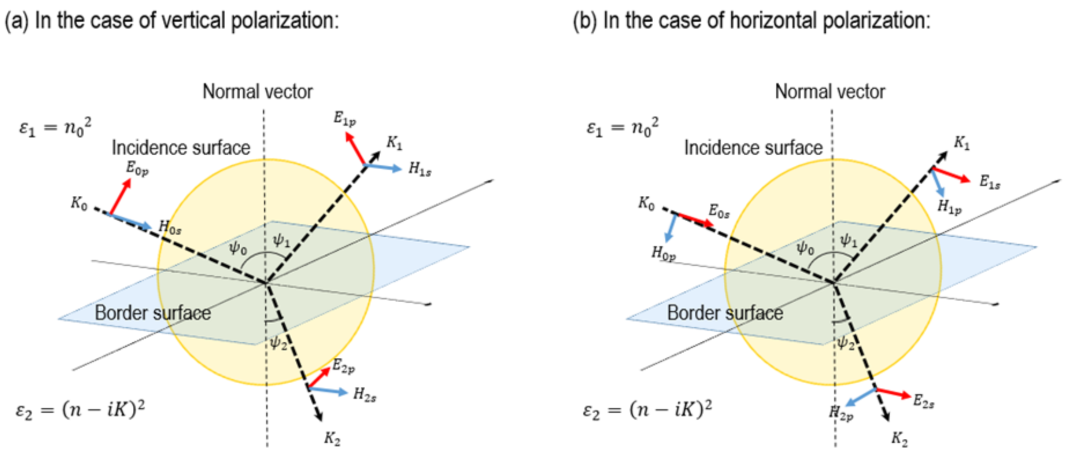
$$R_S = \frac{\left|\sqrt{\varepsilon_1}\cos\psi_0 - \sqrt{\varepsilon_2 - \varepsilon_1 \sin^2\psi_0}\right|^2}{\left|\sqrt{\varepsilon_1}\cos\psi_0 + \sqrt{\varepsilon_2 - \varepsilon_1 \sin^2\psi_0}\right|^2}$$

ψ_0 : Angle of incidence of the electromagnetic wave
ε_r : Dielectric constant of the metal

ω : Angular frequency of the electromagnetic wave
ω_p : Plasma frequency

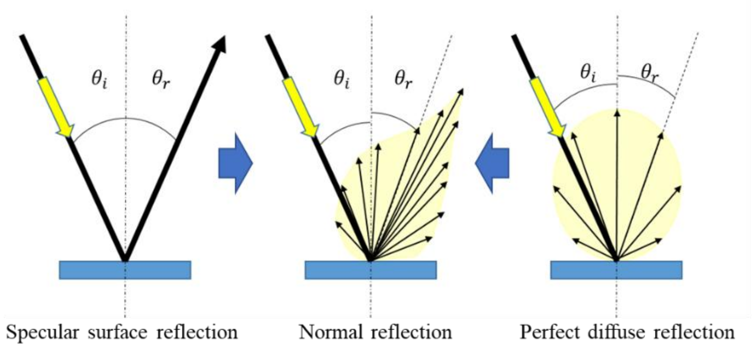
When the recognition target is a metal, the relative dielectric constant, denoted by ε_r is given by:

$$\epsilon_r = 1 - \frac{\omega_p^2}{\omega^2}$$



※The relationship between permittivity and relative permittivity ⇒
Relative permittivity = permittivity of the medium / permittivity in the vacuum

he directivity of the scattered waves is commonly represented as a combination of specular reflection and perfectly diffuse reflections.



Specular surface reflection Normal reflection Perfect diffuse reflection

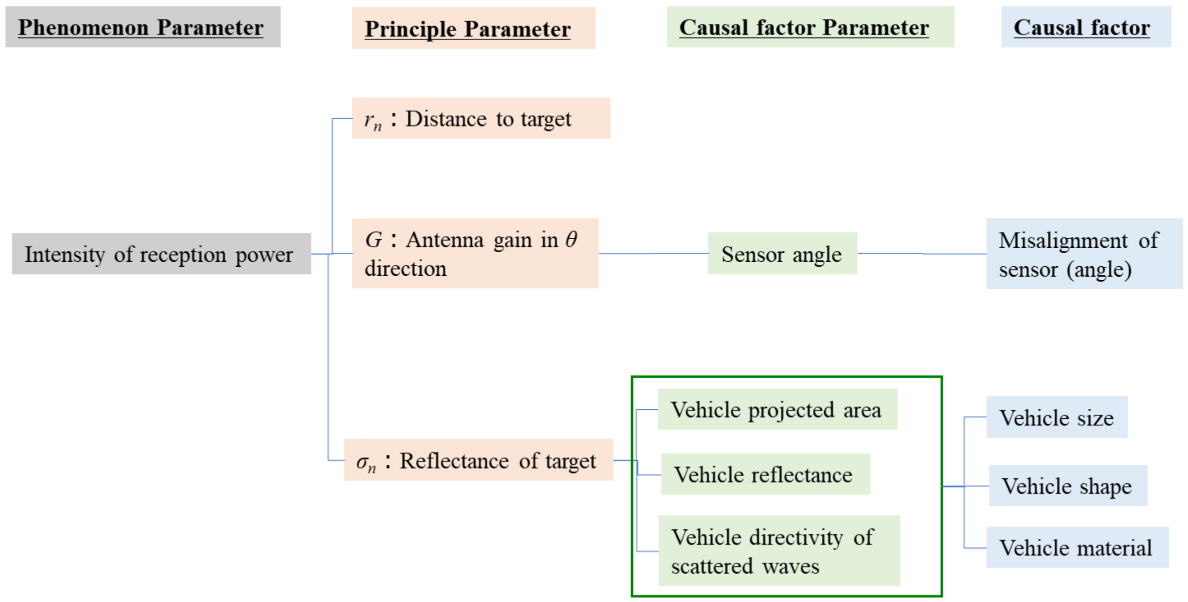
As described above, the intensity of the reflected signal S from a recognition target depends on the signal power P, and the signal power P depends on both the positional relationship between the sensor and the recognition target and the radar cross section (RCS) of the recognition target. Therefore, when describing perception disturbances, it is sufficient to consider the distance and relative angle between the sensor and the recognition target, together with the RCS of the target.

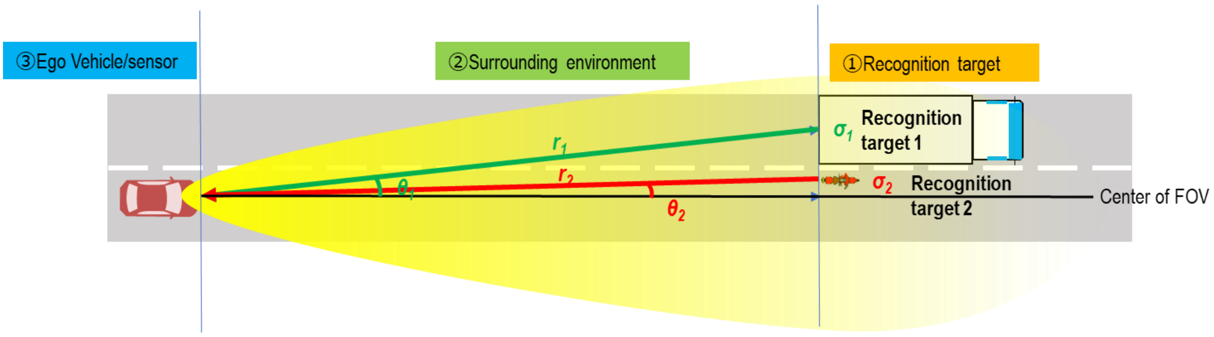
E.2.1.2. Relationship Between Principles and Causal Factors of Perception-Disturbance

This section describes the relationships between phenomenon parameters, principle parameters, causal factor parameters, and the corresponding causal factors for perception disturbances caused by large differences in target signal intensity.

E.2.1.2.1. **Causal** Factors Based on the Principle

Based on the principle model described above, the relationships among phenomenon parameters, principle parameters, causal factor parameters, and the corresponding causal factors are organized as follows.
This organization clarifies how variations in physical phenomena are translated into variations in principle parameters and, ultimately, into concrete causal factors used for scenario definition.

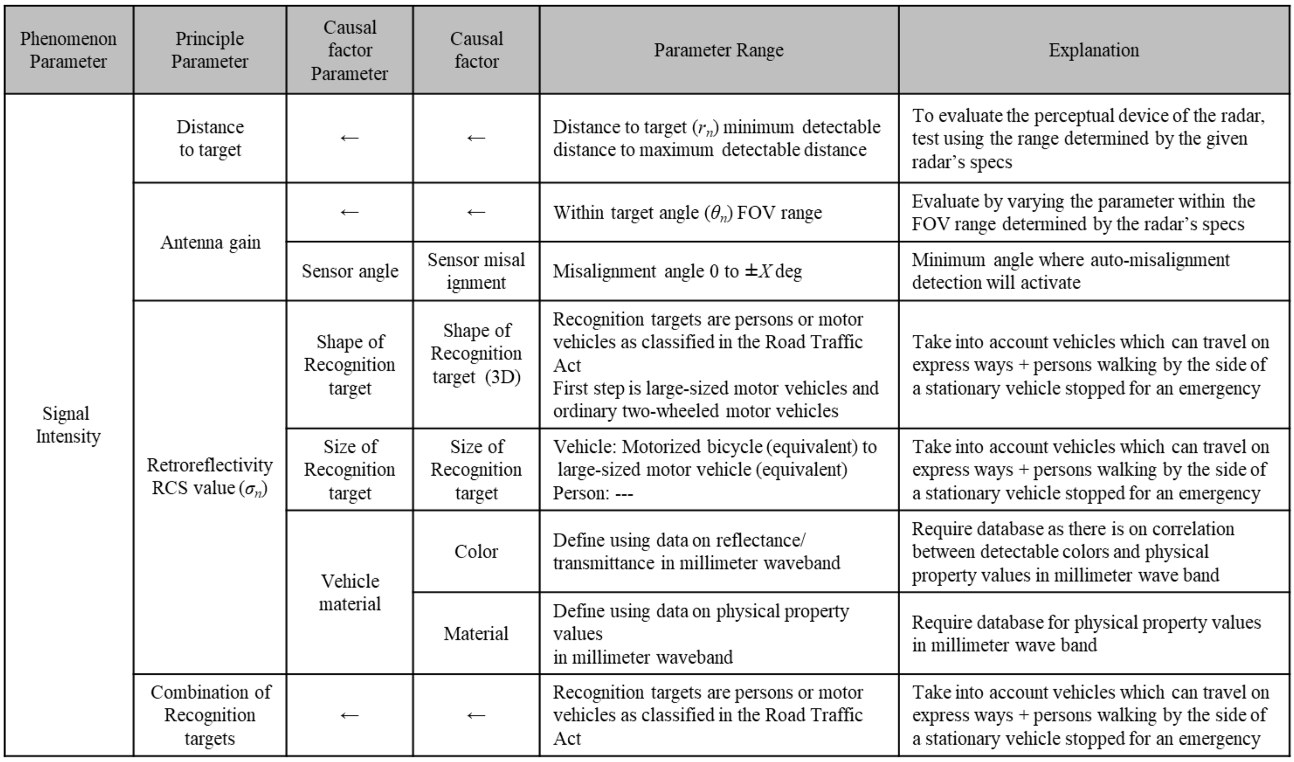




Phenomenon Parameter	Principle Parameter	Causal factor Parameter	Causal factor		
			①Target	②Surrounding environment	③Ego vehicle/sensor
Signal Intensity	Target distance	-	-	-	-
	Antenna gain	-	-	-	-
		Sensor angle	-	-	Sensor misalignment
	Retroreflectivity RCS value (σ_n)	Shape of recognition target	3D shape of subject of target	-	-
		Shape of recognition target	Size	-	-
		Vehicle material (permittivity)	Color	-	-
			Material	-	-
	Combination of recognition targets	←	-	-	-

E.2.1.2.2. **P**arameter Ranges

The applicable ranges of phenomenon parameters, principle parameters, and causal factor parameters are defined based on physical constraints, sensor characteristics, and the ODD.
These parameter ranges are used to ensure that the evaluation scenarios sufficiently cover the conditions under which the corresponding perception disturbances may occur.



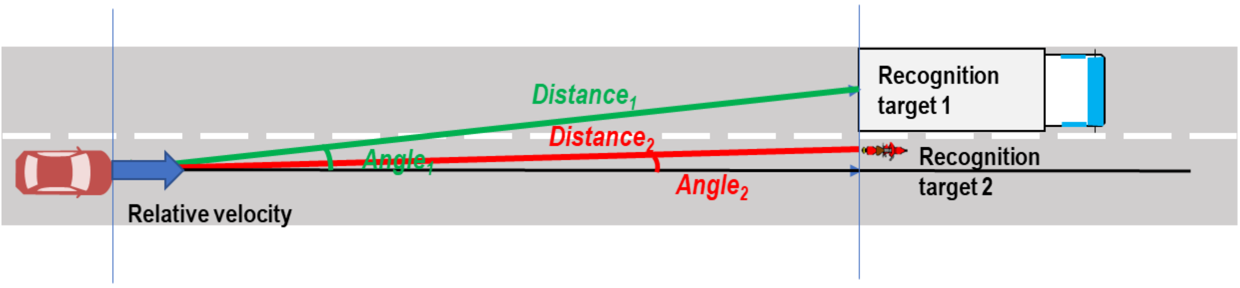
Phenomenon Parameter	Principle Parameter	Causal factor Parameter	Causal factor	Parameter Range	Explanation
Signal Intensity	Distance to target	←	←	Distance to target (r_n) minimum detectable distance to maximum detectable distance	To evaluate the perceptual device of the radar, test using the range determined by the given radar's specs
	Antenna gain	←	←	Within target angle (θ_n) FOV range	Evaluate by varying the parameter within the FOV range determined by the radar's specs
		Sensor angle	Sensor misalignment	Misalignment angle 0 to ±X deg	Minimum angle where auto-misalignment detection will activate
	Retroreflectivity RCS value (σ_n)	Shape of Recognition target	Shape of Recognition target (3D)	Recognition targets are persons or motor vehicles as classified in the Road Traffic Act First step is large-sized motor vehicles and ordinary two-wheeled motor vehicles	Take into account vehicles which can travel on express ways + persons walking by the side of a stationary vehicle stopped for an emergency
		Size of Recognition target	Size of Recognition target	Vehicle: Motorized bicycle (equivalent) to large-sized motor vehicle (equivalent) Person: ---	Take into account vehicles which can travel on express ways + persons walking by the side of a stationary vehicle stopped for an emergency
		Vehicle material	Color	Define using data on reflectance/ transmittance in millimeter waveband	Require database as there is on correlation between detectable colors and physical property values in millimeter wave band
			Material	Define using data on physical property values in millimeter waveband	Require database for physical property values in millimeter wave band
	Combination of Recognition targets	←	←	Recognition targets are persons or motor vehicles as classified in the Road Traffic Act	Take into account vehicles which can travel on express ways + persons walking by the side of a stationary vehicle stopped for an emergency

E.2.1.2.3. Evaluation Scenarios

Evaluation scenarios for this perception-disturbance mechanism are defined based on the following concepts:

- recognition targets with high reflection intensity are combined with recognition targets with low reflection intensity;
- scenarios are defined in which the recognition targets have a relative velocity toward the ego vehicle (approaching direction); and
- the types (e.g., vehicles, motorcycles) and positional relationships of the recognition targets are varied.

By defining scenarios according to these concepts, it becomes possible to systematically evaluate false-negative detection risks caused by large differences in target signal intensity.



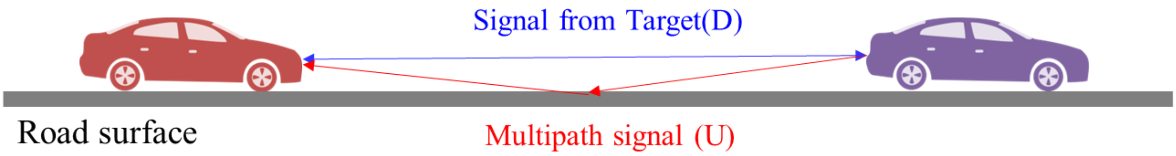
Parameter Item	Range		Explanation
Distance to recognition targets	Variable	Min to max detectable range	Validate by varying the distance between the min and max detectable distance of the sensor
Angle to recognition targets	Variable	Within FOV	Validate by varying the angles within the radar FOV
Number of recognition targets	Fixed	2	Decide on a recognition target with a weak and one with strong reflection (1 each)
Relative velocity to recognition targets	Fixed	Min to max detectable speed	Validate within the radars min and max detectable speed
Type and combination of recognition targets	Fixed	Vehicle, motorcycle, pedestrian	Representative traffic participant/one with high reflectivity and one with low

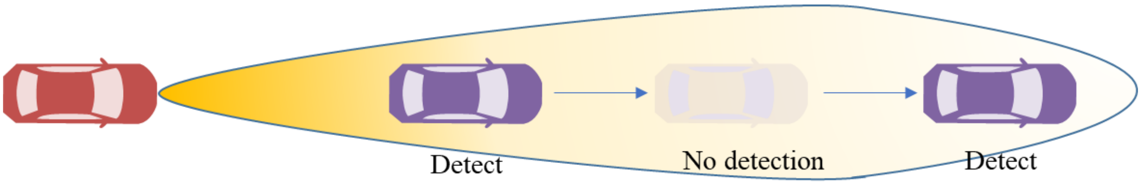
E.2.2. [Millimeter-Wave Radar] Low D/U (Road-Surface Multipath)

E.2.2.1. Phenomenon and Principle

E.2.2.1.1. **Phenomenon**

When the signal reflected from a recognition target (D: Desired Signal) interferes with signals arriving via indirect propagation paths─such as reflections from the road surface (U: Undesired Signal) ─the effective signal strength corresponding to the recognition target is reduced.
As a result, the D/U ratio decreases, and the recognition target may no longer be distinguishable from interference or noise. This degradation can lead to false negatives (missed detections).



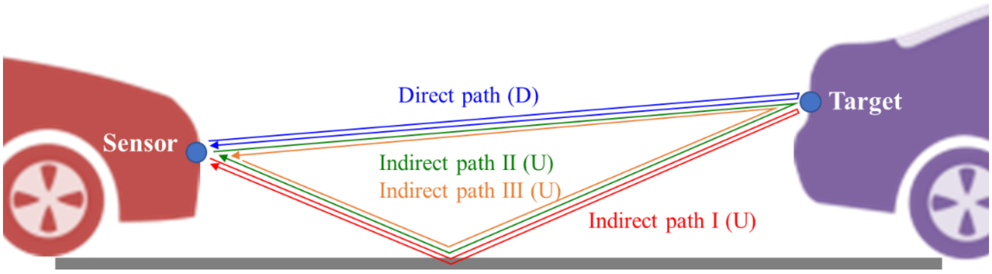


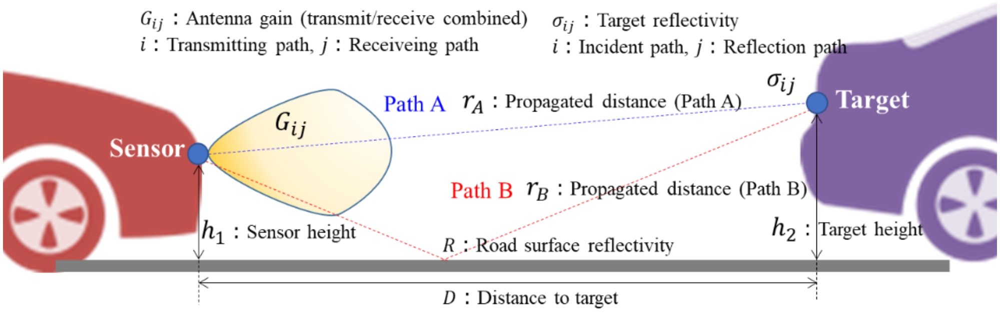
E.2.2.1.2. **Principle**

When electromagnetic waves transmitted from the radar sensor are reflected by a recognition target and received again by the sensor, the propagation paths of the reflected waves can be classified into four representative patterns, as summarized in the table below.

D/U	Signal path	Propagation path
D:Desired-Signal	Direct path	Sensor → Target→ Sensor
U:Undesired-Signal	Indirect path via the road surface Ⅰ	Sensor → Road surface → Target → Road surface → Sensor
	Indirect path via the road surface Ⅱ	Sensor → Target → Road surface → Sensor
	Indirect path via the road surface Ⅲ	Sensor → Road surface → Target → Sensor

The electromagnetic waves received by the sensor are composed of a superposition of reflected waves that have propagated along multiple paths. Because the reflection characteristics and propagation distances differ among these paths, differences arise in the amplitude and phase of the received signals.
As a consequence, the total received signal strength fluctuates—either increasing or decreasing—depending on the relative positional relationships among the sensor, the recognition target, and the road surface.





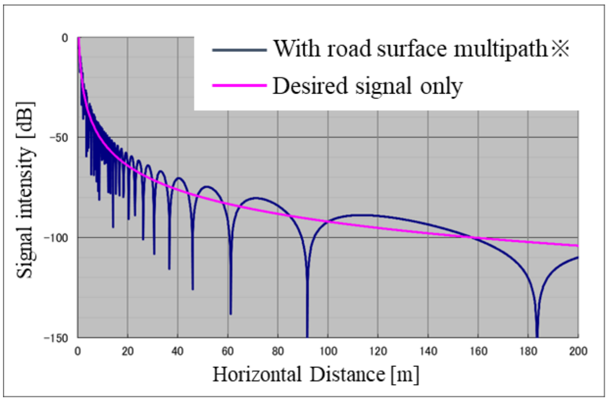
The received signal corresponding to each propagation path is calculated as shown below.

Path	Signal amplitude	Signal phase
Direct path Path A→Path A	$\frac{P_{tx}\lambda^2}{(4\pi)^3} \cdot \frac{G_{AA}\sigma_{AA}}{r_A^4}$	$\phi_0 + \frac{2\pi}{\lambda} \cdot (2r_A)$
Indirect path I Path B→Path B	$\frac{P_{tx}\lambda^2}{(4\pi)^3} \cdot \frac{G_{BB}\sigma_{BB}R^2}{r_B^4}$	$\phi_0 + \frac{2\pi}{\lambda} \cdot (2r_B) + 2\pi$
Indirect path II Path A→Path B	$\frac{P_{tx}\lambda^2}{(4\pi)^3} \cdot \frac{G_{AB}\sigma_{AB}R}{r_A^2 r_B^2}$	$\phi_0 + \frac{2\pi}{\lambda} \cdot (r_A + r_B) + \pi$
Indirect path III Path B→Path A	$\frac{P_{tx}\lambda^2}{(4\pi)^3} \cdot \frac{G_{BA}\sigma_{BA}R}{r_B^2 r_A^2}$	$\phi_0 + \frac{2\pi}{\lambda} \cdot (r_A + r_B) + \pi$

(λ : wavelength)

The propagation distances r_A and $r_{B,}$ as well as the transmission path i and reception path j , are determined by the sensor height h_1 , the target height h_2 , and the horizontal distance D between the sensor and the target. Due to the superposition (interference) of signals from multiple propagation path, the received signal strength may decreases significantly at specific distances, depending on the geometric and environmental conditions.

NOTE: An example configuration consisting of a direct path combined with a single indirect path (Type I) is illustrated below.



※Example of the direct path and an indirect pathI

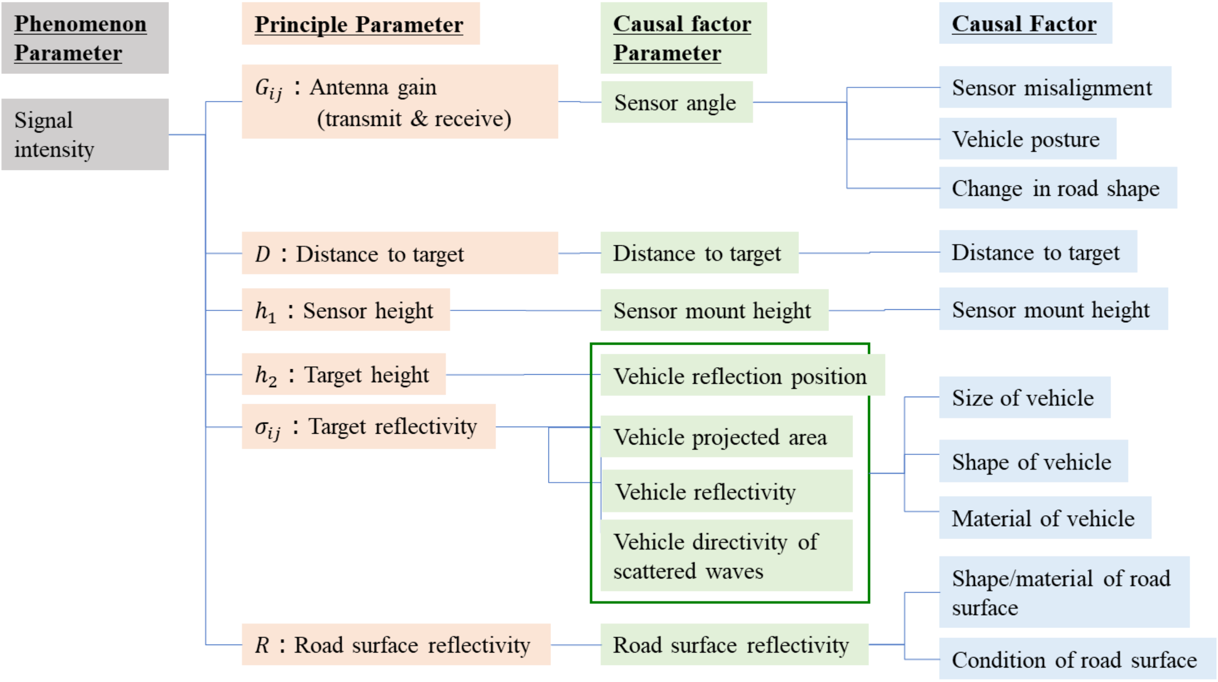
E.2.2.2. Relationship Between Principles and Causal Factors of Perception Disturbance

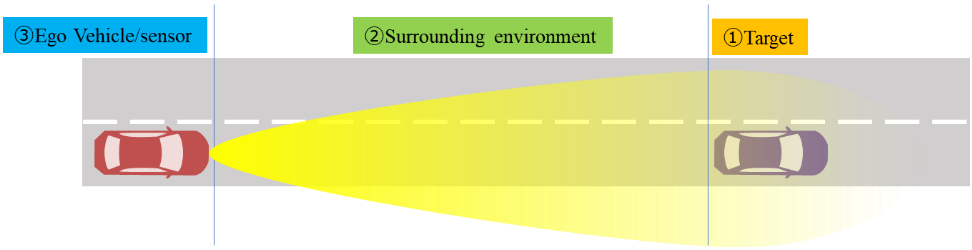
This section describes the relationships among phenomenon parameters, principle parameters, causal factor parameters, and the corresponding causal factors for perception disturbances caused by road-surface multipath.

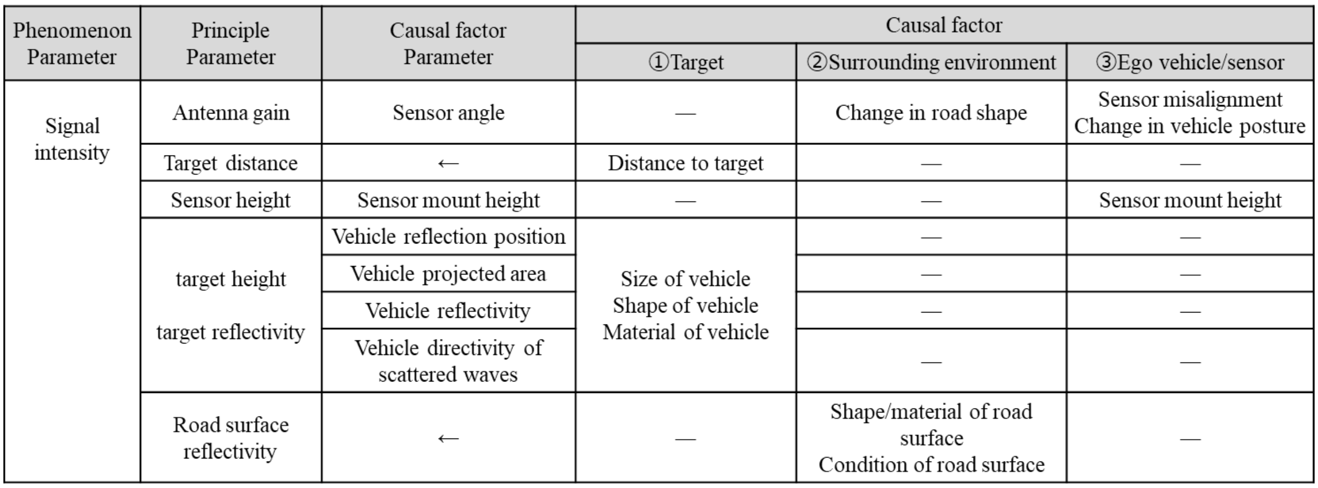
E.2.2.2.1. Disturbance Factors Based on the Principle

In this disturbance mechanism, “Signal intensity” is treated as the primary phenomenon parameter. Based on the principle model described above, the relationships among the contributing principle parameters, causal factor parameters, and causal factors are systematically organized.

This organization clarifies how variations in multipath propagation conditions—such as differences in propagation distance and phase—lead to changes in the D/U ratio and ultimately to perception disturbances.



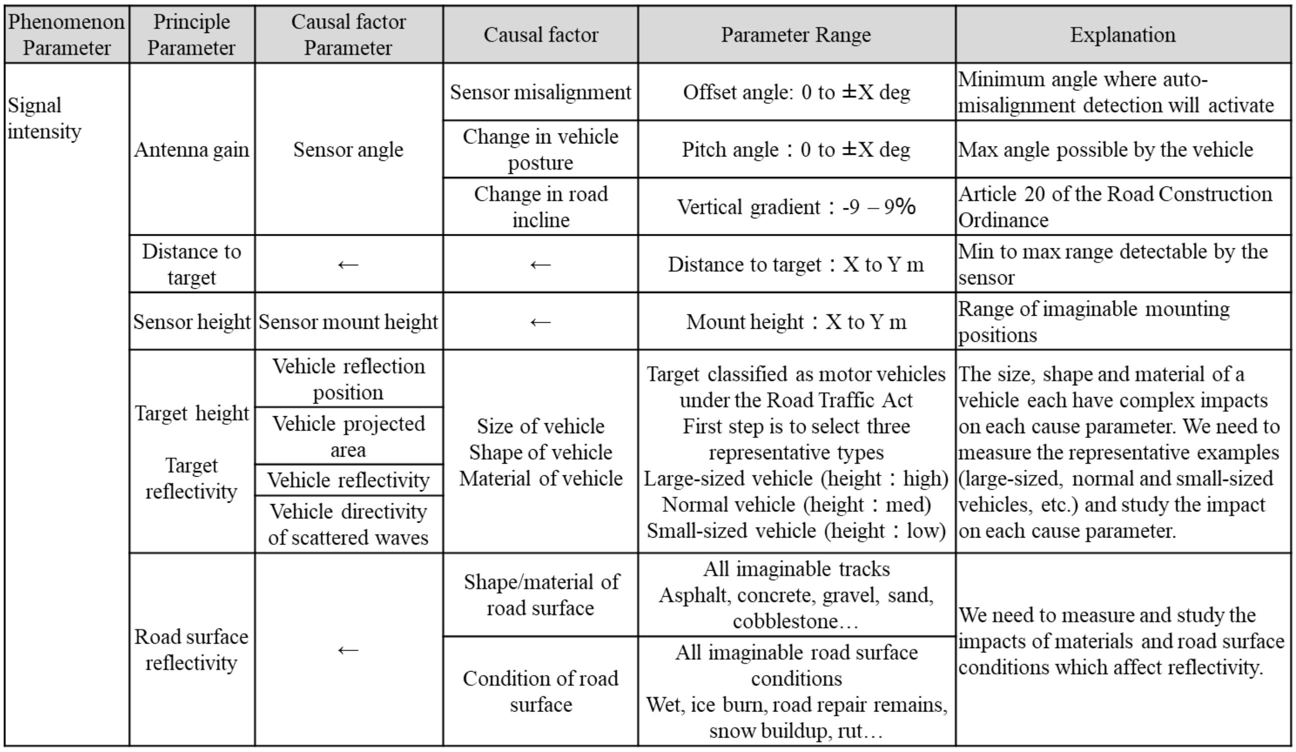




Phenomenon Parameter	Principle Parameter	Causal factor Parameter	Causal factor		
			①Target	②Surrounding environment	③Ego vehicle/sensor
Signal intensity	Antenna gain	Sensor angle	—	Change in road shape	Sensor misalignment Change in vehicle posture
	Target distance	←	Distance to target	—	—
	Sensor height	Sensor mount height	—	—	Sensor mount height
	target height target reflectivity	Vehicle reflection position	Size of vehicle Shape of vehicle Material of vehicle	—	—
		Vehicle projected area		—	—
		Vehicle reflectivity		—	—
		Vehicle directivity of scattered waves		—	—
	Road surface reflectivity	←	—	Shape/material of road surface Condition of road surface	—

E.2.2.2.2. Parameter Ranges

The applicable ranges of the phenomenon parameters, principle parameters, and causal factor parameters are defined based on physical constraints, sensor characteristics, and ODD.



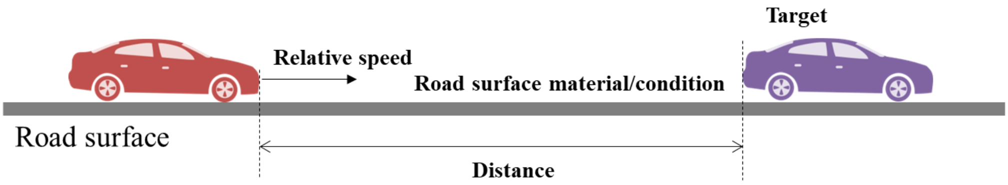
Phenomenon Parameter	Principle Parameter	Causal factor Parameter	Causal factor	Parameter Range	Explanation
Signal intensity	Antenna gain	Sensor angle	Sensor misalignment	Offset angle: 0 to ±X deg	Minimum angle where auto-misalignment detection will activate
			Change in vehicle posture	Pitch angle：0 to ±X deg	Max angle possible by the vehicle
			Change in road incline	Vertical gradient：-9 – 9%	Article 20 of the Road Construction Ordinance
	Distance to target	←	←	Distance to target：X to Y m	Min to max range detectable by the sensor
	Sensor height	Sensor mount height	←	Mount height：X to Y m	Range of imaginable mounting positions
	Target height Target reflectivity	Vehicle reflection position	Size of vehicle Shape of vehicle Material of vehicle	Target classified as motor vehicles under the Road Traffic Act First step is to select three representative types Large-sized vehicle (height：high) Normal vehicle (height：med) Small-sized vehicle (height：low)	The size, shape and material of a vehicle each have complex impacts on each cause parameter. We need to measure the representative examples (large-sized, normal and small-sized vehicles, etc.) and study the impact on each cause parameter.
		Vehicle projected area			
		Vehicle reflectivity			
		Vehicle directivity of scattered waves			
	Road surface reflectivity	←	Shape/material of road surface	All imaginable tracks Asphalt, concrete, gravel, sand, cobblestone…	We need to measure and study the impacts of materials and road surface conditions which affect reflectivity.
			Condition of road surface	All imaginable road surface conditions Wet, ice burn, road repair remains, snow buildup, rut…	

E.2.2.2.3. **Evaluation Scenarios**

Evaluation scenarios for this disturbance mechanism are defined as follows:

- the ego vehicle approaches a recognition target (a stationary vehicle) located ahead in the same lane;
- the ego vehicle travels at a constant velocity; and
- multipath effects caused by reflections from the road surface are considered in the received radar signals.

By defining scenarios under these conditions, it becomes possible to systematically evaluate reductions in the D/U ratio caused by road-surface multipath and the resulting risk of false-negative detection.



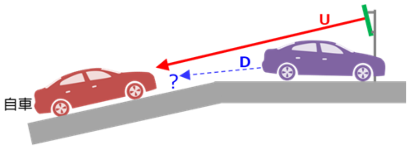
Parameter Item	Variable/Fixed	Range	Explanation
Distance to target	Variable	Min to Max detection Range	Min to max range detectable by the sensor
Relative speed	Fixed	Max speed within ODD	
Target type	Fixed	Large-sized vehicle (height：high) Normal vehicle (height：medium) Small-sized vehicle (height：low)	Three levels of representative examples such as large-sized vehicles, normal vehicles, and small-sized vehicles
Road surface material	Fixed	Asphalt / Metal plate(TBD)	Typical road surface material / highly reflective road surface material
Road surface condition	Fixed	Dry / Wet	Normal road surface condition / highly reflective road surface condition

E.2.3. [Millimeter-Wave Radar] Low D/U (Elevation-Angle Variation)

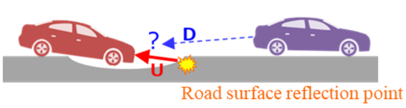
E.2.3.1. Phenomenon and Principle

E.2.3.1.1. **Phenomenon**

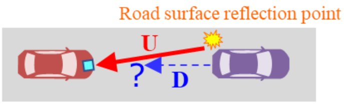
Due to the effects of road gradients, cant (cross slope), vehicle attitude, and sensor mounting-axis misalignment, an angular deviation may arise between the center axis of the radar field of view (FOV center axis) and the road surface or direction of travel. Under such conditions, the reflected signal from the recognition target (D: Desired Signal) becomes relatively weaker than the reflected signals from surrounding structures (U: Undesired Signal). As a result, the desired signal is masked by the undesired signals, leading to false negatives (missed detections).



Change in road gradient



Change in vehicle posture



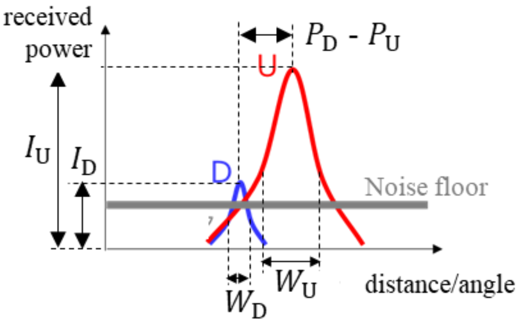
Sensor misalignment

To characterize this phenomenon, the following phenomenon parameters are defined:

Peak intensity ratio: $\frac{I_D}{I_U}$

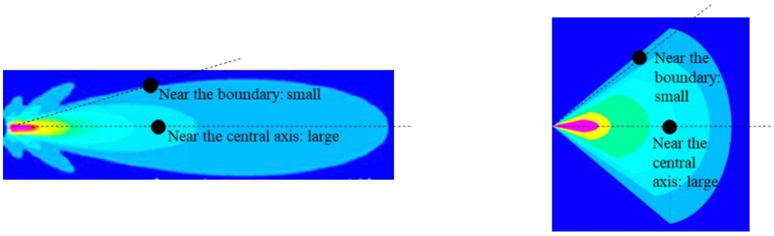
Peak separation degree: $\frac{|P_D - P_U|}{W_D + W_U}$

where *I* denotes peak intensity, *P* denotes peak position, and *W* denotes the full width at half maximum (FWHM) of the reflected-wave peak.



E.2.3.1.2. **Principle**

When the intensity distribution of radar transmitted waves is examined in vertical and horizontal cross sections, the transmitted-wave intensity decreases as the distance from the FOV center axis increases. Consequently, even for the same reflective target, difference arises in the received reflected-signal intensity depending on whether the target is located near the FOV center axis or near the boundary of the FOV.



Vertical section Horizontal section

Radiated electromagnetic-wave intensity distribution from a millimeter-wave radar

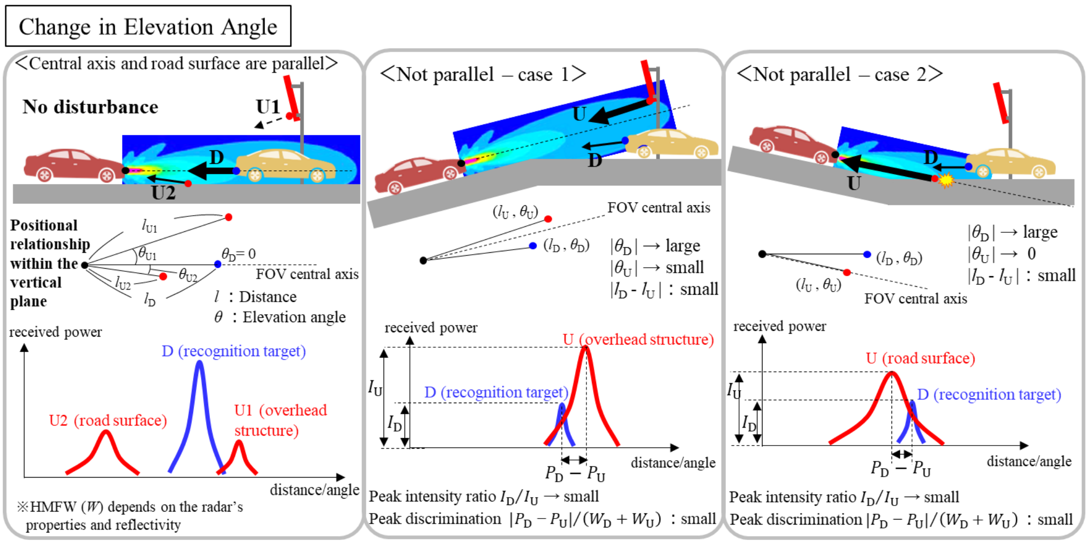
Elevation Angle Variation

When the sensor's FOV center axis is not parallel to the road surface, surrounding structures move closer to the center-axis side, while the recognition target is positioned closer the FOV boundary ($|\theta_U|$→small, $|\theta_D|$ →large).

In this situation, the intensity of the undesired signal I_U from surrounding structures becomes relatively larger than the intensity of the desired signal I_D from the recognition target.

Furthermore, under conditions of low peak separation degree—that is, when $|P_D{-}P_U|$ is small or $|W_D{+}W_U|$ is large—the desired signal D becomes buried within U.

The following representative cases illustrate how the relationship between signals D and U changes with vertical elevation-angle variation:



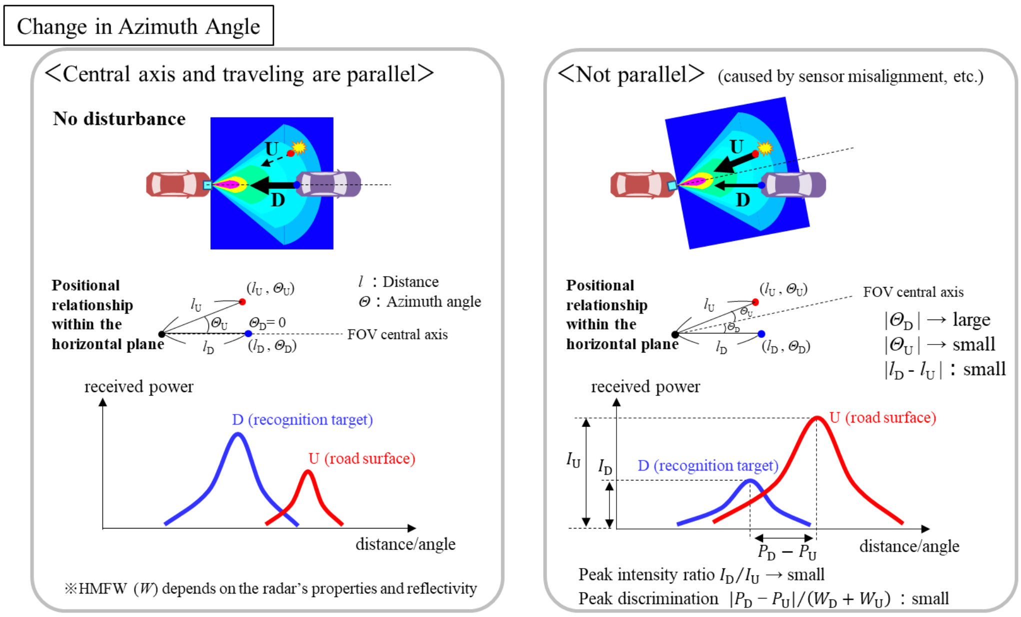
- FOV center axis parallel to the road surface (left figure):

The signal from the recognition target (D) is strong, while reflected signals from the road surface and overhead structures (U_1, U_2) are relatively weak. Stable detection of the recognition target is achieved.

- Upward convex uphill gradient (center figure):
  Overhead structures are closer to the FOV center axis than the recognition target. As a result, the reflected signal from the structures (U) becomes stronger, while the signal from the recognition target (D) becomes weaker.
- Downward convex gradient (right figure):
  The road surface is closer to the FOV center axis than the recognition target, resulting in a stronger reflected signal from the road surface (U) and a weaker signal from the recognition target (D).

Horizontal Azimuth-Angle Variation

A similar phenomenon occurs with horizontal azimuth-angle variation:



Case where the sensor FOV center axis is parallel to the direction of travel (left figure):
The signal from the recognition target (D) is strong, while the reflected signals from surrounding structures (U) are relatively weak. As a result, the recognition target can be detected stably.

Case where the sensor FOV center axis is not parallel to the direction of travel (right figure):
Due to sensor-axis misalignment or similar factors, the FOV center axis deviates from the ego vehicle's direction of travel. In this state, surrounding structures are closer to the sensor FOV center axis than the recognition target, resulting in a stronger reflected signal from the road surface (U) and a weaker signal from the recognition target (D).

- FOV center axis parallel to the direction of travel (left figure):
  The recognition target signal (D) is strong, and undesired reflections (U) from surrounding structures are weak, enabling stable detection.
- FOV center axis not parallel to the direction of travel (right figure):
  Due to sensor-axis misalignment or similar factors, the FOV center axis deviates from the vehicle's direction of travel. Surrounding structures then lie closer to the FOV center axis than the recognition target, resulting in stronger undesired reflections (U) and a weaker desired signal (D).

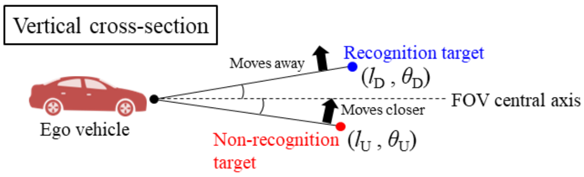
Because the physical mechanisms of vertical and horizontal azimuth-angle variation are equivalent, the following discussion focuses on low D/U caused by vertical elevation-angle variation.

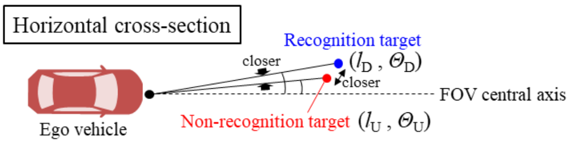
Parameter conditions under which D becomes buried in U

The desired signal D is likely to be buried in the undesired signal U under the following parameter conditions:

- Azimuth/elevation angle $|\theta_{\mathrm{D}}| \rightarrow$ large or $|\Theta_{\mathrm{D}}| \rightarrow$ large (moving away from the FOV center axis)
- Azimuth/elavation angle $|\theta_{\mathrm{U}}| \rightarrow$ small or $|\Theta_{\mathrm{U}}| \rightarrow$ small (approaching the FOV center axis)
- Distance to the targets $l_{\mathrm{D}} \approx l_{\mathrm{U}}$
- Horizontal azimuth angles of the targets $\Theta_{\mathrm{D}} \approx \Theta_{\mathrm{U}}$
- Sum of the full widths at half maximum of the reflected-wave peaks $W_{\mathrm{D}} + W_{\mathrm{U}} \rightarrow$large

(Note: These conditions depend on the characteristics of the radar sensor and the reflection properties of the target.)

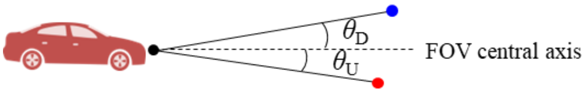


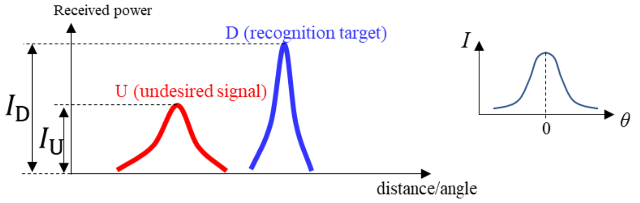


Principle Parameters

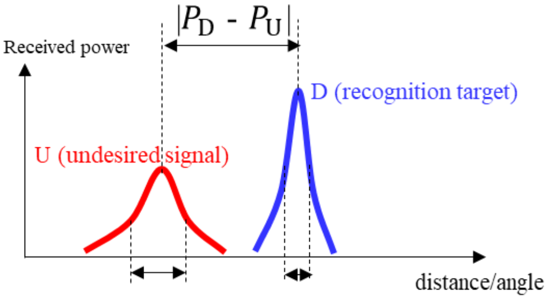
The following parameters are treated as principle parameters:

Elevation angles: θ_D , θ_U , Θ_D , Θ_U (variable principle parameters)
⇒Affect the value of $I_{\mathrm{D}}/I_{\mathrm{U}}$





Distance: l_D , l_U
Horizontal azimuth angles: Θ_D , Θ_U
⇒Affect the value of $|P_{\mathrm{D}} - P_{\mathrm{U}}|/(W_{\mathrm{D}} + W_{\mathrm{U}})$



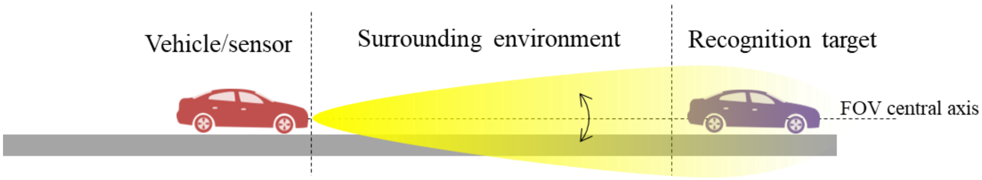
E.2.3.2. Relationship Between Principles and Causal Factors of Perception Disturbance

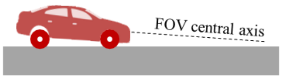
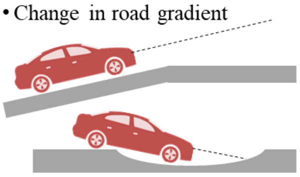
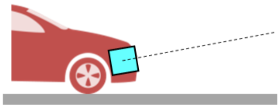
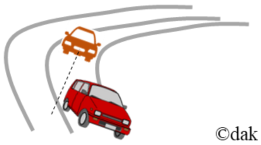
E.2.3.2.1. Causal Factors Based on the Principle

Among the principle parameters identified above, the causal factors that cause variations in the elevation angles—specifically in which

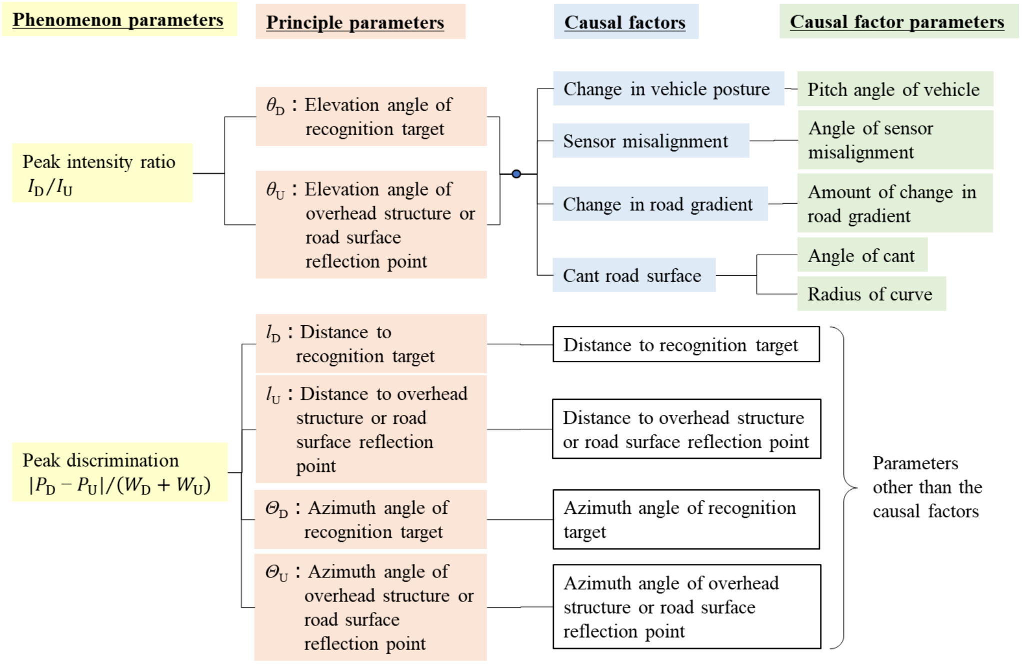
$|\theta_D| \rightarrow$ large and $|\theta_U| \rightarrow$ small

and thereby lead to this perception-disturbance phenomenon—include the following factors.



Variable Principle Parameters	Causal factors of the disturbance		
	Vehicle/sensor	Surrounding environment	Recognition target
Elevation angle $\theta_{D,}\ \theta_U$	• Change of the vehicle posture 	• Change in road gradient 	N/A
	• Misalignment of the sensor 	• Cant road surface  ©dak	

Based on these factors, the relationships among phenomenon parameters, principle parameters, causal factor parameters, and the causal factors are organized as described below.



This organization clarifies how changes in road geometry, vehicle attitude, and sensor alignment propagate through the principle parameters and ultimately result in degradation of the D/U ratio.

E.2.3.2.2. **Parameter Ranges**

The applicable ranges of the phenomenon parameters, principle parameters, and causal factor parameters are defined based on physical constraints, radar characteristics, and the ODD.

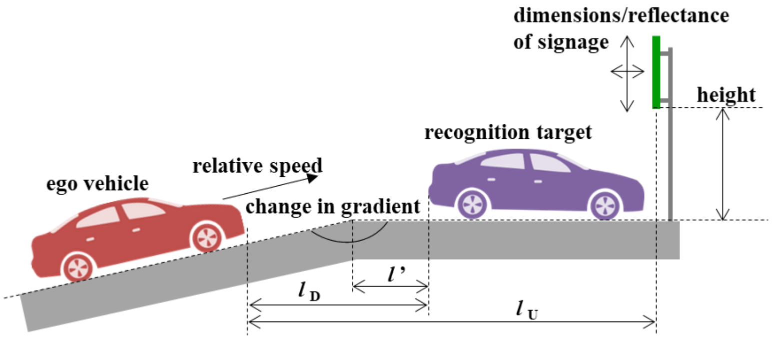
These ranges are selected to ensure that the evaluation scenarios adequately cover conditions under which elevation-angle-variation-induced perception disturbances may occur.

Phenomenon Parameters	Principle Parameters	Contributing Causal Factors	Causal Factor Parameters	Range of Causal Factor Parameters	Explanation
Peak intensity ratio I_D/I_U	Elevation angles $\theta_{D,}\ \theta_U$ (variable parameters)	Change in road gradient	Amount of change in road gradient	0 to 18 % (according to Article 20 of the Road Construction Ordinance, elevation angle -9 to +9 %)	Evaluation range is the maximum angle possible for the sensor, based on a combination of any one or more factors.
		Cant road surface	Angle of cant	0 to 10 % (according to Article 16 of the Road Construction Ordinance)	
			Radius of curve	∞ to 82 m (according to Article 15 of the Road Construction Ordinance)	
		Sensor misalignment	Angle of sensor misalignment	0 to min. angle where auto-misalignment detection will activate	
		Change in vehicle posture	Pitch angle of vehicle	0 to ± (vehicle's max. possible angle)	
Peak discrimination $\frac{\lvert P_D - P_U \rvert}{(W_D + W_U)}$	Distance to objects l_D, l_U	(Not a causal factor)	Distance to recognition target	0 to min. distance required to avoid collision	
			Distance to non-recognition target	0 to min. distance required to avoid collision	
	Azimuth angles $\Theta_{D,}\ \Theta_U$	(Not a causal factor)	Angle of recognition target	0 to ± (max. angle of the sensor's FOV)	
			Angle of non-recognition target	0 to ± (max. angle of the sensor's FOV)	

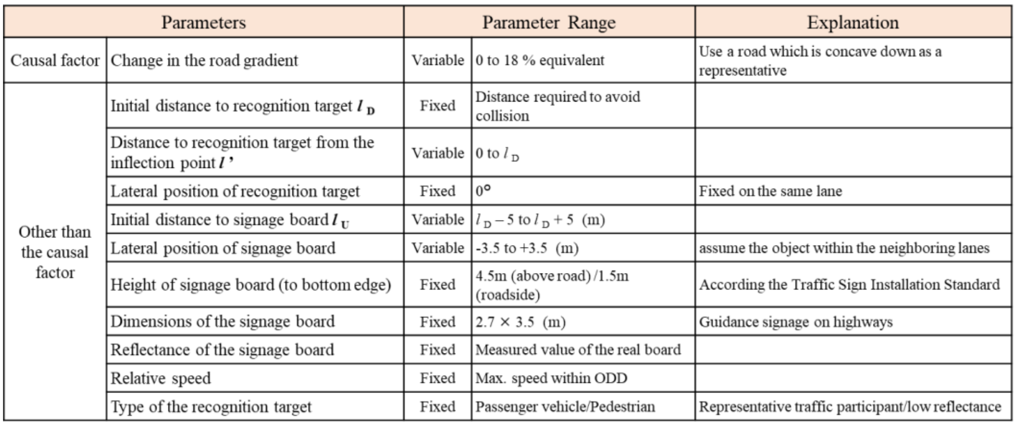
E.2.3.2.3. **Evaluation Scenarios**

Evaluation scenarios for this disturbance mechanism are defined as follows:

- the ego vehicle travels on a road section with an upward convex gradient change; and
- the ego vehicle approaches a recognition target located near a metallic signboard installed beyond the gradient-change section.



NOTE: Because the reflection intensity from metallic overhead structures is highly likely to be greater than that from the road surface, scenarios involving upward convex gradient changes are selected as representative evaluation scenarios for this disturbance mechanism.



Parameters		Parameter Range		Explanation
Causal factor	Change in the road gradient	Variable	0 to 18 % equivalent	Use a road which is concave down as a representative
Other than the causal factor	Initial distance to recognition target l_D	Fixed	Distance required to avoid collision	
	Distance to recognition target from the inflection point l'	Variable	0 to l_D	
	Lateral position of recognition target	Fixed	0°	Fixed on the same lane
	Initial distance to signage board l_U	Variable	$l_D - 5$ to $l_D + 5$ (m)	
	Lateral position of signage board	Variable	-3.5 to +3.5 (m)	assume the object within the neighboring lanes
	Height of signage board (to bottom edge)	Fixed	4.5m (above road) /1.5m (roadside)	According the Traffic Sign Installation Standard
	Dimensions of the signage board	Fixed	2.7 × 3.5 (m)	Guidance signage on highways
	Reflectance of the signage board	Fixed	Measured value of the real board	
	Relative speed	Fixed	Max. speed within ODD	
	Type of the recognition target	Fixed	Passenger vehicle/Pedestrian	Representative traffic participant/low reflectance

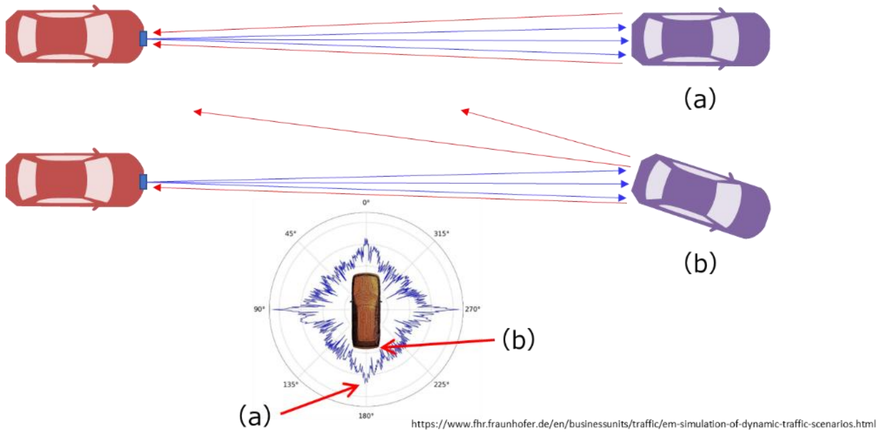
E.2.4. [Millimeter-Wave Radar] Low S/N (Vehicle Orientation)

E.2.4.1. Phenomenon and Principle

E.2.4.1.1. Phenomenon

Electromagnetic waves emitted from the radar are reflected with an intensity that depends on the projected area, reflectivity, and surface orientation of the recognition target. A portion of the reflected energy returns to the radar receiver.

Even for the same vehicle, changes in the vehicle’s orientation can significantly reduce the reflected-signal intensity. As a result, the vehicle may become undetectable, even when it remains within the radar field of view (FOV). This degradation leads to low S/N conditions and may result in false-negative detections.



https://www.fhr.fraunhofer.de/en/businessunits/traffic/em-simulation-of-dynamic-traffic-scenarios.html

E.2.4.1.2. Principle

When a radar receives reflected waves from a recognition target, the intensity of the received signal (S) depends on the received power (P_r) which is given by the following equation:

$$P_r = \frac{\lambda^2 \cdot P_t \cdot G_t(\theta) \cdot G_r(\theta) \cdot \sigma}{(4\pi)^3 \cdot R^4}$$

Where:

- P_t denotes the transmitted power;
- $G_t(\theta)$ the gain of the transmitting antenna;
- $G_r(\theta)$ the gain of the receiving antenna;
- σ the radar cross section (RCS) of the target;
- λ the wavelength, and
- R the distance to the recognition target.

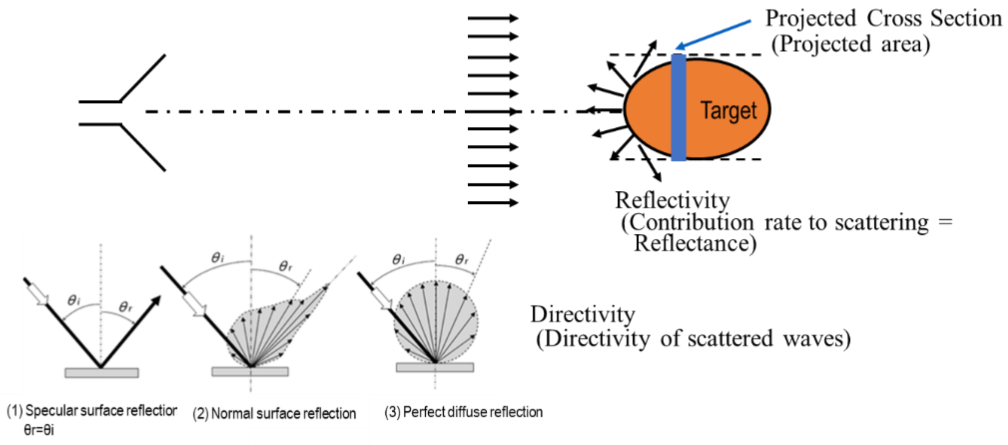
The radar cross section σ can be expressed as the product of:
(a) the projected area of the target,
(b) the contribution ratio to scattering (reflectivity), and
(c) the directivity of the scattered waves.

For objects made of the same material, the reflection intensity increases as the reflecting surface becomes more directly oriented toward the radar. The contribution ratio to scattering, denoted by η, is approximately:

- $\eta \approx 1$ for metallic objects, and
- $0 \leq \eta < 1$ for non-metallic objects.

Accordingly, the radar cross section can be expressed as:

$\sigma =$ Projected Cross Section × Reflectivity × Directivity（m^2）



E.2.4.2. Relationship Between Principles and Causal Factors of Perception Disturbance

E.2.4.2.1. **Causal** Factors Based on the Principle

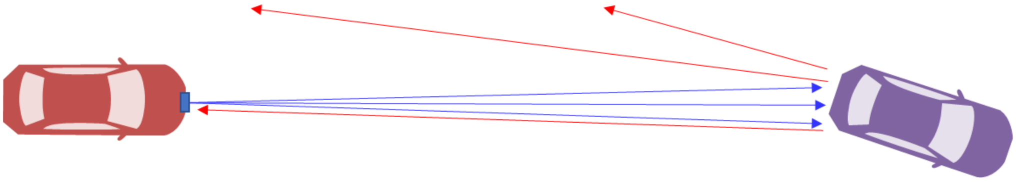
Based on the principle model described above, the relationships among phenomenon parameters, principle parameters, causal factor parameters, and the corresponding causal factors are organized as follows.

Phenomenon Parameter	**Principle Parameter**	**Causal Factor Parameter**	**Causal Factor**
Signal intensity	r：Distance to target	Distance to target	Distance to recognition target when viewed from the radar
	G：Antenna gain in Θ direction	Angle of target when viewed from the center line of the radar	Position (angle) of recognition target of when viewed from the radar
	σ：Target's radar cross-section	Projected area	Size of vehicle
		Contribution rate to scattering (Reflectance)	Material of vehicle
		Directivity of scattered waves	Shape of vehicle

Even when the size, material, and shape of a recognition target are identical, variations in the relative orientation between the ego vehicle and the target result in changes in:

- the projected area of the target,
- the contribution ratio to scattering (reflectivity), and
- the directivity of the scattered waves.

Accordingly, these quantities are treated as causal factor parameters, as variations in these parameters directly affect the received signal strength and may lead to low S/N conditions.

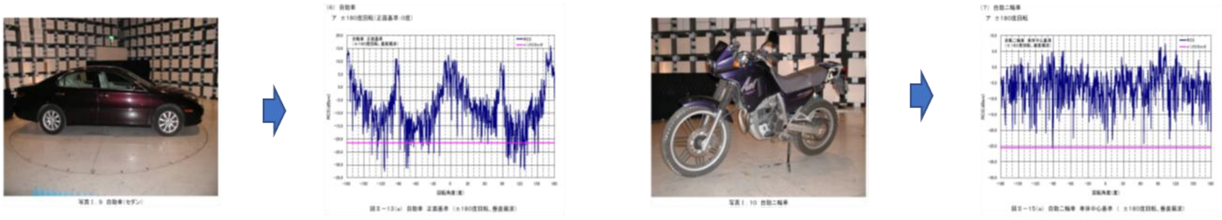


Phenomenon Parameter	Principle Parameter	Causal Factor Parameter	Causal Factors contributing to the change in principle parameter		
			①Recognition target	②Surrounding environment	③Vehicle/sensor
Signal intensity	Radar cross-section	Projected area	Size of vehicle	–	–
		Contribution rate to scattering (Reflectance)	Material of vehicle	–	–
		Directivity of scattered waves	Shape of vehicle	–	–

E.2.4.2.2. **Parameter Ranges**

For recognition targets with complex geometries, such as vehicles, the projected area, reflectivity, and directivity interact in a complex manner. As a result, it is difficult to uniquely represent the reflection characteristics of such targets using a single theoretical model.
Therefore, in this study, based on findings from prior research, the radar cross section (σ) is represented using three representative conditions—large, medium, and small—as discrete representative values. These representative values are used to define parameter ranges for evaluation scenarios.

Examples of Past Research (Measurement Results)



Source) JARI report (J-GLOBAL ID：200909086392246974), 2004

Phenomeno n Parameter	Principle Parameter	Causal factor Parameter	Causal Factor	Parameter Range	Explanation
Signal intensity	Cross-section area of radar reflection	Projected area	Size of vehicle	3 representative models	Stipulate with the sizes of existing vehicles in the world using 3 rep models (large, medium and small)
		Contribution rate to scattering (Reflectance)	Material of vehicle	↑	Stipulate with the materials of existing vehicles in the world using 3 rep models (large, medium and small)
		Direction of scattered waves	Shape of vehicle	↑	Stipulate with the shape of existing vehicles in the world using 3 rep models (large, medium and small)

E.2.4.2.3. **Evaluation Scenarios**

Evaluation scenarios for this disturbance mechanism are defined as follows:

- the ego vehicle travels on a straight road;
- the ego vehicle approaches a recognition target (a stationary vehicle) located ahead in the same lane; and
- the ego vehicle maintains a constant velocity.

By defining scenarios under these conditions, it becomes possible to evaluate perception performance degradation caused by vehicle-orientation-induced low S/N conditions.

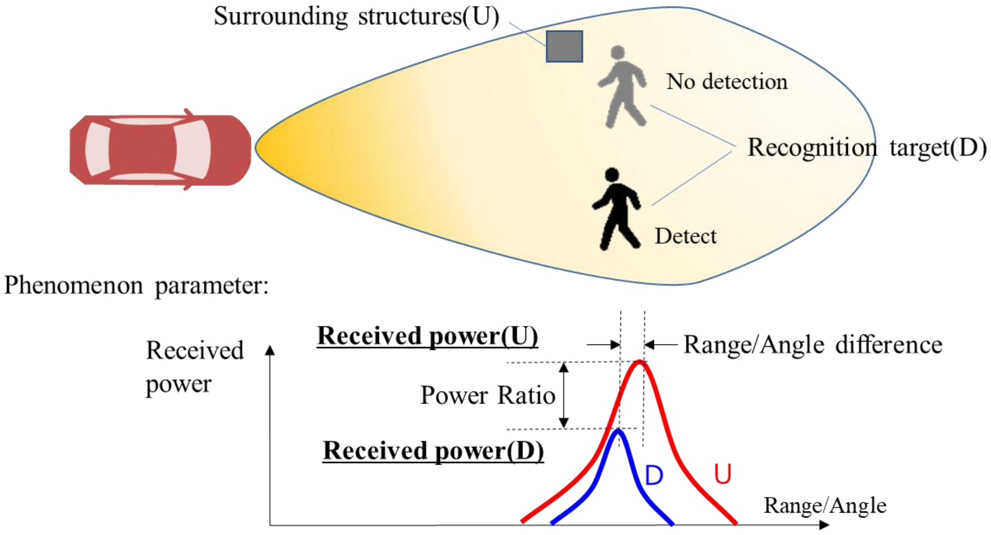
Parameter Item	Variable/ Fixed	Range	Explanation
Type of recognition target	Variable	• Projected area (large/mid/small) • Contribution rate to scattering= Reflectance (heavy use of metal / heavy use of non- metal / in-between) • Directivity of scattered waves (uniform/biased)	• 3 levels of projected area generally • 3 levels (no vehicle has zero metal used) • 3 levels (relying on concentration of normal vectors in microparts of the vehicle)
Orientation of the target	Variable	0 to 30 deg.	According to the line of the road (curve R)
Distance to the target	Variable	5 to 150 m	
Relative speed	Fixed	20 km/h and below	constant

E.2.5. [Millimeter-Wave Radar] Low D/U (Structures)

E.2.5.1. Phenomenon and Principle

E.2.5.1.1. **Phenomenon**

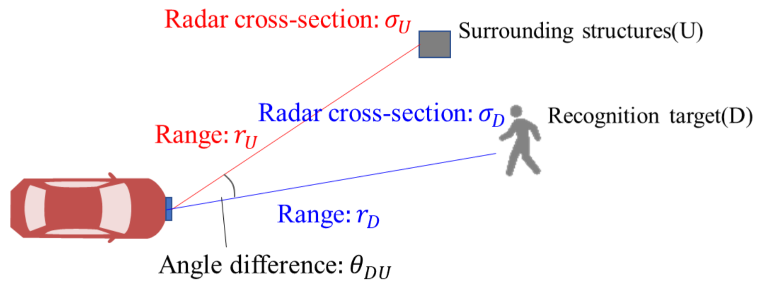
Undesired signals (U: Undesired Signal) reflected from roadside structures or similar objects may dominate the received radar signal when recognition targets with relatively low reflection intensity—such as pedestrians—are located nearby. As a result, the signals from these recognition targets (D: Desired Signal) may be masked, leading to false negatives (missed detections).

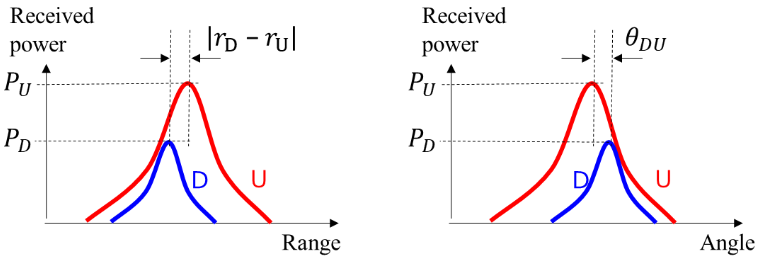


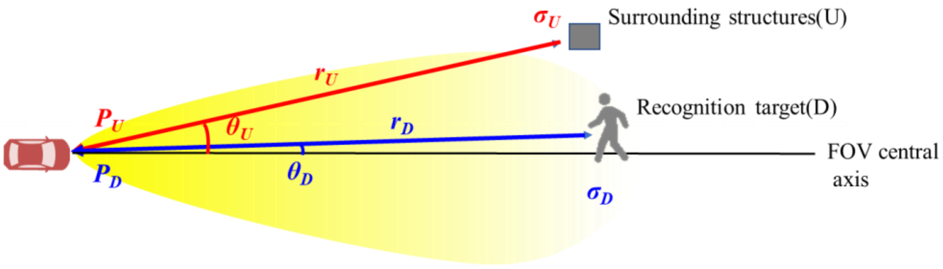
E.2.5.1.2. **Principle**

When the level of the undesired signal (U) reflected from surrounding structures exceeds the level of the desired signal (D) reflected from the recognition target, the desired signal becomes buried within U in both the range and azimuth dimensions. This condition results in missed detection of the recognition target.

Such perception disturbances are likely to occur when strong reflectors—for example, guardrails, walls, or signboards—are located in close proximity to the recognition target within the sensor’s field of view (FOV). When the amplitude of the undesired signal U exceeds that of the desired signal D, the peaks of the two signals overlap, making them indistinguishable in both range and azimuth dimensions.







The received power of the desired signal D from the recognition target and the undesired signal U from surrounding structures can be expressed as follows.

Received power from the recognition target:

$$P_D = \frac{\lambda^2\{G(\theta_D)\}^2 P_t}{(4\pi)^3 r_D^4}\sigma_D$$

Received power from the structure:

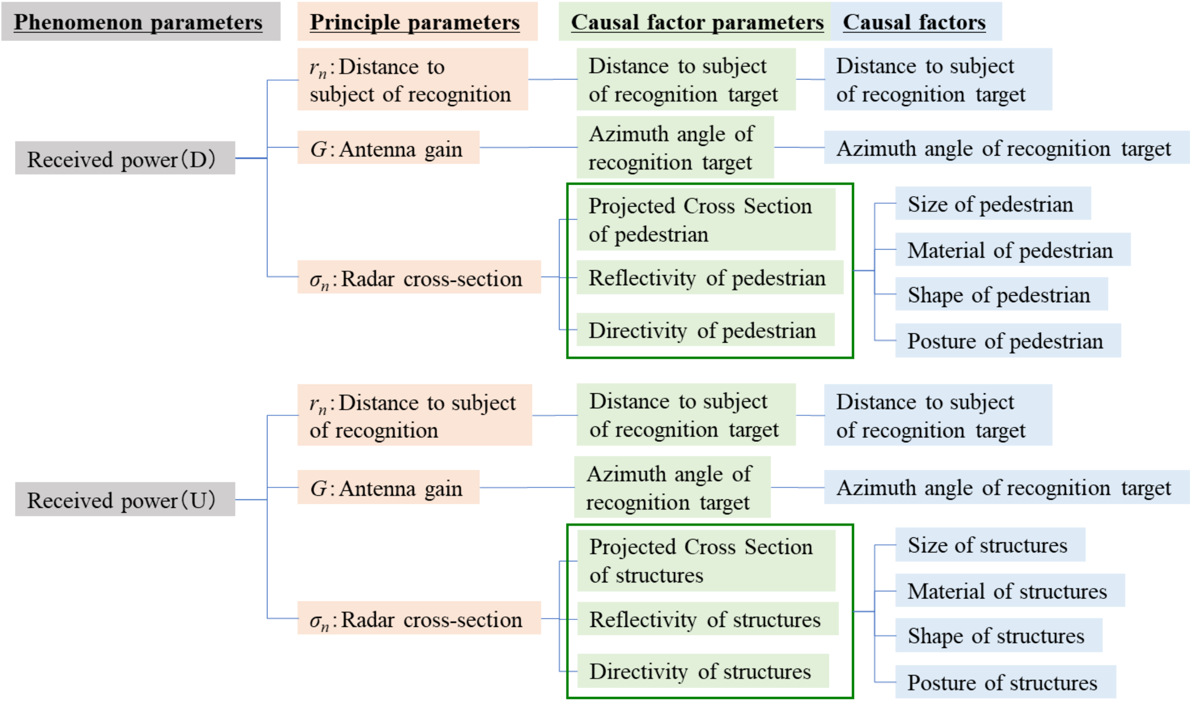
$$P_U = \frac{\lambda^2\{G(\theta_U)\}^2 P_t}{(4\pi)^3 r_U^4}\sigma_U$$

P_t: transmitted signal power
λ: wavelength of the electromagnetic wave
$G(\theta)$: antenna gain as a function of angle

E.2.5.2. Relationship Between Principles and Causal Factors of Perception Disturbance

E.2.5.2.1. **Causal** Factors Based on the Principle

Based on the principle model described above, the relationships among phenomenon parameters, principle parameters, causal factor parameters, and the corresponding causal factors are organized as follows.



For the desired signal D reflected from the recognition target (e.g., a pedestrian), the causal factor parameters are primarily related to factors that influence the radar cross section (RCS) of the target, such as target size, material properties, orientation, and the positional relationship between the target and the sensor.

Phenomenon parameter	Principle parameter	Causal factor parameter	Causal factor		
			①Target	②Surrounding environment	③Ego vehicle/sensor
Received power	Distance to subject of recognition	—	—	—	—
	Antenna gain	Angle to recognition target	Position	—	—
	Radar cross-section (σ_n)	Projected Cross Section	Size	—	—
		Reflectivity	Material	—	—
		Directivity	Shape	—	—
			Posture	—	—

For the undesired signal U reflected from roadside structures, the disturbance-factor parameters include factors that influence the strength and dominance of structural reflections, such as the material and geometry of the structures, their distance from the sensor, and their relative position with respect to both the sensor and the recognition target.

Phenomenon parameter	Principle parameter	Causal factor parameter	Causal factor		
			①Target	②Surrounding environment	③Ego vehicle/sensor
Received power	Distance to subject of recognition	—	—	—	—
	Antenna gain	Angle to recognition target	—	Position	—
	Radar cross-section (σ_n)	Projected Cross Section	—	Size	—
		Reflectivity	—	Material	—
		Directivity	—	Shape	—
			—	Posture	—

This organization clarifies how variations in the relative strength of D and U arise from differences in physical and geometric conditions and how these variations lead to low D/U conditions and perception disturbances.

E.2.5.2.2. **Parameter Ranges**

The applicable ranges of the phenomenon parameters, principle parameters, and causal factor parameters are defined based on physical constraints, radar characteristics, and the ODD.

Phenomenon parameter	Principle parameter	Causal factor parameter	Causal factor	Parameter Range	Explanation
Received power	Distance to subject of recognition	←	←	Min to max detectable range	Validate by varying the distance between the min and max detectable distance of the sensor
	Antenna gain	Angle to recognition target	Position	Within FOV	Validate by varying the angles within the radar FOV
	Radar cross-section (σ_n)	Projected Cross Section	Size	Pedestrian : Adults and children of average body shape Structures : Pole (diameter : 50mm～300mm)	Pedestrian : Adults and children of average body shape Structures : Ex. Telegraph pole, Electric pole
		Reflectivity	Material	Pedestrian : Human body Structures : Metal, Concrete	Require database for physical property values in millimeter wave band
		Directivity	Shape	Pedestrian : Adults and children of average body shape Structures : Cylindrical	Pedestrian : Adults and children of average body shape Structures : Shape with high reflection intensity regardless of apparent angle
			Posture	Pedestrian : Walking Structures : Vertical	Pedestrian : Walking Structures : Nomal Posture

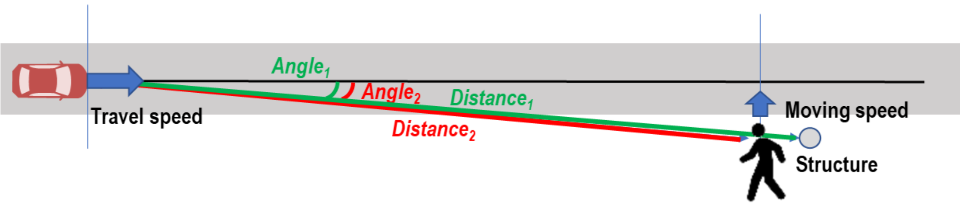
These ranges are selected to ensure that the evaluation scenarios sufficiently cover conditions under which structure-induced low D/U perception disturbances may occur.

E.2.5.2.3. **Evaluation Scenarios**

Evaluation scenarios for this disturbance mechanism are defined as follows:

- the ego vehicle travels in the center of the lane in a road environment where roadside structures (e.g., utility poles) are present along the roadway;
- a pedestrian recognition target crosses the ego vehicle’s path of travel; and
- the roadside structures are located behind the pedestrian from the perspective of the radar sensor.

By defining scenarios under these conditions, it becomes possible to evaluate perception-performance degradation caused by strong structural reflections that mask the reflected signal from pedestrians, leading to false-negative detections.



Parmeter Item	Range		Explanation
Distance to recognition target	Variable	Min to max detectable range	Validate by varying the distance between the min and max detectable distance of the sensor
Angle to recognition target	Variable	Within FOV	Validate by varying the angles within the radar FOV
Number of recognition targets	Variable	Adult,Child	Adults and children of average body shape
Vehicle speed	Fixed	It is specified by ODD Maximum speed	
Moving speed of recognition target	Variable	5km/h～8km/h	Evaluate the moving speed of the recognition target by varying in the range of 5 to 8 km/h

E.3. Principle Models and Evaluation Scenarios for LiDAR

For LiDAR, principle models and representative evaluation scenarios are described for the following three perception-disturbance generation mechanisms:

- Signal attenuation (recognition target)
- Noise
- Signals from non-recognition targets (e.g., reflections from raindrops)

E.3.1.[LiDAR] Signal Attenuation (Recognition Target)

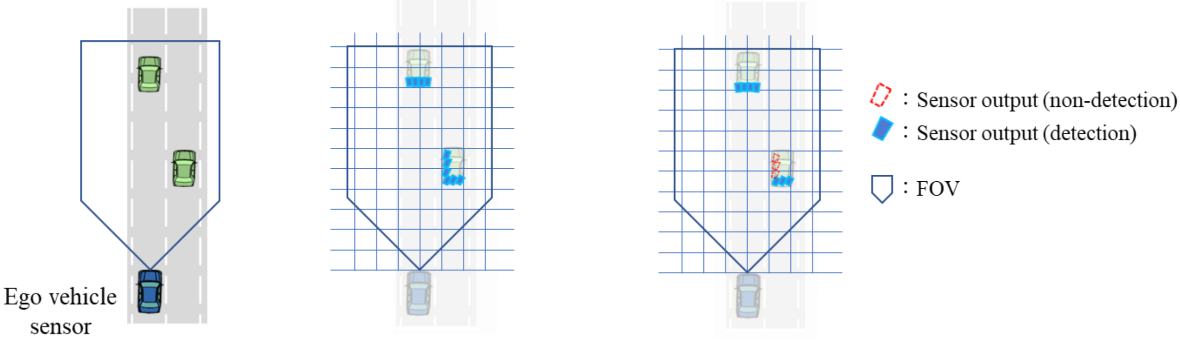
E.3.1.1. Phenomenon and Principle

E.3.1.1.1. **Phenomenon**

Even when a recognition target is located within the sensor's FOV, the reflection points associated with the target may fail to be continuously output as a point cloud. In such cases, the recognition target cannot be reliably reconstructed, leading to false negatives (missed detections).

Actual relative position

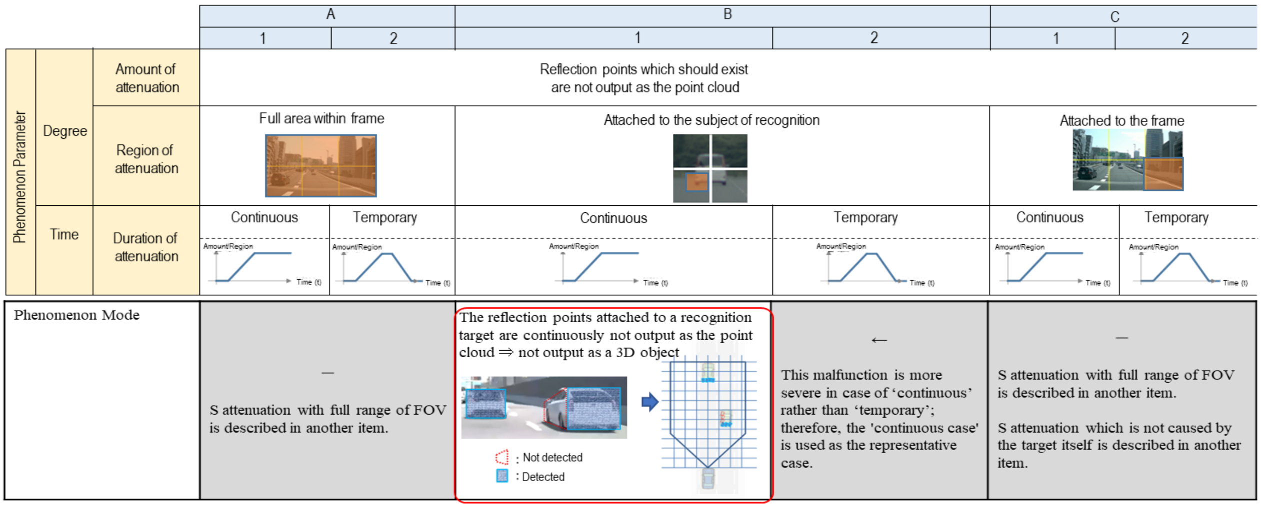
Output of the 3D object



Correct detection

Although a recognition target exits, there is no output of a 3D object due to malfunction.

The figure below organizes the different types of signal attenuation and their associated phenomena. In this section, the phenomenon enclosed by the red frame—representing the most severe condition among the evaluation cases—is selected and addressed as the evaluation condition.

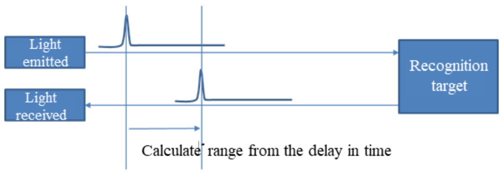


			A		B		C	
			1	2	1	2	1	2
Phenomenon Parameter	Degree	Amount of attenuation	Reflection points which should exist are not output as the point cloud					
		Region of attenuation	Full area within frame		Attached to the subject of recognition		Attached to the frame	
	Time	Duration of attenuation	Continuous	Temporary	Continuous	Temporary	Continuous	Temporary
Phenomenon Mode			— S attenuation with full range of FOV is described in another item.		The reflection points attached to a recognition target are continuously not output as the point cloud ⇒ not output as a 3D object : Not detected : Detected	← This malfunction is more severe in case of 'continuous' rather than 'temporary'; therefore, the 'continuous case' is used as the representative case.	— S attenuation with full range of FOV is described in another item. S attenuation which is not caused by the target itself is described in another item.	

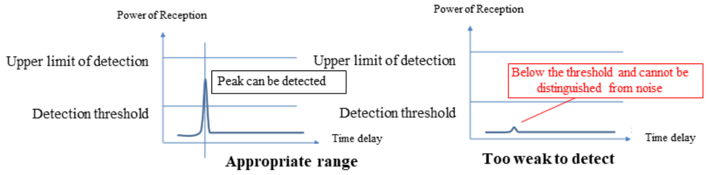
E.3.1.1.2. **Principle**

When the reflection signal from a target object is too weak, a reflection peak cannot be detected even if the object line within the LiDAR FOV. As a result, the target cannot be detected by the perception system.

Detect the peak of the received signal,
and calculate the range from the delay in time.



When the reflection is too weak and does not meet
the detection threshold, then the S cannot be detected.



E.3.1.1.3. Principle Models

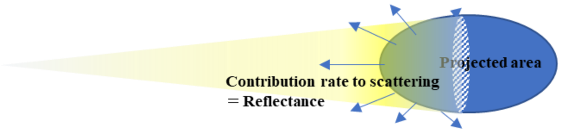
The reflection intensity from a recognition target can be expressed as the product of:

- the projected area of the target,
- the contribution ratio to scattering (reflectivity), and
- the directivity of the scattered waves.

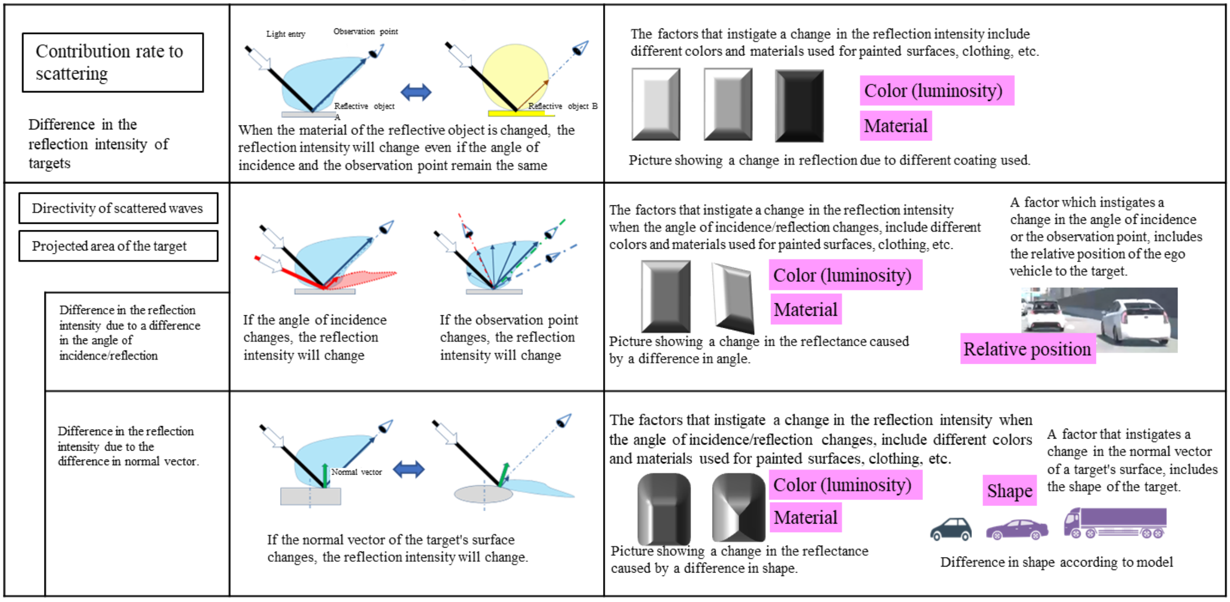
These characteristics are governed by physical principles equivalent to those applied to millimeter-wave radar.

For objects composed of the same surface material, higher reflection intensity is obtained when the LiDAR irradiation direction is close to the surface normal direction of the target, resulting in higher directivity.

$$\text{Reflection intensity} = \boxed{\text{Projected area of the target}} * \boxed{\text{Contribution rate to scattering}} * \boxed{\text{Directivity of scattered waves}}$$



When the principles governing variations in reflection intensity are organized according to the three contributing elements listed above, the resulting relationships are as illustrated in the figure below. From this organization, the color, material, shape, and relative position of the target object can be identified as factors that influence reflection intensity and are therefore treated as disturbance factors.

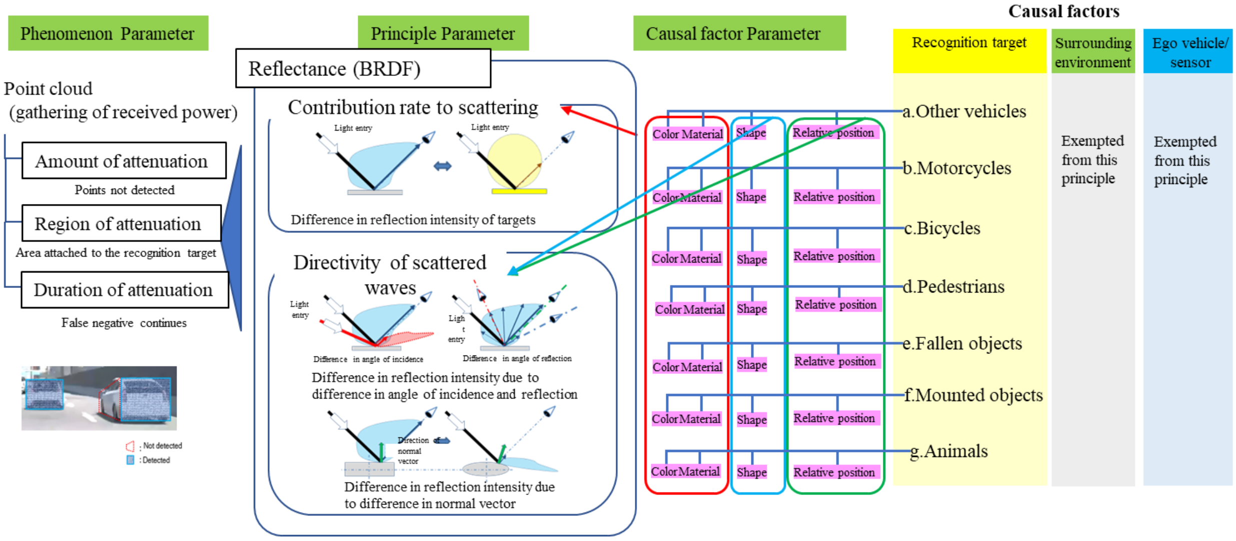


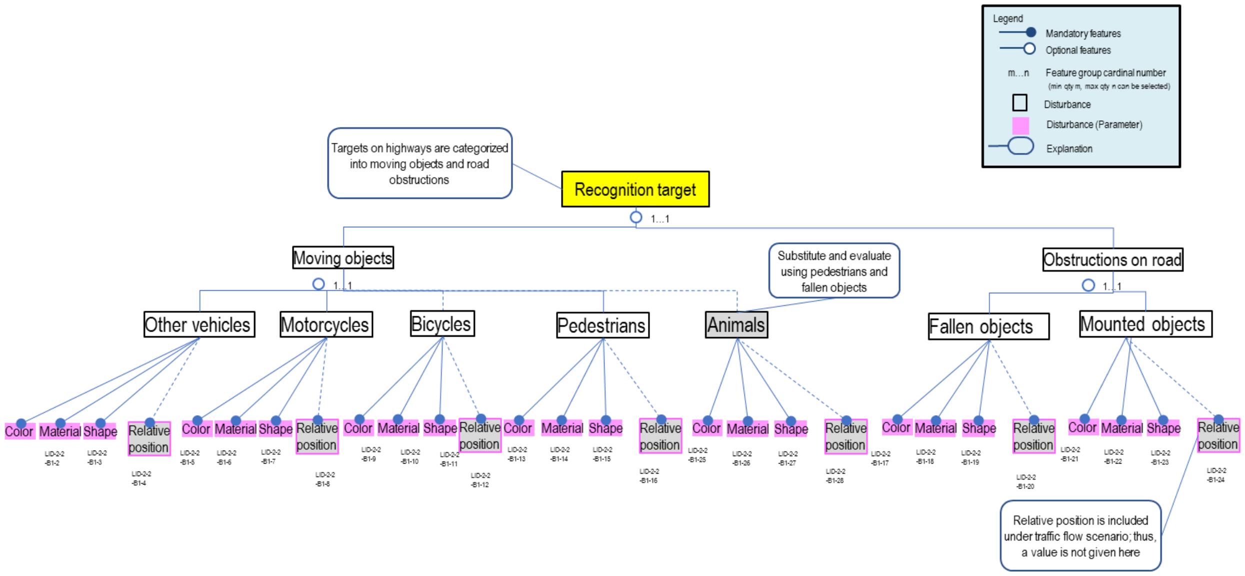
	Principle	Causal factors of disturbance
Contribution rate to scattering Difference in the reflection intensity of targets	Light entry Observation point Reflective object A Reflective object B When the material of the reflective object is changed, the reflection intensity will change even if the angle of incidence and the observation point remain the same	The factors that instigate a change in the reflection intensity include different colors and materials used for painted surfaces, clothing, etc. Color (luminosity) Material Picture showing a change in reflection due to different coating used.
Directivity of scattered waves Projected area of the target Difference in the reflection intensity due to a difference in the angle of incidence/reflection	If the angle of incidence changes, the reflection intensity will change If the observation point changes, the reflection intensity will change	The factors that instigate a change in the reflection intensity when the angle of incidence/reflection changes, include different colors and materials used for painted surfaces, clothing, etc. Color (luminosity) Material Picture showing a change in the reflectance caused by a difference in angle. A factor which instigates a change in the angle of incidence or the observation point, includes the relative position of the ego vehicle to the target. Relative position
Difference in the reflection intensity due to the difference in normal vector.	Normal vector If the normal vector of the target's surface changes, the reflection intensity will change.	The factors that instigate a change in the reflection intensity when the angle of incidence/reflection changes, include different colors and materials used for painted surfaces, clothing, etc. Color (luminosity) Material Picture showing a change in the reflectance caused by a difference in shape. A factor that instigates a change in the normal vector of a target's surface, includes the shape of the target. Shape Difference in shape according to model

E.3.1.2. Relationship Between Principles and Causal Factors of Perception Disturbance

E.3.1.2.1. Causal Factors Based on the Principle

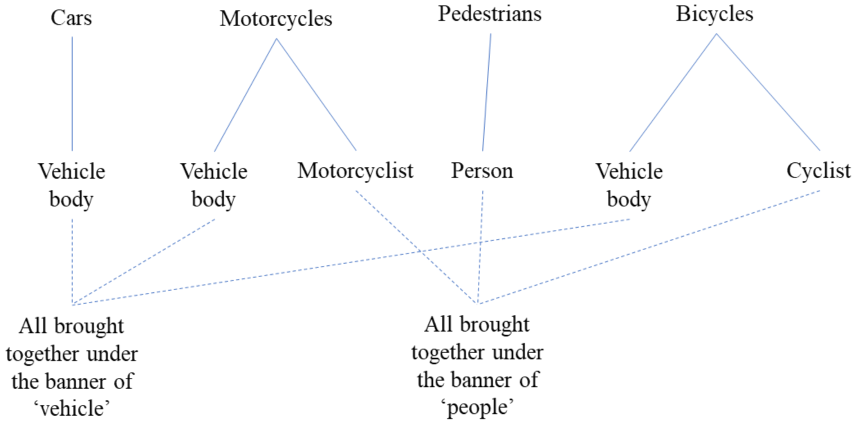
Based on the principle model described above, the relationships among phenomenon parameters, principle parameters, and causal factor parameters are organized as follows.
In the evaluation of perception disturbances based on this principle, combinations of recognition targets are not considered. False negatives arising from combinations of multiple recognition targets are addressed under different perception-disturbance principles and are therefore excluded from this category.





E.3.1.2.2. **Parameter Ranges**

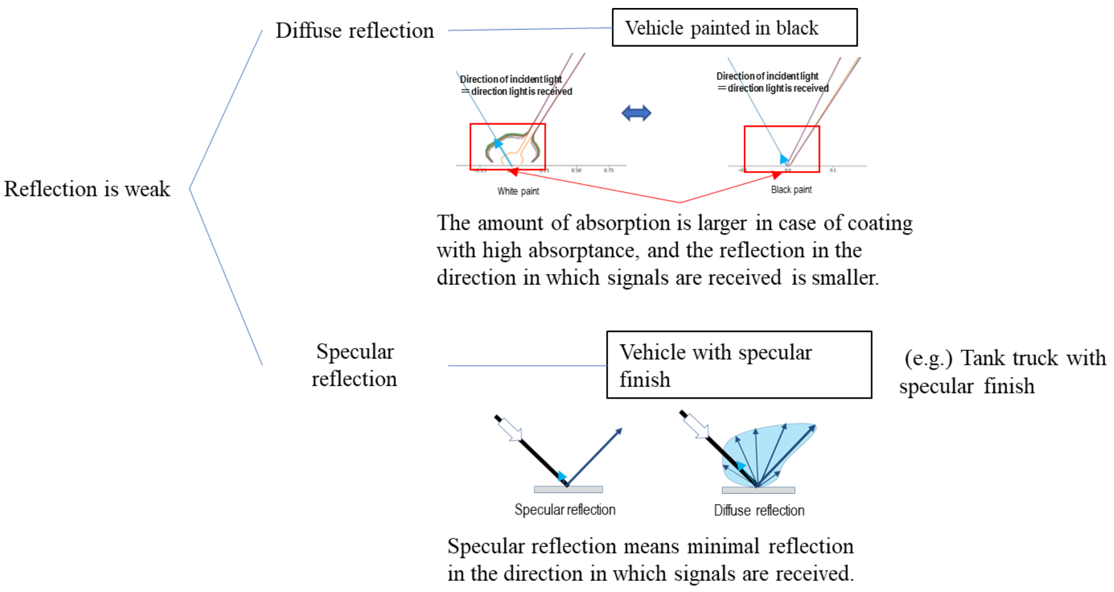
When defining parameter ranges, recognition targets are classified into vehicles and humans, and parameter ranges are determined separately for each category.



Vehicle Recognition Targets

For vehicle color and material, reflection characteristics are evaluated based on the reflective properties of surface coatings. As more stringent evaluation conditions, the following vehicle types are selected:

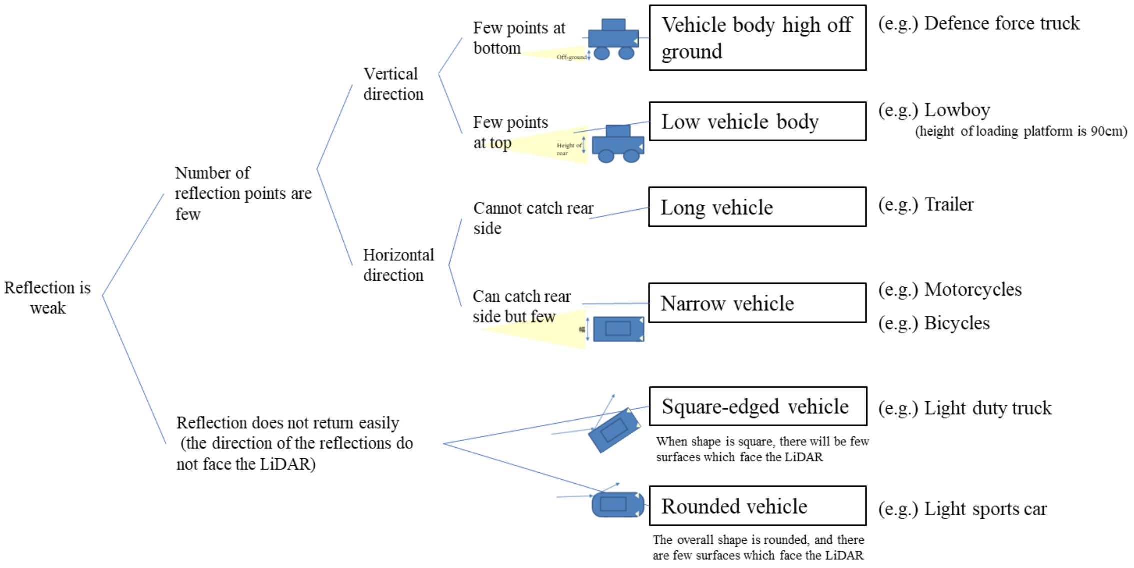
- black vehicles with low diffuse reflectivity; and
- vehicles with mirror-like surface finishes, which tend to produce weak reflections toward the receiving direction.



For vehicle shape, consideration is given to how LiDAR-transmitted beams impinge on the vehicle surface. As more severe evaluation conditions, vehicle shapes are selected that:

- result in a smaller number of beam-hit points; and
- are less likely to produce reflected returns toward the sensor.

These conditions represent worst-case configurations for LiDAR-based perception..



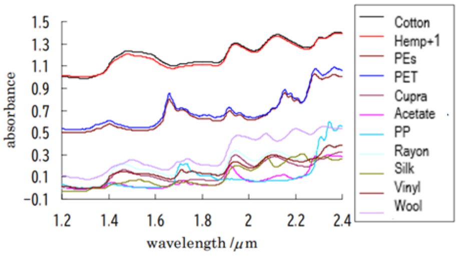
Human Recognition Targets

When the recognition target is a human, such as a pedestrian, motorcycle rider, or cyclist, reflection intensity varies depending on factors such as clothing, carried items, skin and hair color, and helmet usage.

In this study, parameter ranges are determined primarily based on differences in clothing reflectivity, as clothing accounts for a large proportion of the reflective area. Clothing materials are selected from the following categories:

- plant-derived materials (e.g., cotton);
- animal-derived materials (e.g., leather); and
- artificial materials (e.g., synthetic fibers, reflective materials).

Example of the Different Near Infrared Reflections by Material

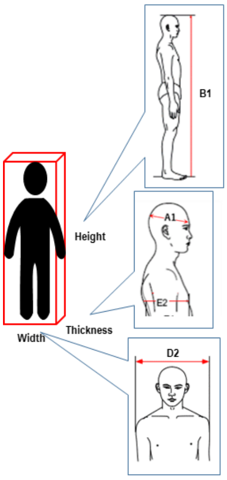


http://molsci.center.ims.ac.jp/discussion_past/2003/BK2003/Abs/4pp/4Pp063.pdf

For human shape, variations in body size and posture are considered. As a more stringent evaluation condition, the relatively small body size of Japanese individuals is treated as the worst-case condition.

① Difference in Size (Standing)

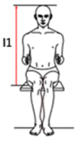
The size of pedestrians is expressed by the frame that surrounds the body.
Height, width and thickness correspond to height (B1), shoulder width (D2) and thickness at chest diameter (E2).



Standing	Average Japanese adult male Height (B1) : 171.4 cm Shoulder width (D2) : 45.6 cm Diameter at chest (E2) : 21.1 cm ※ Digital Human Research Center of the National Institute of Advanced Industrial Science and Technology AIST Human Body Measurements Database 1991 - 1992
	Average Japanese adult female Height (B1) : 159.1 cm Shoulder width (D2) : 40.7 cm Diameter at chest (E2) : 21.1 cm ※ Digital Human Research Center of the National Institute of Advanced Industrial Science and Technology AIST Human Body Measurements Database 1991 - 1992
	Average Japanese 3 y/o boy Height (B1) : 95.1 cm Shoulder width (D2) : Diameter at chest (E2) : ※ 2010 Survey by the Ministry of Health, Labour and Welfare

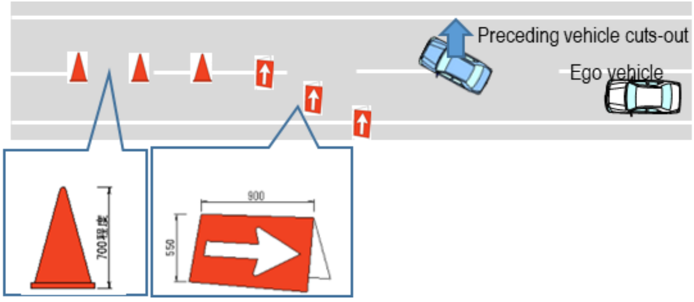
② Difference in Posture

The height from the road will differ depending on posture.
'Posture' is to be considered as a parameter.

Sitting	 I1 Sitting height (I1) Average Japanese adult male : 92.6 cm Average Japanese adult female : 86.7 cm ※ Digital Human Research Center of the National Institute of Advanced Industrial Science and Technology AIST Human Body Measurements Database 1991 - 1992
Lying	 A1 E2 Head length (A1) Average Japanese adult male : 18.9 cm Average Japanese adult female : 18.0 cm, Diameter at chest (E2) Average Japanese adult male : 21.1 cm Average Japanese adult female : 21.1 cm ※ Digital Human Research Center of the National Institute of Advanced Industrial Science and Technology AIST Human Body Measurements Database 1991 - 1992
Riding	For riding posture on motorcycles, bicycles, etc., when the rider comes to a stop and places their foot on the ground they will take the shape of standing; thus, we use the same height as a 'standing' person

Roadside-Installed Objects

When the recognition target is a roadside-installed object, arrow boards used for lane delineation and safety cones are selected as representative evaluation targets.



Fallen Objects on the Roadway

When the recognition target is a fallen object on the roadway, automotive tires are selected as representative evaluation targets, as they rank high among automotive components frequently found as fallen objects.

Reference: According to a survey conducted by NEXCO Central Japan, the ranking of fallen-object types is as follows:

- 1st : Plastic, vinyl, and fabric items (e.g., blankets, sheets): 25,400 cases
  - → Low height; minimal impact even if driven over
- 2nd : Automotive parts (e.g., tires, vehicle accessories): 8,900 cases
  - → Some items exceed 15 cm in height; include hard materials such as metal
- 3rd : Wood materials (e.g., square timber, plywood): 6,900 cases
  - → Square timber may exceed 15 cm in height and is hard; to be examined in the next step
- 4th : Roadkill (animal carcasses): 6,900 cases
  - → In Japan, small animals such as raccoon dogs are considered common
- 5th : Others: 17,400 cases

Based on the above considerations, the parameter ranges are organized into a consolidated list, as shown below.

Principle parameter	Causal factor	Causal factor parameter	Parameter Range	Explanation
Reflectance (BRDF)	Vehicle	Shape	High off-ground vehicle body Low vehicle Motorcycles, bicycles Square-edged vehicles Rounded vehicles	Clears bottom of body and only reflects tires It is difficult for the top layer of beams to hit the loading platform There are few reflections points in the horizontal direction Depending on orientation it is difficult for the normal vector to face the LiDAR It is difficult for the normal vector to face the LiDAR
		Color , Material	Black paint Specular reflection	Has few diffuse reflection elements Depending on the orientation, specular reflection will occur and not return
	Pedestrians	Shape	Big, small Standing, sitting, lying	Evaluate the variations of body build and posture
		Color , Material	Black leather clothing	Of all clothing types, this is assumed to have particularly low reflection
	Mounted objects	Shape	Triangular cones, arrow signs	Appear on tracks as a way of bordering lanes
		Color , Material	Color and material of the above mounted objects	The difference in variations is assumed to be minimal. Low priority.
	Fallen objects	Shape	Tires Wood	Low lying, and difficult for the normal vector to face the LiDAR Low lying, depending on orientation, difficult for the normal vector to face the LiDAR
		Color , Material	Color and material of the above fallen objects	The difference in variations is assumed to be minimal. Low priority.

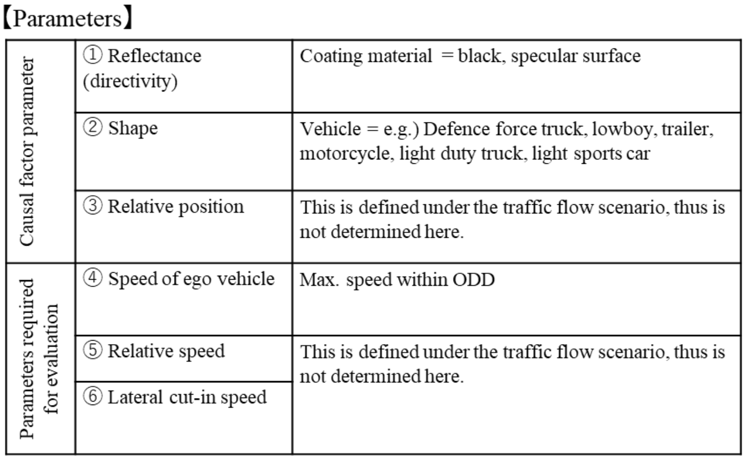
E.3.1.2.3. **Evaluation Scenarios**

The following evaluation scenarios are defined to assess LiDAR perception performance degradation due to signal attenuation. In each scenario, evaluation is conducted by varying the reflectivity and shape of the recognition target in order to represent severe conditions for LiDAR-based perception.

Scenario F-1: Cut-In Scenario on a Straight Road

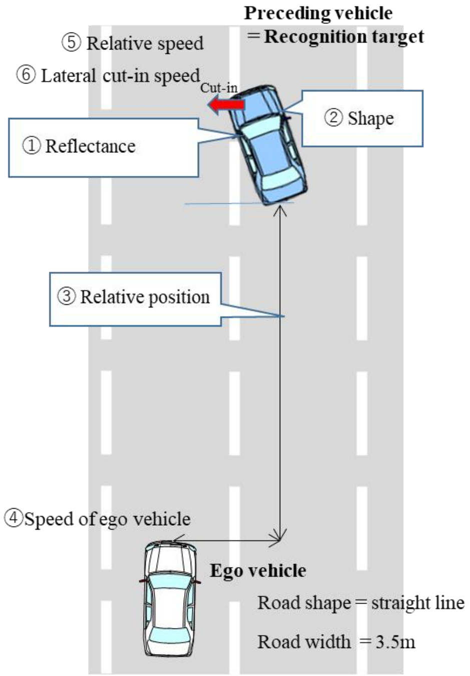
A cut-in vehicle is defined as the recognition target. The ego vehicle travels on a straight road, and another vehicle cuts in front of the ego vehicle.

Evaluation is performed by varying the reflectivity and shape of the cut-in vehicle to examine the effect of signal attenuation on detection performance.



【Parameters】

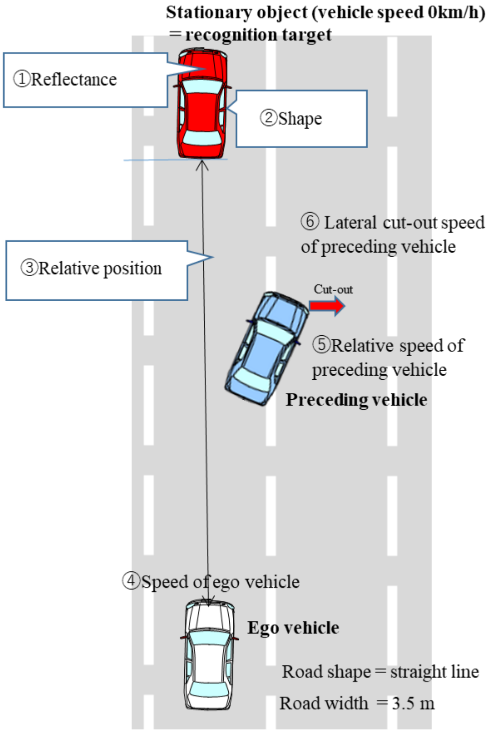
Causal factor parameter	① Reflectance (directivity)	Coating material = black, specular surface
	② Shape	Vehicle = e.g.) Defence force truck, lowboy, trailer, motorcycle, light duty truck, light sports car
	③ Relative position	This is defined under the traffic flow scenario, thus is not determined here.
Parameters required for evaluation	④ Speed of ego vehicle	Max. speed within ODD
	⑤ Relative speed ⑥ Lateral cut-in speed	This is defined under the traffic flow scenario, thus is not determined here.



Scenario F-2: Cut-Out Scenario on a Straight Road

After a lead vehicle performs a cut-out maneuver, a stationary recognition target is present on the roadway ahead of the ego vehicle.

Evaluation is conducted by varying the reflectivity and shape of the stationary target in order to assess the risk of false-negative detection caused by weak LiDAR reflections..



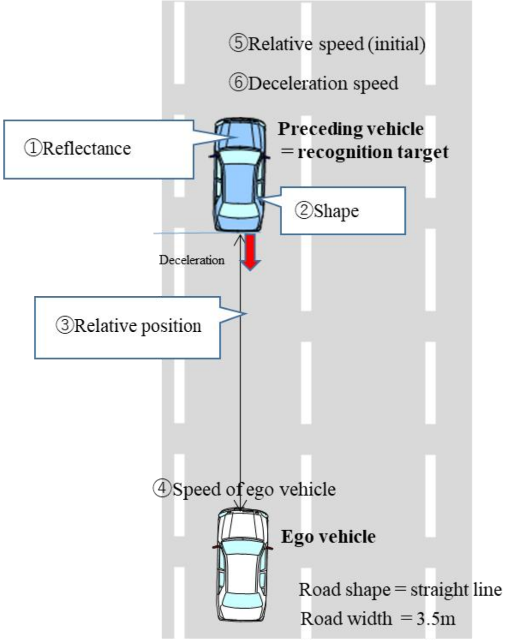
【Parameters】

Causal factor parameter	① Reflectance (directivity)	Vehicle：Coating material ＝black, specular surface Person：clothing＝leather, chemical fibres, cotton, reflective material Mounted/fallen objects：the reflectance of each target
	② Shape	Vehicle＝evaluate using deceleration scenario Person＝standing, sitting, lying, traffic controllers, bicycles Mounted objects＝safety cones, arrow signs Fallen objects＝tires, wood
	③ Relative position	This is defined under the traffic flow scenario; thus, it is not determined here.
Parameters required for evaluation	④ Speed of ego vehicle	Max. speed within ODD
	⑤ Relative speed of preceding vehicle	This is defined under the traffic flow scenario, thus is not determined here.
	⑥ Lateral cut-out speed of preceding vehicle	

Scenario F-3: Deceleration Scenario on a Straight Road

A decelerating vehicle is defined as the recognition target.
The ego vehicle follows the lead vehicle on a straight road while the lead vehicle decelerates.

Evaluation is performed by varying the reflectivity and shape of the decelerating vehicle to examine the effect of signal attenuation under longitudinal motion.



【Parameters】

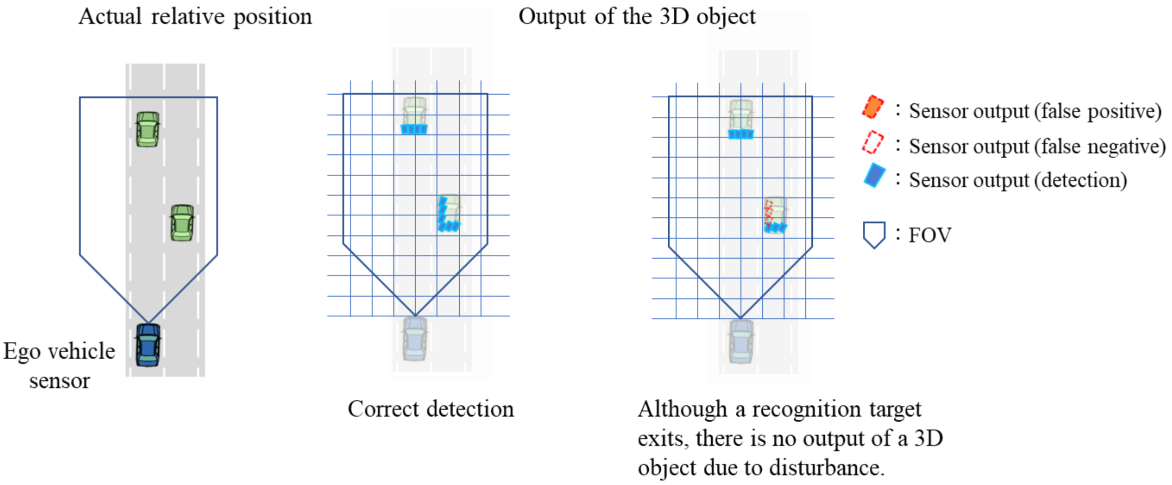
Causal factor parameter	①Reflectance (directivity)	Coating material = black, specular surface
	②Shape	Vehicle = e.g.) Defence force truck, lowboy, trailer, motorcycle, light duty truck, light sports car
	③Relative position	This is defined under the traffic flow scenario; thus, it is not determined here.
Parameters required for evaluation	④Speed of ego vehicle	Max. speed within ODD
	⑤Relative speed (initial)	This is defined under the traffic flow scenario, thus is not determined here.
	⑥Deceleration speed	

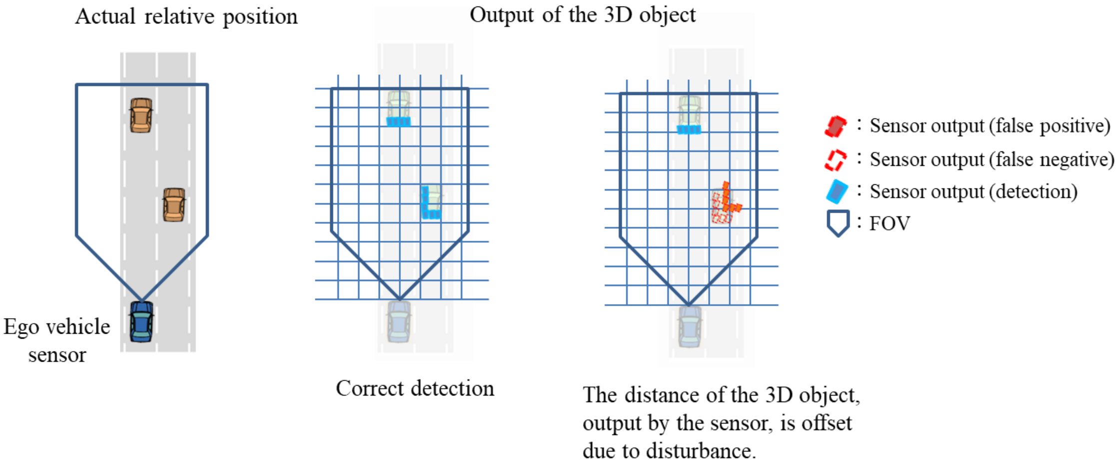
E.3.2. [LiDAR] Noise

E.3.2.1. Phenomenon and Principle

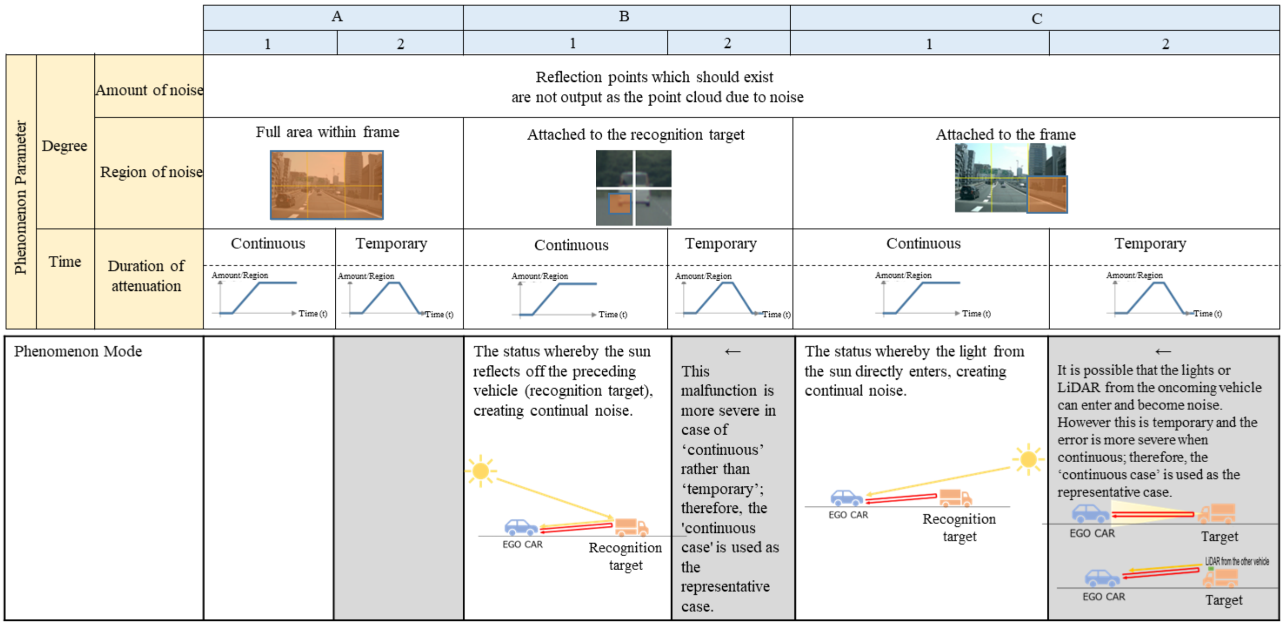
E.3.2.1.1. Phenomenon

There are cases in which, even when a recognition target enters the sensor's FOV, the reflection points associated with the target are not continuously output as a point cloud, resulting in false negatives (missed detections). Conversely, there are also cases in which false positives (false detections) occur, where output points are generated at locations that deviate from the actual position of the target object.





The figure below organizes the types of noise and their associated perception phenomena. In this section, persistent noise, which represents the most severe evaluation condition, is selected as the focus of evaluation.

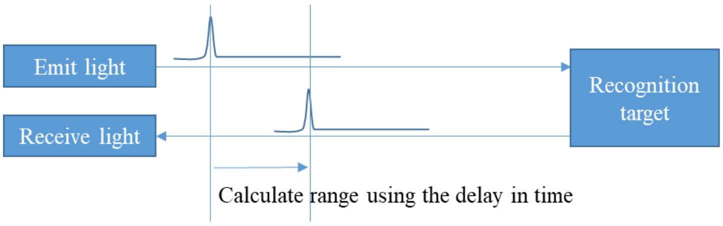


			A		B		C	
			1	2	1	2	1	2
Phenomenon Parameter	Degree	Amount of noise	Reflection points which should exist are not output as the point cloud due to noise					
		Region of noise	Full area within frame		Attached to the recognition target		Attached to the frame	
	Time	Duration of attenuation	Continuous	Temporary	Continuous	Temporary	Continuous	Temporary
Phenomenon Mode					The status whereby the sun reflects off the preceding vehicle (recognition target), creating continual noise.	← This malfunction is more severe in case of 'continuous' rather than 'temporary'; therefore, the 'continuous case' is used as the representative case.	The status whereby the light from the sun directly enters, creating continual noise.	← It is possible that the lights or LiDAR from the oncoming vehicle can enter and become noise. However this is temporary and the error is more severe when continuous; therefore, the 'continuous case' is used as the representative case.

The figure below organizes the types of noise and their associated perception phenomena. In this section, persistent noise, which represents the most severe evaluation condition, is selected as the focus of evaluation.

E.3.2.1.2. **Principle**

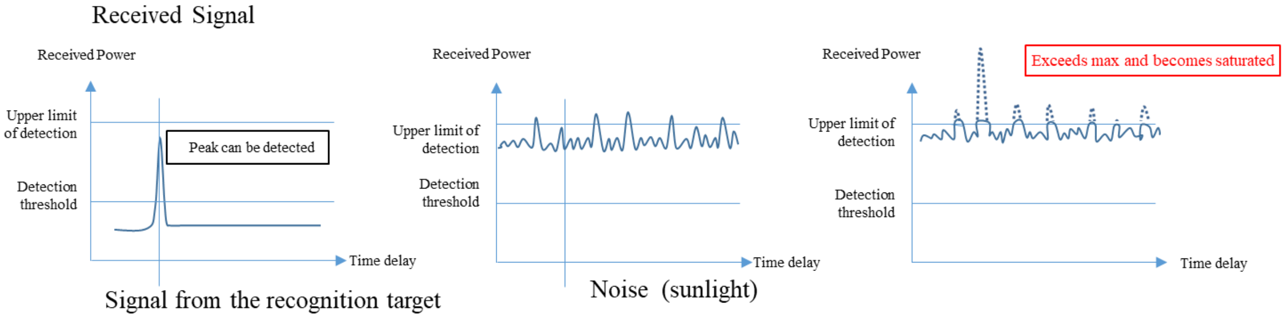
In LiDAR systems, the distance to a target object is determined by detecting the peak of the received reflected-light signal and calculating the corresponding time delay.



Two representative noise-related mechanisms are considered:

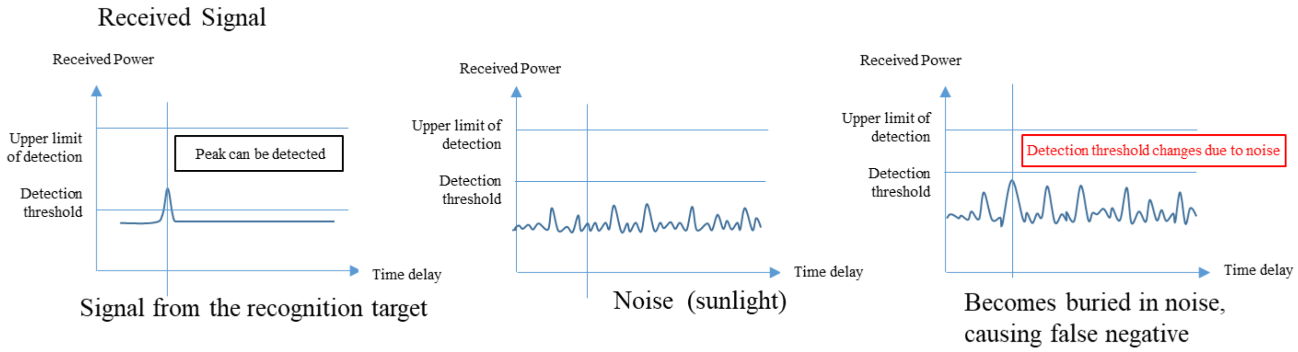
[Saturation case]

When continuously incident infrared light─such as sunlight—enters the receiver as noise, this noise component is superimposed on the reflected signal from the recognition target. As a result, the photodetector becomes saturated, preventing correct detection of the reflected signal.



[Case where the signal is buried in noise]

When continuously incident infrared light enters the receiver, reflected signals from recognition targets with weak reflection intensity may be buried within the noise, making peak detection impossible.



Signal from the recognition target

Noise (sunlight)

Becomes buried in noise, causing false negative

Noise in LiDAR systems can be broadly classified into two categories:

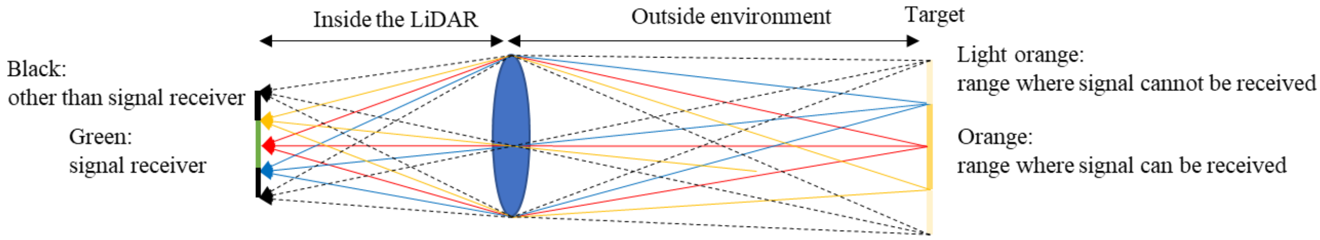
- Noise caused by external disturbance light, and
- Noise caused by internal reflections.

External disturbance light passes through the optical system within the nominal receivable range. However, LiDAR systems cannot optically distinguish among the following components once they enter the same optical path:

1. scattered light from the LiDAR’s own transmitted signal;
2. scattered light from other light sources (e.g., sunlight or LiDARs on other vehicles); and
3. self-emitted ambient light within the detectable wavelength range.

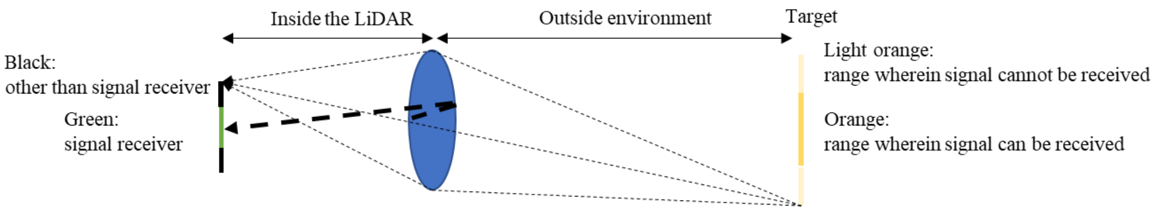
All of these components propagate along the same optical path and reach the receiver.

NOTE: All light other than item (1) above constitutes noise components. Because the transmission wavelength of a LiDAR is known, optical filters are typically used to block light outside the transmission wavelength band. Accordingly, noise components are defined as light within the same wavelength band as the LiDAR transmission.



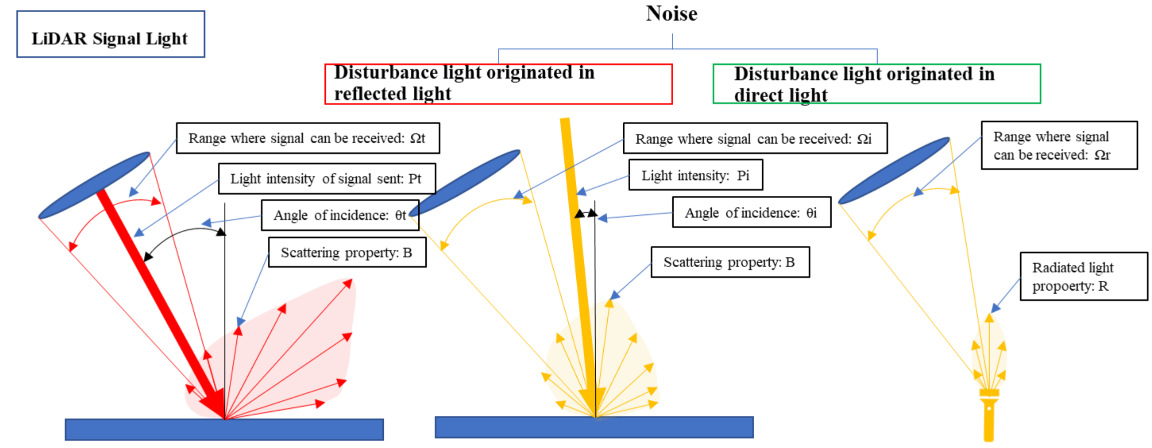
On the other hand, light incident from outside the nominal receivable range is normally guided away from the receiver and is not detected. However, when internal reflections occur (as indicated by the thick line in the figure below), light originating outside the intended reception range may reach the receiver. Although internal reflections are generally suppressed by anti-reflection coatings and similar measures, strong incident light—such as sunlight, headlights, or LiDAR emissions from other vehicles—may still generate internal reflections and cause ghost artifacts.

Because noise due to internal reflections occurs infrequently, it is excluded from perception-disturbance evaluation scenarios in the safety assessment.



E.3.2.1.3. **Principle** Models

In this study, disturbance light caused by both reflected light and direct incident light is treated as noise



Pt : defined by the LiDAR
B (θt) : shape is determined by the angle of incidence (θt) and target property
Ωt : determined by the distance to the target and diameter of entry pupil of the LiDAR

Ps : determined by the propoerty and distance/angle of the radiated light
B (θs) : shape is determined by the angle of incidence (θs) and target property
Ωs : determined by the distance to the target and diameter of entry pupil of the LiDAR

R : shape and size are determined by the property of the self-emitting light
Ωr : determined by the distance to the self-emitting light and diameter of entry pupil of the LiDAR

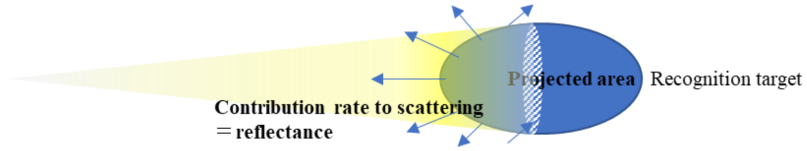
The total received optical power, denoted by P_a is expressed as follows:

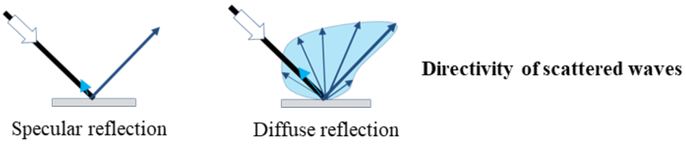
$$Pa = \boxed{Pt \int_{\Omega t} B(\theta t) d\Omega} + \underbrace{\boxed{Pi \int_{\Omega i} B(\theta i) d\Omega} + \boxed{\int_{\Omega r} R d\Omega}}_{\text{Parameters to consider as noise}} + N$$

N : Received optical power due to ghost artifacts

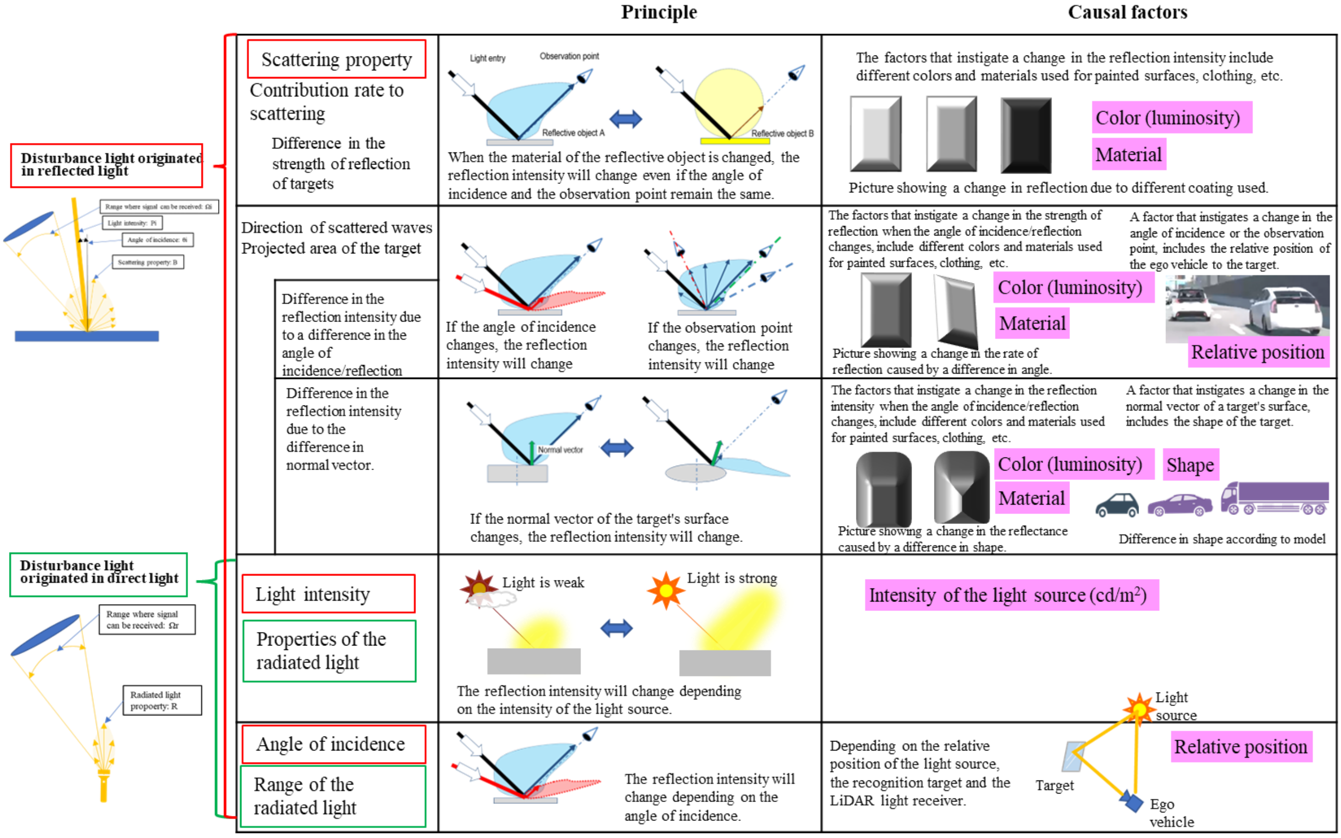
The reflection intensity from a recognition target can be expressed as the product of the projected area of the target, the contribution ratio to scattering(reflectivity), and the directivity of the scattered waves. The physical characteristics governing this relationship are equivalent to those applicable to millimeter-wave radar.
For objects composed of the same surface material, higher reflection intensity is obtained when the LiDAR irradiation direction is closely aligned with the surface normal direction of the target, resulting in higher directivity of the reflected light.

Reflection intensity = Projected area of the target * Contribution rate to scattering * Directivity of scattered waves





When the governing principles and contributing factors associated with each of the three elements affecting reflection intensity are systematically organized—together with the characteristics of disturbance light—the resulting relationships can be represented as shown in the figure below.



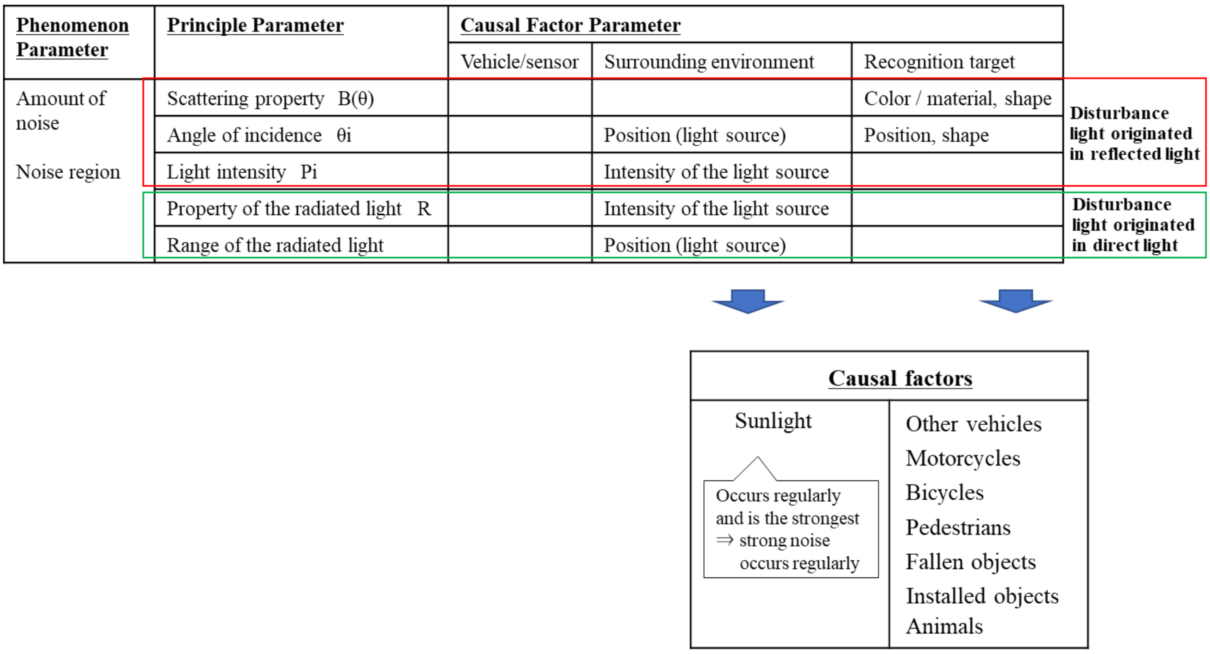
	Principle	Causal factors
Scattering property Contribution rate to scattering Difference in the strength of reflection of targets	When the material of the reflective object is changed, the reflection intensity will change even if the angle of incidence and the observation point remain the same.	The factors that instigate a change in the reflection intensity include different colors and materials used for painted surfaces, clothing, etc. Color (luminosity) Material Picture showing a change in reflection due to different coating used.
Direction of scattered waves Projected area of the target Difference in the reflection intensity due to a difference in the angle of incidence/reflection	If the angle of incidence changes, the reflection intensity will change If the observation point changes, the reflection intensity will change	The factors that instigate a change in the strength of reflection when the angle of incidence/reflection changes, include different colors and materials used for painted surfaces, clothing, etc. Color (luminosity) Material Picture showing a change in the rate of reflection caused by a difference in angle. A factor that instigates a change in the angle of incidence or the observation point, includes the relative position of the ego vehicle to the target. Relative position
Difference in the reflection intensity due to the difference in normal vector.	If the normal vector of the target's surface changes, the reflection intensity will change.	The factors that instigate a change in the reflection intensity when the angle of incidence/reflection changes, include different colors and materials used for painted surfaces, clothing, etc. Color (luminosity) Material Picture showing a change in the reflectance caused by a difference in shape. A factor that instigates a change in the normal vector of a target's surface, includes the shape of the target. Shape Difference in shape according to model
Light intensity Properties of the radiated light	The reflection intensity will change depending on the intensity of the light source.	Intensity of the light source (cd/m^2)
Angle of incidence Range of the radiated light	The reflection intensity will change depending on the angle of incidence.	Depending on the relative position of the light source, the recognition target and the LiDAR light receiver. Relative position

E.3.2.2. Relationship Between Principles and Causal Factors of Perception Disturbance

E.3.2.2.1. **Causal Factors Based on the Principle**

Based on the principle model described above, the relationships among the phenomenon parameters, principle parameters, and causal factor parameters are organized as follows.

In this disturbance mechanism, variations in the intensity of disturbance light—originating from reflected light or direct incident light—directly affect the signal-to-noise conditions of the LiDAR receiver and may lead to perception disturbances.



Phenomenon Parameter	**Principle Parameter**	**Causal Factor Parameter**			
		Vehicle/sensor	Surrounding environment	Recognition target	
Amount of noise	Scattering property B(θ)			Color / material, shape	**Disturbance light originated in reflected light**
	Angle of incidence θi		Position (light source)	Position, shape	
Noise region	Light intensity Pi		Intensity of the light source		
	Property of the radiated light R		Intensity of the light source		**Disturbance light originated in direct light**
	Range of the radiated light		Position (light source)		

Causal factors	
Sunlight Occurs regularly and is the strongest ⇒ strong noise occurs regularly	Other vehicles Motorcycles Bicycles Pedestrians Fallen objects Installed objects Animals

E.3.2.2.2. **Parameter Ranges**

The parameter ranges for disturbance light caused by reflected light are defined based on environmental conditions and surface reflectivity characteristics of surrounding objects.

Causal factors			Causal factor parameter	Range	Explanation (or reason)
Environment	Light source	Sunlight	Elevation angle	20 to 90 deg.	All the range in which the sunlight can be reflected light for the LiDAR (the culmination altitude on the day of the summer solstice around northern latitude of 35 deg: about 78 deg.)
			Azimuth angle	-180 to -150, 150 to 180 deg.	± 30 deg in the rear of the ego vehicle (traveling direction ≡ 0 deg)
			Brightness	20,000 to 120,000 lx	The brightness of the sunlight in daytime on a sunny day in summer: about 120,000 lx in maximum (calculated based on the insolation observational data by Japan Meteorological Agency)

Similarly, the parameter ranges for disturbance light caused by direct incident light are defined based on lighting conditions such as solar intensity, incident angle, and relative position with respect to the LiDAR sensor.

Causal factors			Causal factor parameter	Range	Explanation (or reason)
Environment	Light source	Sunlight	Elevation angle	Range of FOV	The range in which the sunlight can enter to the LiDAR directly
			Azimuth angle	Range of FOV	The range in which the sunlight can enter to the LiDAR directly
			Brightness	20,000 to 100,000 lx	Estimating the brightness of the sunlight in the altitude range around to 60 deg.

These parameter ranges are selected to ensure sufficient coverage of noise conditions that may realistically occur within the system’s ODD

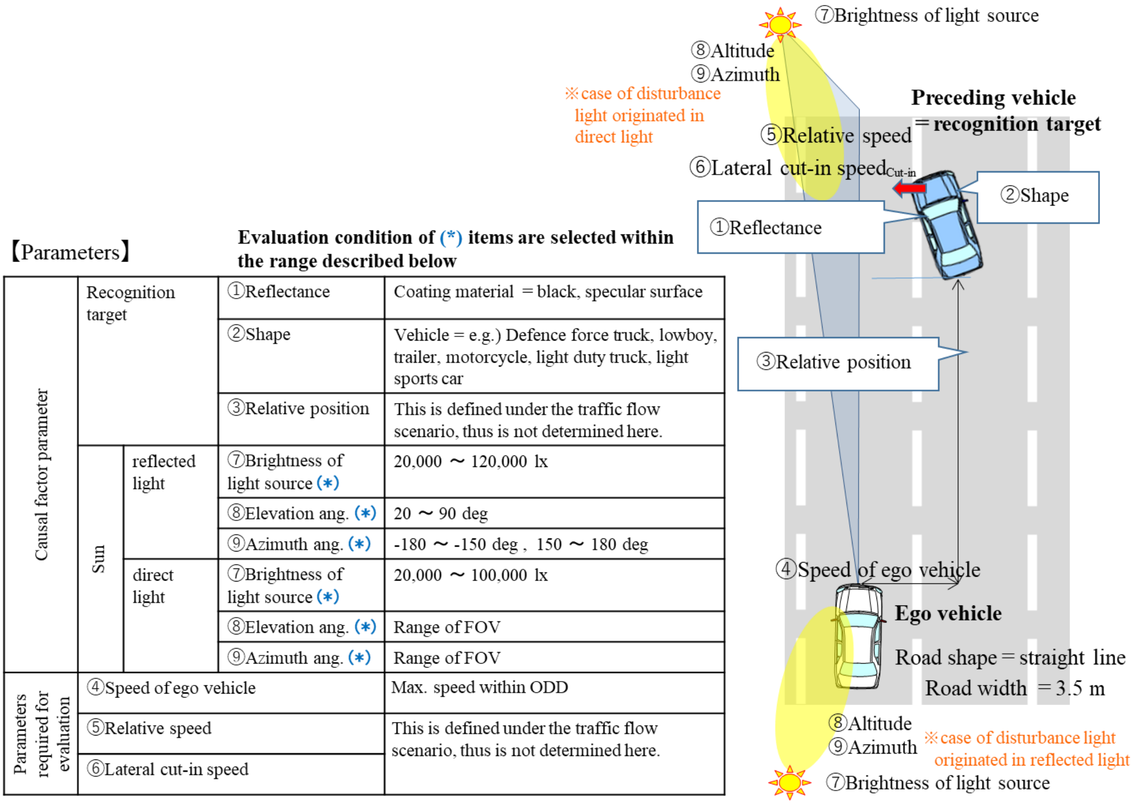
E.3.2.2.3. **Evaluation Scenarios**

Evaluation scenarios for LiDAR noise-induced perception disturbances are defined as follows.
In all scenarios, evaluation is conducted by varying the reflectivity, shape, and lighting conditions of the recognition target.

Scenario F-1: Cut-In Scenario on a Straight Road

A cut-in vehicle is defined as the recognition target.
The ego vehicle travels on a straight road while another vehicle cuts in front of it.

Evaluation is performed under varying reflectivity, shape, and ambient lighting conditions to assess noise-induced degradation of perception performance.



【Parameters】

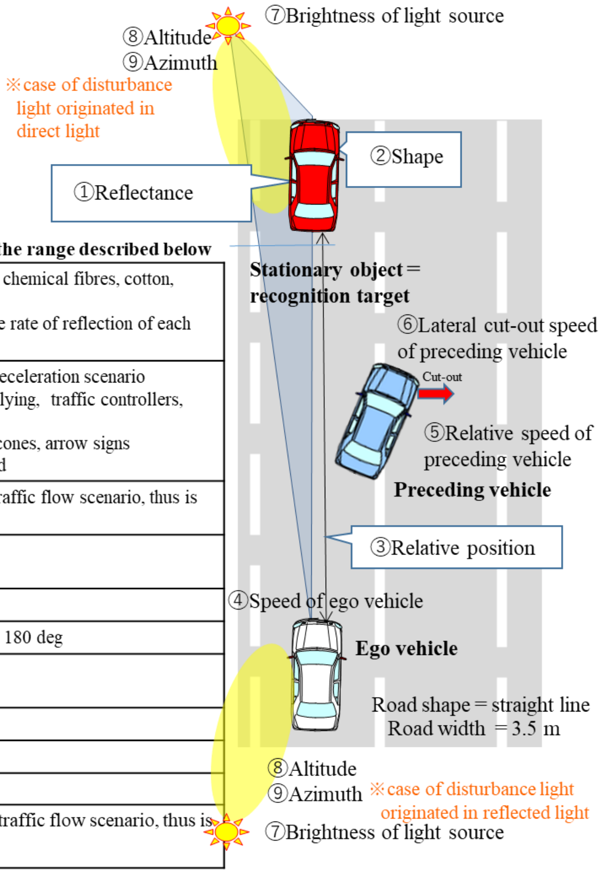
Evaluation condition of (*) items are selected within the range described below

Causal factor parameter	Recognition target		①Reflectance	Coating material = black, specular surface
			②Shape	Vehicle = e.g.) Defence force truck, lowboy, trailer, motorcycle, light duty truck, light sports car
			③Relative position	This is defined under the traffic flow scenario, thus is not determined here.
	Sun	reflected light	⑦Brightness of light source (*)	20,000 ～ 120,000 lx
			⑧Elevation ang. (*)	20 ～ 90 deg
			⑨Azimuth ang. (*)	-180 ～ -150 deg , 150 ～ 180 deg
		direct light	⑦Brightness of light source (*)	20,000 ～ 100,000 lx
			⑧Elevation ang. (*)	Range of FOV
			⑨Azimuth ang. (*)	Range of FOV
Parameters required for evaluation	④Speed of ego vehicle			Max. speed within ODD
	⑤Relative speed			This is defined under the traffic flow scenario, thus is not determined here.
	⑥Lateral cut-in speed			

Scenario F-2: Cut-Out Scenario on a Straight Road

After a lead vehicle performs a cut-out maneuver, a stationary recognition target is present on the roadway ahead of the ego vehicle.

Evaluation is conducted by varying the reflectivity, shape, and lighting conditions of the stationary target.



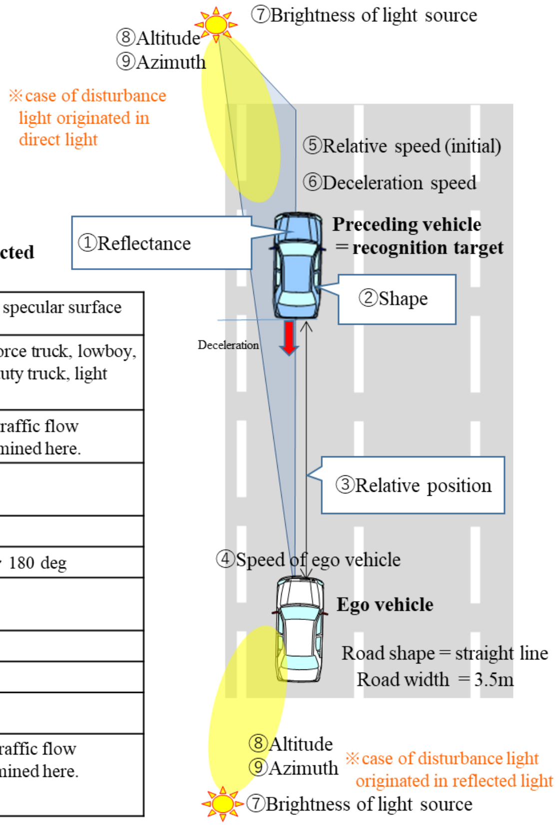
【Parameters】 **Evaluation condition of (*) items are selected within the range described below**

Causal factor parameter	Recognition target		①Reflectance	Person: clothing ＝leather, chemical fibres, cotton, reflective material Mounted/fallen objects: the rate of reflection of each object
			②Shape	Vehicle＝evaluate using deceleration scenario Person＝standing, sitting, lying, traffic controllers, bicycles Mounted objects＝safety cones, arrow signs Fallen objects＝tires, wood
			③Relative position	This is defined under the traffic flow scenario, thus is not determined here.
	Sun	reflected light	⑦Brightness of light source(*)	20,000 ～ 120,000 lx
			⑧Elevation ang. (*)	20 ～ 90 deg
			⑨Azimuth ang. (*)	-180 ～ -150 deg , 150 ～ 180 deg
		direct light	⑦Brightness of light source(*)	20,000 ～ 100,000 lx
			⑧Elevation ang. (*)	Range of FOV
			⑨Azimuth ang. (*)	Range of FOV
Parameters required for evaluation	④Speed of ego vehicle			Max. speed within ODD
	⑤Relative speed			This is defined under the traffic flow scenario, thus is not determined here.
	⑥Lateral cut-in speed			

Scenario F-3: Deceleration Scenario on a Straight Road

A decelerating vehicle is defined as the recognition target.
The ego vehicle follows the lead vehicle on a straight road while the lead vehicle decelerates.

Evaluation is performed under varying reflectivity, shape, and lighting conditions to assess the impact of noise on perception performance during longitudinal maneuvers.



【Parameters】

Evaluation condition of (*) items are selected within the range described below

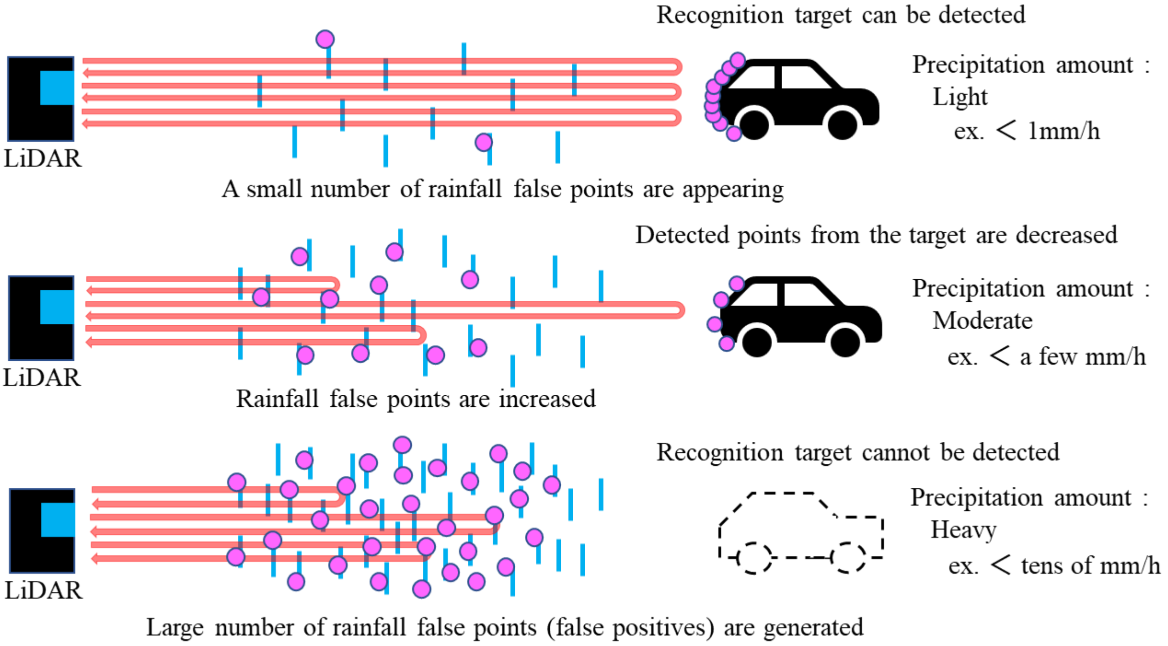
Causal factor parameter	Recognition target		①Reflectance	Coating material ＝black, specular surface
			②Shape	Vehicle = e.g.) Defence force truck, lowboy, trailer, motorcycle, light duty truck, light sports car
			③Relative position	This is defined under the traffic flow scenario, thus is not determined here.
	Sun	reflected light	⑦Brightness of light source (*)	20,000 ～ 120,000 lx
			⑧Elevation ang. (*)	20 ～ 90 deg
			⑨Azimuth ang. (*)	-180 ～ -150 deg , 150 ～ 180 deg
		direct light	⑦Brightness of light source (*)	20,000 ～ 100,000 lx
			⑧Elevation ang. (*)	Range of FOV
			⑨Azimuth ang. (*)	Range of FOV
Parameters required for evaluation	④Speed of ego vehicle			Max. speed within ODD
	⑤Relative speed			This is defined under the traffic flow scenario, thus is not determined here.
	⑥Lateral cut-in speed			

E.3.3. [LiDAR] Signals from Non-Recognition Targets (reflections from raindrops)

E.3.3.1. Phenomenon and Principle

E.3.3.1.1. Phenomenon

LiDAR beams emitted from the sensor are reflected and scattered by raindrops present in the air. This scattering causes attenuation of the reflected signals from the recognition target. In addition, reflections from raindrops generate spurious points (false points) in the surrounding space, which reduces the number of valid detection points associated with the recognition target. As the rainfall intensity increases, the number of spurious points increases correspondingly. Under sufficiently severe conditions, the combined effects of signal attenuation and spurious-point generation result in false negatives (missed detections) of the recognition target.

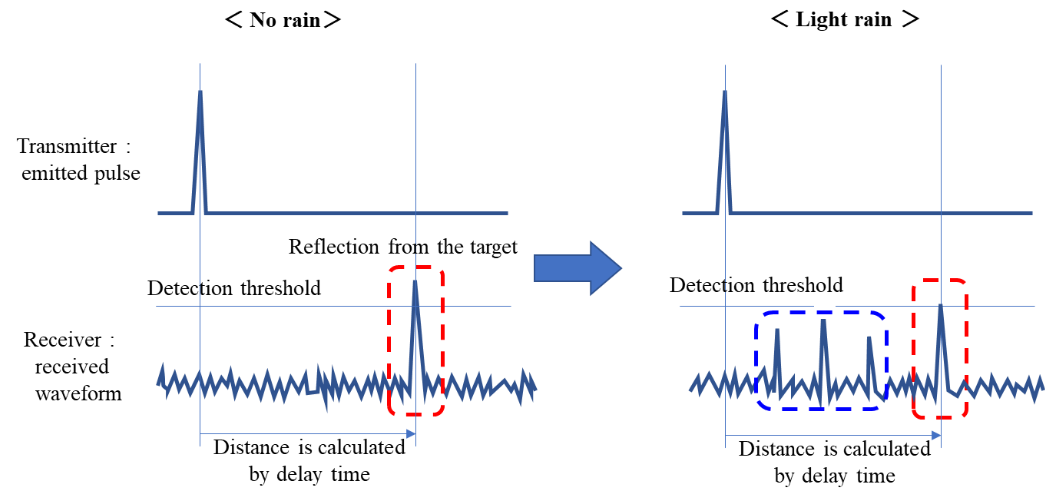


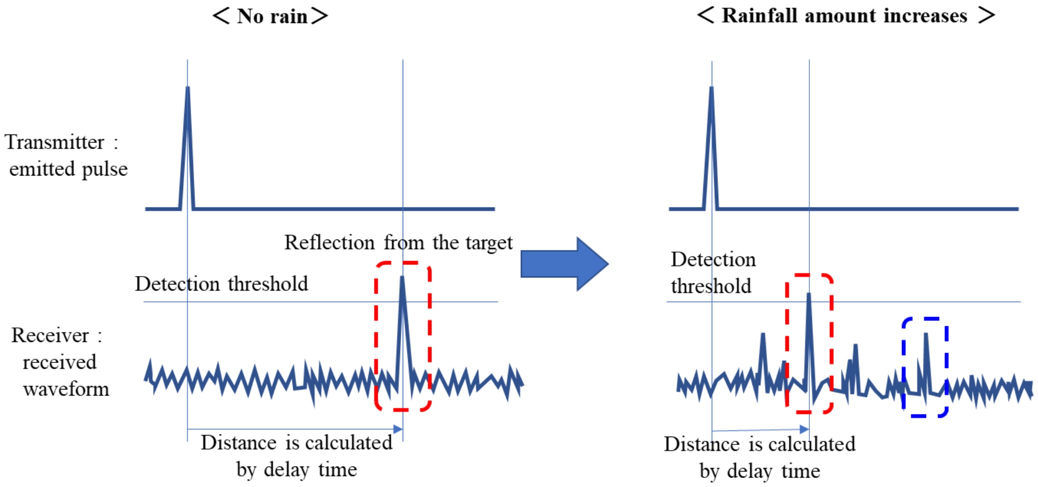
E.3.3.1.2. Principle

In an environment without rainfall, as illustrated on the left side of the figure below, the reflected signal from the recognition target (indicated by the red frame) appears as a distinct peaks waveform, allowing the target signal to be readily separated from noise components.

When rainfall is present, as shown on the right side of the figure, multiple small peaks generated by reflections from raindrops (indicated by the blue frame) appear in addition to the peak reflected from the recognition target. Under light rain conditions, these raindrop-induced peaks remain relatively small and do not exceed the detection threshold, and therefore are not detected as spurious points.

As the rainfall intensity increases, attenuation of the reflected signal from the recognition target becomes more pronounced. Consequently, the peak corresponding to the recognition target (red frame) may fall below the detection threshold, while the peaks generated by raindrop reflections (blue frame) increase in magnitude and may exceed the detection threshold. As a result, spurious points appear in the space closer to the LiDAR sensor than the actual recognition target, obscuring the target and leading to missed detections.



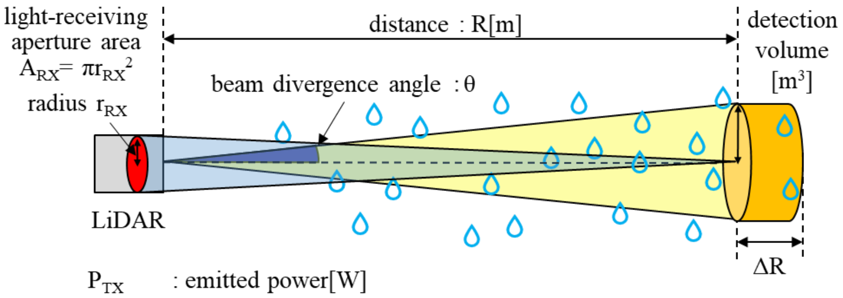


E.3.3.1.3. **Principle Models**

LiDAR equation for scattering by raindrops in space (assuming a coaxial LiDAR)

The received optical power of the scattering component originating from raindrops located in space at a distance *R* from the LiDAR sensor can be expressed by the following equation.

$$P_{RX(rain)}(R) = P_{TX} * \frac{A_{RX}}{R^2} * \rho * T$$



LiDAR parameters affecting detection volume
- beam divergence angle : θ
- minimum spatial resolution : ΔR (Determined by laser pulse width and wavelength)

P_{TX} : emitted power[W]
$P_{RX\,(rain)}$: received power from raindrops [W]

In this formulation, reflections (scattering) from raindrops are treated as scattered light originating from a finite detection volume in space. The equation incorporates:

- a term representing attenuation caused by raindrops, expressed as the spatial transmittance *T*; and
- a term representing the process by which scattered light from raindrops returns to the receiving system, expressed as a reflectivity-equivalent value ρ[sr^{-1}].

Factors that affect the spatial transmittance *T*

The spatial transmittance *T*, which represents attenuation due to raindrops, is affected by the following factors:

- rainfall intensity and raindrop distribution (drop size and fall velocity);
- scattering distance; and
- LiDAR wavelength.

Factors Affecting Reflectivity-Equivalent Value ρ

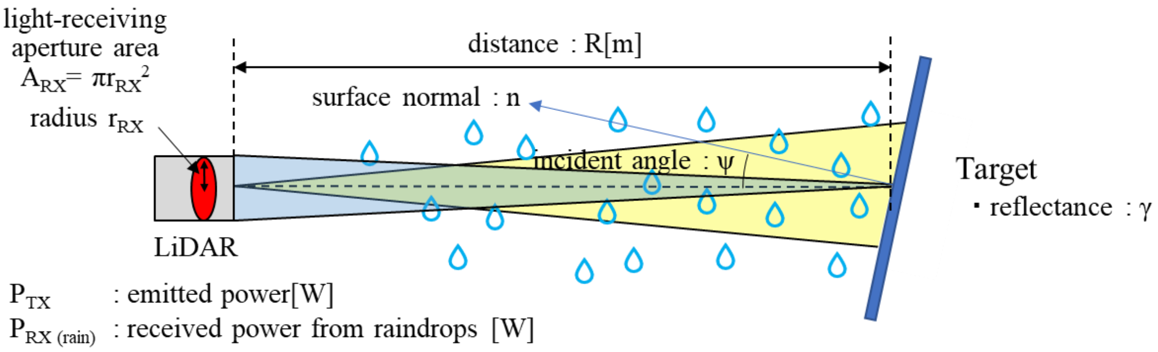
The reflectivity-equivalent value ρ, which represents the strength of scattered light returning to the receiver, is affected by:

- rainfall intensity and raindrop distribution (drop size and fall velocity);
- scattering distance; and
- LiDAR system characteristics, including beam divergence angle, pulse width, and wavelength.

LiDAR equation for attenuation of reflections from a recognition target by raindrops (assuming a coaxial LiDAR)

When the reflection signal from a recognition target located at a distance *R* from the LiDAR sensor is attenuated by raindrops present in the propagation path, the received optical power can be expressed by the following equation:

$$P_{RX(Target)}(R) = P_{TX} * \frac{A_{RX}}{R^2} * \gamma * \cos(\psi) * T$$



Here, the reduction in received optical power under rainfall conditions is modeled by multiplying the conventional LiDAR equation ―which account for the bidirectional reflectance distribution function (BRDF) γ[sr^{-1}] of the recognition target ―by a term representing attenuation due to raindrops, namely the spatial transmittance *T*.

The spatial transmittance *T*, which represents attenuation caused by raindrops, is affected by the following factors:

- rainfall intensity and raindrop distribution (drop size and fall velocity);
- distance to the recognition target; and
- LiDAR wavelength.

Under conditions where the received optical power of the scattering component caused by raindrops,

$$P_{\mathrm{RX\ (rain)}}\ (\mathrm{R})\ ,$$

exceeds the received optical power from the recognition target,

$$> P_{\mathrm{RX\ (Target)}}\ (\mathrm{R})\ ,$$

spurious points generated by raindrops appear in the perception output.

E.3.3.2. Relationship Between Principles and Causal Factors of Perception Disturbance

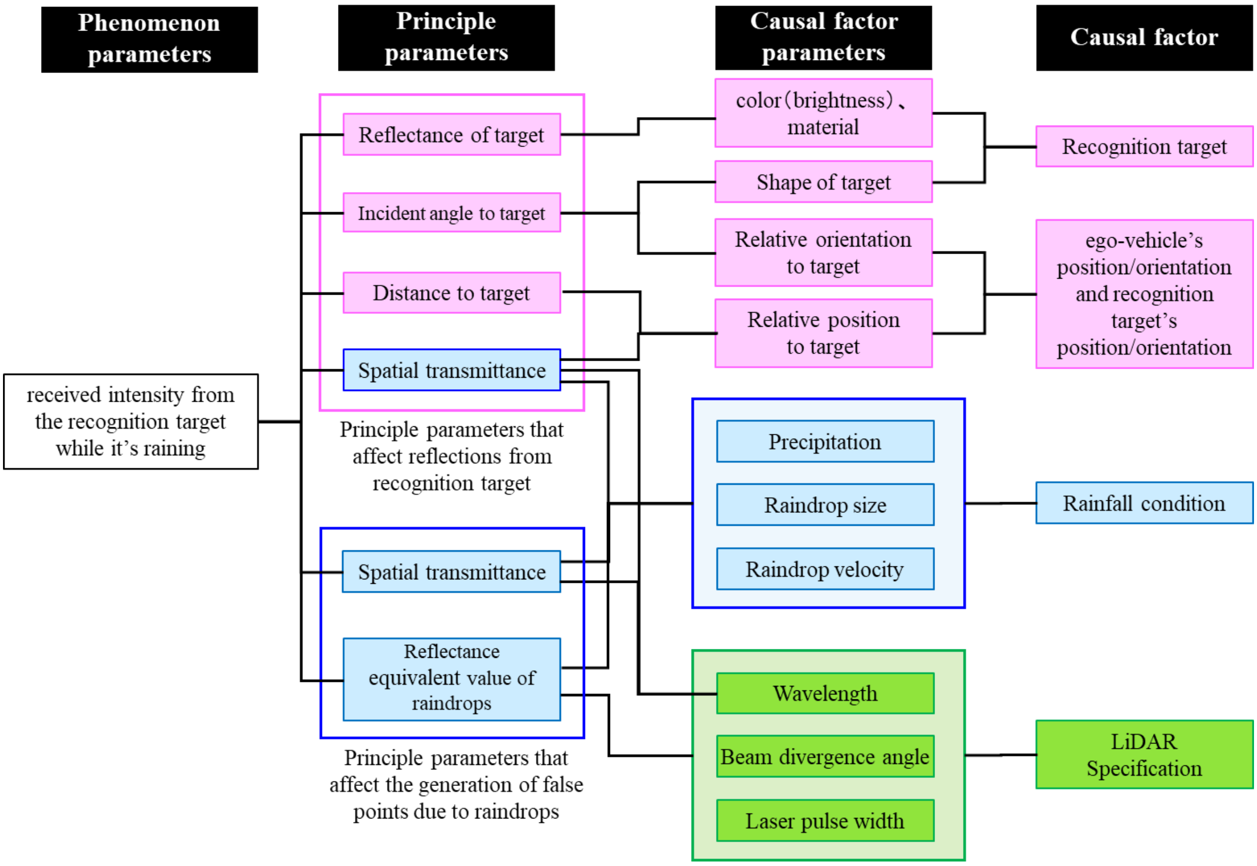
E.3.3.2.1. Causal Factors Based on the Principle

In this perception-disturbance principle, the phenomenon parameter is defined as the received signal intensity from the recognition target.

Based on this parameter, the perception-disturbance factors can be organized into the following four categories:

1. Material, shape, and reflective characteristics of the recognition target
2. Position and posture of the ego vehicle and the position and posture of the recognition target
3. Rainfall conditions, including rainfall intensity, raindrop size distribution, and rainfall direction
4. LiDAR specifications , including wavelength, output power, receiver sensitivity, and scanning method

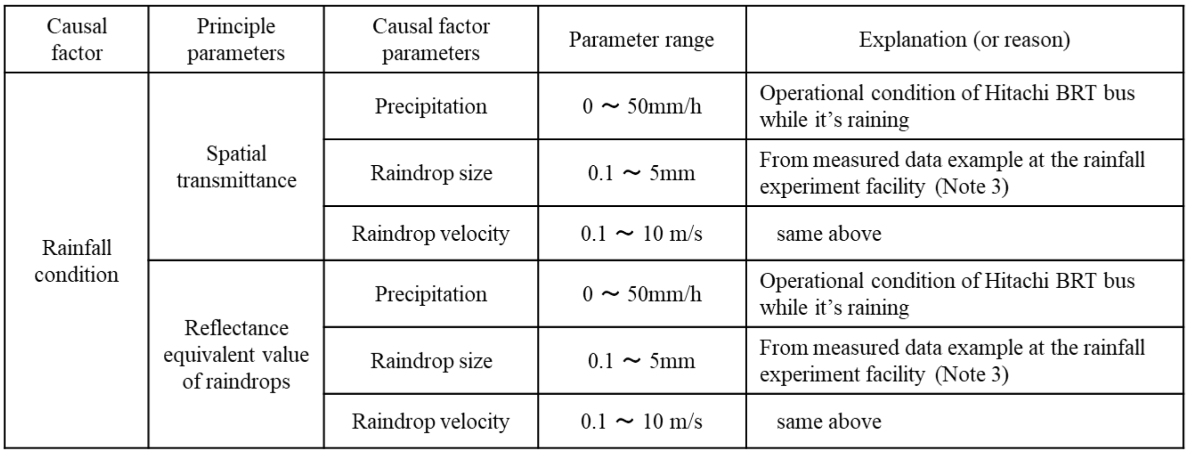
When the relationships among these disturbance factors, the phenomenon parameter, and the associated principle parameters are organized, they can be represented as shown below.



E.3.3.2.2. **Parameter Ranges**

Among the disturbance factors listed above, the factors related to the recognition target, ego-vehicle position and posture, and recognition-target position and posture are addressed under other perception-disturbance principles. In addition, LiDAR specifications are treated as fixed parameters specific to the LiDAR device under evaluation.

Accordingly, in this section, only the parameter ranges related to rainfall conditions are defined and presented in the table below.



Causal factor	Principle parameters	Causal factor parameters	Parameter range	Explanation (or reason)
Rainfall condition	Spatial transmittance	Precipitation	0 ～ 50mm/h	Operational condition of Hitachi BRT bus while it's raining
		Raindrop size	0.1 ～ 5mm	From measured data example at the rainfall experiment facility (Note 3)
		Raindrop velocity	0.1 ～ 10 m/s	same above
	Reflectance equivalent value of raindrops	Precipitation	0 ～ 50mm/h	Operational condition of Hitachi BRT bus while it's raining
		Raindrop size	0.1 ～ 5mm	From measured data example at the rainfall experiment facility (Note 3)
		Raindrop velocity	0.1 ～ 10 m/s	same above

NOTE:
The rainfall parameter settings are based on raindrop size and fall-velocity distribution data measured using a disdrometer at the Large-Scale Rainfall Experiment Facility of the National Research Institute for Earth Science and Disaster Resilience (NIED). The following conditions are applied:

- Rainfall intensity setting: 50 mm/h
- Second-system nozzle used

E.3.3.2.3. **Evaluation Scenarios**

Evaluation scenarios for perception disturbances caused by reflections from raindrops are defined as follows. In all scenarios, evaluation is conducted by varying the reflectivity, shape, and rainfall conditions of the recognition target.

Scenario F-1: Cut-In Scenario on a Straight Road

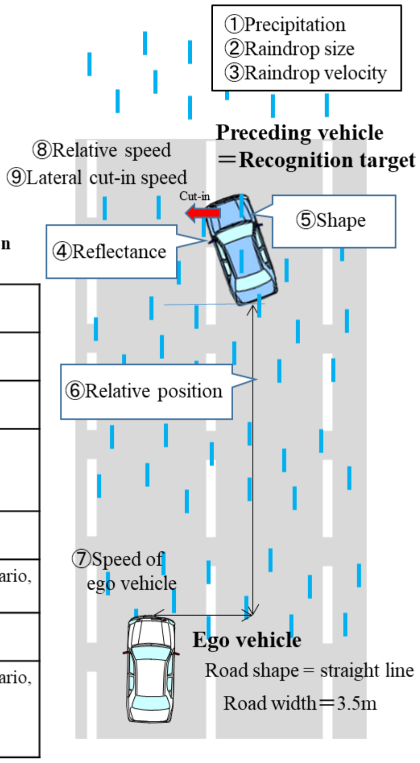
A cut-in vehicle is defined as the recognition target.

Evaluation is performed while varying the reflectivity, shape, and rainfall conditions of the cut-in vehicle.

【Parameters】

For the items marked with (*), select the evaluation conditions from the description range.

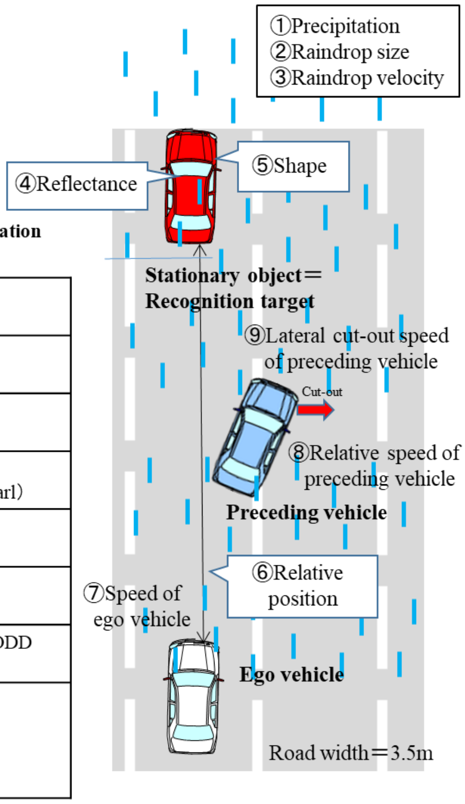
Causal factor Parameters	Rainfall condition	①Precipitation (*)	0 ～ 50 mm/h
		②Raindrop size (*)	0.1 ～ 5mm
		③Raindrop velocity (*)	0.1 ～ 10m/s
Parameters required for evaluation	Recognition target	④Reflectance	Coating material＝black, white effect pigment（metallic/pearl）
		⑤Shape	Vehicle＝passenger car, motorcycle
		⑥Relative position	Range defined under the traffic flow scenario, not determined here
	⑦Speed of ego vehicle		Maximum speed defined within the ODD
	⑧Relative speed		Range defined under the traffic flow scenario, not determined here
	⑨Lateral cut-in speed		



Scenario F-2: Cut-Out Scenario on a Straight Road

After a lead vehicle performs a cut-out maneuver, a stationary recognition target is present on the roadway ahead of the ego vehicle.

Evaluation is conducted while varying the reflectivity, shape, and rainfall conditions of the stationary target.



【Parameters】

For the items marked with (*), select the evaluation conditions from the description range.

Causal factor Parameters	Rainfall condition	①Precipitation (*)	0 〜 50 mm/h
		②Raindrop size (*)	0.1 〜 5mm
		③Raindrop velocity (*)	0.1 〜 10m/s
Parameters required for evaluation	Recognition target	④Reflectance	Coating material＝black, white effect pigment（metallic/pearl）
		⑤Shape	Vehicle＝passenger car, motorcycle
		⑥Relative position	Range defined under the traffic flow scenario, not determined here
	⑦Speed of ego vehicle		Maximum speed defined within the ODD
	⑧Relative speed		Range defined under the traffic flow scenario, not determined here
	⑨Lateral cut-in speed		

Scenario F-3: Deceleration Scenario on a Straight Road

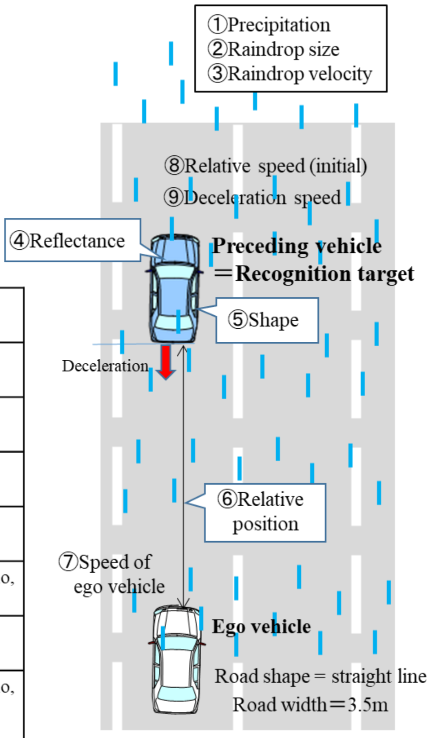
A decelerating vehicle is defined as the recognition target.

Evaluation is conducted while varying the reflectivity, shape, and rainfall conditions of the decelerating vehicle.

【Parameters】

For the items marked with (*), select the evaluation conditions from the description range.

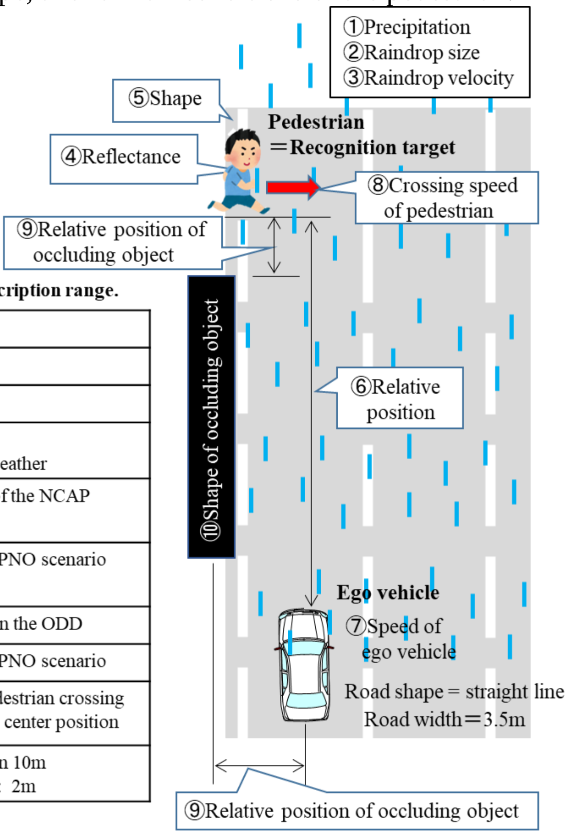
Causal factor Parameters	Rainfall condition	①Precipitation (*)	0 ～ 50 mm/h
		②Raindrop size (*)	0.1 ～ 5mm
		③Raindrop velocity (*)	0.1 ～ 10m/s
Parameters required for evaluation	Recognition target	④Reflectance	Coating material＝black, white effect pigment (metallic/pearl)
		⑤Shape	Vehicle＝passenger car, motorcycle
		⑥Relative position	Range defined under the traffic flow scenario, not determined here
	⑦Speed of ego vehicle		Maximum speed defined within the ODD
	⑧Relative speed (initial)		Range defined under the traffic flow scenario, not determined here
	⑨Deceleration speed		



Pedestrian Case: Pedestrian Crossing Scenario

A pedestrian is defined as the recognition target.

Evaluation is conducted while varying the reflectivity, shape, and rainfall conditions of the pedestrian.



【Parameters】

For the items marked with (*), select the evaluation conditions from the description range.

Causal factor parameters	Rainfall condition	①Precipitation (*)	0 ～ 50 mm/h
		②Raindrop size (*)	0.1 ～ 5mm
		③Raindrop velocity (*)	0.1 ～ 10m/s
Parameters required For evaluation	Recognition target	④Reflectance	Clothing color＝black, white Material ＝ cotton, polyester, leather
		⑤Shape	Conforms to the target shape of the NCAP Pedestrian test（adult/child）
		⑥Relative position	Range defined in the NCAP CPNO scenario
	⑦Speed of ego vehicle		Maximum speed defined within the ODD
	⑧Crossing speed of pedestrian		Range defined in the NCAP CPNO scenario
	⑨Relative position of occluding object		Longitudinal：1.0m before pedestrian crossing Lateral：3.0m left from vehicle center position
	⑩Shape of occluding object		Longitudinal length：more than 10m Lateral length：2m　　Height：2m

E.4. Principle Models and Evaluation Scenarios for Camera

For camera-based perception, principle models and representative evaluation scenarios are described for the following three perception-disturbance principles:

- Occlusion (partial visibility / truncation)
- Reduction in spatial frequency and contrast (spatial obstacles)
- Saturation (overexposure) and blown highlights

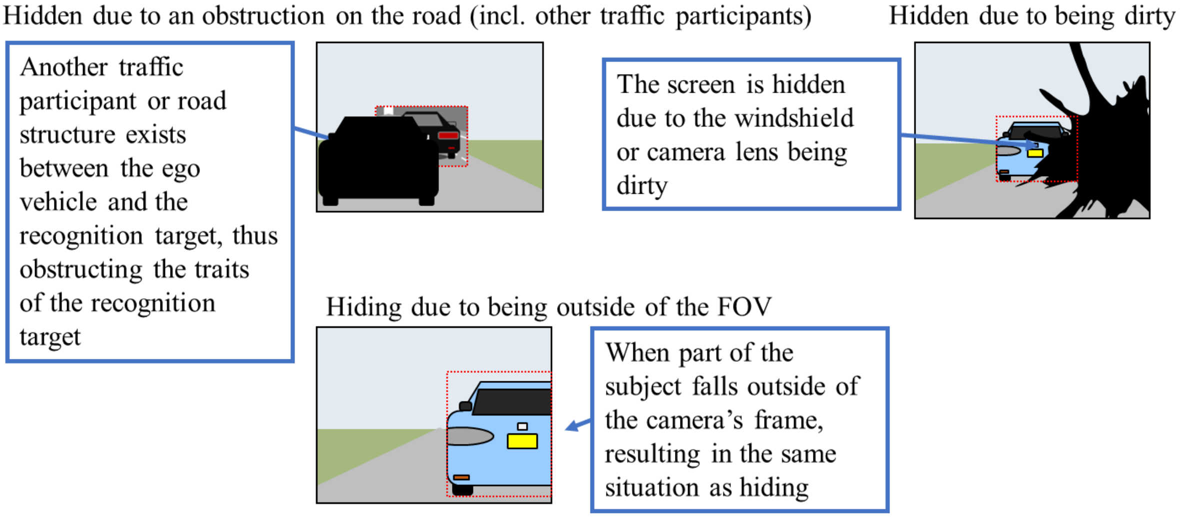
E.4.1. [Camera] Occlusion (Truncation)

E.4.1.1. Phenomenon and Principle

E.4.1.1.1. **Phenomenon**

When a recognition target is occluded by another object, or when the recognition target moves partially or entirely out of the camera's field of view (FOV), part or all of the target becomes invisible.
As a result, visual information required for feature extraction is missing. This loss of information may lead to false negatives (missed detections) or, in some cases, errors in estimated position information.

Examples of such situations are illustrated in the figure below.



Hidden due to an obstruction on the road (incl. other traffic participants)

Another traffic participant or road structure exists between the ego vehicle and the recognition target, thus obstructing the traits of the recognition target

Hidden due to being dirty

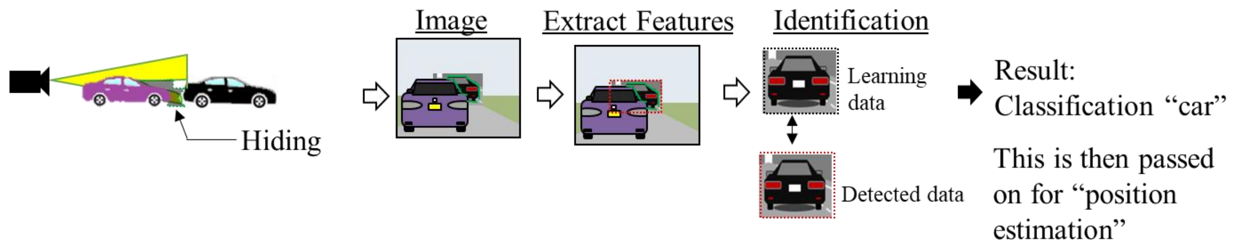
The screen is hidden due to the windshield or camera lens being dirty

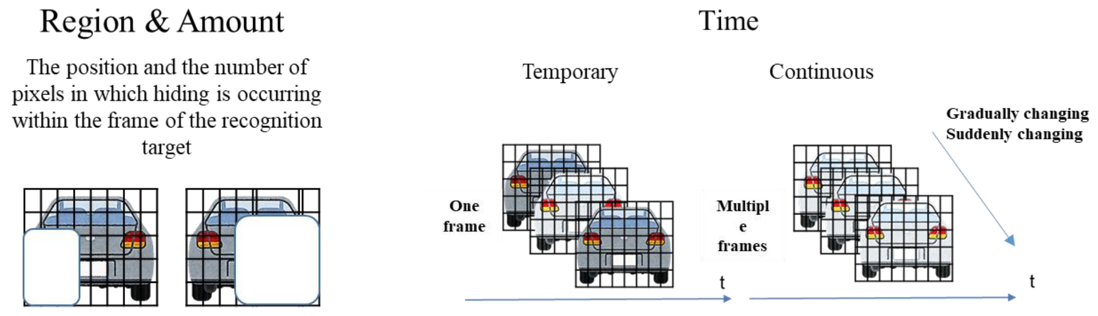
Hiding due to being outside of the FOV

When part of the subject falls outside of the camera's frame, resulting in the same situation as hiding

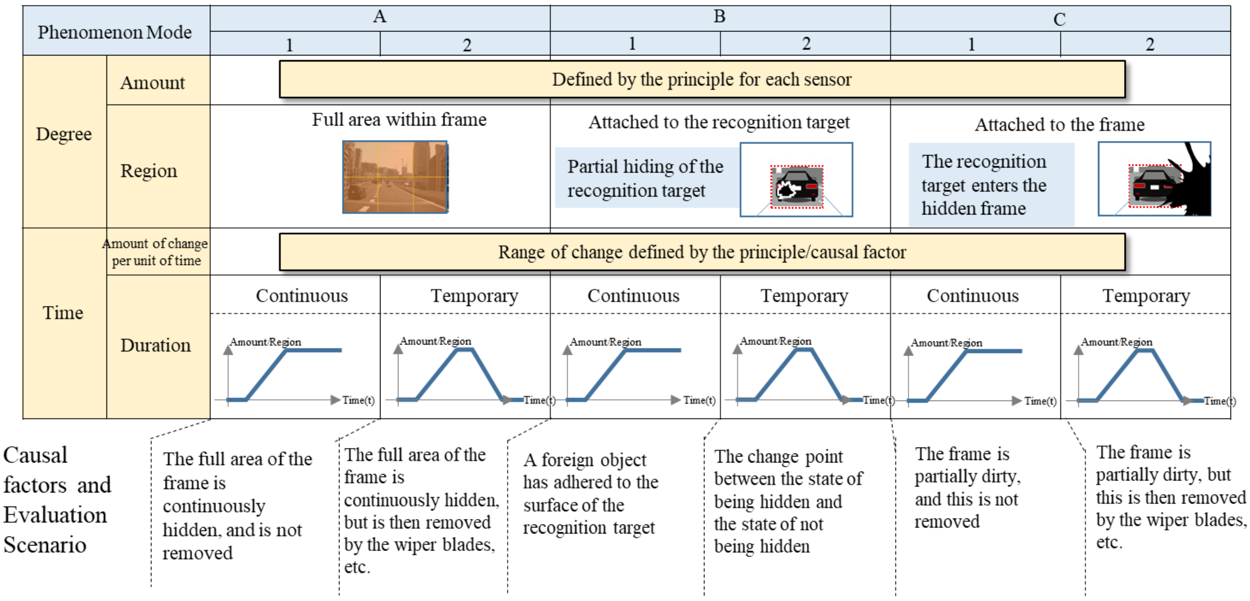
E.4.1.1.2. Principle

When part of a recognition target is occluded, the camera-based perception system may fail to perform correct feature extraction. Alternatively, even if feature extraction is partially successful, the classification or identification function may fail to correctly match the extracted features with trained data, resulting in missed detection or misclassification.





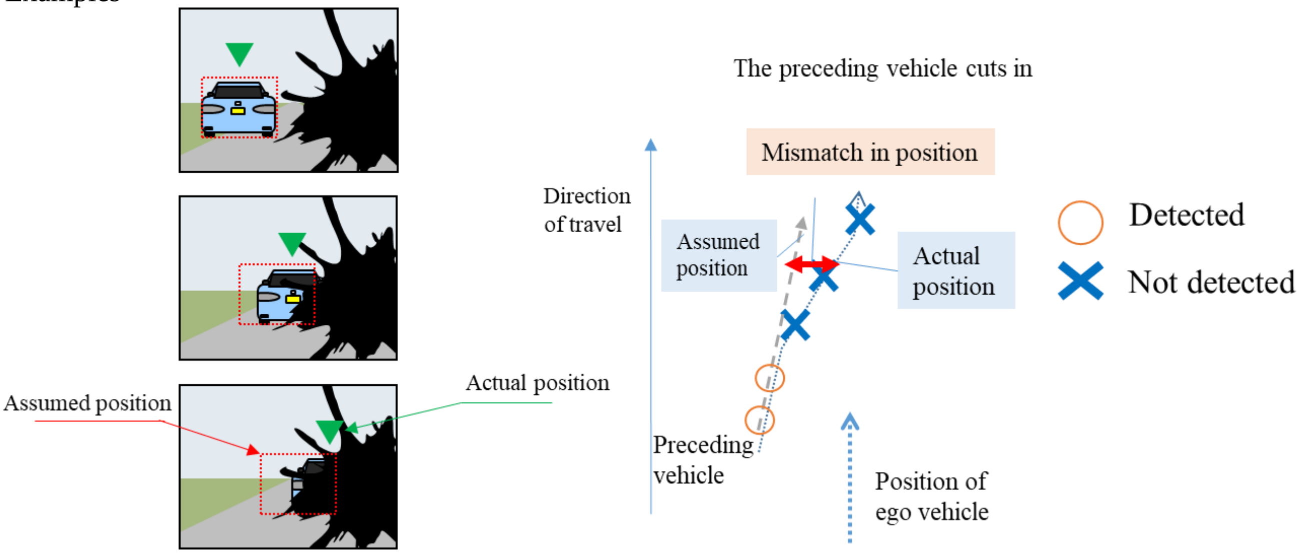
The figure below organizes the relationship between the degree of occlusion and the duration of occlusion, and the resulting perception phenomena.



Phenomenon Mode		A		B		C	
		1	2	1	2	1	2
Degree	Amount	Defined by the principle for each sensor					
	Region	Full area within frame		Attached to the recognition target Partial hiding of the recognition target		Attached to the frame The recognition target enters the hidden frame	
Time	Amount of change per unit of time	Range of change defined by the principle/causal factor					
	Duration	Continuous	Temporary	Continuous	Temporary	Continuous	Temporary
Causal factors and Evaluation Scenario		The full area of the frame is continuously hidden, and is not removed	The full area of the frame is continuously hidden, but is then removed by the wiper blades, etc.	A foreign object has adhered to the surface of the recognition target	The change point between the state of being hidden and the state of not being hidden	The frame is partially dirty, and this is not removed	The frame is partially dirty, but this is then removed by the wiper blades, etc.

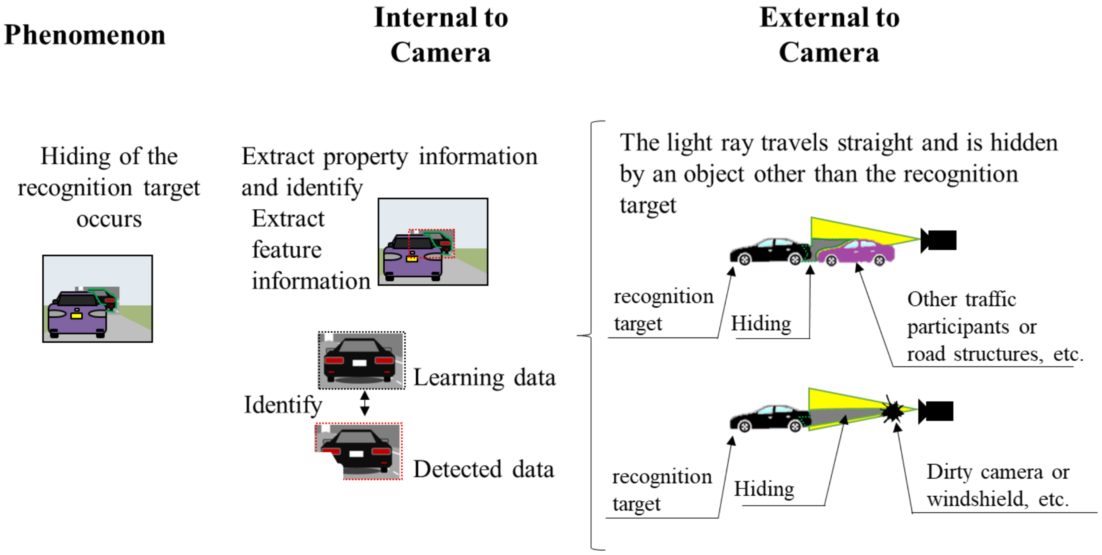
When correct feature extraction cannot be performed, it becomes impossible to accurately estimate fundamental attributes of the target object, such as its size, orientation, and position. Furthermore, when the estimation of orientation or position is inaccurate, errors propagate to the tracking process, leading to perception errors in estimated position, velocity, and other derived attributes.

<Examples>



E.4.1.1.3. **Principle Models**

The internal camera model and the external model are related as illustrated in the figure below.

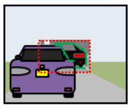


Internal Camera Model

There are various approaches to feature extraction and classification in camera-based perception, and it is not possible to define a single definitive method. Accordingly, classical computer-vision methods are presented here as representative examples for the purpose of describing perception-disturbance mechanisms.

These methods provide a generic representation of how visual features are extracted from image data and how recognition targets are identified, which is sufficient for analyzing occlusion-related perception disturbances.

Extract feature

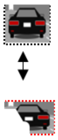


【Detect Shape】
The differentiation operator is approximated to extract the trait points, corner points, and edges, and then unique analysis, extreme value search, etc. are conducted.
E.g. edge detection, corner detection, blob detection, etc.

【Detect Figure】
Straight line detection, curve detection (Hough transform)

【Detect Region】
Divides the area of the image/cut out the area of the target and distinguishes it from the remaining area.

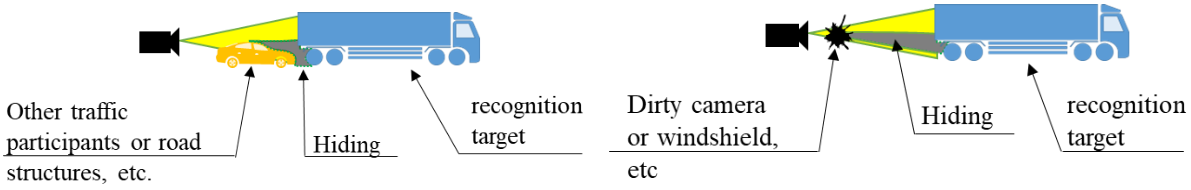
Identify



The process for screening points which are highly similar to the learning data.
E.g. template matching, detection based on color, detection using edges, matching of trait information.

External Camera Model

In the external camera model, light rays are assumed to propagate in straight lines within a homogeneous medium. Occlusion occurs when these light rays are blocked by objects other than the recognition target before reaching the camera sensor.



<Models with a Direct Impact on Perception Disturbances>

The following model is treated as having a direct impact on occlusion-related perception disturbances:

- a model in which light emitted or reflected from objects propagates linearly through a homogeneous medium.

This model directly governs whether visual information from the recognition target reaches the camera sensor or is blocked by intervening objects.

<Models with a Minor Impact on Perception Disturbances> (Reference)

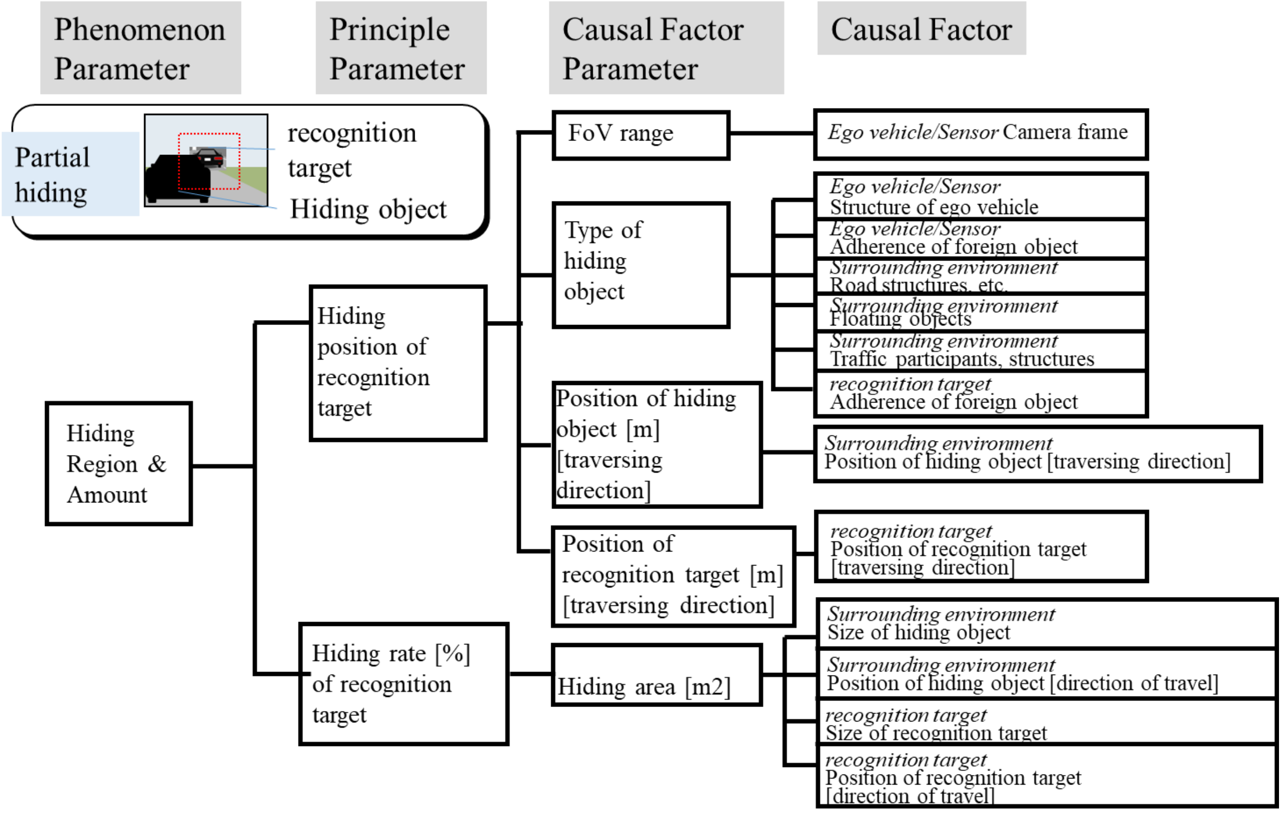
The following phenomena are recognized but are treated as having a minor impact on occlusion-related perception disturbances and are therefore not explicitly considered in the evaluation scenarios:

- Refraction at interfaces between different media, such as glass surfaces or rainwater;
- Diffraction, which is a known phenomenon of electromagnetic waves (including visible light). Although diffraction exists in principle, its magnitude is sufficiently small that it is not considered a dominant factor in occlusion-related perception disturbances.

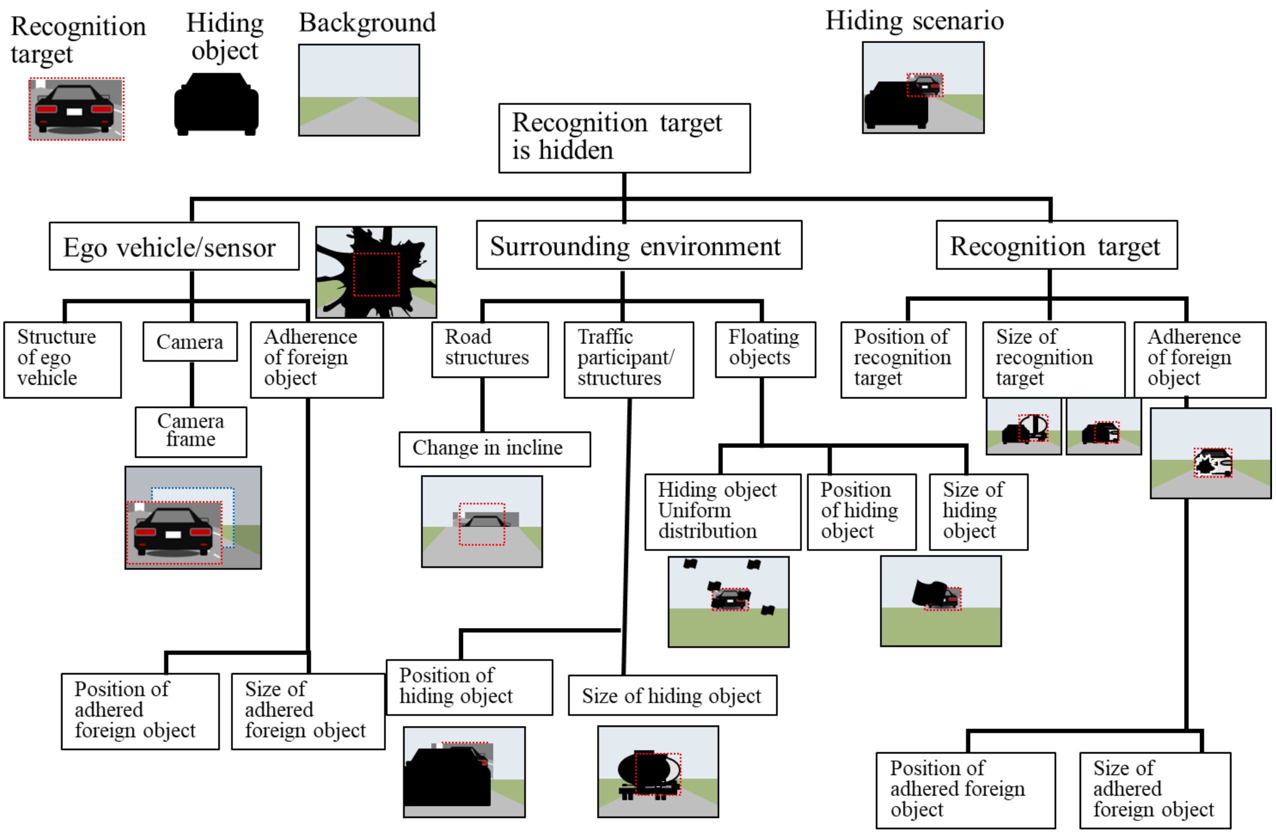
E.4.1.2. Relationship Between Principles and Causal Factors of Perception Disturbance

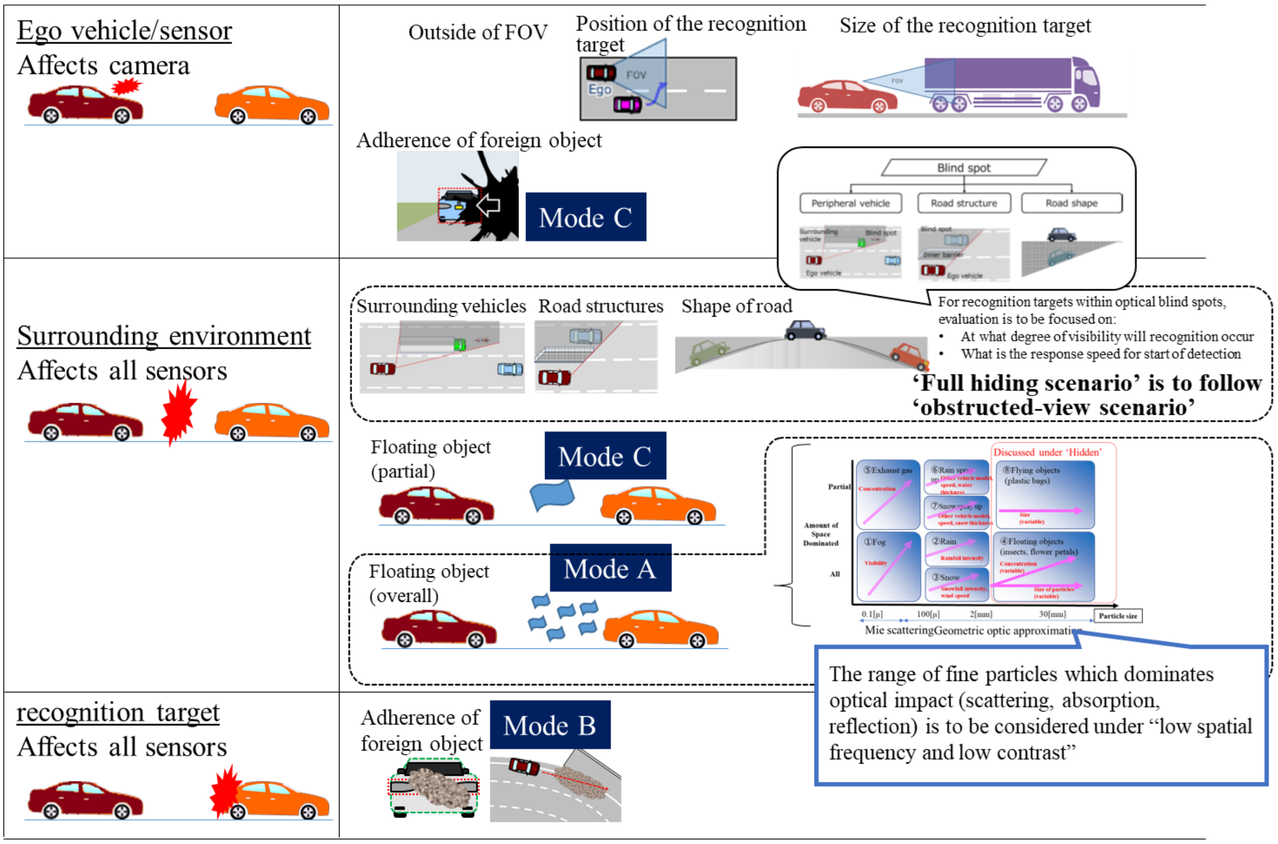
E.4.1.2.1. **Causal Factors Based on the Principle**

Based on the principle models described above, the causal factors associated with occlusion-related perception disturbances can be reorganized and summarized as follows.



These factors represent the conditions under which visual information from a recognition target is partially or fully blocked before reaching the camera sensor, leading to degradation of feature extraction, classification, or tracking performance.





For recognition targets within optical blind spots, evaluation is to be focused on:

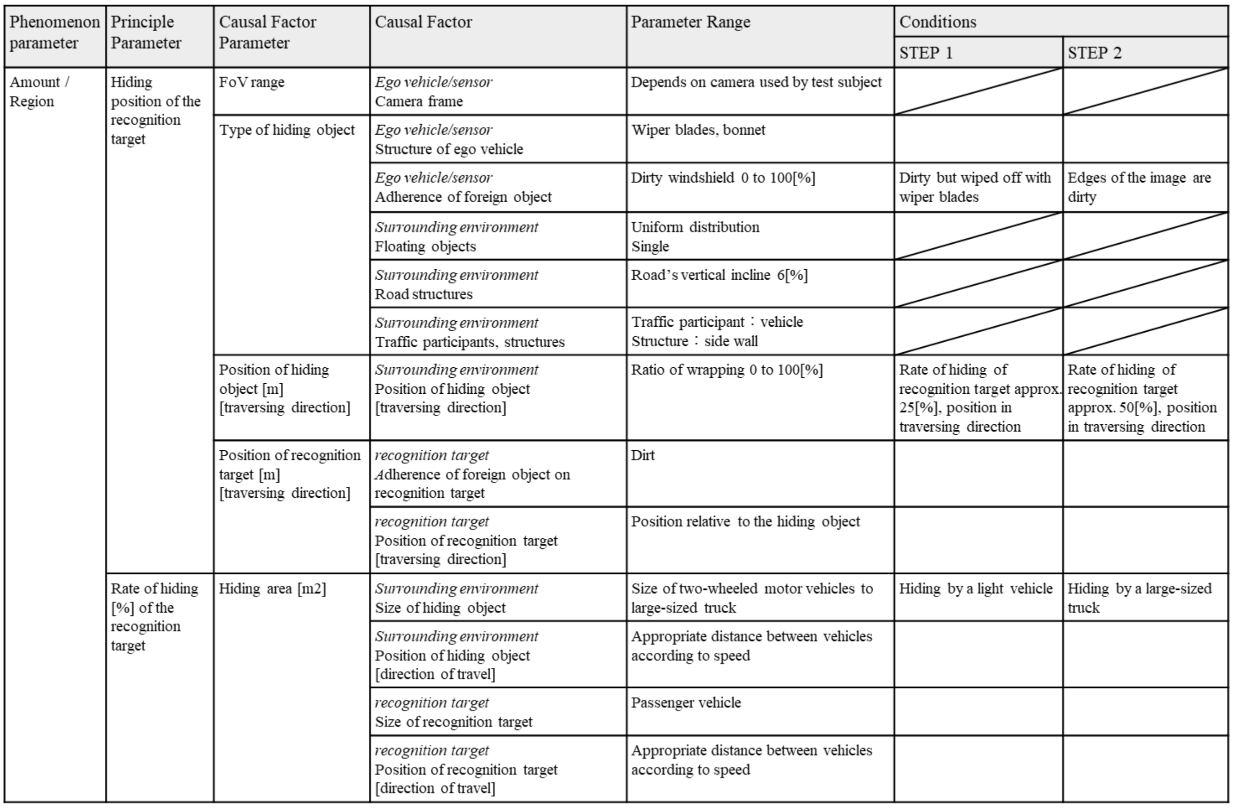
- At what degree of visibility will recognition occur
- What is the response speed for start of detection

'Full hiding scenario' is to follow 'obstructed-view scenario'

The range of fine particles which dominates optical impact (scattering, absorption, reflection) is to be considered under "low spatial frequency and low contrast"

E.4.1.2.2. **Parameter Ranges**

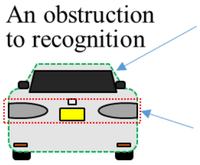
The applicable ranges of each parameter are defined as shown below.



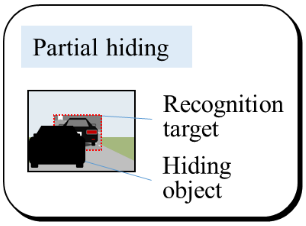
Phenomenon parameter	Principle Parameter	Causal Factor Parameter	Causal Factor	Parameter Range	Conditions	
					STEP 1	STEP 2
Amount / Region	Hiding position of the recognition target	FoV range	*Ego vehicle/sensor* Camera frame	Depends on camera used by test subject		
		Type of hiding object	*Ego vehicle/sensor* Structure of ego vehicle	Wiper blades, bonnet		
			Ego vehicle/sensor Adherence of foreign object	Dirty windshield 0 to 100[%]	Dirty but wiped off with wiper blades	Edges of the image are dirty
			Surrounding environment Floating objects	Uniform distribution Single		
			Surrounding environment Road structures	Road's vertical incline 6[%]		
			Surrounding environment Traffic participants, structures	Traffic participant：vehicle Structure：side wall		
		Position of hiding object [m] [traversing direction]	*Surrounding environment* Position of hiding object [traversing direction]	Ratio of wrapping 0 to 100[%]	Rate of hiding of recognition target approx. 25[%], position in traversing direction	Rate of hiding of recognition target approx. 50[%], position in traversing direction
		Position of recognition target [m] [traversing direction]	*recognition target* Adherence of foreign object on recognition target	Dirt		
			recognition target Position of recognition target [traversing direction]	Position relative to the hiding object		
	Rate of hiding [%] of the recognition target	Hiding area [m2]	*Surrounding environment* Size of hiding object	Size of two-wheeled motor vehicles to large-sized truck	Hiding by a light vehicle	Hiding by a large-sized truck
			Surrounding environment Position of hiding object [direction of travel]	Appropriate distance between vehicles according to speed		
			recognition target Size of recognition target	Passenger vehicle		
			recognition target Position of recognition target [direction of travel]	Appropriate distance between vehicles according to speed		

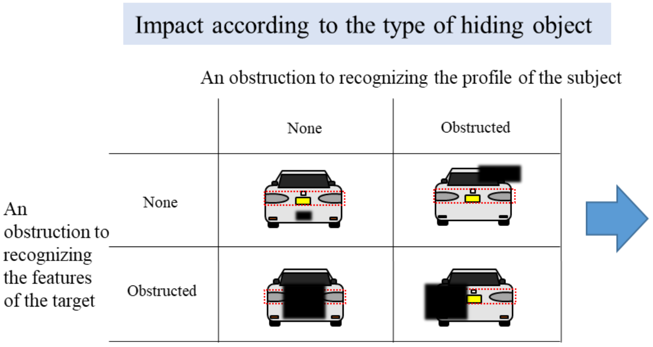
Because the impact on perception varies depending on the location of occlusion within the image, occlusion occurring in Areas C and D in the figure below—where critical features of the recognition target are hidden—is selected as the evaluation target. These conditions represent more severe cases in which feature extraction and subsequent recognition are significantly degraded.

The Hiding Position



1. An obstruction to recognizing the profile of the target. The difference in contrast to the background disappears. The profile is hidden.
2. An obstruction to recognizing the features of the target. The traits identifying the recognition target are hidden (in the case on the left this would be the tail lamps and the license plate)



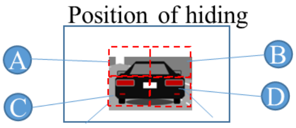


Mandatory evaluation scenario

Evaluation of Ⓒ Ⓓ

which hides features is a must

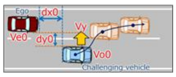
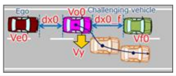
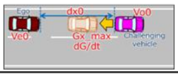
Note) Including hiding of C&D at the same time



E.4.1.2.3. Evaluation Scenarios

By associating ALKS-related scenarios with the occlusion-related causal factors described above, corresponding Functional Scenarios are derived.

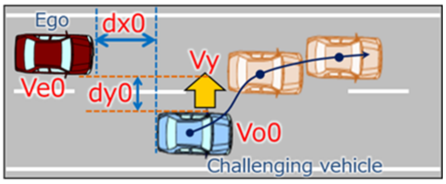
The following evaluation scenarios are defined for camera-based perception disturbances caused by occlusion.

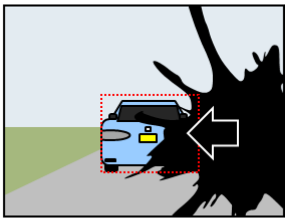
Functional Scenario	ALKS Scenario	Lane			Traffic Information			Moving Object				Obstruction on Road			Environment		
		Lane markings	Structures	Edge of road	Traffic lights	Road signs	Road surface signs	Other vehicles	Motorcycles	Bicycles	Pedestrians	Fallen objects	Mounted objects	Animals	Sunlight	Road surface	Up above/Tunnels
F-1	Cut-in 	○					○	○	○				○				
F-2	Cut-out 	○					○	○	○	○	○		○				
F-3	Deceleration 	○					○	○	○				○				
F-B1-14	Lane-keeping 	○	○	○	○							○	○				
F-4	Blind-spot (Vertical) 	○						○	○			○	○				

Scenario F-1: Cut-In Scenario on a Straight Road

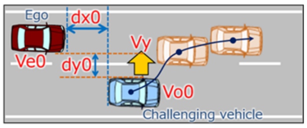
Under condition in which the sensor field of view is partially restricted due to deposits or attachments, a recognition target enters the lane ahead of the ego vehicle with a constant lateral velocity.

This scenario evaluates the effect of partial occlusion on the detection and classification of a cut-in vehicle.

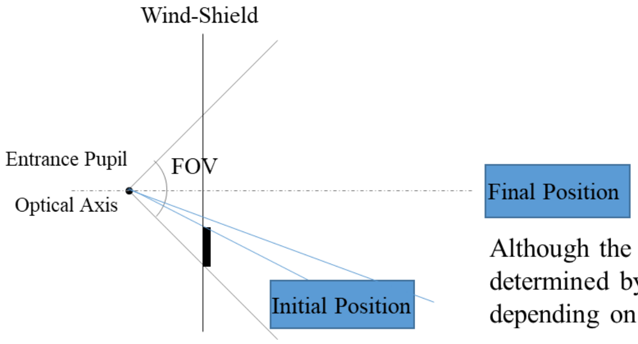




Parameter	Variable/Fixed	Range	Explanation
Distance to the target	Variable	Longitudinal position dx0 [m]	Cut-in distance at the slowest velocity to the maximum sensing distance of the sensor.
		Lateral position y0：3.5[m]	
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph] Lateral velocity Vy [kph]	Fastest and slowest velocities with respect to the preventable criteria in ALKS.
Type of the target	Fixed	Shape: sedan Color: White	Since the scenario is specified by the hiding ratio, it does not depend on the size and shape of the object part. Select a standard object.
Degree of hiding of the detection-target due to adherence of foreign object	Variable	In relation to the bounding box of the detection-target ① Initial50[%] → Final0[%] ② Initial100[%] → Final50[%]*	*In case of "initial 100[%]", the final value depends on the scenario (as a rule of thumb, determine the size of the hiding to be close to 50[%])



Whether or not the position and distance after the cut-in is correctly output will determine whether or not it is safely controlled.



Although the hiding rate of the final position is determined by the scenario, it has a certain range depending on the placement of the hiding.

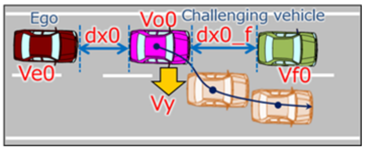
Since the distance between the entrance pupil and the windshield is constant, once the initial target position and the hiding rate are determined, the limits on the size of the hiding are determined. Since the position of the hiding object is arbitrary, the size is not uniquely determined (it can be larger than the viewing angle to the target).

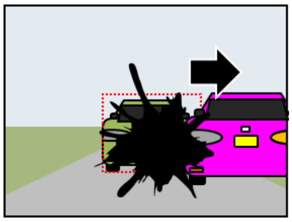
It is desirable to set the size and position as close as possible to the final hiding ratio while adhering to the initial hiding ratio.

Scenario F-2: Cut-Out Scenario on a Straight Road

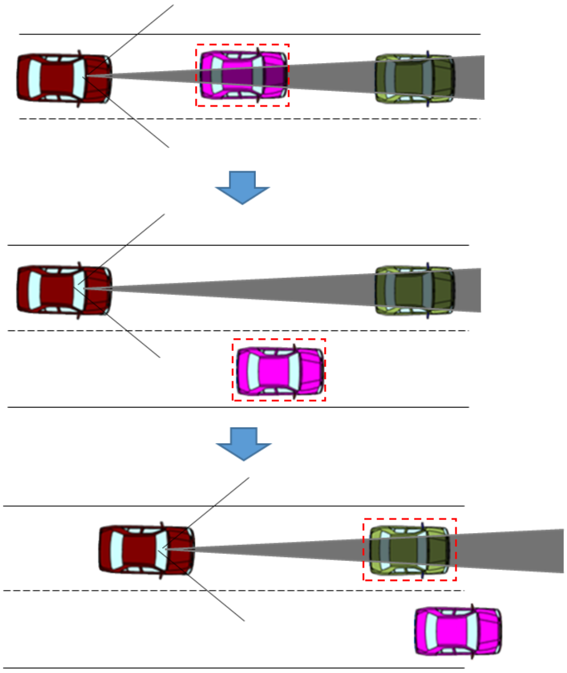
A recognition target performs a cut-out maneuver from an occluded position. In this scenario, the nearer recognition target is partially visible, whereas the recognition target that appears after the cut-out is subject to a higher occlusion ratio.

This scenario evaluates the transition from partial visibility to severe occlusion during a cut-out event.





Parameter	Variable/Fixed	Range	Explanation
Distance to the target	Variable	Longitudinal position dx0 [m]	Cut-out distance at the slowest speed to the maximum sensing distance of the sensor.
		Longitudinal position dx0_f [m]	
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph]	The fastest and slowest speeds against the preventable criteria in the cut-out scenario.
		Longitudinal velocity Vo0-Vf0 [kph]	
		Lateral velocity Vy [kph]	
Type of the target	Fixed	Shape: sedan Color: White	Since the scenario is specified by the hiding ratio, it does not depend on the size and shape of the object part. A standard object is selected.
Degree of hiding of the detection-target due to adherence of foreign object	Variable	In relation to the bounding box of the detection-target ① Initial50[%] → Final[0%]	The hiding ratio should be set for the vehicle ahead.

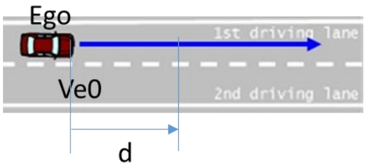


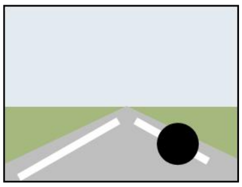
If the vehicle ahead is completely occluded, camera recognition is not possible, so this is another case such as the occlusion detection function. Since the problem here is the error in the output result of the position and distance to the recognition target due to the occlusion, the complete occlusion of the vehicle ahead is not included.

Scenario F-B1-14: Lane-Keeping Scenario on a Straight Road

Under an occluded condition, the ego vehicle travels along its lane at a constant velocity.

This scenario evaluates the stability of perception performance during lane keeping when the recognition target remains partially occluded.



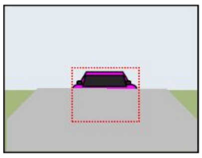


Parameter	Variable/Fixed	Range	Explanation
Velocity of ego vehicle	Fixed	Ve0: 120 [kph]	The maximum speed limit for the high way in Japan
Width of driving lane	Fixed	3.5[m]	Typical lane width of the high way in Japan
Curvature of lane	Fixed	R380	
Type of the target	Variable	Shape: solid line, dotted line Color: white, yellow	
Amount which the ego vehicle's driving lane marking lines are hidden due to the adherence of a foreign object (disturbance)	Fixed	Degree of hiding :50[%]	
Longitudinal position according to the center of the adherence of a foreign object	Fixed	d: 20[m]/ 60[m]/ 100[m]	

Obstructed-View Scenario (Longitudinal Gradient)

The ego vehicle travels on a road surface with a longitudinal gradient (convex profile) and approaches a recognition target located ahead in the same lane at a constant velocity.

This scenario evaluates occlusion effects caused by road geometry, in which parts of the recognition target are hidden due to changes in road elevation.



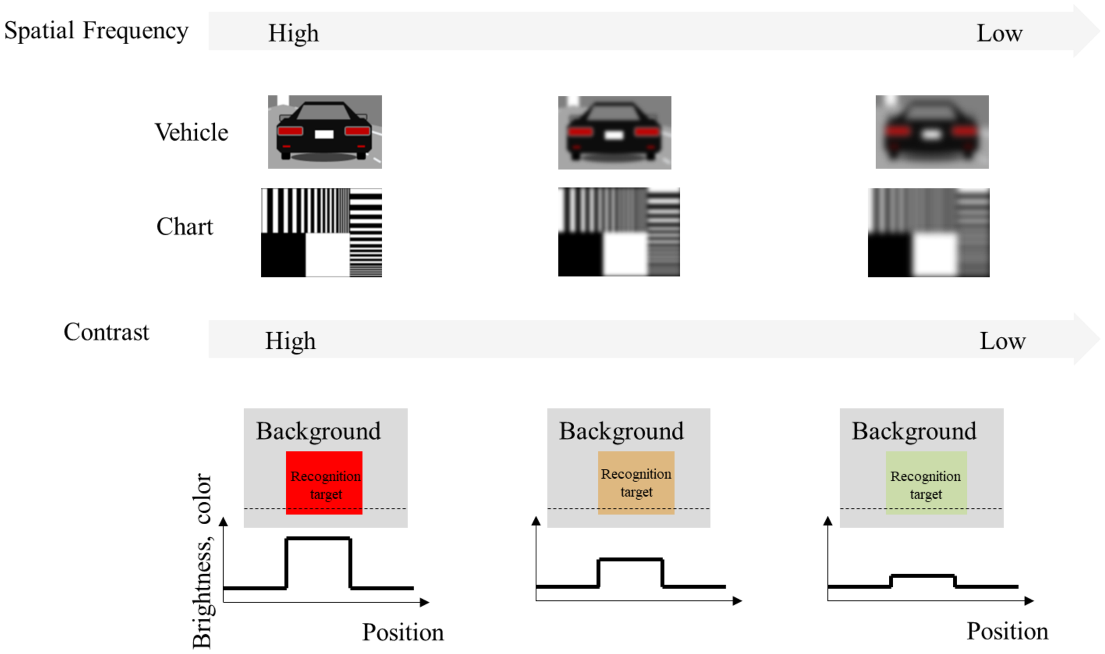
Parameter	Variable/Fixed	Range	Explanation
Distance to the target	Variable	Longitudinal position dx0 [m]	From the limit where the ground surface of the recognition target is visible to the limit where the top of the recognition target is visible.
Relative velocity to the target	Fixed	Longitudinal velocity Vo0-Ve0 [kph]	Follow the traffic flow scenario to be combined.
Type of the target	Fixed	Shape: sedan Color: white	It does not depend on the size and shape of the object because the scenario is defined by the hiding rate. Select a standard object.
Road structure vertical incline	Fixed	Vertical cross sectional incline: 6[%]	The most severe value with reference to the Road Structure Ordinance.

E.4.2. [Camera] Reduction in Spatial Frequency and Contrast (Spatial Obstacles)

E.4.2.1. Phenomenon and Principle

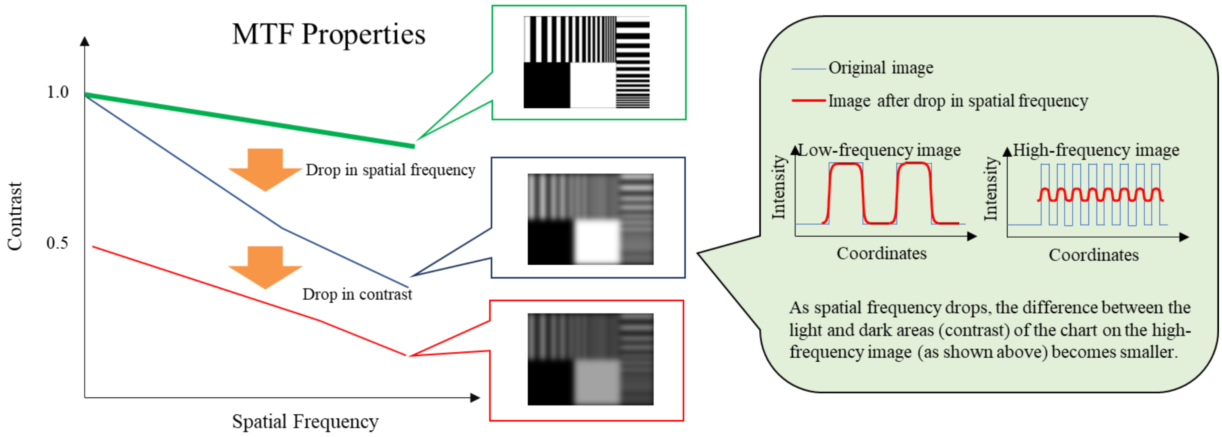
E.4.2.1.1. **Phenomenon**

Spatially suspended objects, such as rain, snow, and fog, cause blurring of the contours of recognition targets. This blurring results in a reduction in spatial frequency. At the same time, these phenomena also lead to a reduction in overall image contrast (see the figure below).



The degree of spatial-frequency reduction and contrast degradation in an image can be quantitatively described using the Modulation Transfer Function (MTF). A reduction in spatial frequency appears as a decrease in the MTF at high spatial frequencies, which corresponds to image blur and reduced effective resolution.

In contrast, image contrast is defined by the difference─or ratio─of luminance and chrominance between the recognition target and the background. A reduction in overall image contrast is represented as a decrease in the MTF across the entire spatial-frequency band.



As spatial frequency drops, the difference between the light and dark areas (contrast) of the chart on the high-frequency image (as shown above) becomes smaller.

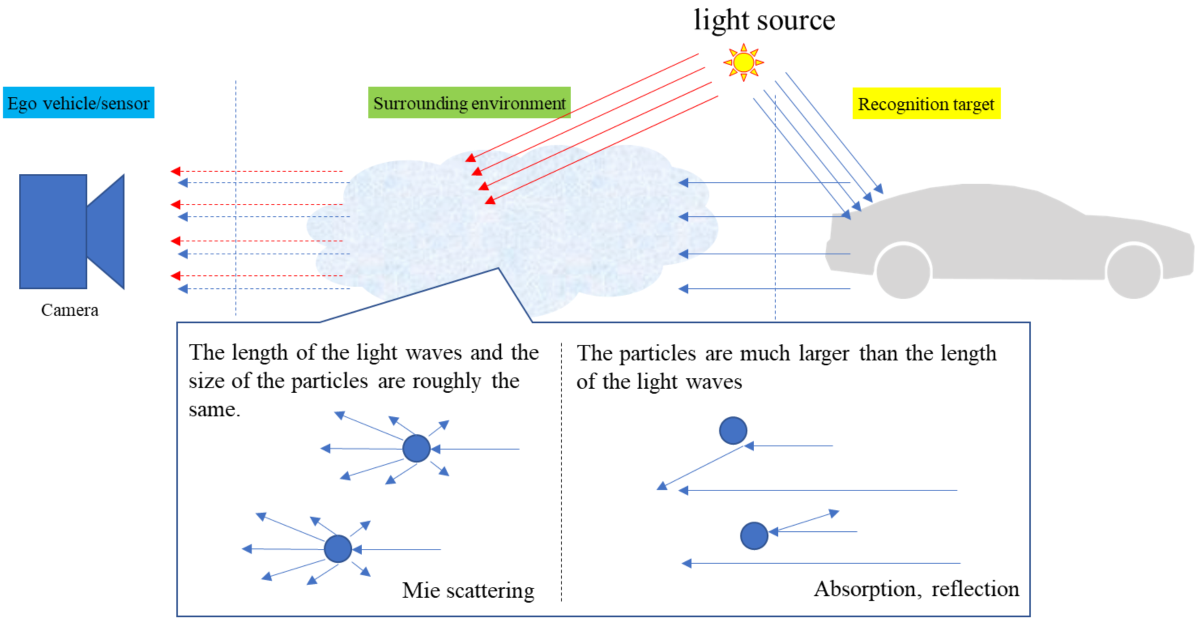
The Modulation Transfer Function (MTF) characterizes the relationship between the input spatial frequency and the amplitude ratio of the input and output signals when a sinusoidal pattern is applied to the imaging

system. It serves as an index that indicates how accurately light originating from a given position on an object is reproduced at the corresponding position in the image.
MTF is a representative metric widely used for numerically evaluating and inspecting of lens and imaging-system performance, and it enables simultaneous assessment of image resolution and contrast reproduction capability.

E.4.2.1.2. **Principle**

When obstacles (particles) are present in the propagation path, light reflected from a recognition target interacts with these particles through scattering, absorption, and reflection. As a result, the reflected light is attenuated before reaching the camera sensor. The degree of scattering, absorption, and reflection depends primarily on the particle size and spatial density of the obstacles.
The final luminance incident on the camera can therefore be expressed as the sum of:

- the attenuated luminance of the light reflected from the recognition target; and
- the luminance component generated by direct light from a light source that is scattered by particles present in space.

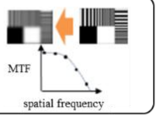


As illustrated in the figure below, the phenomenon parameters characterizing this perception disturbance consist of the following five elements:

1. Spatial frequency,
2. Contrast,
3. Spatial range over which the phenomenon occurs,
4. Rate of change per unit time, and
5. Duration of the phenomenon.

Amount

Spatial frequency



Contrast

Difference in brightness & color between the target and the background

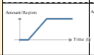
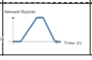
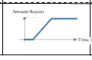
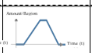
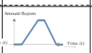
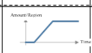
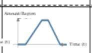
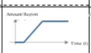
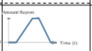
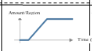
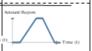
Region Covers the whole frame or is only localized and accompanies the recognition target.

Amount of change over time Spatial frequency and contrast drop over time (gradually or suddenly)

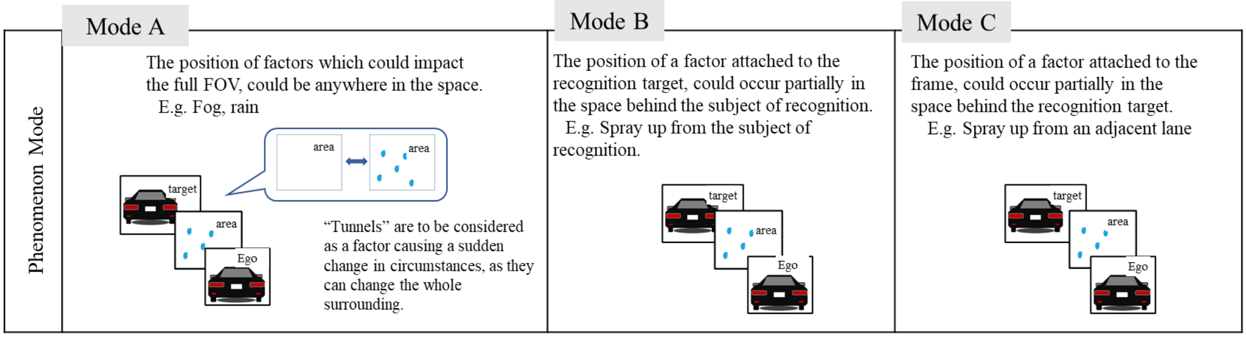
Duration Temporary or continuous

Exhibit: Pxhere.com: CC0 License

When the relationships between these parameters and the resulting perception phenomena are systematically organized, they can be represented as shown in the figure below.

		Mode	A				B				C			
			1	2	3	4	1	2	3	4	1	2	3	4
Phenomenon (Parameter)	Degree	Amount	Categorized by error principle of sensors											
		Region	Full area within frame 				Attached to the subject of recognition 				Attached to the frame 			
	Time	Amount of time per unit of time	Gradually changes		Suddenly changes		Gradually changes		Suddenly changes		Gradually changes		Suddenly changes	
		Duration	Continuous	Temporary	Continuous	Temporary	Continuous	Temporary	Continuous	Temporary	Continuous	Temporary	Continuous	Temporary
														

Depending on the spatial range over which the phenomenon occurs, the perception disturbance can be classified into the following three modes (A through C).



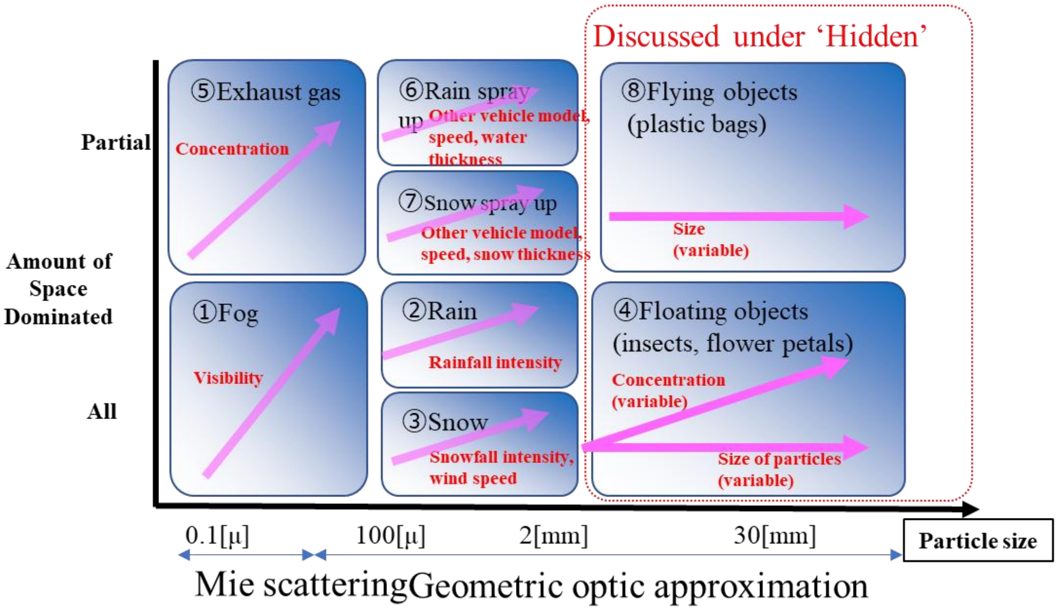
The position of factors which could impact the full FOV, could be anywhere in the space.
E.g. Fog, rain

"Tunnels" are to be considered as a factor causing a sudden change in circumstances, as they can change the whole surrounding.

The position of a factor attached to the recognition target, could occur partially in the space behind the subject of recognition.
E.g. Spray up from the subject of recognition.

The position of a factor attached to the frame, could occur partially in the space behind the recognition target.
E.g. Spray up from an adjacent lane

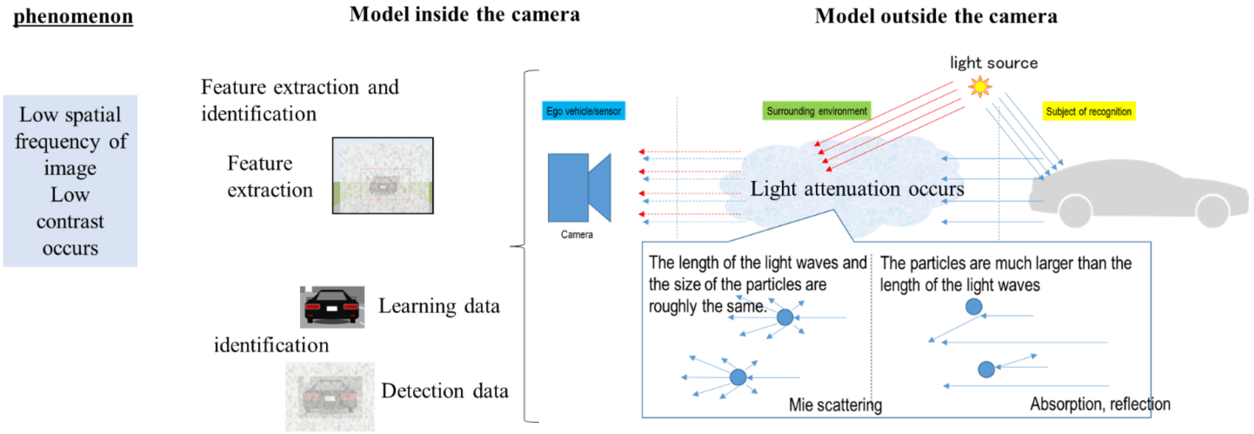
In addition, the figure below illustrates the relationship between types of spatial obstacles, particle size, and spatial occupancy ratio. Among these obstacle types, ④ suspended particles and ⑧ flying objects are treated within the scope of E.4.1 Occlusion, and are therefore excluded from the present evaluation scope.



※Red font refers to the parameter of the disturbance

E.4.2.1.3. **Principle Models**

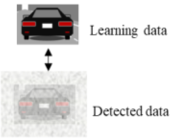
The internal camera model and the external camera model are related as illustrated in the figure below.



Internal Camera Model

There are various approaches to feature extraction and classification in camera-based perception, and it is not possible to define a single definitive method. Accordingly, classical computer-vision methods are presented here as representative examples for describing the perception-disturbance mechanism.

These methods provide a generic representation of how reductions in spatial frequency and contrast affect feature extraction and subsequent recognition performance.

Extract trait information		【Detect Shape】 The differentiation operator is approximated to extract the trait points, corner points, and edges, and then unique analysis, extreme value search, etc. are conducted. E.g. Edge detection, corner detection, blob detection, etc.	【Detect Figure】 Straight line detection, curve detection (Hough transform) 【Detect Region】 Divides the area of the image/cuts out the area of the target and distinguishes it from the remaining area.
Identify		The process for screening points which are highly similar to the learning data. E.g. Template matching, detection based on color, detection using edges, matching of trait information.	

External Camera Model

For modeling the effect of spatial obstacles such as fog, rain, or snow on image contrast, the Koschmieder luminance attenuation model is applied, as shown in the equation below.
In this model, as the attenuation coefficient σ (which approximately corresponds to visibility) and the distance d between the camera and the recognition target increase, the apparent luminance of the recognition target approaches the background (ambient) luminance.
As a result, the luminance contrast between the recognition target and the background decreases, leading to degradation in perception performance due to reduced spatial frequency and contrast.

$$L = L_0 e^{-\sigma d} + L_f(1 - e^{-\sigma d})$$

L : apparent intensity of the target
L_0 : targets intensity without scattering
L_f : brightness of surrounding environment (intensity of the sky)

Here, L denotes the apparent luminance of the recognition target, L_0 denotes the luminance of the recognition target in the absence of scattering, and L_f denotes the ambient (background) luminance.
(Source: *Mori, "Fog Density Recognition by In-vehicle Camera and Millimeter Wave Radar", IJICIC vol.3, Num.5 Oct 2007*)

In addition, due to attenuation of light in the atmosphere, the contrast C of a recognition target observed from a distance d can be expressed as follows:

$$C = e^{-\sigma d}$$

Here, σ denotes the light attenuation coefficient (also referred to as the extinction coefficient), which represents the rate at which light intensity attenuates with distance in the atmosphere.

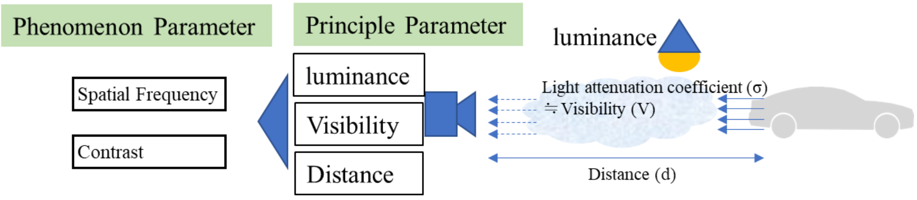
If the contrast discrimination threshold is denoted by ε_0, the visibility distance V can be expressed as shown below using Koschmieder's equation. Empirically, the value of ε_0 typically takes values such as 0.02 or 0.05.

$$V = \frac{1}{\sigma} ln\left(\frac{1}{\varepsilon 0}\right)$$

$$V = \begin{cases} 3.912/\sigma & (\varepsilon 0 = 0.02) \\ 2.996/\sigma & (\varepsilon 0 = 0.05) \end{cases}$$

General visibility meters measure the Meteorological Optical Range (MOR) as defined by the World Meteorological Organization (WMO). MOR is defined as the distance at which the illuminance of a parallel beam from a 2700 K incandescent lamp is reduced to 5% of its original value.
(Sources: *Journal of Snow Engineering of Japan, Vol. 20 (2004), No. 3, "Measurement of Visibility," Takada; Journal of Geography, Vol. 100(2), pp. 264–272, 1991, "Snow Particles in the Atmosphere and Visibility," Takeuchi*)

Accordingly, the factors that affect contrast are considered to be the brightness (luminance) of the light source, the light attenuation coefficient σ, and the distance d. Because the attenuation coefficient σ and the visibility distance V have a one-to-one correspondence, and because visibility is commonly used as a measure of visual range, the principle parameters are defined as luminance, visibility, and distance.



With respect to the relationship between spatial obstacles and spatial frequency, although qualitative descriptions exist in the literature, no explicit governing equations have been identified. Therefore, the same principle parameters as those used for contrast are adopted.

The principles corresponding to the previously described phenomenon Modes A through C are described below.

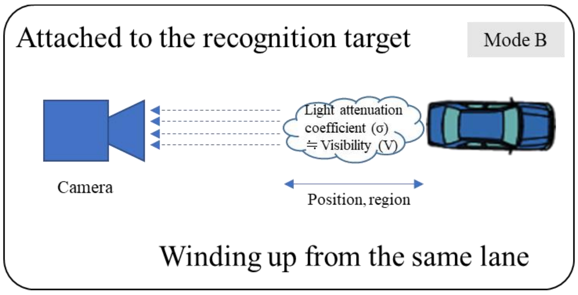
Mode A: Uniform Spatial Obstacles

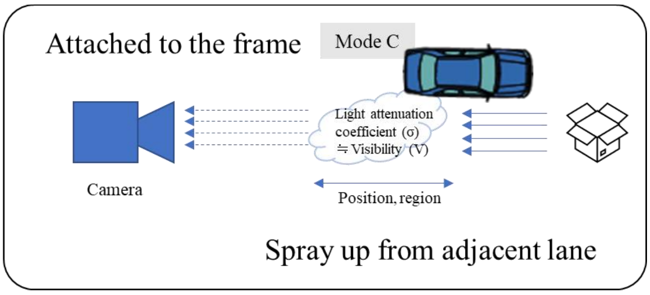
In this mode, spatial obstacles such as fog are uniformly distributed in space, and the resulting attenuation and contrast degradation occur consistently over the entire visual field.

① **Fog**	The density of fog (attenuation coefficient) is generally expressed in terms of **visibility**, therefore the causal factor parameters will similarly be 'visibility'.
② **Rain**	There are several literature, however visibility will change according to the **intensity of rainfall**. E.g. $V = 8807.1e^{-0.1R}$ Source：Nishimura, 2015, 'Relationship Between Muddy Water Causing Evacuation and Optical Distance', International Journal of Erosion Control Engineering, Tsukuba University. R: Intensity of rainfall [mm/10min]
③ **Snow**	There are several literature, however visibility will change according to the **intensity of snowfall, wind speed**, etc. E.g. $V = 1150 \cdot \left(\frac{5}{3}R\right)^{-0.76}$ R: Intensity of snowfall [mm/h] Source：Saito, 1971, 'Intensity of Snow Fall and Visibility', Report of the National Research Center for Disaster Prevention. $V = 10^{-0.77\log(M_f)+2.85}$ M_f：Blizzard rate (according to intensity of snowfall and wind speed) Source：Matsuzawa, 2007, 'Study Related to Improvement of Methods for Estimating Visibility in Blizzards', Bulletin of Glaciological Research.

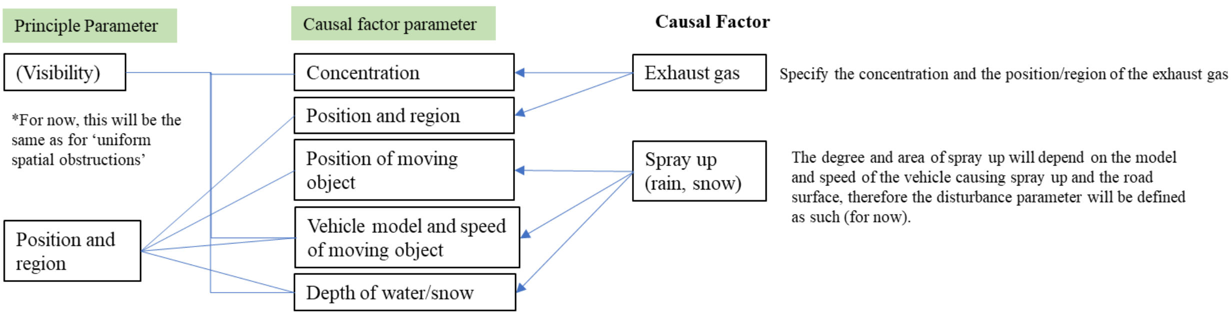
Modes B and C: Localized Spatial Obstacles

The underlying physical principle is the same as that for uniform spatial obstacles. However, in these modes, the spatial extent of the obstacle is limited, resulting in localized degradation of spatial frequency and contrast..

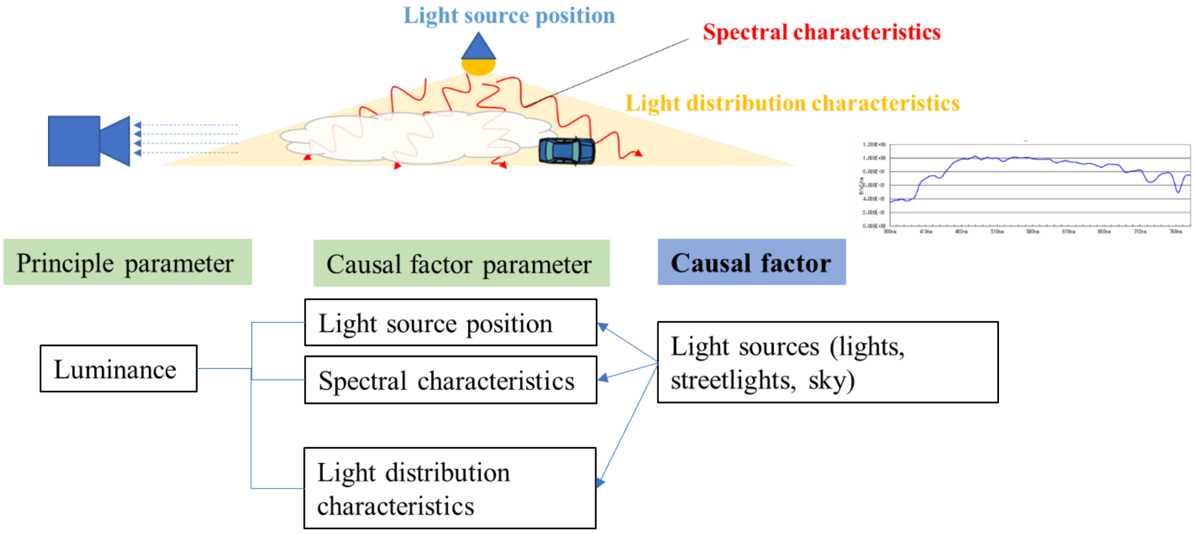




Based on these considerations, the principle parameters and causal-factor parameters are provisionally defined as follows.



In addition, the brightness (luminance) of a light source is determined by the spectral characteristics of the light source, the position of the light source, and its light-distribution characteristics.



Regarding the impact of light sources on visibility ─particularly in nighttime environments─light sources associated with recognition targets (e.g., tail lamps) can serve as primary features for detection. However, when spatial obstacles such as fog are present, a veiling effect occurs, in which the luminance distribution of the veil is superimposed on the luminance distribution of the light source itself. In this case, the luminance of the veil exhibits a distribution that gradually decreases outward from the light source.

The ratio between the luminance of the veil and that of the light source varies according to a fixed relationship, that depends on the density of the fog (e.g., particle density or visibility). Furthermore, the greater the luminance contrast between the light source and the background, the more pronounced the veiling effect becomes.

E.4.2.2. Relationship Between Principles and Causal Factors of Perception Disturbance

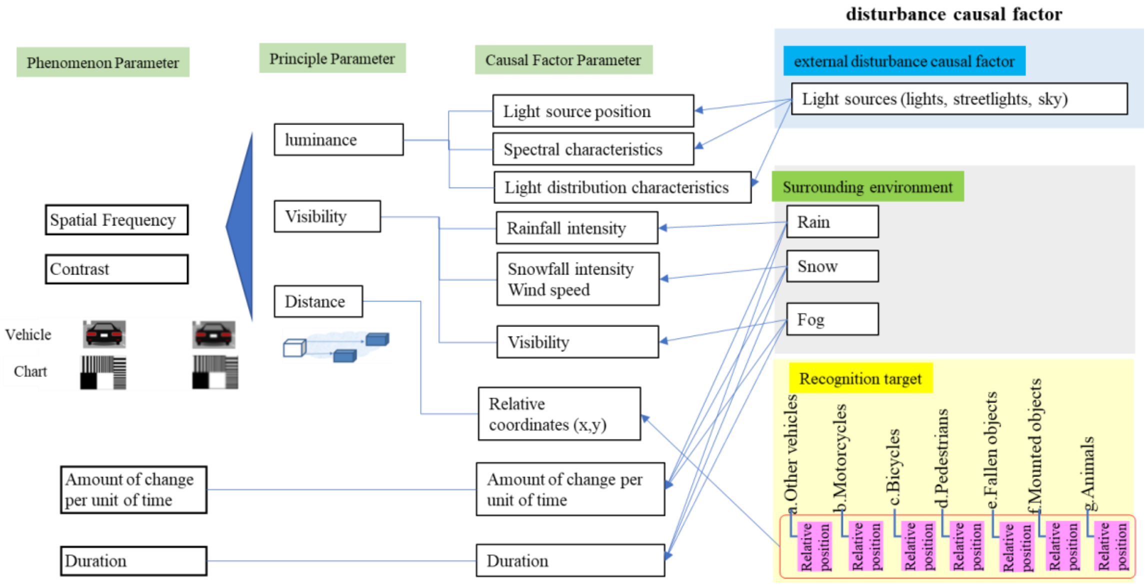
This section describes the relationship between perception-disturbance principles related to reductions in spatial frequency and contrast and the causal factors caused by spatial obstacles.

E.4.2.2.1. **Causal** Factors Based on the Principle

The causal factors associated with spatial obstacles and their corresponding causal factor parameters are illustrated in the figure below.

Mode A: Entire field of view

In Mode A, spatial obstacles are distributed across the entire field of view of the camera. Typical examples include dense fog or heavy snowfall, in which attenuation and contrast degradation occur uniformly over the whole image.

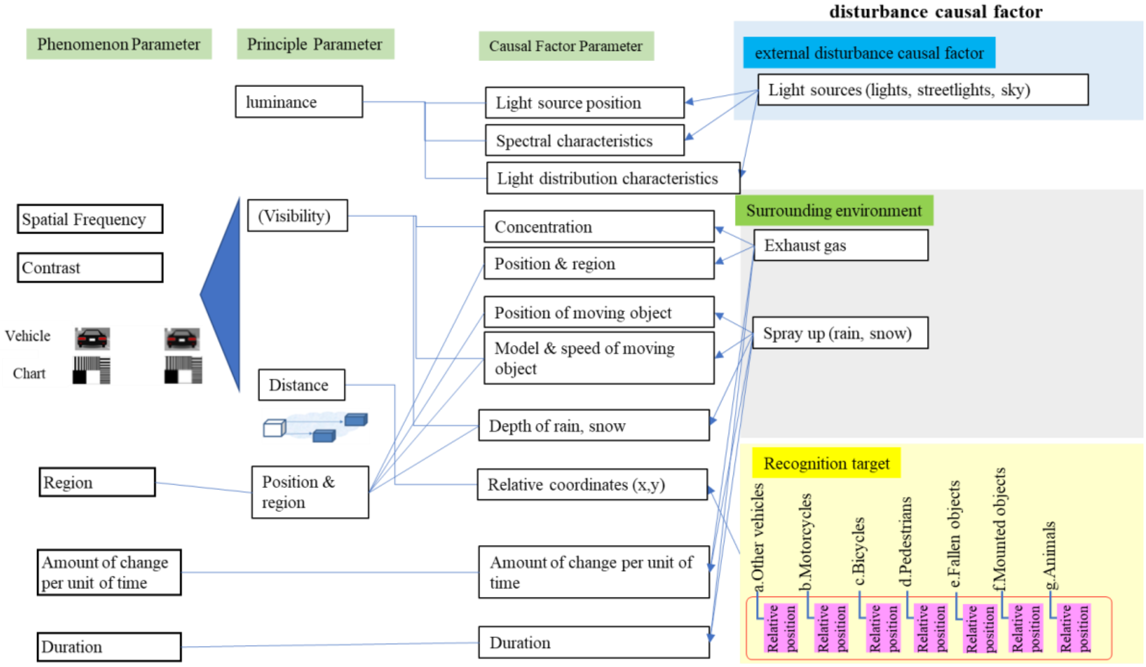


Modes B and C: Localized spatial obstacles

In Modes B and C, spatial obstacles are localized, and their impact on perception is limited to specific regions within the image.

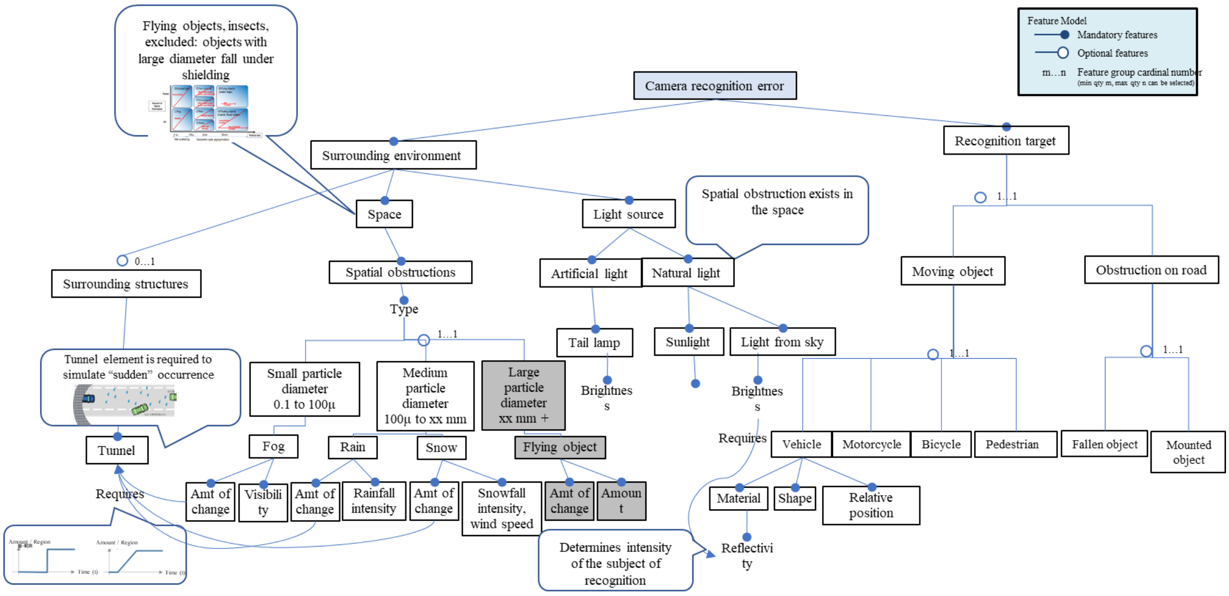
Mode B represents localized spatial obstacles that are associated with the recognition target itself, such as fog patches or localized precipitation surrounding the target.

Mode C represents localized spatial obstacles that are associated with the lane or road environment, such as fog banks or spray generated by preceding vehicles.

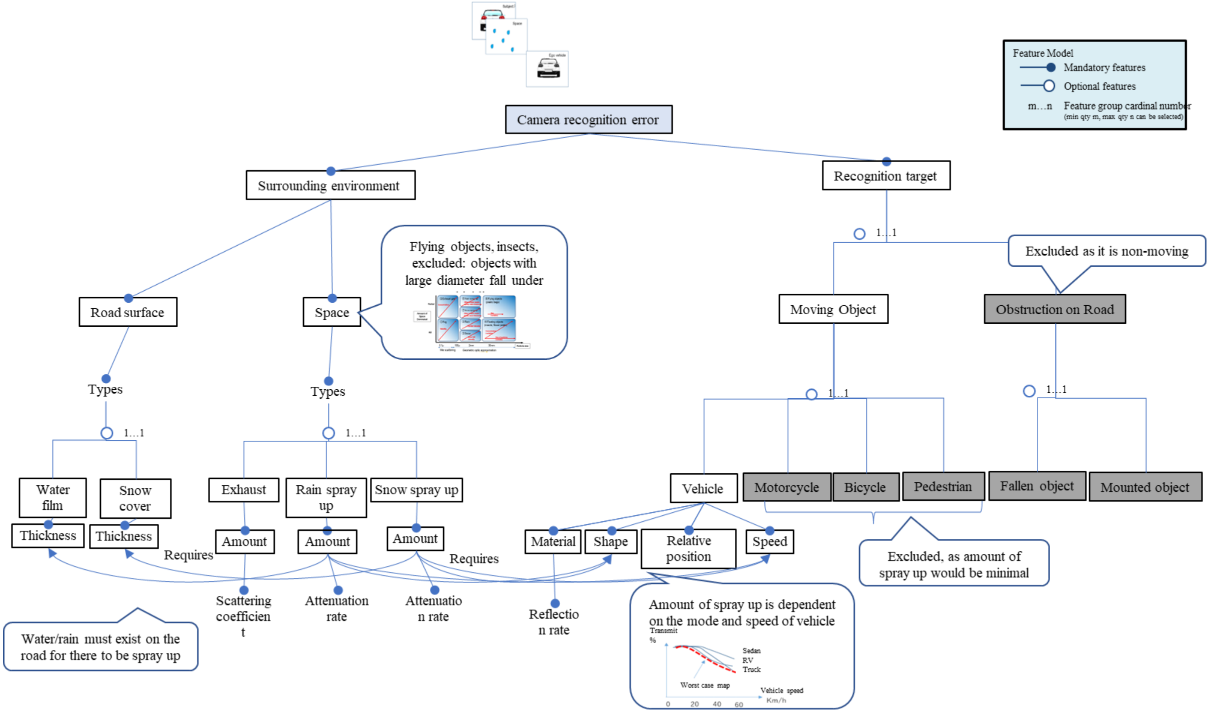


When the causal factors are represented in a hierarchical structure, they can be organized as shown in the figure below.

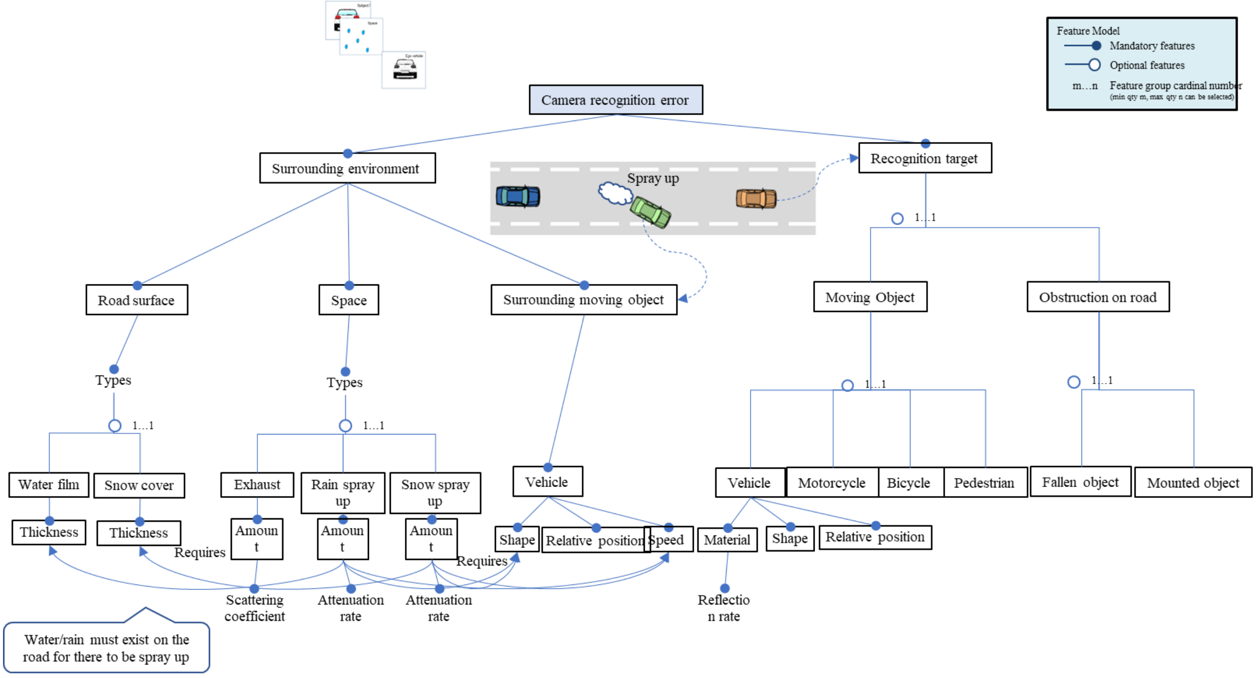
Mode A: Entire field of view
In this mode, causal factors are classified according to spatial obstacles that affect the entire image uniformly, without dependence on the position of the recognition target or lane.



Mode B: Localized spatial obstacles associated with the recognition target
In this mode, causal factors are organized according to spatial obstacles that are localized around the recognition target, directly affecting the spatial frequency and contrast of target features.



Mode C: Localized spatial obstacles associated with the lane
In this mode, causal factors are organized according to spatial obstacles that are localized along the lane or road structure, affecting the visibility of lane-related features and recognition targets positioned within those regions.



E.4.2.2.2. **Parameter Ranges**

The applicable ranges of each causal-factor parameter are defined as shown in the table below.

Phenomenon Parameter	Principle Parameter	Causal Factor Parameter		Parameter Range	Conditions		Basis
				Until limit of ODD	STEP 1	STEP 2	
Spatial frequency Contrast	Visibility	Visibility	Fog	limit of ODD[m]〜∞ [m]			
		Rainfall intensity	Rain	0〜limit of ODD [mm/h] (50[mm/10min])	30, 50, 80[mm/h]		
		Snowfall intensity Wind speed	Snow	0〜limit of ODD [mm/h] 0〜limit of ODD [m/s]			Standard until traffic regulations apply
	Distance	Relative coordinates	Recognition target：relative position	Refer to traffic flow scenario			
Amount of change per unit of time				∞ *Assume the exit point of a tunnel or sudden change in weather			Difficult to define worst case (realistic) scenario (max amount of change), thus for now is ∞
Duration				Continuous			'Continuous' is more severe

<Concept for Recognition Targets>
Recognition targets with colors is similar to that of the background result in low image contrast and therefore represent more severe conditions.
Accordingly, the following background conditions are selected:

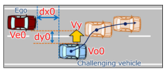
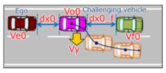
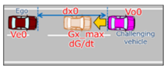
- asphalt and concrete surfaces (black, gray); and
- snow-covered surfaces (white).

For evaluation purposes, recognition targets are assigned the same colors as the background, thereby minimizing luminance and chrominance contrast and representing worst-case conditions for camera-based perception.

Types	Parameters
Vehicles	【Color (body color)】 Black, Gray, White
Motorcycles	【Color (body color, motorcyclist wear)】 Black, Gray, White
Bicycles	【Color (motorcyclist wear)】 Black, Gray, White
Pedestrians	【Color (clothing)】 Black, Gray, White
Mounted objects	Generally these are highly visible and thus are not usually low in contrast. Use arrow signs and safety cones which are often found bordering lanes.
Fallen objects	【Color】 Black (tire) Here we use tires (car component) which are over 15cm in height and ranked one of the highest when looking at occurrences of fallen objects
Animals	Road kill to be included under fallen objects.

E.4.2.2.3. Evaluation Scenarios

By associating ALKS-related scenarios with the causal factors described above, corresponding Functional Scenarios are derived.

Functional Scenario	ALKS scenario	Track			Traffic Information			Moving Object				Obstruction on Road			Explanation
		Lane markings	Structures	Edge of road	Traffic lights	Road signs	Road surface signs	Other vehicles	Motorcycles	Bicycles	Pedestrians	Fallen objects	Mounted objects	Animals	
F-1	Cut-in 							○	○						Evaluates the case whereby the moving object which cuts-in becomes difficult to see due to a spatial obstruction.
F-2	Cut-out 							○	○	○	○	○			Evaluates the case whereby a stationary object or slow moving object which suddenly appears becomes difficult to see due to a spatial obstruction.
F-3	Deceleration 							○	○						Evaluates the case whereby the preceding vehicle which decelerates suddenly becomes difficult to see due to a spatial obstruction.
F-B1-14	Lane Keep	○													Evaluates the case whereby a lane marking becomes difficult to see due to a spatial obstruction.

In real-world environments, combinations of causal factors may occur simultaneously. Representative combinations extracted from the feature model are illustrated below.
Although raindrops adhering to the sensor cover due to rainfall are primarily addressed under the principle of “refraction” , they are also described here because primarily. (Spatial obstacles may also occur simultaneously; however, for the purpose of systematic evaluation, they are treated as mutually exclusive in this document.)

Scenario No.	Vehicle/Sensor		Surrounding environment						Notes	Mode
	In front of sensor		Spatial obstruction			Accompanying target		Light source		
	Rain drops (Refraction)	Snow (Shielding)	Fog	Rain	Snow	Spray up	Exhaust			
01	×	×	○	×	×	×	×	Day		A
02	×	×	○	×	×	×	×	Night		A
03	×	×	○	×	×	○	×	Day		A,B
04	×	×	○	×	×	○	×	Night		A,B
05	○	×	×	○	×	○	×	Day		A,B,(C)
06	○	×	×	○	×	○	×	Night		A,B,(C)
07	○	×	×	○	×	×	×	Day	05 is harsher	A,(C)
08	○	×	×	○	×	×	×	Night	06 is harsher	A,(C)
09	×	○	×	×	○	○	×	Day		A,B,(C)
10	×	○	×	×	○	○	×	Night		A,B,(C)
11	×	○	×	×	○	×	×	Day	09 is harsher	A,B
12	×	○	×	×	○	×	×	Night	10 is harsher	A,B
13	×	×	×	×	×	○Rain	×	Day		B
14	×	×	×	×	×	○Rain	×	Night		B
15	×	×	×	×	×	○Snow	×	Day		B
16	×	×	×	×	×	○Snow	×	Night		B
17	×	×	×	×	×	×	○	Day		B
18	×	×	×	×	×	×	○	Night		B

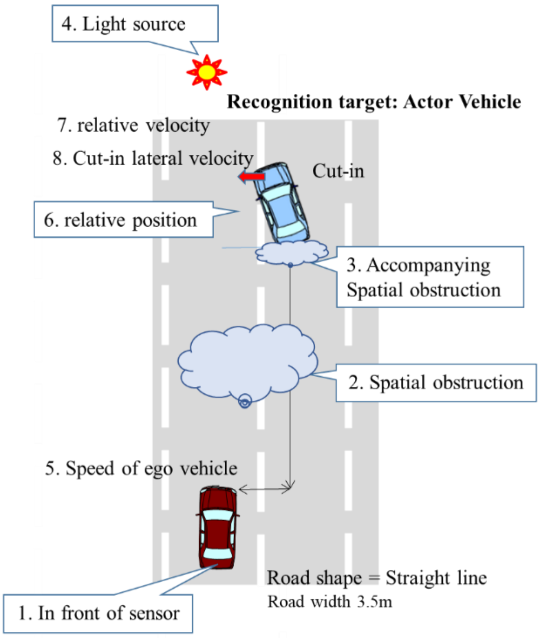
The following evaluation scenarios are defined.

Scenario F-1: Cut-In Scenario on a Straight Road

A cut-in vehicle is defined as the recognition target.

Evaluation is conducted under conditions of reduced spatial frequency and contrast, including low-contrast target–background combinations and spatial obstacles.

Causal factor parameter	1. In front of sensor	Rain drops	
		Snow	
	2. Spatial obstruction	Fog	Visibility 10m〜1km
		Rain	Rainfall intensity 0〜limit of ODD
		Snow	Snowfall intensity 0〜limit of ODD Wind speed 0〜limit of ODD
	3. Accompanying Spatial obstruction	spray up	
		Exhaust gas	
	4 .Light source	Day	
		Night	
Parameters required for evaluation	5. Speed of ego vehicle	Not decided here because of the scope of definition in the traffic flow scenario.	
	6. relative position		
	7. relative velocity		
	8. Cut-in lateral velocity		

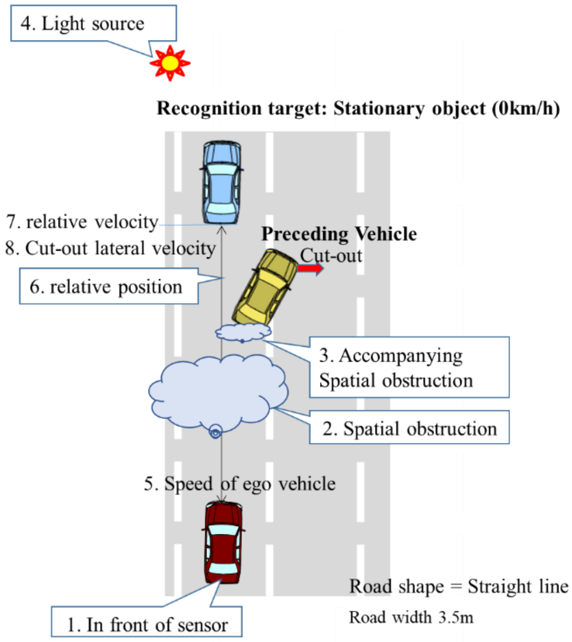


Scenario F-2: Cut-Out Scenario on a Straight Road

After a lead vehicle performs a cut-out maneuver, a recognition target appears ahead of the ego vehicle.

Evaluation is conducted under reduced-contrast conditions caused by spatial obstacles and background similarity.

Causal factor parameter	1, In front of sensor	Rain drops
		Snow
	2. Spatial obstruction	Fog
		Rain
		Snow
	3. Accompanying Spatial obstruction	spray up
		Exhaust gas
	4.Light source	Day
		Night
Parameters required for evaluation	5. Speed of ego vehicle	Not decided here because of the scope of definition in the traffic flow scenario.
	6. relative position	
	7. relative velocity	
	8. Cut-out lateral velocity	

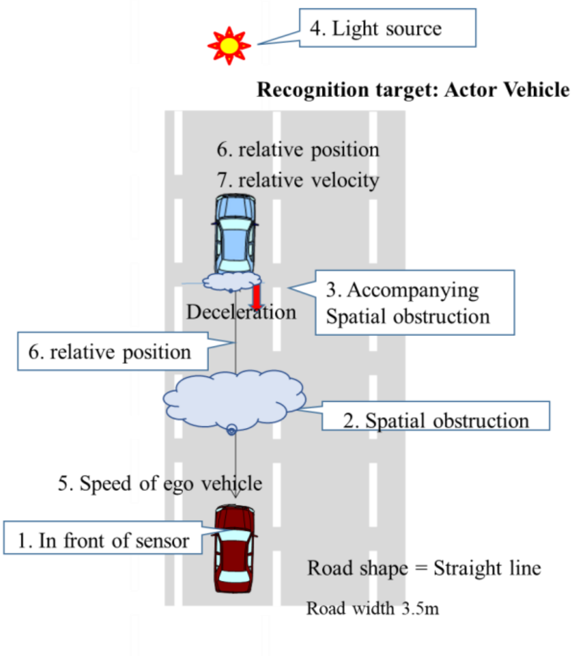


Scenario F-3: Deceleration Scenario on a Straight Road

A decelerating vehicle is defined as the recognition target.

Evaluation is conducted under conditions of reduced spatial frequency and contrast during longitudinal maneuvers.

Causal factor parameter	1. In front of sensor	Rain drops
		Snow
	2. Spatial obstruction	Fog
		Rain
		Snow
	3. Accompanying Spatial obstruction	spray up
		Exhaust gas
	4. Light source	Day／Night
Parameters required for evaluation	5. Speed of ego vehicle	Not decided here because the scope of definition in the traffic flow scenario.
	6. relative position	
	7. relative velocity	

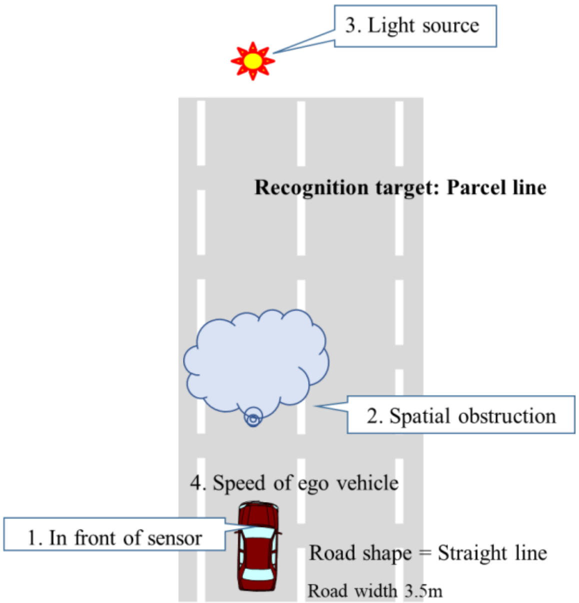


Scenario F-B1-14: Lane-Keeping Scenario on a Straight Road

Under reduced spatial-frequency and contrast conditions, the ego vehicle performs lane keeping at a constant velocity.

This scenario evaluates the stability of perception performance when recognition targets and lane features are degraded by spatial obstacles.

Causal factor parameter	1. In front of sensor	Rain drops
		Snow
	2. Spatial obstruction	Fog
		Rain
		Snow
	3. Light source	Day／Night
Parameters required for evaluation	4. Speed of ego vehicle	Not decided here because the scope of definition in the traffic flow scenario.



E.4.3. [Camera] Saturation (Overexposure) and Blown Highlights

E.4.3.1. Phenomenon and Principle

E.4.3.1.1. **Phenomenon**

When a high-luminance region within the camera’s field of view exceeds the upper limit of the sensor’s representable luminance range (dynamic range), differences in luminance levels (gradations) can no longer be reproduced. As a result, image information in that region is lost, leading to false negatives (missed detections).

Representative examples of such situations are illustrated below.

Overexposure of the vehicle ahead due to the reflection of the test vehicles headlamps

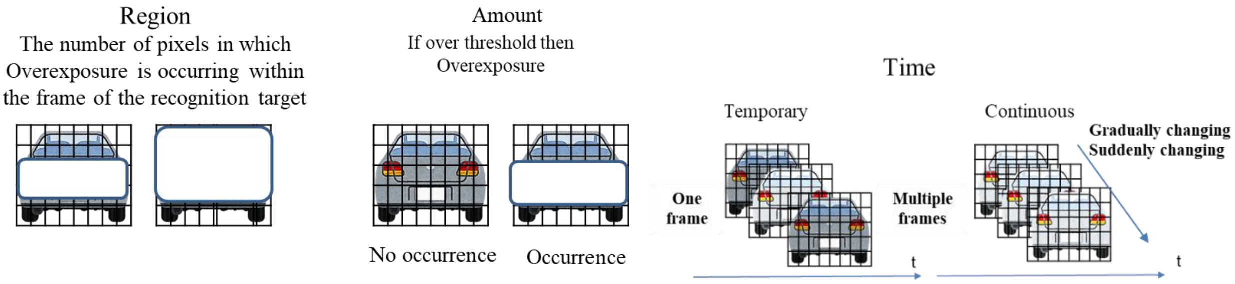
The background shines white making it difficult to make out profiles such as license plates

Overexposure caused by the sunlight at the exit point of a

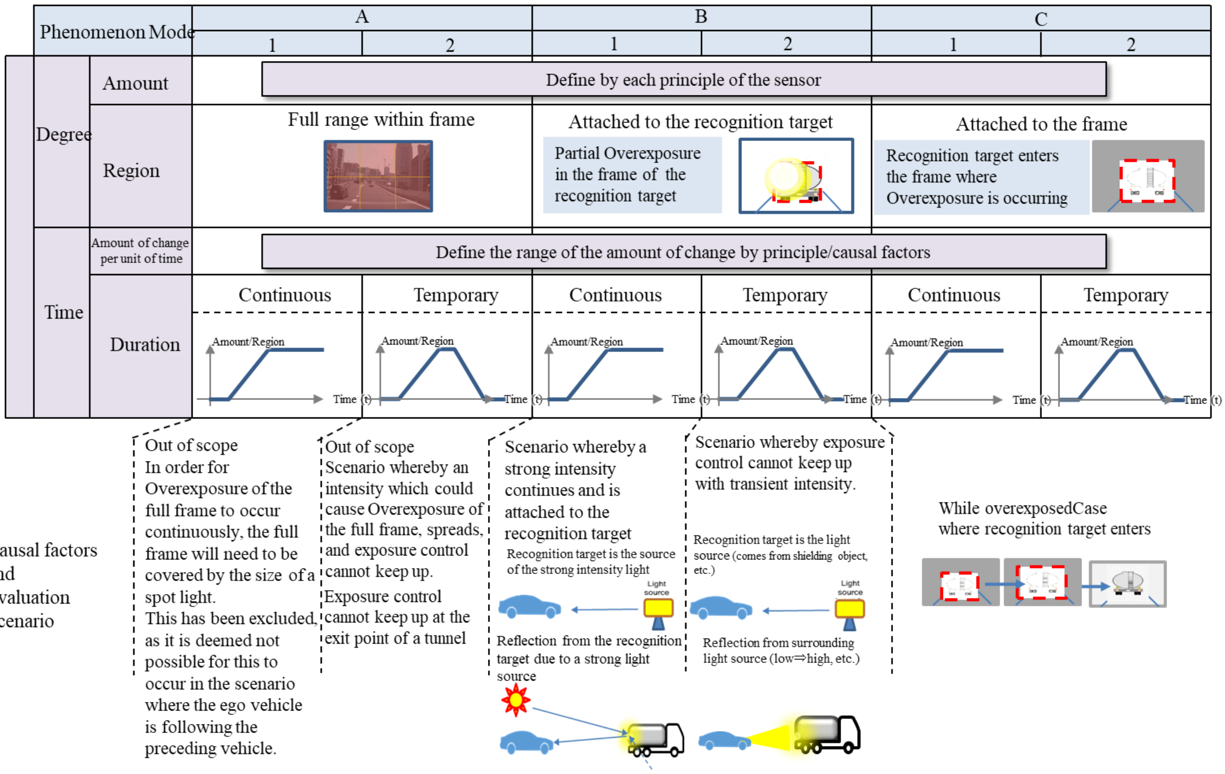
The whole area of the preceding vehicles becomes white, making it difficult to make out any profiles

E.4.3.1.2. **Principle**

When the phenomenon occurs in a portion of a recognition target, the camera-based perception system may fail to perform correct feature extraction. Alternatively, even if feature extraction is successful, the identification function may fail to correctly match the extracted features with trained data, resulting in missed detection or misclassification.



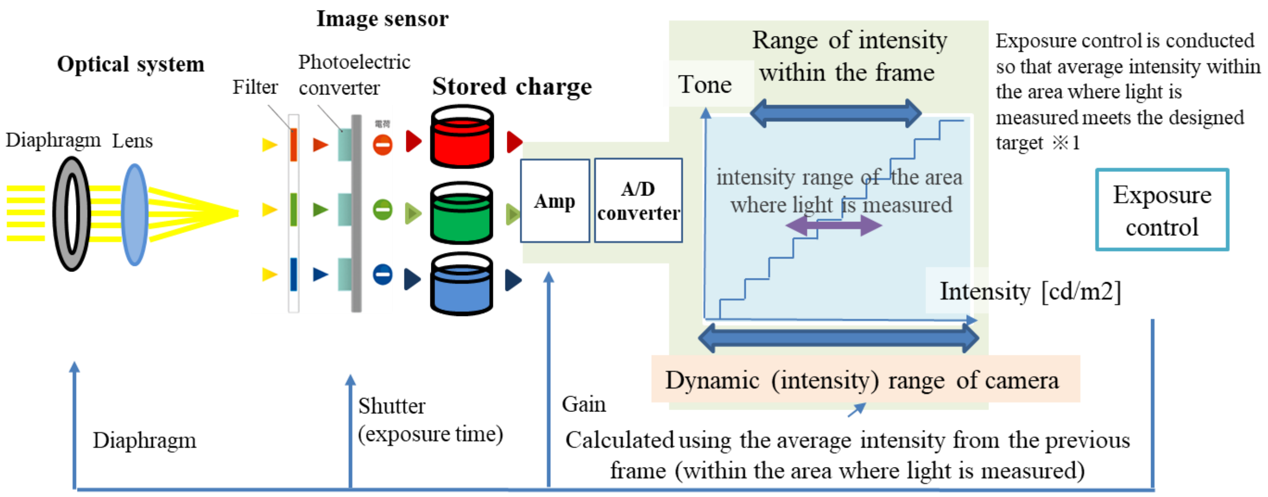
The relationship between the principle and the phenomenon addressed here is organized as shown in the figure below.



Phenomenon Mode		A		B		C	
		1	2	1	2	1	2
Degree	Amount	Define by each principle of the sensor					
	Region	Full range within frame		Attached to the recognition target Partial Overexposure in the frame of the recognition target		Attached to the frame Recognition target enters the frame where Overexposure is occurring	
Time	Amount of change per unit of time	Define the range of the amount of change by principle/causal factors					
	Duration	Continuous	Temporary	Continuous	Temporary	Continuous	Temporary
Causal factors and Evaluation Scenario		Out of scope In order for Overexposure of the full frame to occur continuously, the full frame will need to be covered by the size of a spot light. This has been excluded, as it is deemed not possible for this to occur in the scenario where the ego vehicle is following the preceding vehicle.	Out of scope Scenario whereby an intensity which could cause Overexposure of the full frame, spreads, and exposure control cannot keep up. Exposure control cannot keep up at the exit point of a tunnel	Scenario whereby a strong intensity continues and is attached to the recognition target Recognition target is the source of the strong intensity light Reflection from the recognition target due to a strong light source	Scenario whereby exposure control cannot keep up with transient intensity. Recognition target is the light source (comes from shielding object, etc.) Reflection from surrounding light source (low⇒high, etc.)	While overexposedCase where recognition target enters	

E.4.3.1.3. **Principle Models**

The phenomenon addressed in this section occurs when the luminance range of the scene exceeds the dynamic range of the camera, which is determined through exposure control. Exposure control determines the effective luminance range by setting parameters such as aperture value, shutter speed, and gain, based on the deviation between the average luminance within the metering area of the previous frame and a target luminance. By mapping the luminance distribution within the FOV onto the determined dynamic range, brightness differences in the scene are represented as color values and gradation levels.



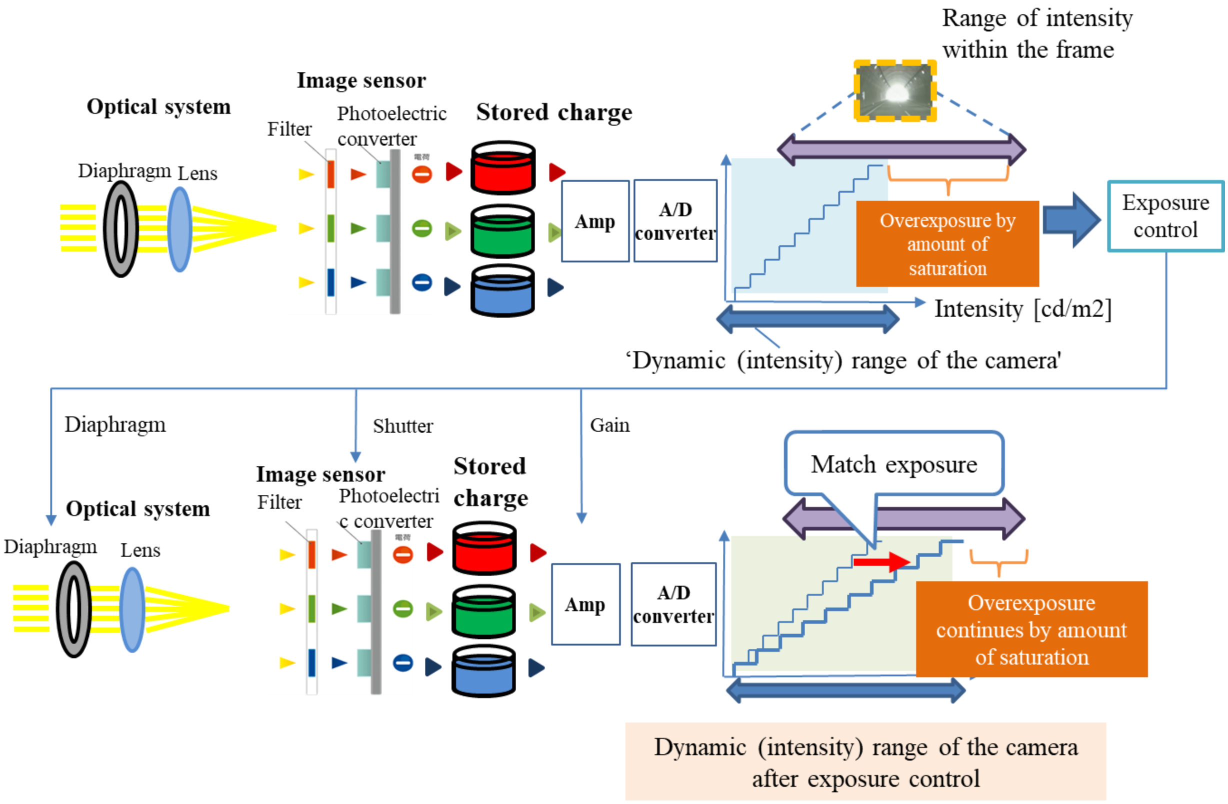
※1 Details of control differs depending on manufacturer

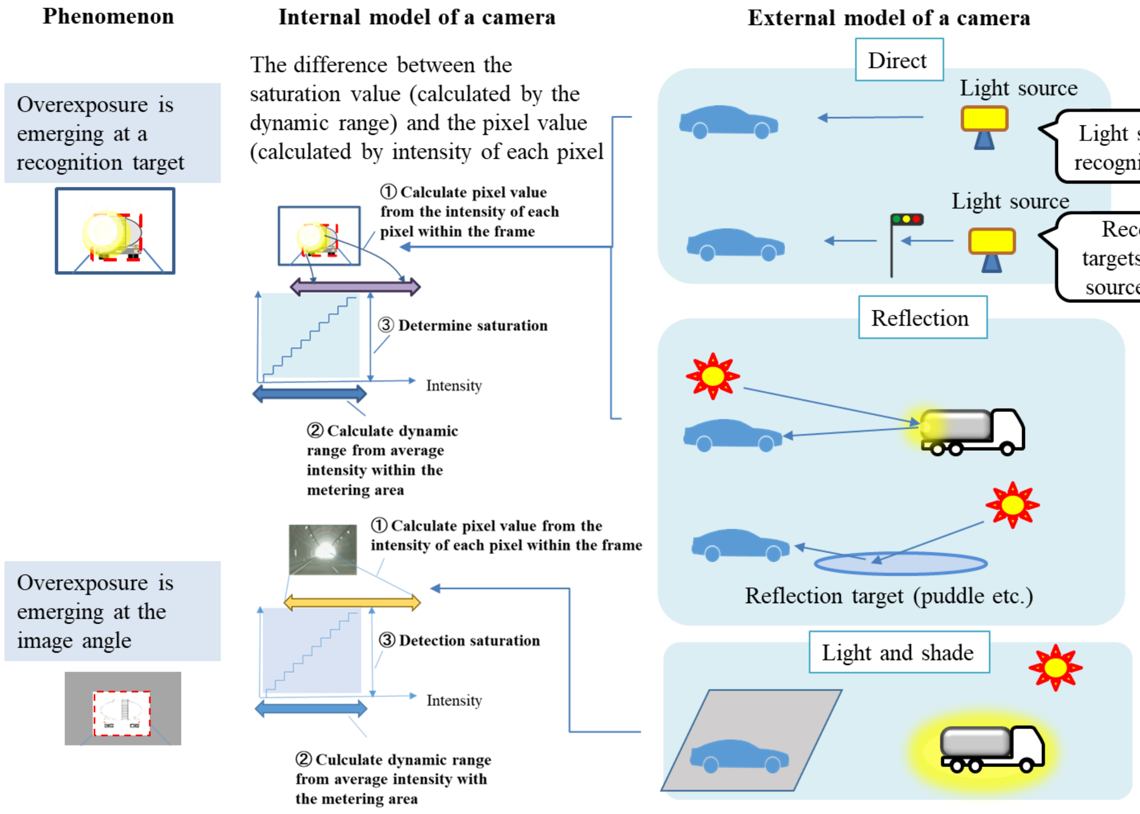
Exposure Control and Saturation Mechanism

Before exposure control (upper part of the figure below), light entering through the lens reaches the imaging device (image sensor) and is converted into RGB signals, which are amplified and then subjected to A/D conversion. If the luminance range within the FOV exceeds the camera’s dynamic range, the sensor output reaches a saturation state, resulting in the loss of luminance information. In these saturated regions, blown highlights (white-out) occur, and gradation and shape information in bright areas is lost.

The exposure-control function detects this condition and applies correction in the next frame.

After exposure control (lower part of the figure below), parameters such as aperture value, shutter speed, and gain are automatically adjusted, and the camera’s dynamic range is reconfigured to better match the scene. As a result, saturated regions are reduced and gradation representation is improved. However, when the light source is extremely intense or when luminance changes abruptly, blown highlights may persist (indicated by the red arrows in the figure).





Internal Camera Model

The process leading up to the occurrence of blown highlights (white-out) is described as follows:

① Calculation of pixel values from per-pixel luminance
Pixel values (R, G, B) are calculated as:

$$\text{Pixel value (R, G, B)}=\mathit{Luminance\ per\ pixel}\ [\mathrm{cd/m^2}]\times Rt[\mathrm{ms}]\times G\times Wg\times E\times K$$

where:

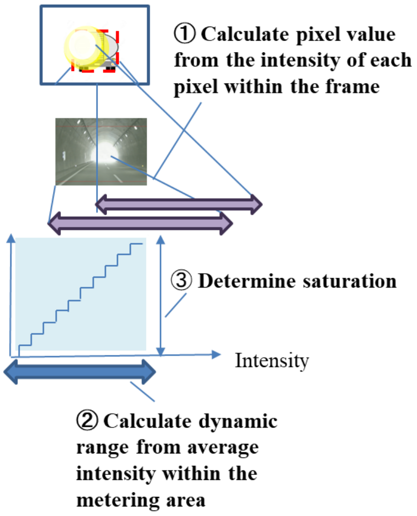
Rt: exposure time [ms]
G: gain
Wg: white gain (fixed value)
E: photoelectric conversion coefficient (fixed value)
K: color filter transmittance

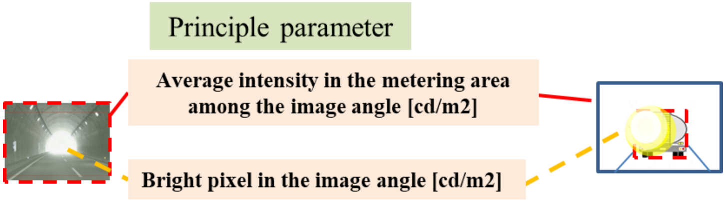
② Determination of dynamic range
The dynamic range is determined based on the average luminance within the metering area of the previous frame:

$$\text{Average luminance in the metering area} = \sum \text{pixel values / number of pixels}$$

③ Saturation determination
Pixels whose luminance exceeds the saturation threshold corresponding to the determined dynamic range become blown out. At this point, the following condition holds:

$$\text{Bright pixel within the field of view } [\mathrm{cd/m^2}] > \text{saturation threshold}$$



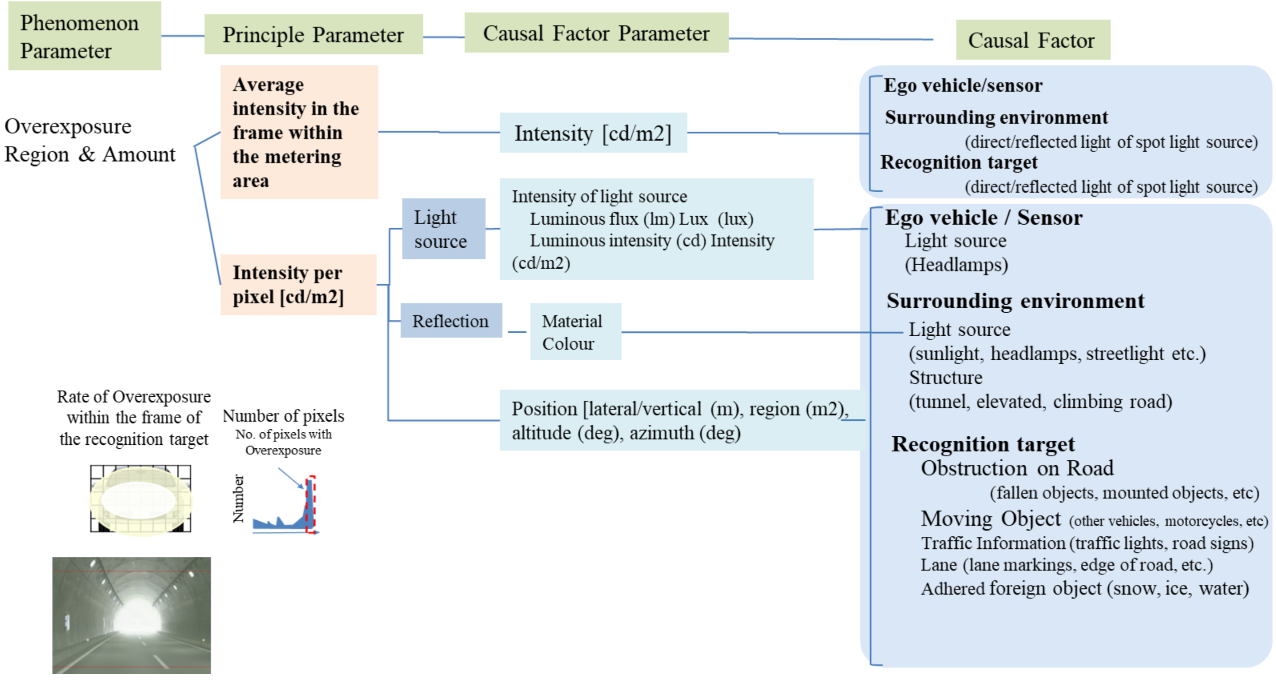


E.4.3.2. Relationship Between Principles and Causal Factors of Perception Disturbance

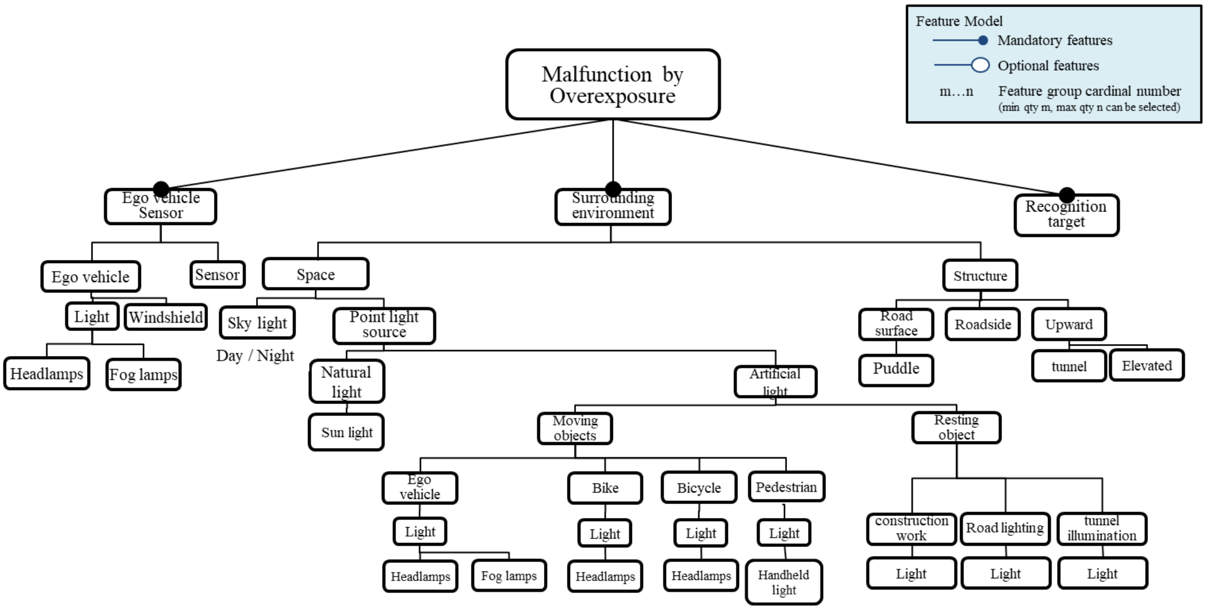
This section describes the relationships among the phenomenon parameters, principle parameters, and causal-factor parameters for perception disturbances caused by saturation and blown highlights.

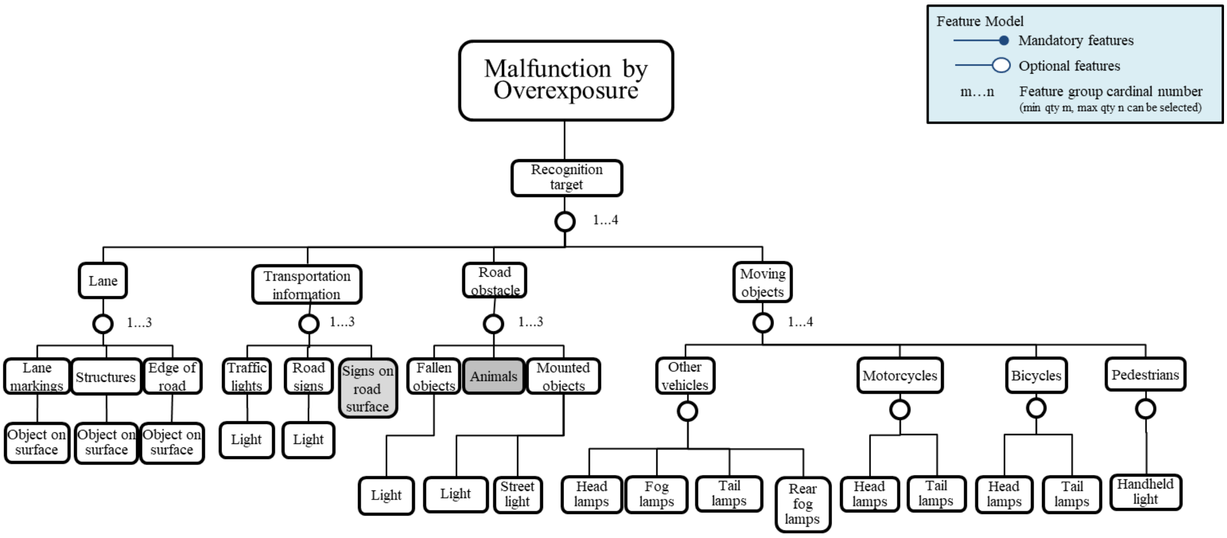
E.4.3.2.1. Causal Factors Based on the Principle

Based on the principle model described in the preceding section, the relationships among the phenomenon parameters, principle parameters, and causal-factor parameters are organized as follows.



When these causal factors are systematically arranged, they can be represented in the hierarchical structure shown in the figure below. This organization clarifies how factors related to the ego vehicle and sensor, the surrounding environment, and the recognition target contribute to saturation-induced perception disturbances.



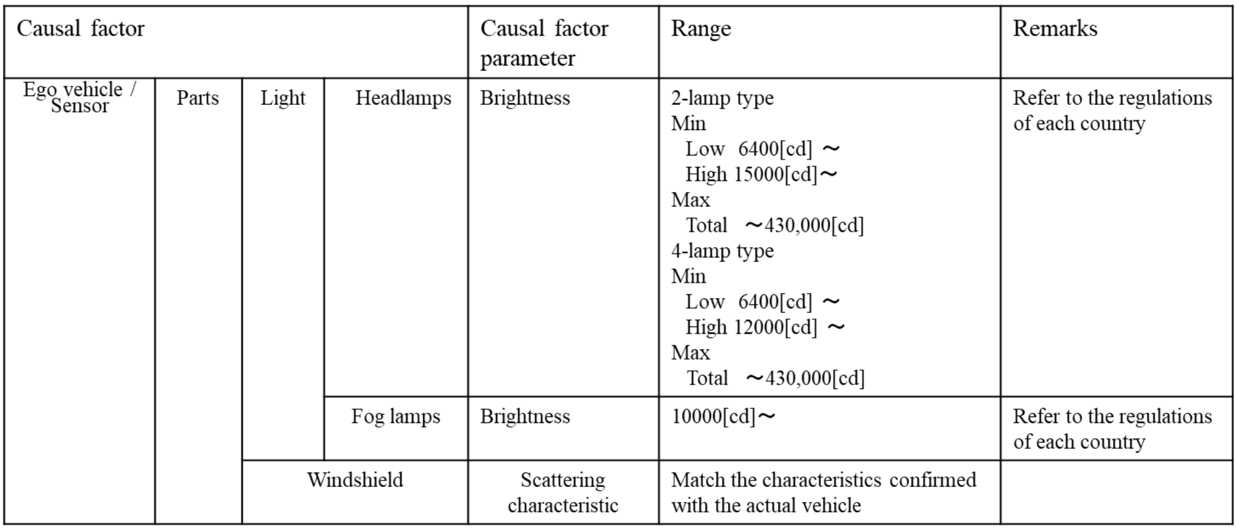


E.4.3.2.2. **Parameter Ranges**

Parameter ranges for this perception-disturbance principle are defined according to the three causal-factor categories introduced in Chapter 3.

Ego Vehicle / Sensor

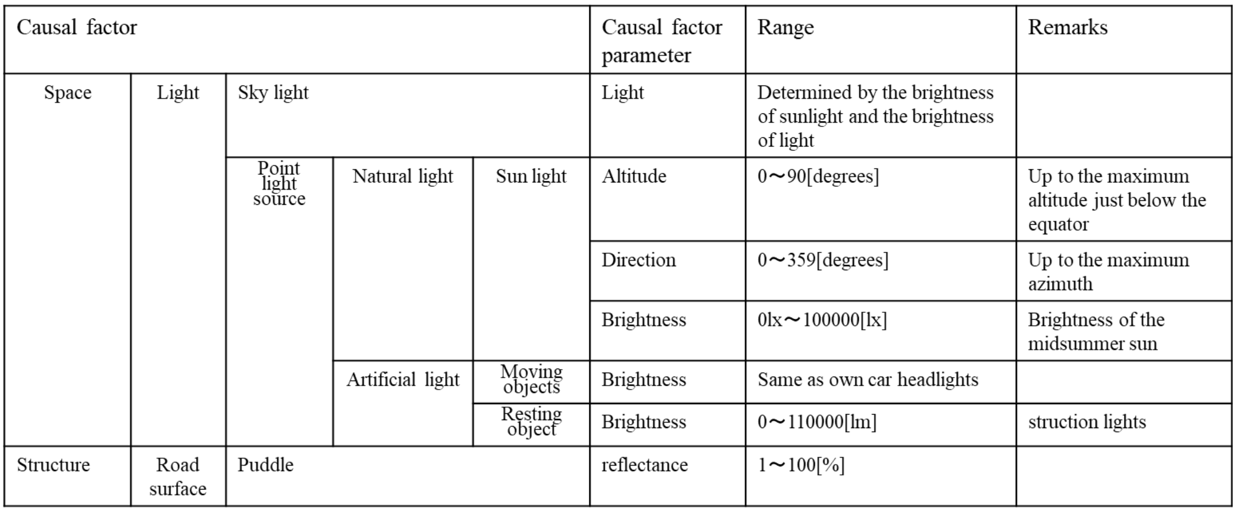
For perception disturbances classified as “Ego Vehicle / Sensor”, the parameter ranges are defined to capture variations in camera exposure control and sensor response, including parameters related to aperture value, shutter speed, gain, and sensor dynamic range.



Causal factor				Causal factor parameter	Range	Remarks
Ego vehicle / Sensor	Parts	Light	Headlamps	Brightness	2-lamp type Min Low 6400[cd] ～ High 15000[cd]～ Max Total ～430,000[cd] 4-lamp type Min Low 6400[cd] ～ High 12000[cd] ～ Max Total ～430,000[cd]	Refer to the regulations of each country
			Fog lamps	Brightness	10000[cd]～	Refer to the regulations of each country
		Windshield		Scattering characteristic	Match the characteristics confirmed with the actual vehicle	

Surrounding Environment

For perception disturbances classified as “Surrounding Environment”, the parameter ranges are defined to capture variations in environmental luminance conditions, including strong light sources such as sunlight, headlights, reflections from wet road surfaces, and other high-luminance backgrounds.



Causal factor					Causal factor parameter	Range	Remarks
Space	Light	Sky light			Light	Determined by the brightness of sunlight and the brightness of light	
		Point light source	Natural light	Sun light	Altitude	0～90[degrees]	Up to the maximum altitude just below the equator
					Direction	0～359[degrees]	Up to the maximum azimuth
					Brightness	0lx～100000[lx]	Brightness of the midsummer sun
			Artificial light	Moving objects	Brightness	Same as own car headlights	
				Resting object	Brightness	0～110000[lm]	struction lights
Structure	Road surface	Puddle			reflectance	1～100[%]	

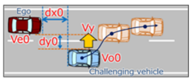
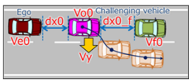
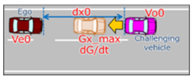
Recognition Target

For perception disturbances classified as “Recognition Target”, the parameter ranges are defined to capture variations in the luminance and reflective characteristics of the recognition target, including highly reflective surfaces and light-emitting components that may contribute to local saturation.

Causal factor	Causal factor parameter	Range	Remarks
Other vehicles	Color / Material	Color(White)	Colors that are prone to overexposure
	Light source	Tail lamps（300[cd]）,Brake lamps (600[cd]）,Hazard lamps (600[cd]),Rear fog lamps(345[cd])	Refer to the regulations of each country
Vehicle with specular reflection	Color / Material	Material (Aluminum)	Material that is prone to overexposure
Motorcycles Bicycles	Color / Material	Color(White)	Colors that are prone to overexposure
	Light source	Tail lamps（300[cd]）,Brake lamps (600[cd]）,Hazard lamps (600[cd])	Refer to the regulations of each country
Pedestrians	Color / Material	Color(White)	Colors that are prone to overexposure
	Light source	Handheld light (20～800[lm])	Brightness of handheld lights for sale

E.4.3.2.3. **Evaluation Scenarios**

By linking ALKS-related scenarios with the causal factors described above, corresponding Functional Scenarios are derived.

Functional Scenario	ALKS Scenario	Lane			Traffic Information			Moving Object				Obstruction on Road			Structure	Explanation
		Lane markings	Structures	Edge of road	Traffic lights	Road signs	Road surface signs	Other vehicles	Motorcycles	Bicycles	Pedestrians	Fallen objects	Mounted objects	Animals	Upward tunnel	
F-1	Cut-in 							○	○						○	
F-2	Cut-out 							○	○	○	○	○	○		○	
F-3	Deceleration 							○	○						○	
F-B1-14	Lane-keeping	○	○	○	○	○	○								○	

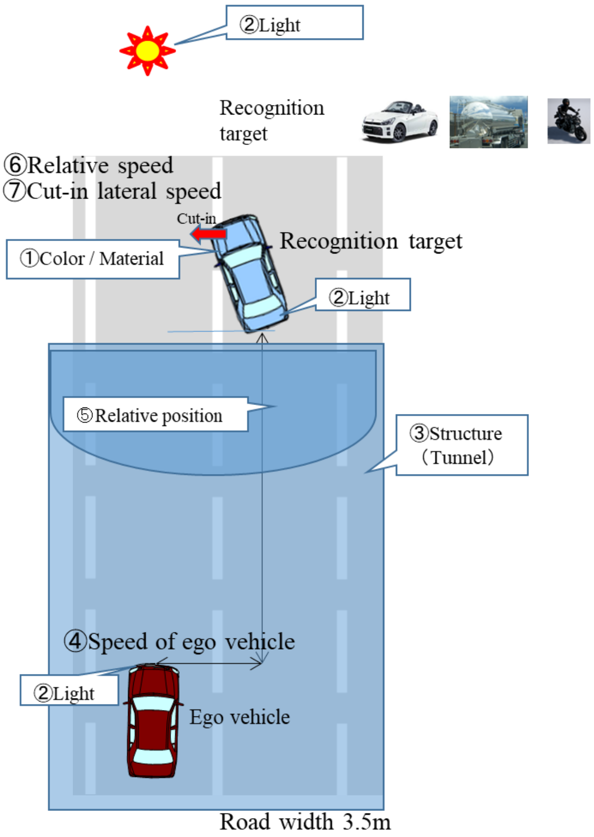
The following evaluation scenarios are defined for camera-based perception disturbances caused by saturation and blown highlights.

Scenario F-1: Cut-In Scenario on a Straight Road

A cut-in vehicle is defined as the recognition target.

Evaluation is conducted under high-luminance conditions that may cause local saturation in regions of the recognition target or surrounding environment.

Causal factor parameter	①Color / Material	Color : White Material : Aluminum
	②Light	Natural light Sun light Artificial light Headlamps Tail lamps Rear fog lamps
	③Structure	Tunnel
Parameters required for evaluation	④Speed of ego vehicle	The range is defined by the traffic flow scenario, thus not defined here
	⑤Relative position	
	⑥Relative speed	
	⑦Cut-in lateral speed	

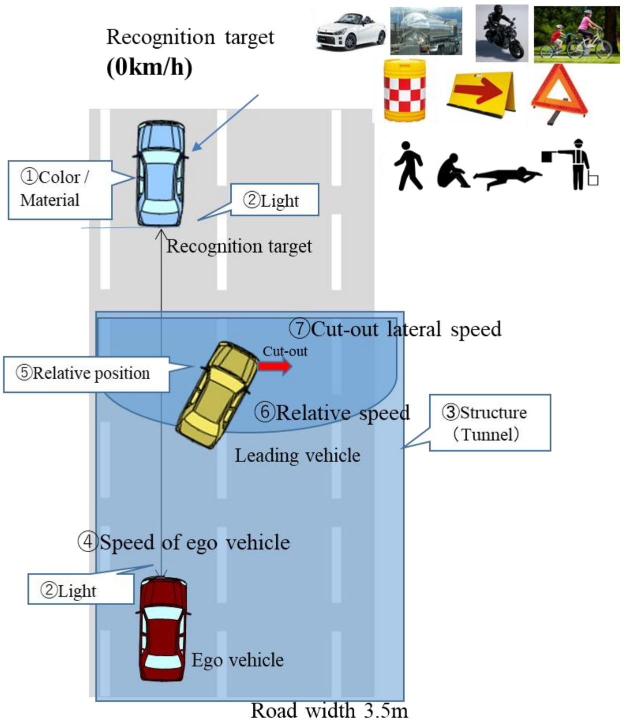


Scenario F-2: Cut-Out Scenario on a Straight Road

After a lead vehicle performs a cut-out maneuver, a recognition target appears ahead of the ego vehicle.

Evaluation is conducted under conditions where blown highlights may occur due to abrupt changes in luminance.

Causal factor parameter	①Color / Material	Color : White Material : Aluminum
	②Light	Artificial light Headlamps Tail lamps Rear fog lamps
	③Structure	Tunnel
Parameters required for evaluation	④Speed of ego vehicle	The range is defined by the traffic flow scenario, thus not defined here
	⑤Relative position	
	⑥Relative speed	
	⑦Cut-out lateral speed	

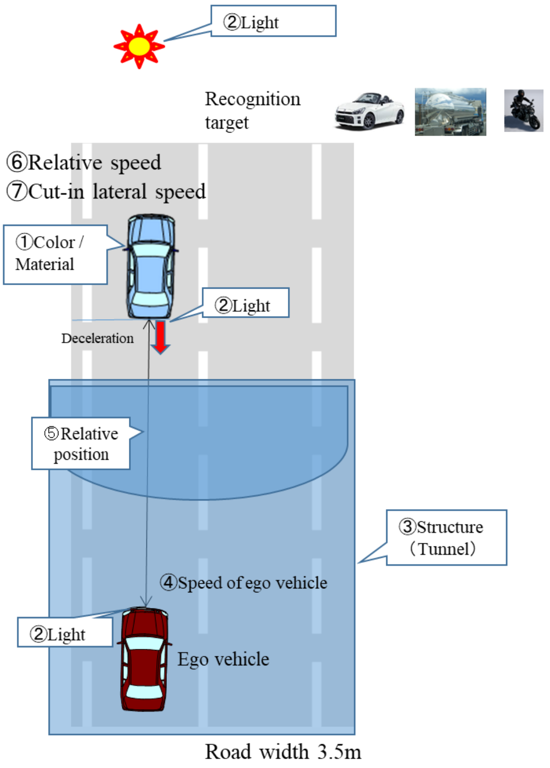


Scenario F-3: Deceleration Scenario on a Straight Road

A decelerating vehicle is defined as the recognition target.

Evaluation is conducted under conditions of strong luminance contrast that may induce saturation during longitudinal maneuvers.

Causal factor parameter	①Color / Material	Color : White Material : Aluminum
	②Light	Natural light Sun light Artificial light Headlamps Tail lamps Rear fog lamps
	③Structure	Tunnel
Parameters required for evaluation	④Speed of ego vehicle	The range is defined by the traffic flow scenario, thus not defined here
	⑤Relative position	
	⑥Relative speed	
	⑦Deceleration	

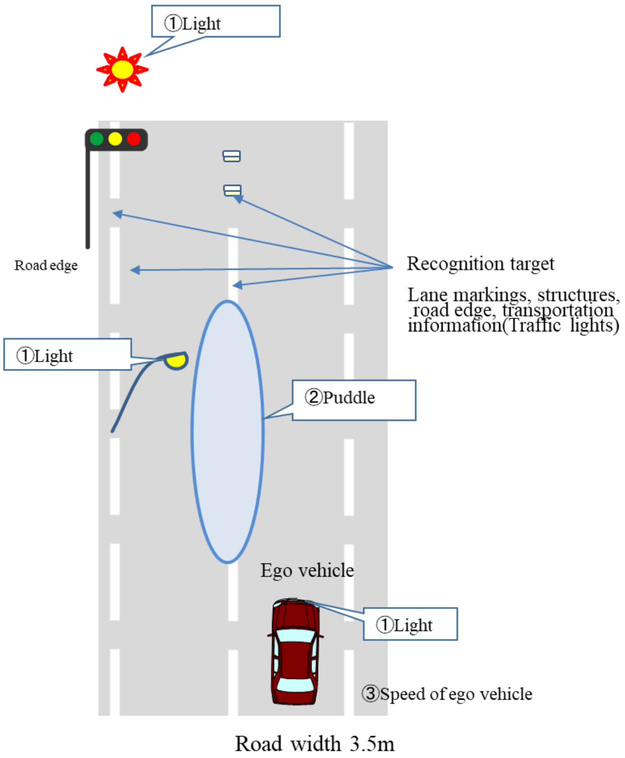


Scenario F-B1-14: Lane-Keeping Scenario on a Straight Road

Under high-luminance conditions, the ego vehicle performs lane keeping at a constant velocity.

This scenario evaluates the stability of camera-based perception performance when saturation or blown highlights affect lane-related and object-related features.

Causal factor parameter	①Light	Natural light Sun light Artificial light Headlamps
	②Road surface	Puddle
Parameters required for evaluation	③Speed of ego vehicle	The range is defined by the traffic flow scenario, thus not defined here



Annex F (Reference): Guidelines for Validating Virtual Environments for Perception-Disturbance Evaluation

The environments in which vehicles operate—including not only automated driving vehicles but also conventional vehicles—are not limited to clear-weather conditions with good visibility. In practice, driving is expected to occur under a wide range of meteorological conditions, such as rain, fog, and snowfall. Under such conditions, sensor-based perception may be affected by various disturbances, potentially leading to performance degradation or misdetections. Accordingly, in the safety evaluation of automated driving systems, it is essential to conduct assessments that explicitly take perception-disturbance factors into account.

One effective approach to evaluating perception performance under disturbance conditions is the use of simulation technologies based on physical modeling, which have advanced rapidly in recent years. While evaluation using simulation technologies (i.e., virtual environments) offers significant convenience and flexibility, it also introduces the challenge of how to ensure the validity of the virtual environment itself.

In this annex, for each sensor type addressed in Annex E—namely camera, millimeter-wave radar, and LiDAR—the requirements that should be verified when reproducing principle models of perception disturbances in a virtual environment are identified and systematically organized. In addition, methods are proposed for verifying whether the constructed virtual environment is valid with respect to these requirements. It should be noted that the numerical values presented in this annex are not intended to be definitive. For this reason, this annex is treated as reference material.

An overview of the components subject to evaluation in this annex is shown in Figure F-1.

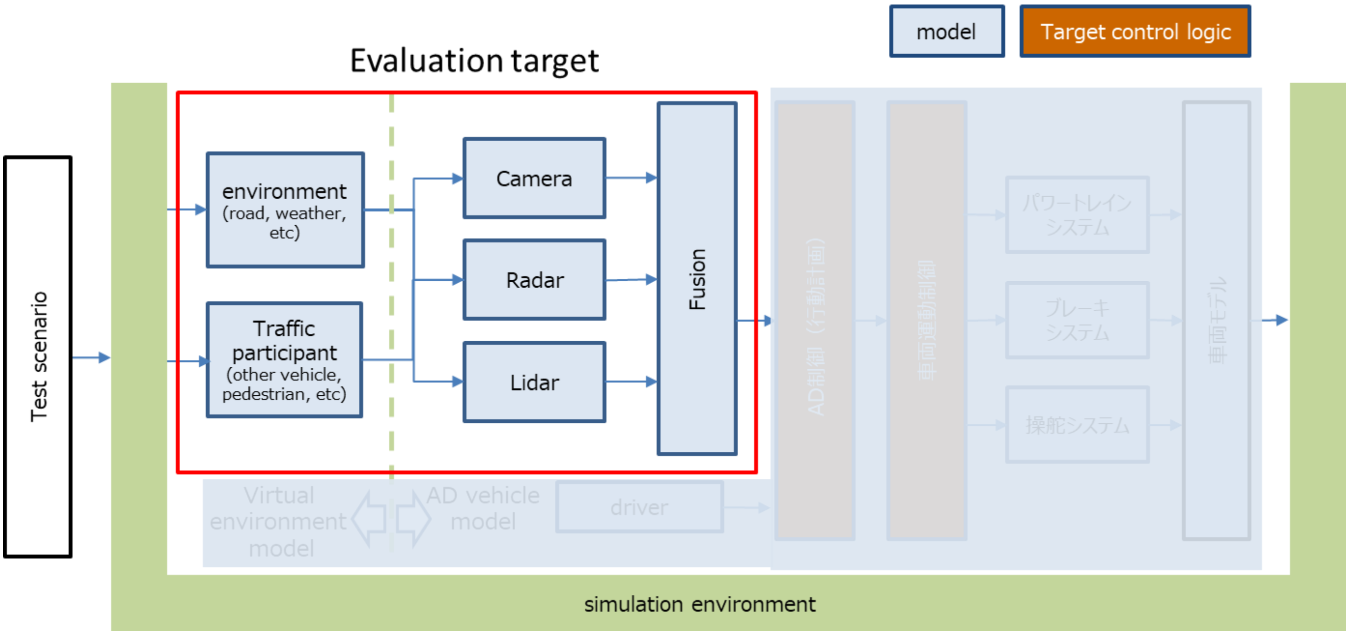


Figure F- 1. Evaluation Targets of Annex F

F.1. Overall Structure of the Requirements Defined in This Annex

To determine whether perception-performance evaluation using virtual environments is suitable for practical application, it is important that all relevant stakeholders share a common understanding of how to verify the validity of the models and environmental conditions implemented in the virtual environment.

The ultimate objective is for evaluation results obtained in a virtual environment under disturbance conditions to be consistent with results obtained from real vehicles. However, as a prerequisite for defining such consistency, it is necessary to clearly establish verification methods under ideal environments without disturbances.

By first establishing verification methods under ideal, disturbance-free conditions, it becomes possible to more easily analyze the causes of discrepancies when inconsistencies arise under the final target conditions—namely, environments in which perception disturbances are present.

Accordingly, in this annex:

- requirements for consistency verification under ideal environments are defined as A. Common Requirements; and
- requirements for consistency verification under environments with perception disturbances are defined as B. Perception-Disturbance Reproduction Requirements.

For each item defined under A. Common Requirements and B. Perception-Disturbance Reproduction Requirements, corresponding validation methods are proposed.

The overall structure of this annex is shown in Figure F-2.

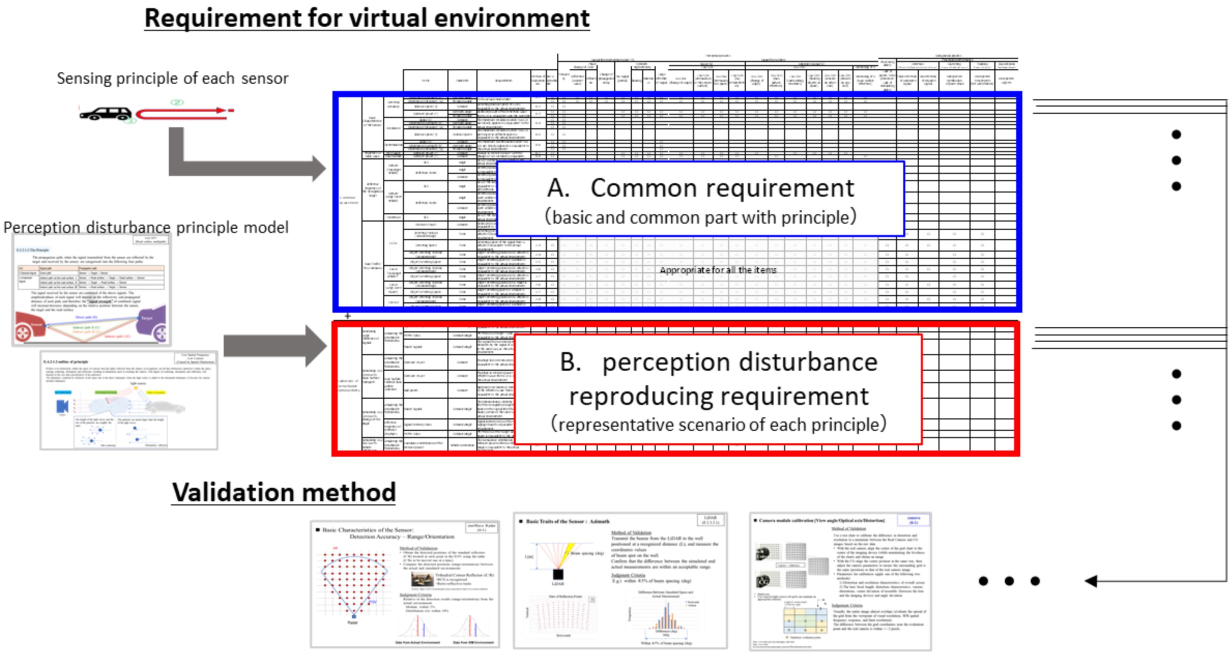


Figure F- 2. Overall Structure of Annex F

A. Common Requirements

- Define the requirements to be verified under conditions without perception disturbances, based on the sensing principles of each sensor.

B. Perception-Disturbance Reproduction Requirements

- Define the requirements to be verified in virtual environments that reproduce perception disturbances.

- Classify the wide variety of perception disturbances based on their underlying physical principles, and describe each disturbance principle as a model, thereby organizing the principle parameters and causal-factor parameters required for disturbance reproduction.

F.2. Common Requirements and Validation Methods

This section explains the items to be verified as common requirements and the corresponding validation methods.

First, the conceptual approach for selecting items to be defined as common requirements is described, including the viewpoints used for item selection. Next, based on this approach, validation methods for each sensor type are organized.
Because these validation methods are established based on the principle characteristics of each sensor, when sensor principles differ, it is necessary to organize verification items according to the same conceptual approach and to apply appropriate validation methods.
The validation methods presented in this section may be replaced by other methods capable of verifying equivalent content. In addition, if sensor calibration is required, validation is assumed to be performed after calibration has been completed.

F.2.1. Conceptual Approach to Common Requirements

This subsection describes the conceptual approach used to define items to be treated as common requirements. As with the classification of perception-disturbance factors, the evaluation elements are divided into the following three categories (Figure F-3):

①. The sensor and the vehicle itself
②. The space through which signals propagate
③. Recognition targets

For each element, the following are organized:

- the items to be verified under ideal, disturbance-free conditions; and
- the corresponding reference values (evaluation criteria).

In addition, to comprehensively verify these items, a method is defined to confirm whether recognition targets can be appropriately detected and recognized under ④basic traffic-disturbance scenarios.

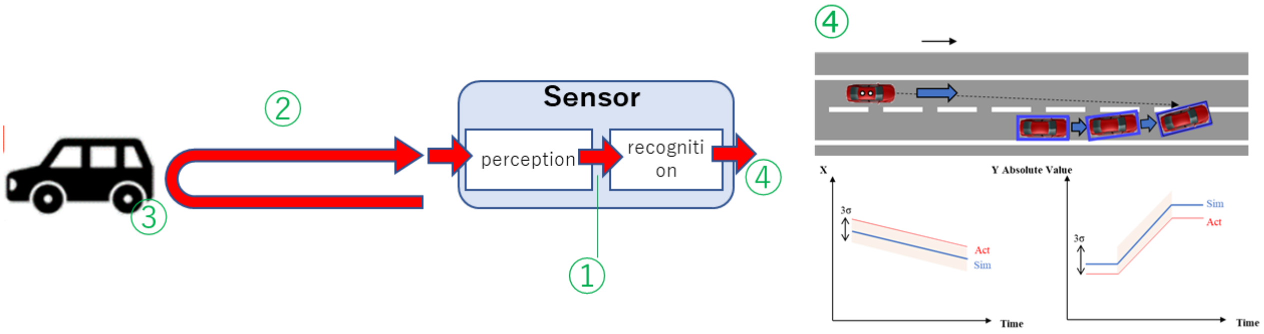


Figure F- 3. Scope for Defining Common Requirements

① Basic characteristics of the sensor itself

Verify whether the basic perception characteristics of the sensor—such as range, azimuth, relative velocity, and received signal intensity—are appropriately reproduced under ideal, disturbance-free conditions. The specific target items and conditions differ depending on the sensing principle of each sensor.

② Propagation characteristics and optical characteristics

Verify whether the signal-propagation process from the recognition target to the sensor—such as radio-wave propagation and optical transmission and reflection—is appropriately reproduced under ideal, disturbance-free conditions.

③ Reflective characteristics of recognition targets

Verify whether the appearance of recognition targets (i.e., how they are perceived by the sensor) is correctly reproduced under ideal conditions. Validation is performed not only on perception results but also on object-recognition results based on the acquired data.

④ Target recognition under traffic-disturbance scenarios

Verify whether target-recognition results are appropriately reproduced under basic traffic-disturbance scenarios, specifically Following, Cut-in, and Cut-out, as defined in the main text.

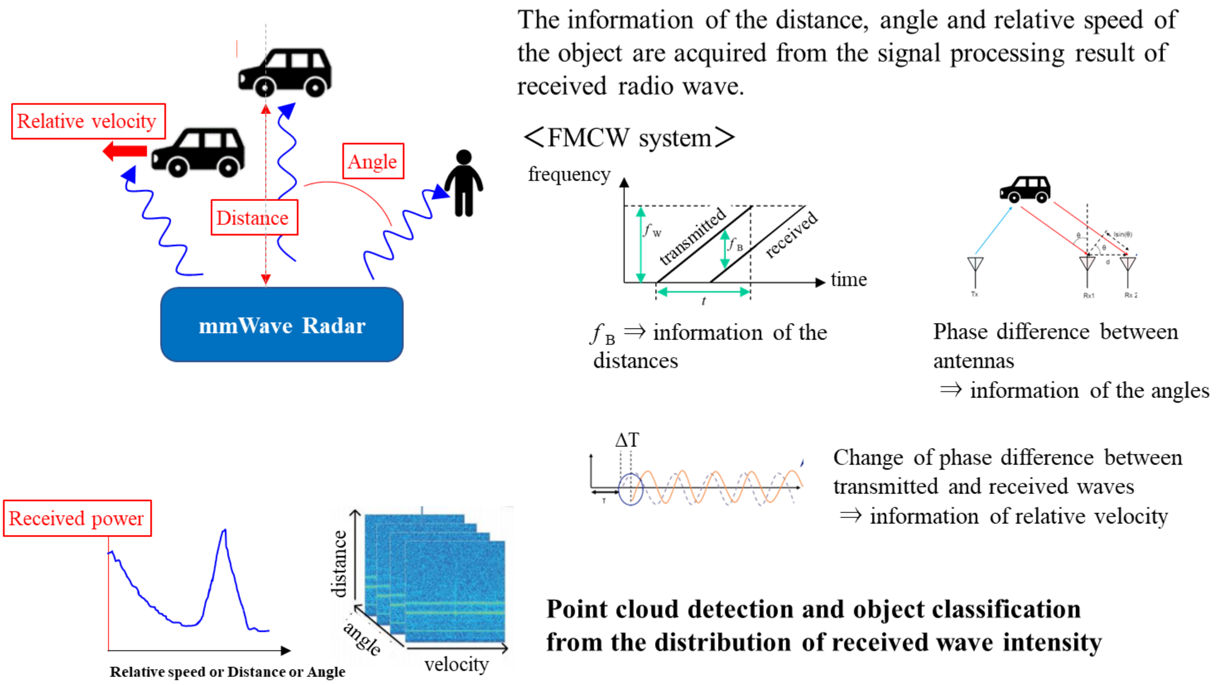
F.2.2. **Conceptual Approach to Common Requirements for Each Sensor**

This section describes the conceptual approach used to define common requirements for each sensor type, based on the sensing principles specific to that sensor.

F.2.2.1. Conceptual Approach to Common Requirements for Millimeter-Wave Radar

For millimeter-wave radar, verification is performed to determine whether fundamental physical quantities derived from radar sensing principles are appropriately reproduced in the virtual environment. These quantities include range, azimuth, relative velocity, and received signal intensity. Figure F-4 illustrates, from a signal-processing perspective, how these quantities are obtained in a millimeter-wave radar system.

- Range:
  The distance to a target is calculated from the round-trip time required for the transmitted electromagnetic wave to strike the target, be reflected, and return to the radar receiver (upper left of Figure F- 4).
- Relative velocity:
  When the target is moving (e.g., a traveling vehicle), the reflected wave experiences a frequency shift due to the Doppler effect. The relative velocity between the radar and the target is calculated from this frequency difference (lower left of Figure F- 4).
- Azimuth:
  By deploying multiple receiving antennas and analyzing the phase differences among the received signals, the azimuth angle of the target is estimated (upper right of Figure F- 4).
- Received signal intensity:
  The intensity of the received signal (i.e., reflected energy) varies depending on the material, shape, and surface-reflection characteristics of the target. In the received-intensity graph shown in the lower left of Figure F- 4, the distribution of signal intensity along the range direction is illustrated. Target detection and reflection characteristics are evaluated based on the peak position and peak magnitude of this distribution.



The information of the distance, angle and relative speed of the object are acquired from the signal processing result of received radio wave.

f_B ⇒ information of the distances

Phase difference between antennas ⇒ information of the angles

Change of phase difference between transmitted and received waves ⇒ information of relative velocity

Point cloud detection and object classification from the distribution of received wave intensity

Figure F- 4. Detection Principles of Millimeter-Wave Radar

Based on this conceptual approach, the specific common requirements for millimeter-wave radar are organized and summarized in Table F- 1.

Table F- 1. Common Requirements for Millimeter-Wave Radar

								Perception process																			Recognition process					
								Signal from perception target (S)								Signal from others											Processing ability	Processing performance				
									Phase			Strength				Noise (N)				Undesired signal (U)								Detection (Output of reflected point cloud of target)		Clustering (grouping of reflected points)	Tracking (tracking of target)	Classification (Identification of target)
									Change of DOA				High intensity			Low S/N				Low D/U						Increasing of U						
			Items	Paramters	Requirements	Method of Validation No.	not a disturbance	Frequency	Reflection (indirect wave)	Refraction	Change of propagation delay	No signal (partial)	Aliasing	Harmonic	Large differnce of signal	Low S/N (change of angle)	Low S/N (attenuation at the sensor surface)	Low S/N (attenuation in space)	Low S/N (low retroreflection)	Low D/U (change of angle)	Low D/U (road surface reflection)	Low D/U (surrounding structures)	Low D/U (floating objects in space)	Low D/U (sensors on other cars)	Low D/U (sensors on ego cars)	Increasing of U (road surface reflection)	Lack of points to be processed Lack of calculating ability	False detection of undesired signal	No detection of required signal	Unexpected distribution of point cloud	Unexpected movements (between frames)	Unexpected objects
Common Requirement	Basic Characteristics of the Sensor	Detection Accuracy	Range (R)	Distance	Detecting position of C/R is equivalent to the actual environment.	0-1	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○						
			Orientation (azimuth) (θ)	Azimuth angle			○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○						
			Orientation (elevation) (φ)	Elevation angle			○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○						
			Relative speed (V)	Distance	Detecting relative speed of C/R is equivalent to the actual environment.	0-2	○	○																								
			Received power (P)	Azimuth angle	Received power of the reflection wave from C/R is equivalent, and the side lobe is	0-3	○	○				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○						
				Elevation angle			○	○				○	○	○	○	○	○	○	○	○	○	○	○	○	○	○						
		Resolution	Range (R)	Distance	The minimum resolution when two C/R are closely apposed is equivalent to the actual environment.	0-4	○	○																								
			Orientation (azimuth) (θ)	Azimuth angle			○	○																								
			Orientation (elevation) (φ)	Elevation angle			○	○																								
			Relative speed (V)	Relative speed	The minimum resolution when two C/R are moved in different speed is equivalent to the actual environment.	0-5	○	○																								
		Discrimination	Range (R)	Distance	The minimum discrimination when two C/R are closely apposed is equivalent to the actual environment.	0-6	○	○							○																	
			Orientation (azimuth) (θ)	Azimuth angle			○	○							○																	
			Orientation (elevation) (φ)	Elevation angle			○	○							○																	
	Properties of radio wave	Free Space	Received power (P)	Distance	Change in received power with the change of C/R distance is equivalent, and the	0-7	○					○	○	○	○	○	○	○	○	○		○	○	○	○							
		Road surface	Received power (P)	Distance		0-8	○					○	○	○	○	○	○	○	○		○					○						
	Reflective Properties of the Recognition Target	Vehicle (Passenger Vehicle)	RCS	Angle	RCS of a vehicle is equivalent to the actual environment in all directions.	1-1	○																									
			Reflection Points	Angle	Refection peak intensity from a vehicle is equivalent to the actual environment.	1-2	○		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○							
				Distance	Refection peak intensity from a vehicle is equivalent to the actual environment.	1-2	○		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○							
		Vehicle (Large-Sized Vehicle)	RCS	Angle	RCS of the large-sized vehicle is equivalent to the actual environment in all directions.	1-1	○																									
			Reflection Points	Angle	Refection peak intensity from a large-sized vehicle is equivalent to the actual environment.	1-2	○		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○							
				Distance	Refection peak intensity from a large-sized vehicle is equivalent to the actual environment.	1-2	○		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○							
		Pedestrian	RCS	Angle	RCS of the dummy is equivalent to the actual environment in all directions.	1-3	○																									
	Basic Traffic Flow Scenario	CCRs	Received Power	Distance	Received power from a vehicle is equivalent to the actual environment.	2-1	○																									
			Detecting Position (Distance/Angle)	Time	Detecting position of the signal from a vehicle is equivalent to the actual environment.	2-2	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
			Detecting Speed	Time	Detecting speed of the signal from a vehicle is equivalent to the actual environment.	2-3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
			Object Detecting Position (Distance/Angle)	Time	Object detecting position of a vehicle is equivalent to the actual environment.	2-4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	
			Object Detecting Speed	Time	Object detecting speed of a vehicle is equivalent to the actual environment.	2-5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	
		Cut-in (Passenger vehicle)	Object Detecting Position (Distance/Angle)	Time	Object detecting position of a vehicle is equivalent to the actual environment.	2-6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
			Object Detecting Speed	Time	Object detecting position of a vehicle is equivalent to the actual environment.	2-7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	
		Cut-in (Large-sized trailer)	Object Detecting Position (Distance/Angle)	Time	Object detecting position of a trailer is equivalent to the actual environment.	2-6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
			Object Detecting Speed	Time	Object detecting speed of a trailer is equivalent to the actual environment.	2-7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	
		Cut-out	Object Detecting Position (Distance/Angle)	Time	Object detecting position of a vehicle is equivalent to the actual environment.	2-8	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
			Object Detecting Speed	Time	Object detecting speed of a vehicle is equivalent to the actual environment.	2-9	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○	○	

Appropriate for all the items

In Table F- 1, the vertical axis lists the verification items, while the horizontal axis lists the corresponding causal factors. A circle (○) is placed at the intersections where a verification item is relevant to a given causal factor. This representation is intended to enable clear differentiation, when inconsistencies arise during disturbance-reproduction validation, between:

- issues attributable to disturbance reproduction, and
- issues attributable to sensor common requirements.

F.2.2.2. Conceptual Approach to Common Requirements for LiDAR

For LiDAR, verification is performed to determine whether fundamental physical quantities derived from LiDAR sensing principles are appropriately reproduced in the virtual environment. These quantities include range, azimuth, received intensity, number of detection points, and object size.

Figure F- 5. Detection Principles of LiDAR schematically illustrates the structure of point-cloud data generated by LiDAR and the underlying principles of angle detection and range detection.

Angle detection

LiDAR scans laser beams over a fixed angular range in both the horizontal and vertical directions using mechanisms such as rotating mirrors or MEMS scanners.

In the left part of Figure F- 5. Detection Principles of LiDAR, a semicircular region represents the field of view (FOV) of the LiDAR. Within this region, LiDAR rapidly emits and receives laser pulses, acquiring the surrounding environment as grid-like point-cloud data.

The number of detection points, indicated at the top center of the figure, represents the point-cloud density obtained in a single scan. This density is determined by factors such as:

- scan resolution (angular step size),
- rotation speed, and
- reflectivity of the recognition target.

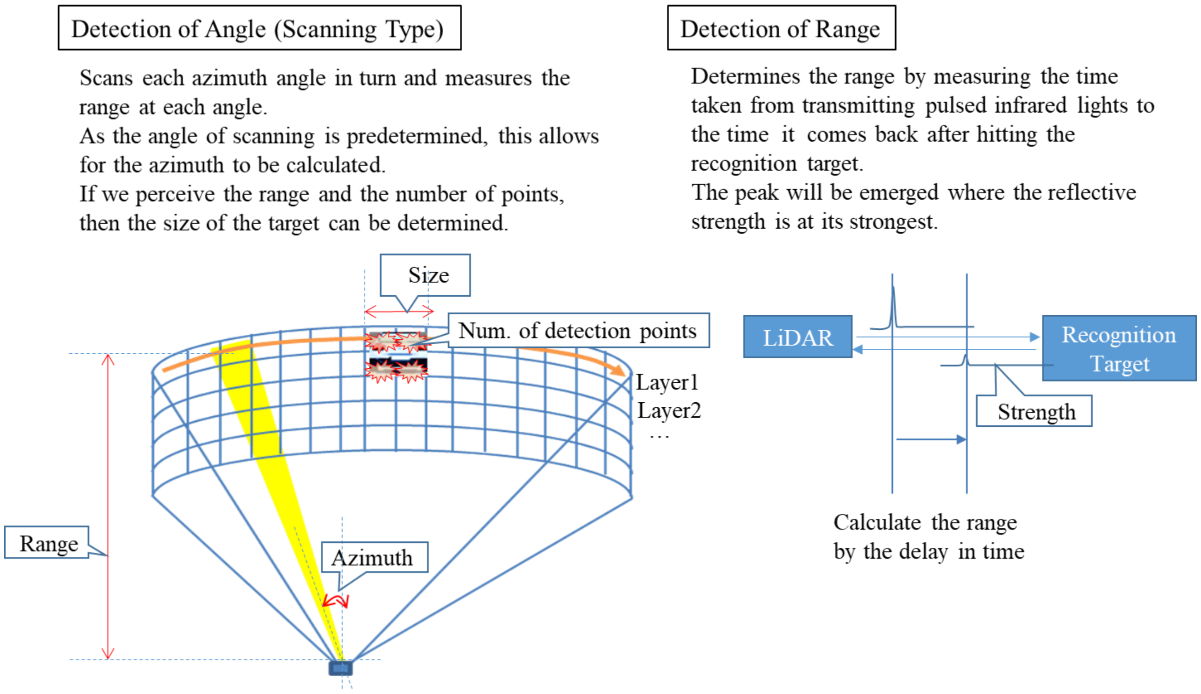
The yellow fan-shaped region in the figure represents the scan direction (scan lines). The scan-angle resolution directly determines the spatial resolution of the point cloud and therefore affects shape reproduction accuracy and small-object detection performance.

In addition, LiDAR systems typically employ multiple vertical scan layers (e.g., 16 to 128 layers), enabling three-dimensional perception of the environment.

Range detection

In the right part of Figure F- 5. Detection Principles of LiDAR, LiDAR's fundamental ranging principle—the Time of Flight (ToF) method—is illustrated.

LiDAR measures the time difference (Δt) between the emission of a laser pulse and the reception of its reflection from a target. The distance to the target is then calculated based on this time difference and the speed of light.



Detection of Angle (Scanning Type)

Scans each azimuth angle in turn and measures the range at each angle.
As the angle of scanning is predetermined, this allows for the azimuth to be calculated.
If we perceive the range and the number of points, then the size of the target can be determined.

Detection of Range

Determines the range by measuring the time taken from transmitting pulsed infrared lights to the time it comes back after hitting the recognition target.
The peak will be emerged where the reflective strength is at its strongest.

Calculate the range by the delay in time

Figure F- 5. Detection Principles of LiDAR

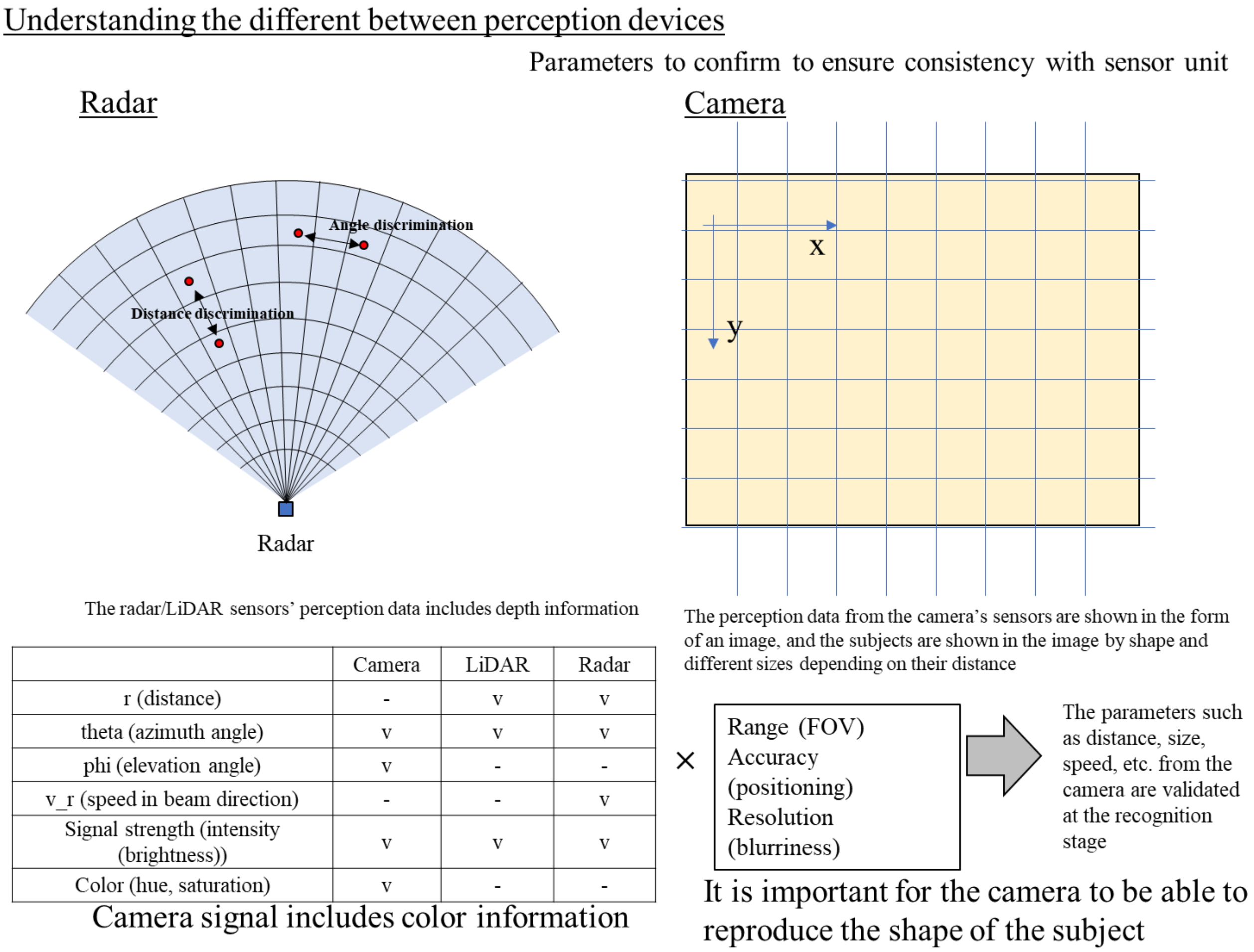
Based on this conceptual approach, the specific common requirements for LiDAR are organized and summarized in Table F- 2.

Table F- 2. Common Requirements for LiDAR

										Perceptual part																
										Signal from recognition target (S)												Signal from non-recognition target				
										Scan timing		S strength							S Propagation direction		S speed	N factor		U factor		
									No disturbance	Misalignment of overall spatial position	Misalignment of position of recognition target	Saturation of S	Attenuation of S					No S due to occlusion	Reflection	Refraction	Arrival time of S	Pulsed noise	DC noise	Multiple reflections	Signal from non-recognition target (Reflection)	Signal from non-recognition target (Refraction)
	Verification perspective		Explanation	target	item	Parameters	request	Validation Method No.					Low reflection of the recognition target	Adhesion to the recognition target	Rain/Snow/Fog	Exhaust gas/Hoisting	Adhesion to the sensor									
common requirement	Basic characteristics of the sensor itself		In order to verify whether the basic performance of LiDAR can be reproduced, the direction, distance, detection probability, intensity, number of detection points, and size are compared by actual measurement and simulation using a standard reflector with known reflection.	Standard reflector	[Point cloud data] Direction, Distance Reflectance Shape	Direction	The direction of the reflector can be detected in the same way as in the real environment.	F.2.3.2.1	○	○	○									○				There is no item marked with ○ because it is a reflection from outside the target and does not affect the appearance to the recognition target.。		
						Distance	The distance of the reflector can be detected in the same way as in the real environment.	F.2.3.2.1.1	○			○	○	○	○	○	○	○	○		○	○	○			
						Detection probability	The detection probability of the reflector can be detected in the same way as in the actual environment.	F.2.3.2.1.2	○			○	○	○	○	○	○	○				○	○			
						Strength	The reflection strength of the reflector can be detected in the same way as in the actual environment.	F.2.3.2.1.3	○			○	○	○	○	○	○	○				○	○			
	Reflection characteristics of the object to be recognized	Static verification	After verifying the basic performance of LiDAR, verify whether the target can be reproduced. As a premise, since the reflection of a target depends on the shape, color, and material, the measured reflectance (BRDF) of the shape and paint should be applied. Comparison of direction, distance, detection probability, intensity, number of detection points, and size with actual measurement and simulation with a stationary target.	Vehicles set for basic verification (passenger car + large vehicle)	[Point cloud data] Direction, Distance, Direction Reflectance (BRDF) Shape	Number of detection points	The number of vehicle detection points can be detected in the same way as in the actual environment.	F.2.3.2.2.1	○				○	○	○	○	○	○				○	○			
						Size	The size of the vehicle can be detected in the same way as in the actual environment.	F.2.3.2.2.2	○				○	○	○	○	○	○				○	○			
		Dynamic verification (CCRs)	Approach a stationary vehicle and compare changes in direction, distance, number of detection points, and size over time by actual measurement and simulation.	Vehicles set for basic verification (passenger car + large vehicle)	[Point cloud data] Temporal changes in direction and distance	Distance	Being able to detect changes in vehicle distance in the same way as in the actual environment	F.2.3.2.2.3	○			○	○	○	○	○	○	○	○		○	○	○			
						Number of detection points	The change in the number of detected points of the vehicle can be detected in the same way as in the actual environment.	F.2.3.2.2.3	○				○	○	○	○	○	○				○	○			
						Size	Being able to detect changes in the size of the vehicle in the same way as in the actual environment	F.2.3.2.2.3	○				○	○	○	○	○	○				○	○			
					【object】 Temporal change in position and size	Distance	Being able to detect changes in vehicle distance in the same way as in the actual environment	F.2.3.2.2.4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○			
						Size	Being able to detect changes in the size of the vehicle in the same way as in the actual environment	F.2.3.2.2.4	○				○	○	○	○	○	○				○	○			
	Basic traffic flow scenario	Cut-in (Standard-sized car)	Comparison of changes in time direction, distance, number of detection points, and size of vehicles that have been cut-in by actual measurement and simulation	Vehicles set for basic verification (passenger car + large vehicle)	[Point cloud data] Temporal changes in direction and distance	Distance	Being able to detect changes in vehicle distance in the same way as in the actual environment	F.2.3.2.3.1	○	All items to be confirmed are applicable.																
						Number of detection points	The change in the number of detected points of the vehicle can be detected in the same way as in the actual environment.	F.2.3.2.3.1	○																	
						Size	Being able to detect changes in the size of the vehicle in the same way as in the actual environment	F.2.3.2.3.1	○																	
					【object】 Temporal change in position and size	Distance	Being able to detect changes in vehicle distance in the same way as in the actual environment	F.2.3.2.3.2	○																	
						Size	Being able to detect changes in the size of the vehicle in the same way as in the actual environment	F.2.3.2.3.2	○																	
		Cut-in (Large car)	Comparison of changes in time direction, distance, number of detection points, and size of vehicles that have been cut-in by actual measurement and simulation	Vehicle with a long vehicle length	[Point cloud data] Temporal changes in direction and distance	Distance	Being able to detect changes in vehicle distance in the same way as in the actual environment	F.2.3.2.3.3	○																	
						Number of detection points	The change in the number of detected points of the vehicle can be detected in the same way as in the actual environment.	F.2.3.2.3.3	○																	
						Size	Being able to detect changes in the size of the vehicle in the same way as in the actual environment	F.2.3.2.3.3	○																	
					【object】 Temporal change in position and size	Distance	Being able to detect changes in vehicle distance in the same way as in the actual environment	F.2.3.2.3.4	○																	
						Size	Being able to detect changes in the size of the vehicle in the same way as in the actual environment	F.2.3.2.3.4	○																	
		Cut-out	After the preceding vehicle cuts out, approach the stopped vehicle and compare the changes in the temporal direction, distance, number of detection points, and size by actual measurement and simulation.	Vehicles set for basic verification (white Prius, etc. Both preceding and stopped vehicles)	[Point cloud data] Temporal changes in direction and distance	Distance	Being able to detect changes in vehicle distance in the same way as in the actual environment	F.2.3.2.3.5	○																	
						Number of detection points	The change in the number of detected points of the vehicle can be detected in the same way as in the actual environment.	F.2.3.2.3.5	○																	
						Size	Being able to detect changes in the size of the vehicle in the same way as in the actual environment	F.2.3.2.3.5	○																	
					【object】 Temporal change in position and size	Distance	Being able to detect changes in vehicle distance in the same way as in the actual environment	F.2.3.2.3.6	○																	
						Size	Being able to detect changes in the size of the vehicle in the same way as in the actual environment	F.2.3.2.3.6	○																	

F.2.2.3. Conceptual Approach to Common Requirements for Camera Sensors

Unlike active sensors such as millimeter-wave radar and LiDAR, which actively emit signals and receive their reflections,, camera sensors are passive sensors that perceive the external environment by utilizing ambient light. As a result, the nature of the information acquired by camera sensors fundamentally differs from that acquired by active sensors (Table F- 6).
In active sensors, distance information is directly embedded in the signal at the perception stage. In contrast, camera sensors do not directly acquire distance information at the perception stage. Instead, distance is inferred at later processing stages through recognition and estimation algorithms. Conversely, camera sensors are capable of acquiring color information, which cannot be obtained by radar or LiDAR.
This difference arises from the perception principle of camera sensors, which form images using optical elements and image sensors arranged on a two-dimensional plane. Accordingly, these optical and imaging characteristics become particularly important elements in consistency validation for camera sensors.



The radar/LiDAR sensors' perception data includes depth information

	Camera	LiDAR	Radar
r (distance)	-	v	v
theta (azimuth angle)	v	v	v
phi (elevation angle)	v	-	-
v_r (speed in beam direction)	-	-	v
Signal strength (intensity (brightness))	v	v	v
Color (hue, saturation)	v	-	-

Camera signal includes color information

The perception data from the camera's sensors are shown in the form of an image, and the subjects are shown in the image by shape and different sizes depending on their distance

The parameters such as distance, size, speed, etc. from the camera are validated at the recognition stage

It is important for the camera to be able to reproduce the shape of the subject

Figure F- 6. Comparison of Characteristics between Active Sensors and Passive Camera Sensors

Necessity of Image-Level Validation
For camera sensors, it is therefore necessary to verify not only physical quantities derived from recognition results (e.g., estimated distance), but also the image data itself generated at the perception stage.

Image data are defined or generated by a wide range of parameters, including—but not limited to—the following:

- transmittance;
- refractive index;
- photoelectric conversion efficiency;
- number of pixels;
- pixel size;
- distortion ratio;
- focal length;
- orientation of the optical axis; and
- camera mounting height.

These parameters jointly determine the characteristics of the captured image and must be appropriately reproduced in the virtual environment.

Structure of Validation Methods for Camera Sensors

- From this section onward, validation methods for camera sensors are described by classifying them into four domains:
- standalone camera,
- in-vehicle camera,
- assets, and
- scenarios,

and into six validation levels (Levels 0 through 5).
The combinations of items defined in each validation method must be cross-checked with
Table F- 6: List of Perception-Disturbance Reproduction Requirements for Camera Sensors, described later in this annex. Parameter values are then adjusted while considering the assumed camera specifications.

It should be noted that, when mounted on a vehicle, camera sensors are typically affected by mounting errors and optical effects of the windshield to a greater extent than other sensor types. Accordingly, as a prerequisite to this validation, items related to aiming and calibration are explicitly defined and verified.

Organization of Common Requirements for Camera Sensors

Based on the above characteristics, the common requirements for the perception module of camera sensors are organized as shown in Figure F- 7.

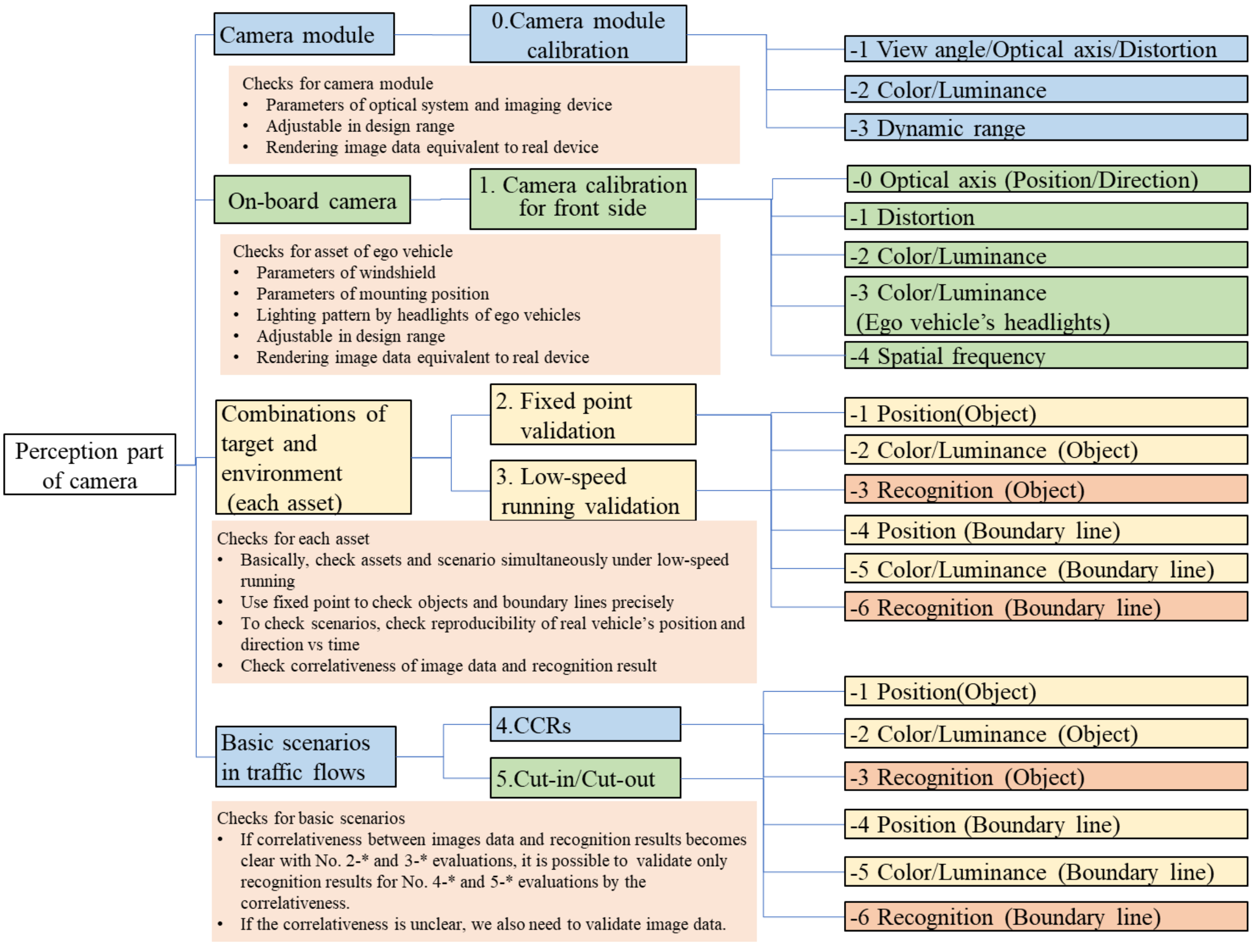


Figure F- 7. Common Requirements for Camera Sensors (Perception Module)

Similarly, the common requirements for the recognition module of camera sensors are organized as shown in Figure F- 8.

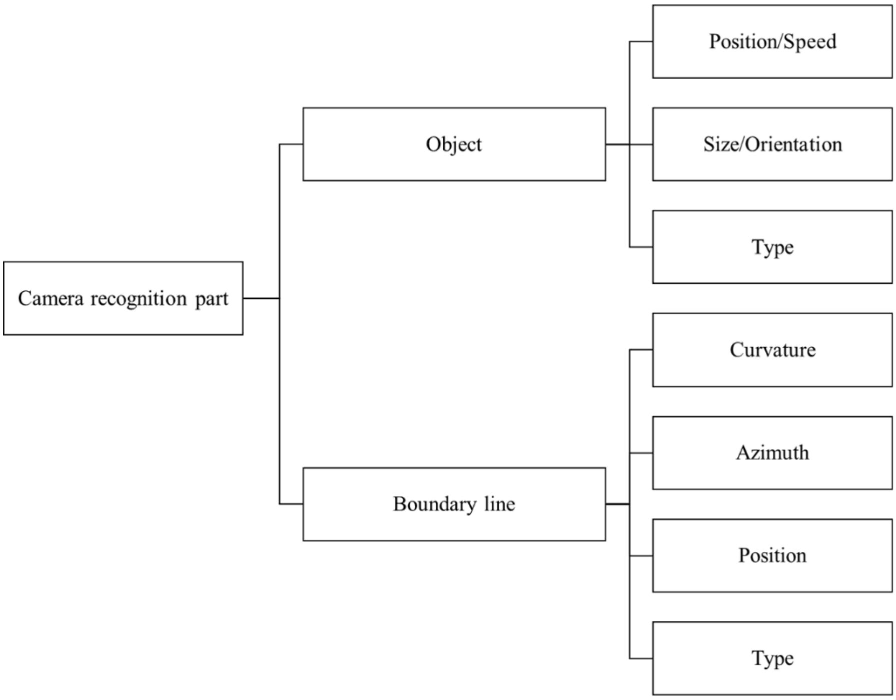


Figure F- 8. Common Requirements for Camera Sensors (Recognition Module)

Based on this conceptual approach, the specific common requirements for camera sensors are organized and summarized in Table F- 3.

Table F- 3.   Common Requirements for Camera Sensors

		Verification							Perception																	Recognition									
									Optics					Imager									Image			Feature			Detection,			Positioning		Tracking	
									Refraction	Reflection	Scattering	Diffraction	Absorption	Noise	Color filter	Exposure time	Exposure period	Time rag for exposure	Overexposure		Underexposure	Lack of Gradation	Brightness	Hue	Chroma	Hidden	Low spatial frequency	Low contrast	No classification	Detection or classification error		Base-position error	Target-position error	Tracking error	Velocity error
		Items/ Target Parts	Measurement items	Parameters	Requirement	Requirement ID	Normal condition(Day)	Normal condition(Night)	Blur, Dislocation, Distortion	Flare, Artifact, Mirrored Objects	Flare	Linear Flare	Vignetting	Random, Fixed-pattern	Fade	Shaked Image	Flicker	Distortion depended on Rolling-shutter	Clipped whites (Too long exposure time)	Clipped whites + Flare (Backlight)	Crushed shadows	Crushed shadows	Out of correct exposure	WB deviation		(Invisible)	(Solid color)(Flattish surface)	(Weak edge)(Similar colors)	(No classification)	(False positive detection)	(False negative detection, or classification error)	(Self-position) (Target-position)	(Size, position, or direction error(s))	(Lost) (Change to another object)	(Orientation error) (Magnitude error)
Common Basic Verification	Stand-alone camera	Adjusting the camera module (Lens)(CMOS)	Angle of view / Optical axis / Distortion	Imaging range Image center position Distortion, Focus	Using test chart, minimize the value gaps of evaluation parameters between RAW images captured by the real camera and created by virtual environment.	0-1	—	レ	◎	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Color brilliance	Luminance, Hue, Color	Using test chart, minimize the value gaps of evaluation parameters between RAW images captured by the real camera and created by virtual environment.	0-2	—	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	—	—	—	—
			Dynamic range	Photoelectric conversion characteristics	Measure photoelectric conversion characteristic of the real sensor. Then minimize the gap between the characteristics of real and virtual sensors.	0-3	—	レ	—	—	—	—	—	—	—	—	—	—	◎	◎	◎	◎	—	○	—	—	—	—	—	—	—	—	—	—	—
	Vehicle-mounted camera	Verification in front of the camera (Installed windshield)	Optical axis (Mounting position/Direction)	Image center position Optical axis	Using real camera, minimize image position differences between targets placed at different distances on reference optical axis.	1-0	レ	—	(◎)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Distortion	Shape, Size	Check distortion characteristics caused by WS. Boundary lines of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 2-1 or 2-4)	1-1	(レ)	—	(◎)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			Color luminance verification	Luminance, Hue, Color	Check similarity on 5x5 points on whole image (RAW format) between real and virtual environment with WS under known lighting conditions. (except geometric view point) (Omittable by substituting 2-2 or 2-5)	1-2	(レ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(◎)	(◎)	—	—	—	—	—	—	—	—	—	—	—
		(Headlight distribution for own car)	Color luminance verification	Luminance, Hue, Color	Check differences of evaluation parameter values between images of real and virtual environment at observation point.	1-3	—	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	—	—	—	—
			Spatial frequency	MTF	Adjust spatial frequency characteristics to meet judgement criteria based on RAW images of real and virtual (CG) environment	1-4	—	レ	○	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—
	Recognition target and environment (asset)	Fixed point verification (Pedestrians) (Passenger cars: Prius) (Passenger car: NCAP dummy car) (Large vehicles) (Boundaries: white line, solid line, dashed line) (Road surface: straight, asphalt)	placement verification (landmarks)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-1)	2-1	(レ)	(レ)	◎	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			color luminance verification(Object)	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-2)	2-2	(レ)	(レ)	—	○	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	—	—	—	—
			Recognition result (Object)	Relative distance	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-3-1)	2-3-1	(レ)	(レ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-3-2)	2-3-2	(レ)	(レ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Relative velocity	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-3-3)	2-3-3	(レ)	(レ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	○	○	◎
				Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-3-4)	2-3-4	(レ)	(レ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	◎	◎	—	—	○	—
			Placement verification(boundary line)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-4)	2-4	(レ)	(レ)	◎	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			color luminance verification(boundary line)	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-5)	2-5	(レ)	(レ)	—	○	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	—	—	—	—
			Recognition result (boundary line)	Curvature	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-6-1)	2-6-1	(レ)	(レ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	○	—
				Azimuth	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-6-2)	2-6-2	(レ)	(レ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	○	—
				Lateral position	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-6-3)	2-6-3	(レ)	(レ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment. (Omittable by substituting 3-6-4)	2-6-4	(レ)	(レ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	◎	◎	—	—	○	—
	Combination of recognition target and environment (asset)	Low-speed movement verification (approach, separation) (Passenger car: Prius) (Road surface: straight, asphalt) (Surface: curved, asphalt) (Boundaries: white line, solid line, dashed line)	Placement verification (landmarks)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-1	レ	レ	◎	○	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			color luminance verification(Object)	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-2	レ	レ	—	○	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	—	—	—	—
			Recognition result (Object)	Relative distance	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-3-1	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-3-2	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Relative velocity	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-3-3	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	○	◎	◎
				Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-3-4	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	◎	◎	—	—	○	—
			Placement verification(boundary line)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-4	レ	レ	◎	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			color luminance verification(boundary line)	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-5	レ	レ	—	○	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	—	—	—	—
			Recognition result (boundary line)	Curvature	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-6-1	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	○	—
				Azimuth	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-6-2	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	○	—
				Lateral position	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-6-3	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-6-4	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	◎	◎	—	—	○	—
	Basic scenario of traffic flow	CCRs	Placement verification (landmarks)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	4-1	レ	—	◎	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			color luminance verification	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	4-2	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	—	—	—	—
			Recognition result (Object)	Relative distance	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	4-3-1	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	4-3-2	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Relative velocity	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	4-3-3	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	○	◎	◎
				Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	4-3-4	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	◎	◎	—	—	○	—
		Cut-in (Passenger car) Cut-in (large vehicle) Cutout (Passenger car) Cutout (large vehicle) (Boundaries: white line, solid line, dashed line) (Road surface: straight, asphalt)	Placement verification (landmarks)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-1	レ	レ	◎	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			color luminance verification(Object)	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-2	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	—	—	—	—
			Recognition result (Object)	Relative distance	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-3-1	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-3-2	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Relative velocity	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-3-3	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	○	◎	◎
				Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-3-4	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	◎	◎	—	—	○	—
			Placement verification(boundary line)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-4	レ	レ	◎	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
			color luminance verification(boundary line)	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-5	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	—	—	—	—
			Recognition result (boundary line)	Curvature	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-6-1	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	○	—
				Azimuth	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-6-2	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	○	—
				Lateral position	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-6-3	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	○	—
				Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-6-4	レ	レ	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	○	◎	◎	—	—	○	—

F.2.3. Validation Methods for Common Requirements

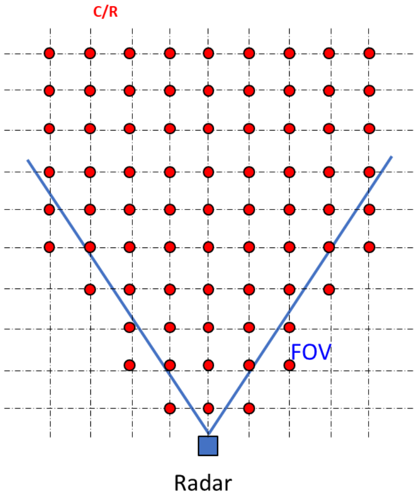
For each sensor type, this section describes the validation methods corresponding to the common requirement items defined in Section F.2.2.

F.2.3.1. Validation Methods for Common Requirements of Millimeter-Wave Radar

F.2.3.1.1. Basic Characteristics of the Sensor Itself: Detection Accuracy (Range and Azimuth)

Validation Method

- Measure the detected positions (range and azimuth) of a corner reflector (C/R) placed at discrete locations within the radar’s field of view (FOV).
- The C/R is moved to one location at a time.
- Compare the detected positions obtained in the real-world environment with those obtained in the simulation environment.



Trihedral Corner Reflector (C/R)

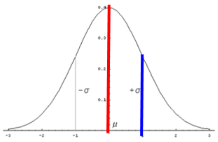
- RCS is recognized
- Retro reflective traits

Source: https://www.everythingrf.com/community/what-is-a-corner-reflector

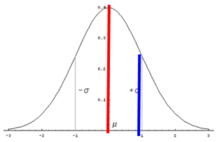
Acceptance Criteria

With respect to the statistical values of the detection results in the real-world environment:

- Median : within 5%
- Variance (σ) : within 10%



Data from Actual Environment

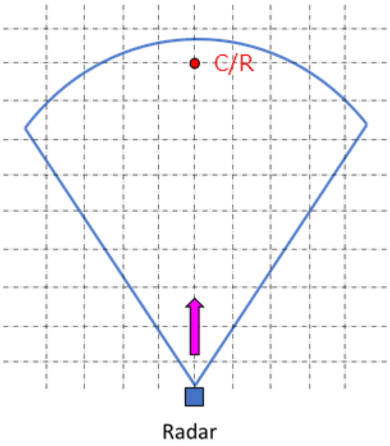


Data from SIM Environment

F.2.3.1.2. Basic Characteristics of the Sensor Itself: Detection Accuracy (Relative Velocity)

Validation Method

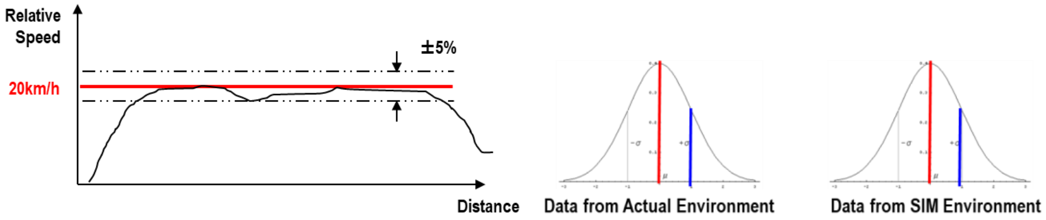
- Install a corner reflector (C/R) directly in front of the radar.
- Move the radar toward the C/R at a constant velocity.
- Compare the detected relative velocity between the real-world environment and the simulation environment.



Acceptance Criteria

With respect to the statistical values of the detection results in the real-world environment:

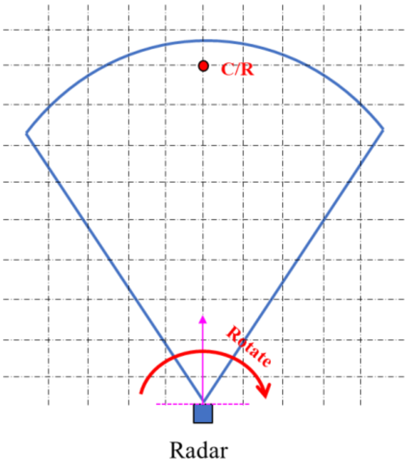
- Median : within 5%
  Variance (σ) : within 10%



F.2.3.1.3. Basic Characteristics of the Sensor Itself: Detection Accuracy (Received Power)

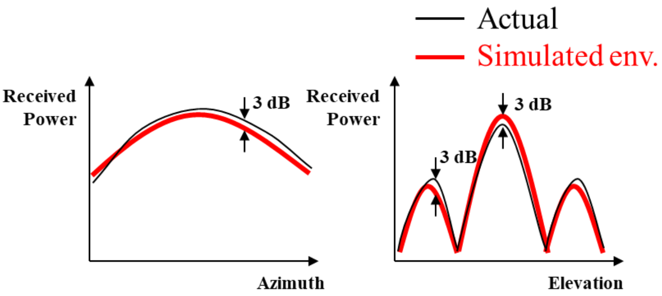
Validation Method

- Install a corner reflector (C/R) directly in front of the radar.
- Rotate the radar horizontally and vertically and measure the received signal power.



Acceptance Criteria

Difference in received power between the real system and the simulation: within 3 dB

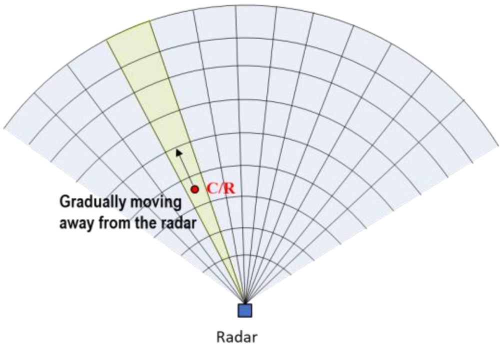


F.2.3.1.4. Basic Characteristics of the Sensor Itself: Resolution (Range and Azimuth)

<Range Resolution>

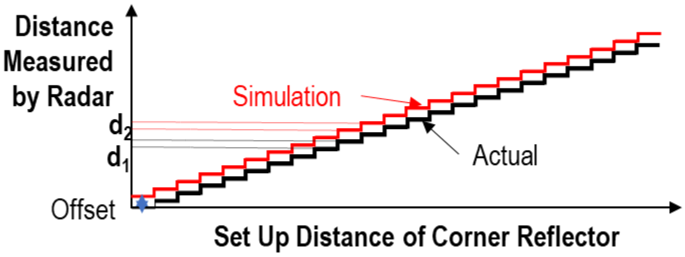
Validation Method

- Install a corner reflector (C/R) within the radar's FOV.
- Gradually increase the distance of the C/R along the normal direction from the radar.
- Evaluate the relationship between the installed distance and the distance measured by the radar.



Acceptance Criteria

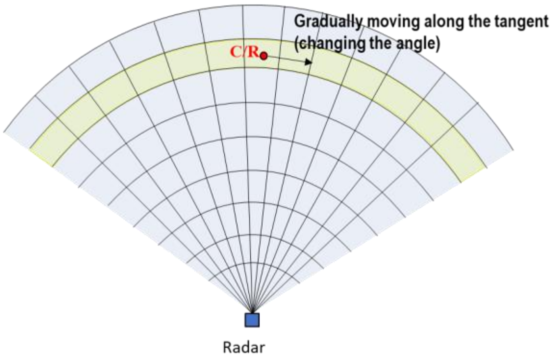
- The number of step levels derived from the installed distance versus measured distance relationship shall match between the real system and the simulation.
- The difference between the step sizes d_1 (real system) and d_2 (simulation) shall be within 15%.



<Horizontal Azimuth Resolution>

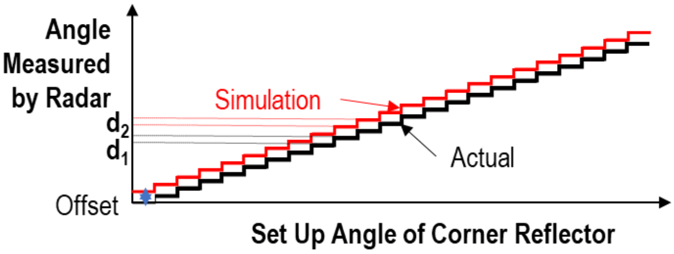
Validation Method

- Install a corner reflector (C/R) within the radar's FOV.
- Gradually move the C/R in the horizontal tangential direction.
- Compare the measured azimuth angles with the installed azimuth angles.



Acceptance Criteria

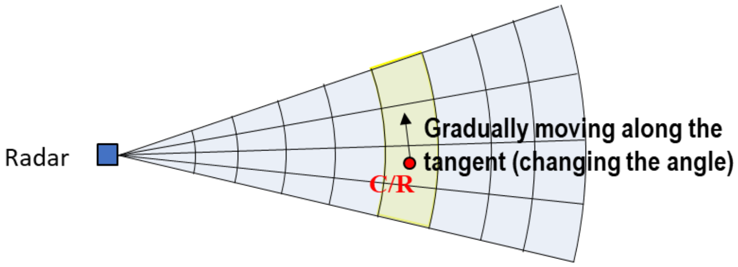
- The number of step levels derived from the measured-angle versus installed-angle relationship shall match between the real system and the simulation.
- The difference between the step sizes d_1 and d_2 shall be within 15%.



<Vertical Elevation Resolution>

Validation Method

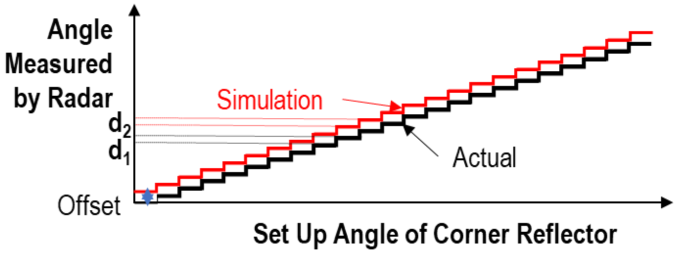
- Install a corner reflector (C/R) within the radar's FOV.
- Gradually move the C/R in the vertical tangential direction.
- Compare the measured elevation angles with the installed elevation angles.



Acceptance Criteria

- The number of step levels derived from the measured-angle versus installed-angle relationship shall match between the real system and the simulation.

- The difference between the step sizes d_1 and d_2 shall be within 15%.

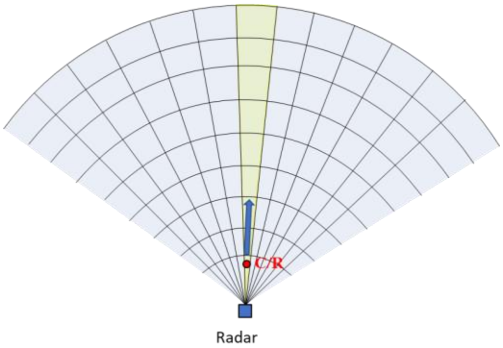


F.2.3.1.5. Basic Characteristics of the Sensor Itself: Resolution (Relative Velocity)

<Velocity Resolution>

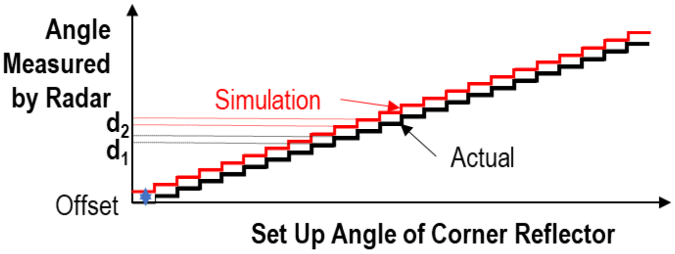
Validation Method

- Install a corner reflector (C/R) within the radar’s FOV.
- Move the C/R at multiple constant velocities.
- Evaluate the relationship between the measured velocities and the actual movement velocities.



Acceptance Criteria

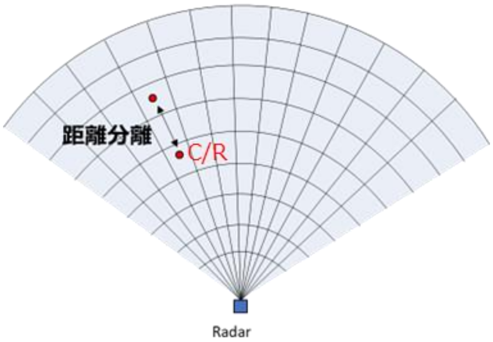
- The number of step levels derived from the measured-velocity versus actual-velocity relationship shall match between the real system and the simulation.
- The difference between the step sizes d_1 and d_2 shall be within 15%.



<Range Resolution (Target Separation)>

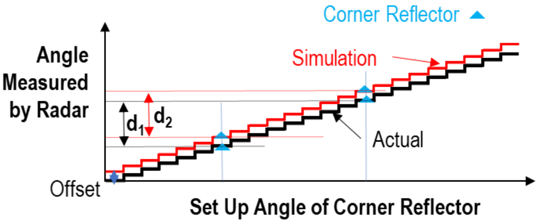
Validation Method

- Install two C/Rs of identical specifications in close proximity within the radar's FOV.
- Conduct multiple measurements while gradually varying the separation distance between the two C/Rs.
- Verify the radar's target separation capability based on the measured results.



Acceptance Criteria

- The average separable distance calculated from multiple measurements, shall differ by no more than a 15% between the real system value d_1 and the simulation value d_2.

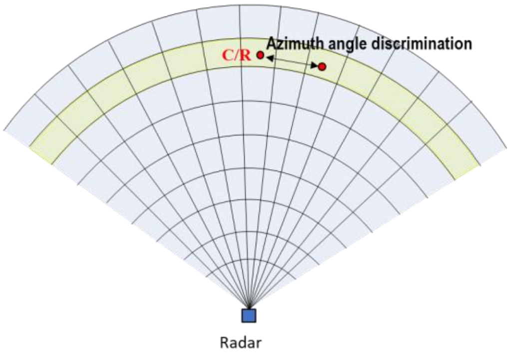


F.2.3.1.6. Basic Characteristics of the Sensor Itself: Separation Capability (Range and Azimuth)

<Horizontal Azimuth Separation Capability>

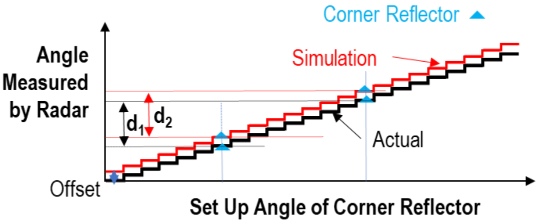
Validation Method

- Install two C/Rs of identical specifications at the same range within the radar's FOV.
- Place the two C/Rs in close proximity in the horizontal azimuth direction.
- Perform multiple measurements while stepwise varying the installation angles of the two C/Rs.
- Verify the radar's horizontal azimuth separation capability based on the measured results.



Acceptance Criteria

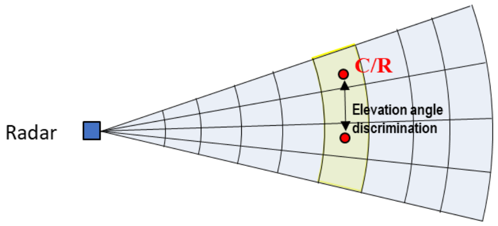
- The average separable azimuth angle, calculated from multiple measurements shall differ by no more than a 15% between the real system value d_1 and the simulation value d_2.



<Vertical Elevation Separation Capability>

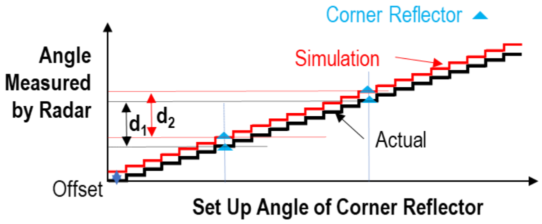
Validation Method

- Install two C/Rs of identical specifications at the same range within the radar's FOV.
- Place the two C/Rs in close proximity in the vertical elevation direction.
- Perform multiple measurements while stepwise varying the installation angles of the two C/Rs.
- Verify the radar's vertical elevation separation capability based on the measured results.



Acceptance Criteria

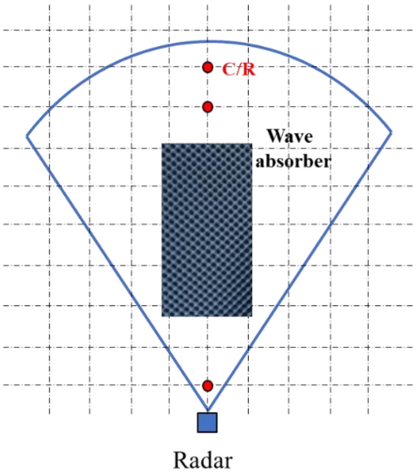
- The average separable elevation angle, calculated from multiple measurements, shall differ by no more than a 15% between the real system value d_1 and the simulation value d_2.



F.2.3.1.7. Basic Characteristics of the Sensor Itself: Free-Space Received Power

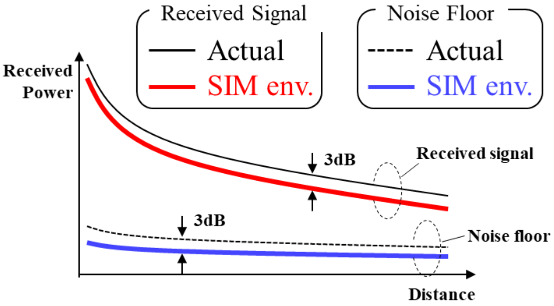
Validation Method

- Install a C/R directly in front of the radar.
- Measure the received power at multiple distances by varying the installation distance of the C/R.
- To eliminate the influence of road-surface reflections, install electromagnetic wave absorbers near the anticipated road-surface reflection points.



Acceptance Criteria

Difference in received power	: within 3 dB
Difference in noise-floor power	: within 3 dB
Difference in SNR	: within 3 dB

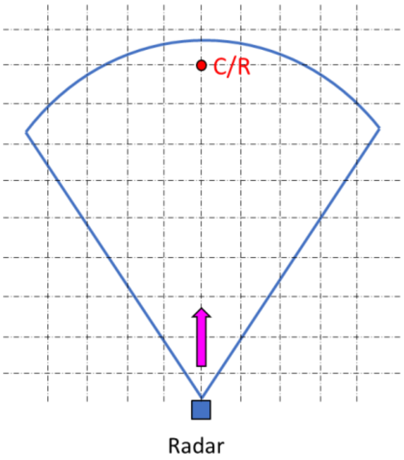


F.2.3.1.8. Basic Characteristics of the Sensor Itself: On-Road Received Power

Validation Method

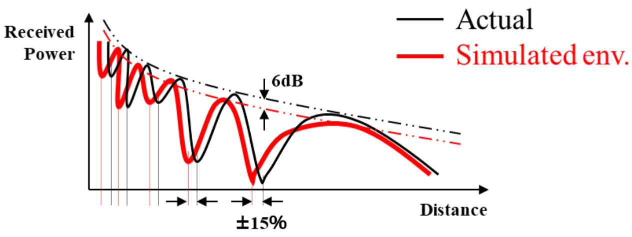
Install a corner reflector (C/R) directly in front of the radar and move the radar toward the corner reflector.

- Install a C/R directly in front of the radar.
- Move the radar toward the corner reflector along the roadway while continuously measuring the received signal.



Acceptance Criteria

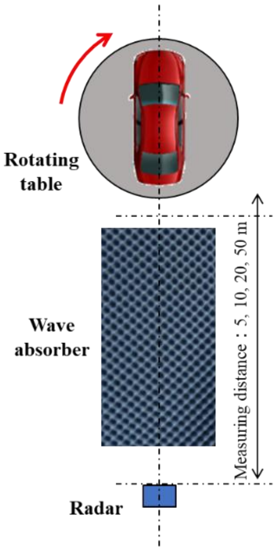
- Difference in received-power envelope : within 6 dB
- Difference in null-point distance : within ±15%



F.2.3.1.9. Reflective Characteristics of Recognition Targets: Vehicles (Passenger Cars and Large Vehicles) — RCS

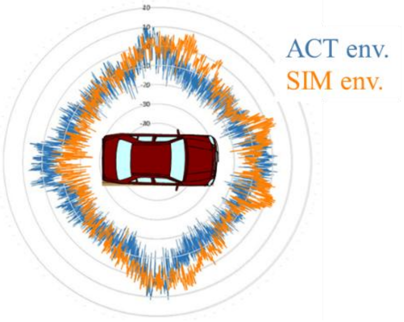
Validation Method

- Irradiate radar electromagnetic waves onto a vehicle mounted on a turntable.
- Rotate the vehicle and measure the received signal power as a function of the rotation (azimuth) angle.
- Conduct measurements at the following distances: 5 m, 10 m, 20 m, and 50 m.
- Use the following vehicle types as recognition targets: passenger car and large trailer.
- Compare the received power characteristics obtained in the real-world environment with those obtained in the simulation environment.



Acceptance Criteria

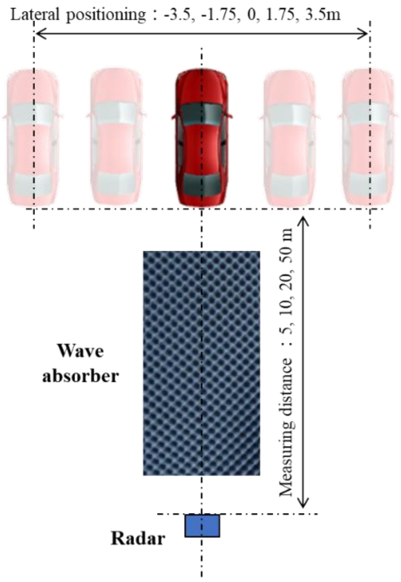
- Difference in received power: within 3 dB over all azimuth angles



F.2.3.1.10. Reflective Characteristics of Recognition Targets: Vehicles (Passenger Cars and Large Vehicles) — Reflection Points

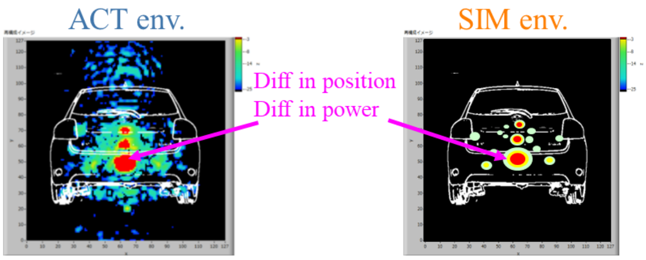
Validation Method

- Irradiate radar electromagnetic waves toward the rear of the vehicle and generate radar images.
- Conduct measurements at the following distances: 5, 10, 20, and 50 m
- Use the following vehicle types as recognition targets: passenger car and large trailer.
  Set the lateral positions of the vehicle to 0 m, ±1.75 m, and ±3.5 m, corresponding to positions within the ego lane, on lane markings, and in adjacent lanes, respectively.
- Compare the distribution of reflection intensity obtained in the real-world environment with that obtained in the simulation environment.



Acceptance Criteria

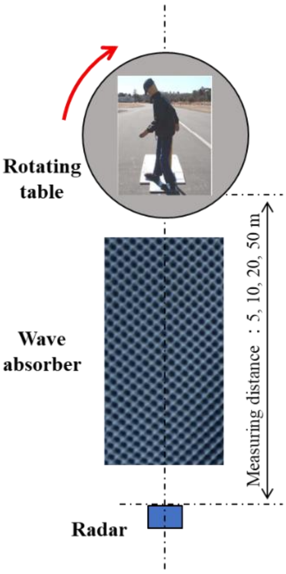
- Difference in reflection-intensity peak position : within 3° of FOV angle
- Difference in received power at the peak position : within 3 dB



F.2.3.1.11. Reflective Characteristics of Recognition Targets: Pedestrian — RCS

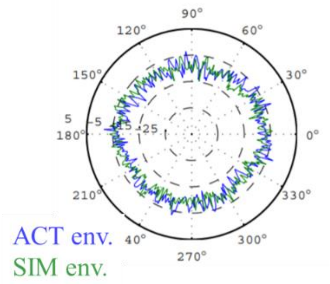
Validation Method

- Irradiate radar electromagnetic waves onto a pedestrian dummy mounted on a turntable.
- Rotate the dummy and measure the received signal power as a function of the rotation (azimuth) angle.
- Conduct measurements at the following distances: 5 m, 10 m, 20 m, and 50 m.
- Compare the received-power characteristics obtained in the real-world environment with those obtained in the simulation environment.



Acceptance Criteria

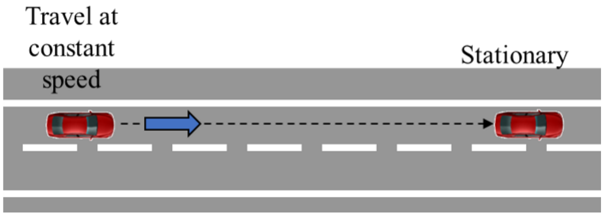
- Difference in received power: within 3 dB over all azimuth angles



F.2.3.1.12. Basic Traffic-Flow Scenario: NCAP CCRs — Received Power

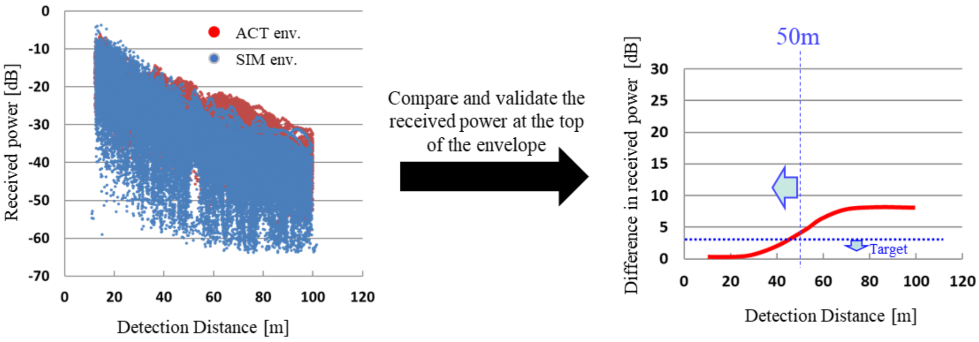
Validation Method

- Reproduce the NCAP CCRs scenario.
- Set the ego-vehicle velocity at two representative points corresponding to low and high speeds within the range of 20 km/h to 60 km/h.
- Measure the received power from the stationary target vehicle located ahead of the ego vehicle and plot the upper-bound envelope curve of the received power.
- Compare the changes in the received-power envelope curve obtained in the real-world environment with those obtained in the simulation environment.



Acceptance Criteria

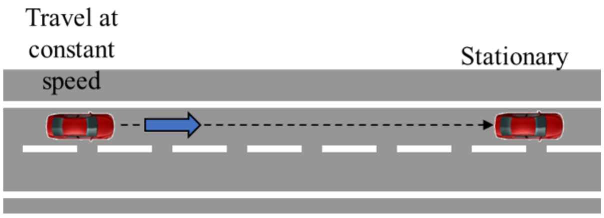
- Difference in received-power envelope: within 3 dB for relative distances of 50 m or less



F.2.3.1.13. Basic Traffic-Flow Scenario: NCAP CCRs — Detection Position

Validation Method

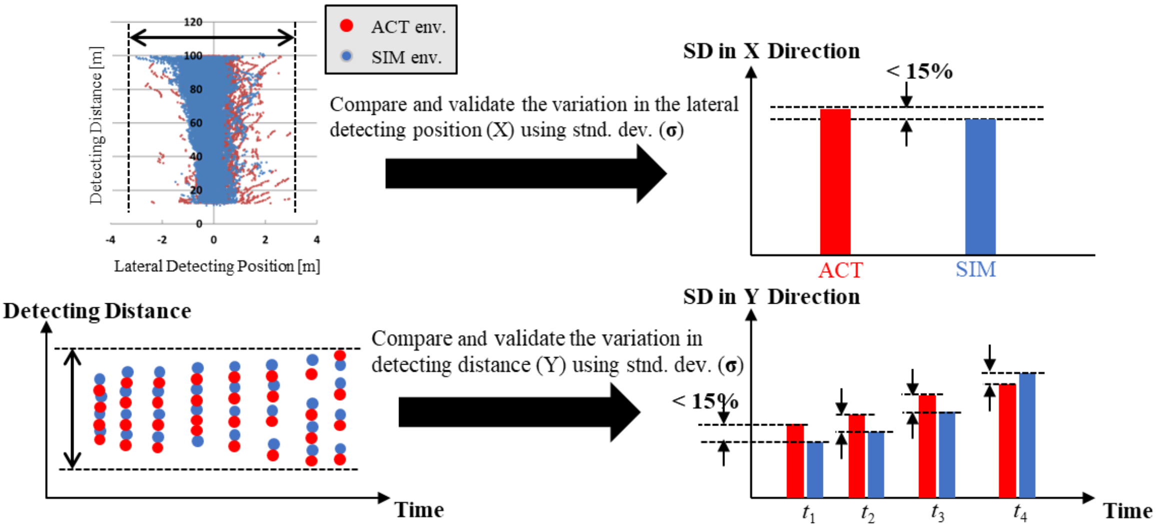
- Reproduce the NCAP CCRs scenario.
- Set the ego-vehicle velocity at two representative points corresponding to low and high speeds within the range of 20 km/h to 60 km/h.
- Measure the detected reflection-point positions (X, Y) of the stationary target vehicle located ahead of the ego vehicle.
- Compare the degree of variability in detected positions between the real-world environment and the simulation environment.



Acceptance Criteria

For relative distances of 50 m or less, the difference in standard deviation of the detected positions shall satisfy the following conditions:

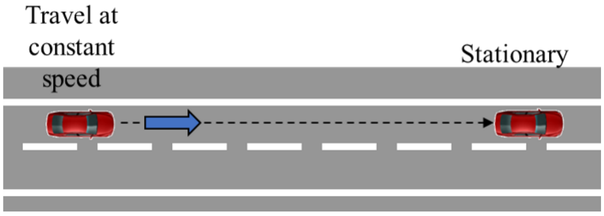
- X direction (lateral) : within 15%
- Y direction (longitudinal) : within 15%



F.2.3.1.14. Basic Traffic-Flow Scenario: NCAP CCRs — Detection Velocity

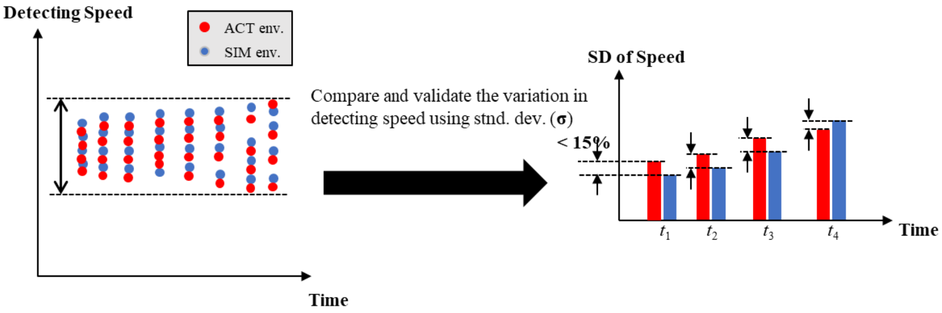
Validation Method

- Reproduce the NCAP CCRs scenario.
- Set the ego-vehicle velocity at two representative points corresponding to low and high speeds within the range of 20 km/h to 60 km/h.
- Measure the detected velocity of the reflection points from the stationary target vehicle located ahead, focusing on the Y direction (longitudinal direction).
- Compare the degree of variability in detected velocity between the real-world environment and the simulation environment.



Acceptance Criteria

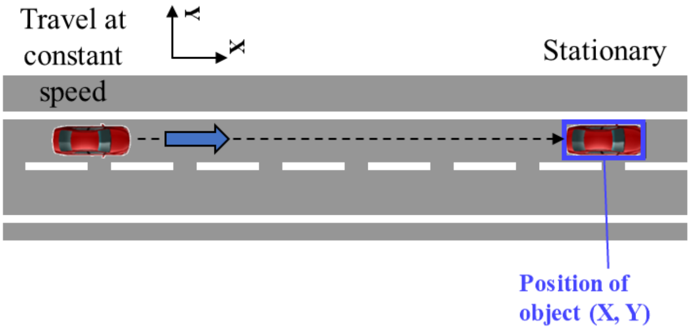
- For relative distances of 50 m or less, the difference in standard deviation of the detected velocity shall be within 15%.



F.2.3.1.15. Basic Traffic-Flow Scenario: NCAP CCRs — Object Detection Position (Range and Azimuth)

Validation Method

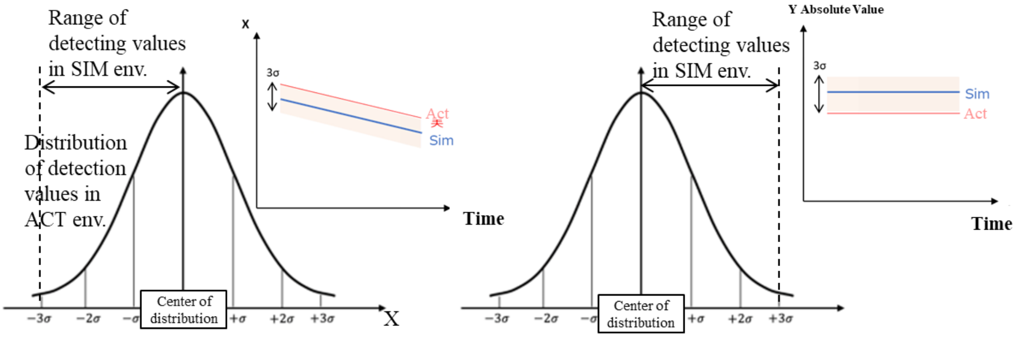
- Reproduce the NCAP CCRs scenario.
- Measure the object-level detected position of the stationary target vehicle located ahead of the ego vehicle.
- Set the ego-vehicle velocity at two representative points corresponding to low and high speeds within the range of 20 km/h to 60 km/h.
- Compare the object X–Y coordinates obtained in the real-world environment with those obtained in the simulation environment.



Acceptance Criteria

For relative distances of 50 m or less, the detected object position in the virtual environment shall satisfy the following conditions with respect to the detection-value distribution obtained in the real-world environment:

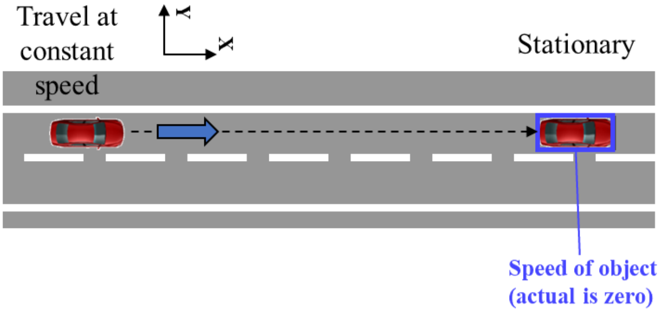
- X direction (lateral):
  The detected value in the virtual environment shall lie within 3σ on the short-distance side of the real-world detection-value distribution.
- Y direction (longitudinal):
  The detected value in the virtual environment shall Lie within 3σ on the long-distance side of the real-world detection-value distribution.



F.2.3.1.16. Basic Traffic-Flow Scenario: NCAP CCRs — Object Detection Velocity

Validation Method

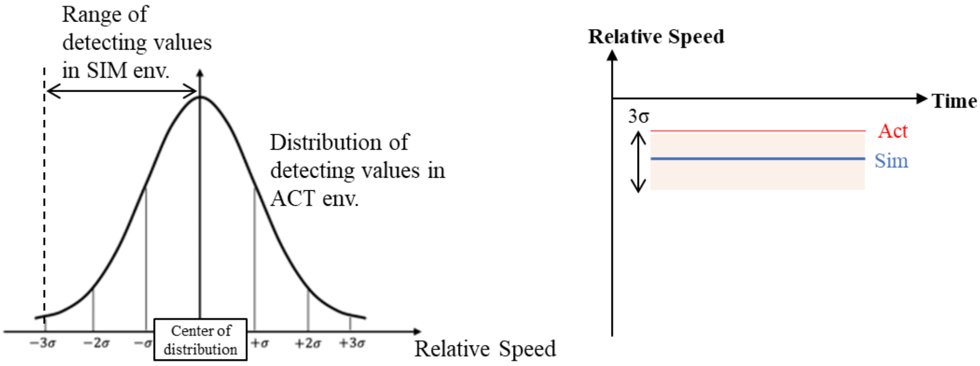
- Reproduce the NCAP CCRs scenario.
- Measure the object-level detected velocity of the stationary target vehicle located ahead of the ego vehicle.
- Set the ego-vehicle velocity at two representative points corresponding to 20 km/h and 60 km/h.
- Compare the object-level detected velocity obtained in the real-world environment with that obtained in the simulation environment.



Acceptance Criteria

For relative distances of 50 m or less, the detected object velocity in the virtual environment shall satisfy the following condition with respect to the distribution of detected velocities obtained in the real-world environment:

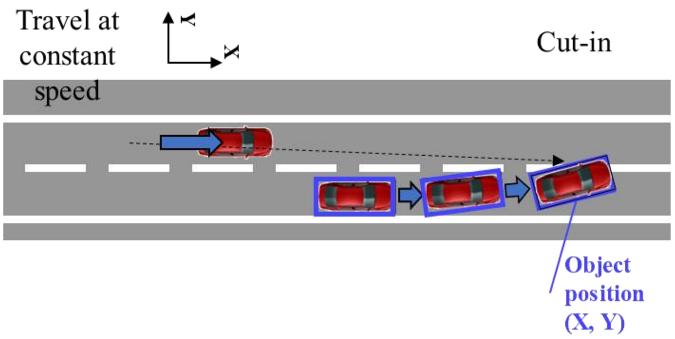
- The detected value shall lie within 3σ on the lower-velocity side of the real-world detection-velocity distribution.



F.2.3.1.17. Basic Traffic-Flow Scenario: Cut-In — Object Detection Position (Range and Azimuth)

Validation Method

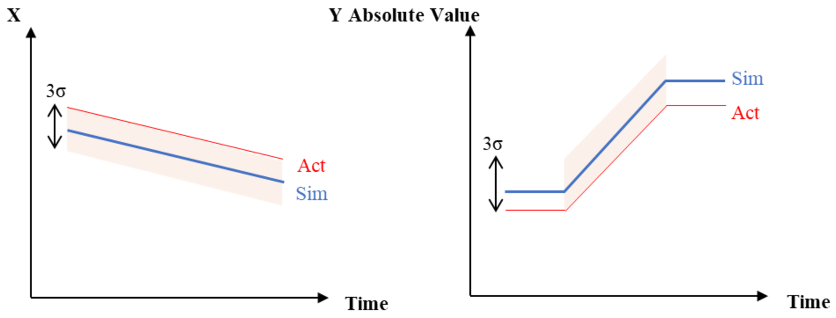
- Reproduce a cut-in scenario in which another vehicle cuts in ahead of the ego vehicle.
- Plot the object-level detected positions of the cut-in vehicle.
- Set the ego-vehicle velocity to a constant speed of 60 km/h.
- Set the object vehicle velocity as follows:
  Longitudinal direction: constant velocity of approximately 40 km/h;
  Lateral direction: three representative values within the range of 0.2 m/s to 2.0 m/s.
- Use the following object types as recognition targets: passenger car and large trailer.
- Compare the object-level detected positions obtained in the real-world environment with those obtained in the simulation environment.



Acceptance Criteria

For relative distances of 50 m or less, the detected object position in the virtual environment shall satisfy the following conditions with respect to the distribution of detected positions obtained in the real-world environment:

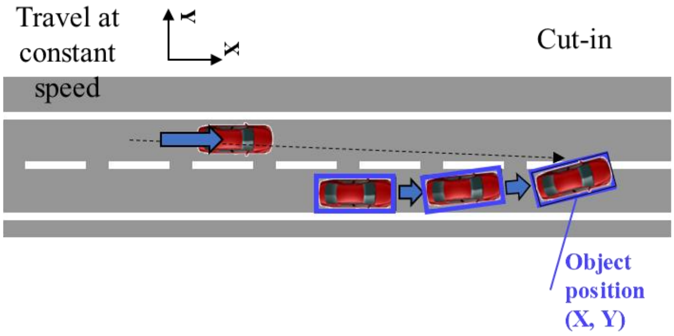
- X direction (lateral): the detected value shall lie within 3σ on the short-distance side of the real-world detection-position distribution.
- Y direction (longitudinal): the detected value shall lie within 3σ on the long-distance side of the real-world detection-position distribution.



F.2.3.1.18. Basic Traffic-Flow Scenario: Cut-In — Object Detection Velocity

Validation Method

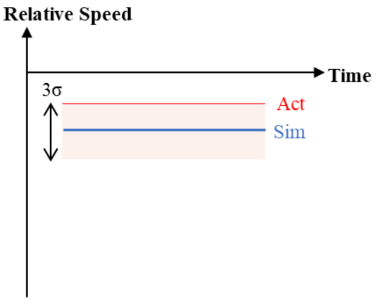
- Reproduce a cut-in scenario in which another vehicle cuts in ahead of the ego vehicle.
- Plot the object-level detected velocity of the cut-in vehicle.
- Set the ego-vehicle velocity to a constant speed of approximately 60 km/h.
- Set the object vehicle velocity as follows:
  Longitudinal direction: constant velocity of approximately 40 km/h;
  Lateral direction: three representative values within the range of 0.2 m/s to 2.0 m/s.
- Use the following object types as recognition targets: passenger car and large trailer.
- Compare the object-level detected velocity values obtained in the real-world environment with those obtained in the simulation environment.



Acceptance Criteria

For relative distances of 50 m or less, the detected object velocity in the virtual environment shall satisfy the following condition with respect to the distribution of detected velocities obtained in the real-world environment:

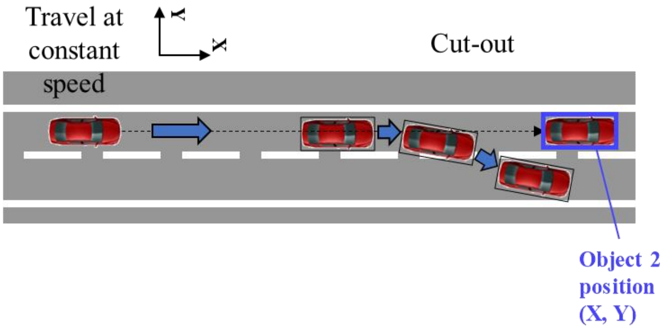
- The detected value shall lie within 3σ on the lower-velocity side of the real-world detection-velocity distribution.



F.2.3.1.19. Basic Traffic-Flow Scenario: Cut-Out — Object Detection Position (Range and Azimuth)

Validation Method

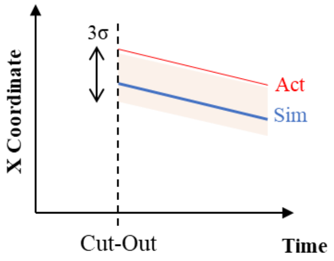
- Reproduce a cut-out scenario in which a lead vehicle performs a cut-out maneuver and a stationary vehicle is present ahead.
- Plot the object-level detected position of the stationary vehicle (Object 2) after the cut-out maneuver.
- Set the ego-vehicle velocity to a constant speed of approximately 60 km/h.
- Set the velocity of Object 1 (cut-out vehicle) as follows:
  Longitudinal direction: constant velocity of approximately 40 km/h;
  Lateral direction: approximately 1.0 m/s.
- Use the following object types:
  Object 1: passenger car (cut-out vehicle);
  Object 2: passenger car (stationary).
- Compare the detected positions of Object 2 obtained in the real-world environment with those obtained in the simulation environment.

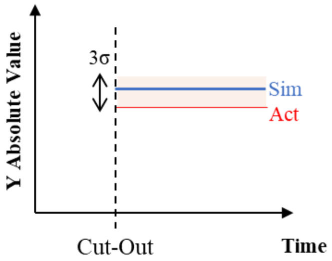


Acceptance Criteria

For the post–cut-out detection positions, the detected object position in the virtual environment shall satisfy the following conditions with respect to the distribution of detected positions obtained in the real-world environment:

- X direction (lateral): the detected value shall lie within 3σ on the short-distance side of the real-world detection-position distribution.
- Y direction (longitudinal): the detected value shall lie within 3σ on the long-distance side of the real-world detection-position distribution.

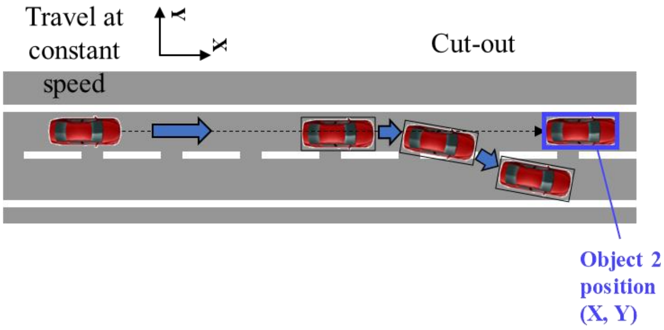




F.2.3.1.20. Basic Traffic-Flow Scenario: Cut-Out — Object Detection Velocity

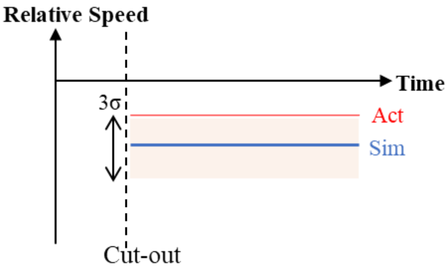
Validation Method

- Reproduce a cut-out scenario in which a lead vehicle performs a cut-out maneuver and a stationary vehicle is present ahead.
- Plot the object-level detected velocity of the stationary vehicle (Object 2) after the cut-out maneuver.
- Set the ego-vehicle velocity to a constant speed of approximately 60 km/h.
- Set the velocity of Object 1 (cut-out vehicle) as follows:
  Longitudinal direction: constant velocity of approximately 40 km/h;
- Lateral direction: approximately 1.0 m/s.
- Use the following object types:
  Object 1: passenger car (cut-out vehicle);
  Object 2: passenger car (stationary).
- Compare the detected velocity of Object 2 obtained in the real-world environment with that obtained in the simulation environment.



Acceptance Criteria

- The detected value in the virtual environment shall lie within 3σ on the lower-velocity side of the distribution of detected velocities obtained in the real-world environment.



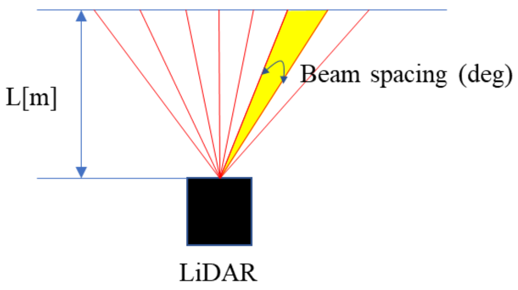
F.2.3.2. Validation Methods for Common Requirements of LiDAR

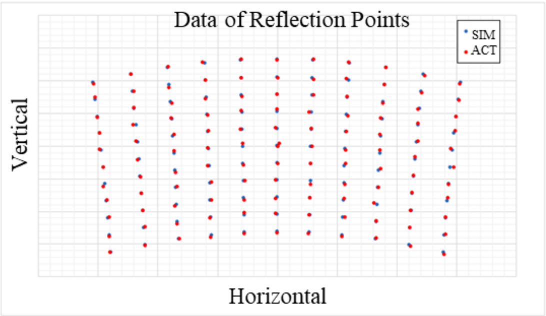
This subsection describes the validation methods for verifying the common requirements of LiDAR sensors, as defined in Section F.2.2.

F.2.3.2.1. Basic Characteristics of the Sensor Itself: Azimuth

Validation Method

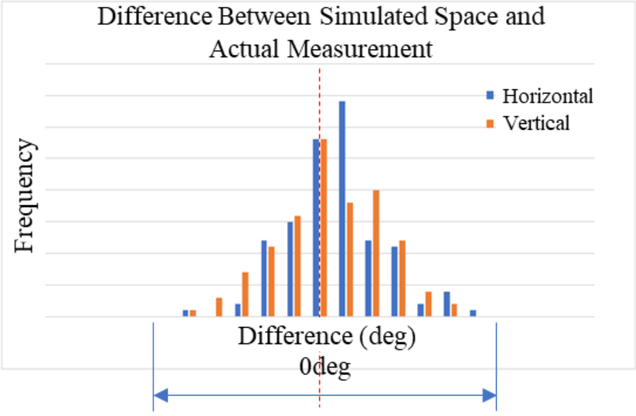
- Emit laser light from the LiDAR toward a wall located at a known distance L
- Measure the coordinate positions of the laser spots on the wall.
- Confirm that the difference between the results obtained in the virtual environment and those measured in the real-world environment fall within the acceptable range.





Acceptance Criteria

- Emission interval (angular resolution): within ±5%

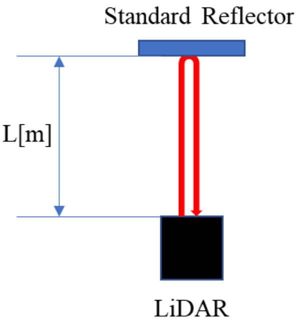


Within ±5% of beam spacing (deg)

F.2.3.2.2. Basic Characteristics of the Sensor Itself: Range

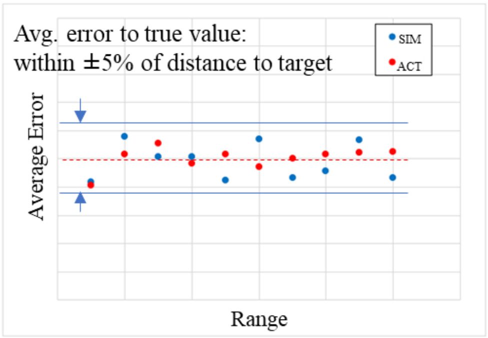
Validation Method

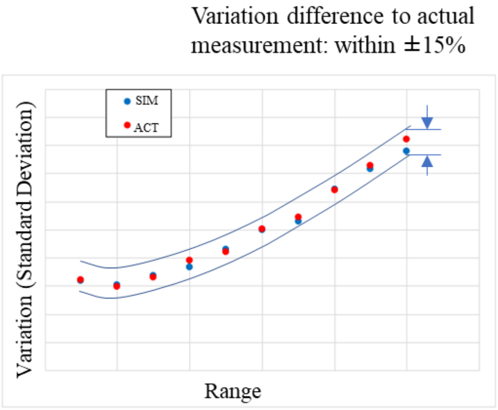
- Measure the range error and variability while changing the distance between the LiDAR and a standard reflective plate.



Acceptance Criteria

- Mean error relative to the true value: within ±5% of the target distance.
- Difference in variability compared with measured values: within ±15%.

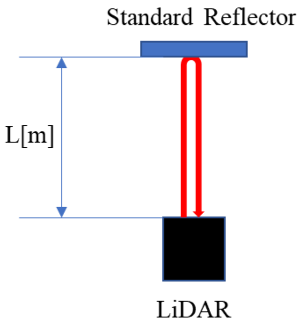




F.2.3.2.3. Basic Characteristics of the Sensor Itself: Intensity and Detection Probability

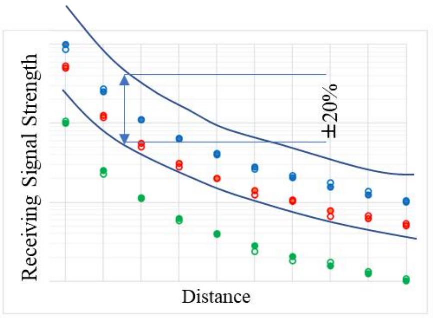
Validation Method

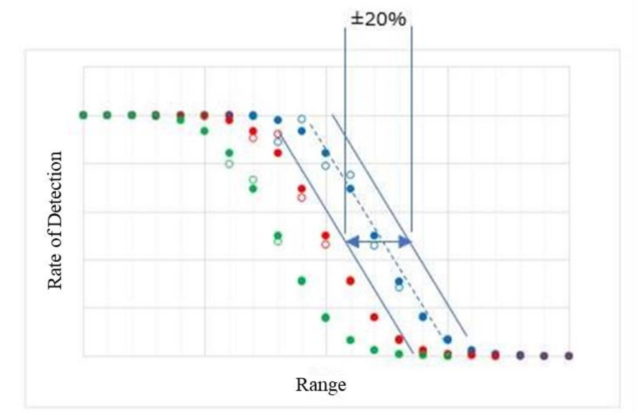
- Measure the received intensity and detection probability while changing the distance between the LiDAR and a standard reflective plate.



Acceptance Criteria

- Intensity error compared with measured values: within ±20%
- Difference in detection probability compared with measured values at:
  90% detection probability: within ±20%;
  50% detection probability: within ±20%;
  10% detection probability: within ±20%.



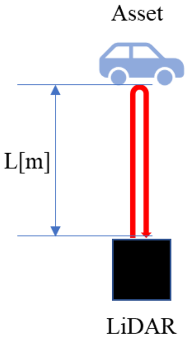


※Blue: reflectivity xx% Red: reflectivity xx% Green: reflectivity xx%
※●Actual ○Simulation

F.2.3.2.4. Reflective Characteristics of Recognition Targets: Number of Points

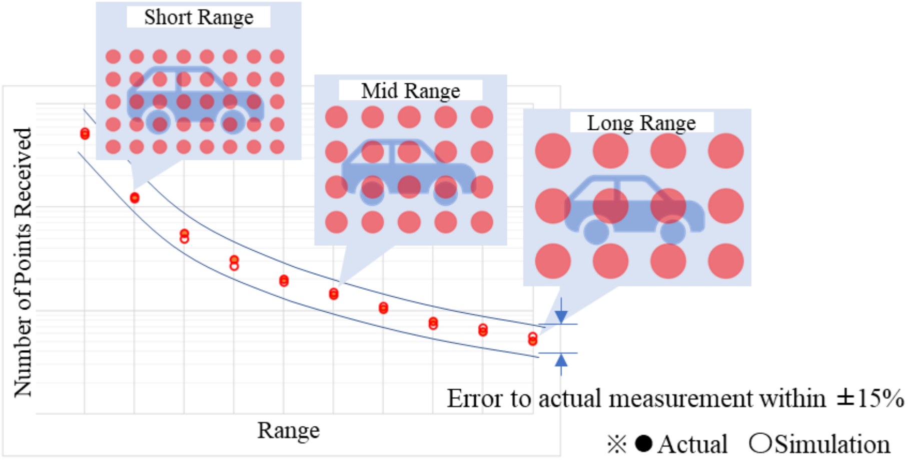
Validation Method

- Measure the number of detected points while changing the distance between the LiDAR and the recognition-target asset.



Acceptance Criteria

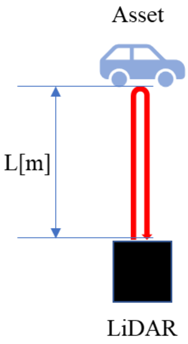
- Error relative to measured number of points: within ±15%,
  excluding long-distant ranges in which the number of received points becomes inherently small.



F.2.3.2.5. Reflective Characteristics of Recognition Targets: Size

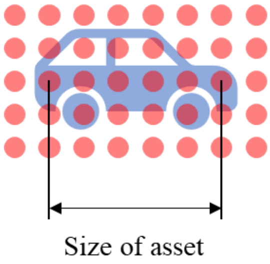
Validation Method

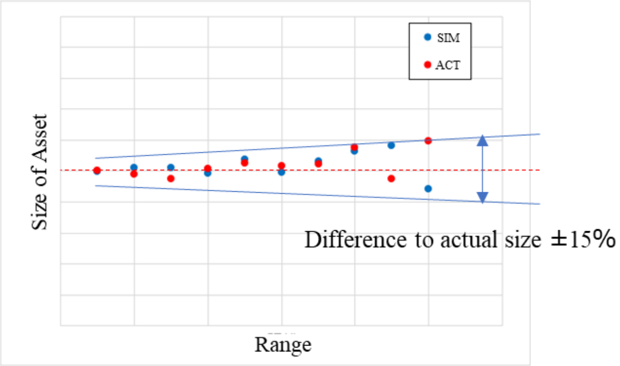
- Measure the estimated object size while changing the distance between the LiDAR and the recognition-target asset.



Acceptance Criteria

- Deviation from the actual object size: within 15%.

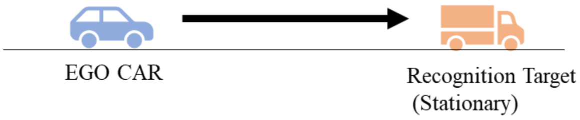


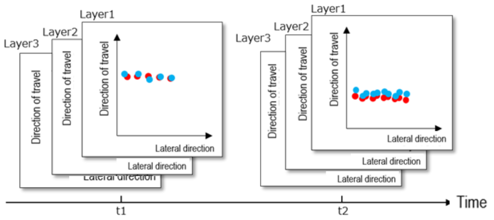


F.2.3.2.6. Reflective Characteristics of Recognition Targets: Dynamic Validation — Point Cloud Level

Validation Method

- Approach a stationary vehicle and compare, between the real-world environment and the simulation environment, the temporal changes in the following point-cloud-level quantities:
  azimuth,
  range,
  number of detection points, and
  estimated size.
- Example condition: approach the recognition target at 40 km/h, apply braking, and come to a stop at a position 20 m in front of the target.





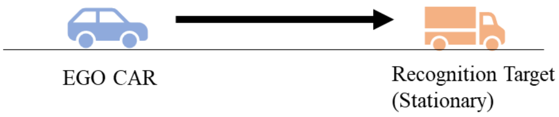
Acceptance Criteria

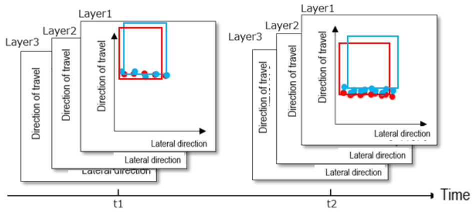
- At each time step, range, number of detection points, and size shall satisfy the criteria defined in F.2.3.2.2, F.2.3.2.4, and F.2.3.2.5.

■Reflective Characteristics of Recognition Targets: Dynamic Validation — Object Level

Validation Method

- Approach a stationary vehicle and compare, between the real-world environment and the simulation environment, the temporal changes in:
  range (longitudinal and lateral directions), and
  object size,
  at the object level.
- Example condition: approach the recognition target at 40 km/h, apply braking, and come to a stop at a position 20 m in front of the target.





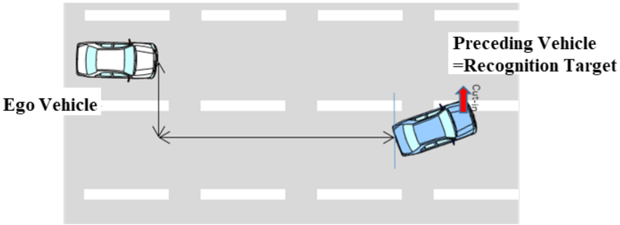
Acceptance Criteria

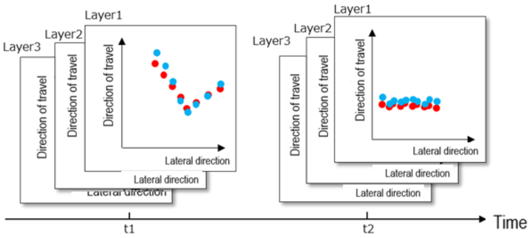
- At each time step, range (longitudinal and lateral) and size shall satisfy the criteria defined in F.2.3.2.2 and F.2.3.2.5.

F.2.3.2.7. Basic Traffic-Flow Scenario: Cut-In Scenario (Passenger Car) — Point Cloud Level

Validation Method

- In a cut-in scenario involving a passenger car, compare, between measured results and simulation results, the temporal changes in:
  azimuth,
  range,
  number of detection points, and
  size,
  at the point-cloud level.
- Example condition: ego-vehicle velocity 60 km/h, lead-vehicle longitudinal velocity 40 km/h, lateral velocity 1.0 m/s during the cut-in maneuver.





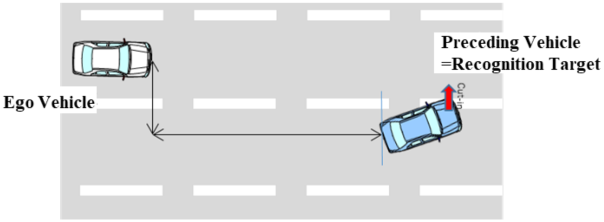
Acceptance Criteria

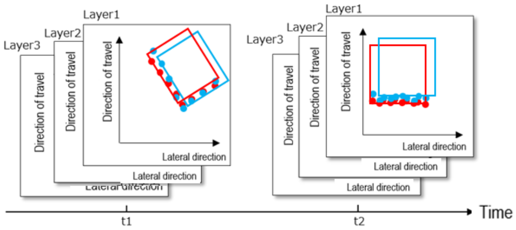
- At each time step, range (longitudinal and lateral), number of detection points, and size shall satisfy the criteria defined in F.2.3.2.2, F.2.3.2.4, and F.2.3.2.5.

F.2.3.2.8. Basic Traffic-Flow Scenario: Cut-In Scenario (Passenger Car) — Object Level

Validation Method

- In a cut-in scenario involving a passenger car, compare, between measured results and simulation results, the temporal changes in:
  range (longitudinal and lateral directions), and
  size,
  at the object level.
- Example condition: ego-vehicle velocity 60 km/h, lead-vehicle longitudinal velocity 40 km/h, lateral velocity 1.0 m/s during the cut-in maneuver.





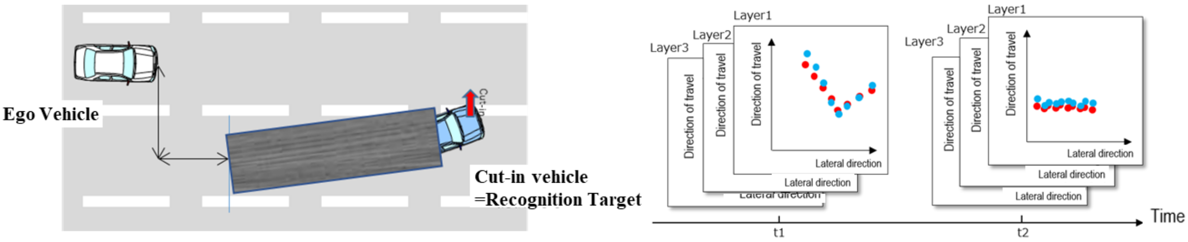
Acceptance Criteria

- At each time step, range (longitudinal and lateral) and size shall satisfy the criteria defined in F.2.3.2.2 and F.2.3.2.5.

F.2.3.2.9. Basic Traffic-Flow Scenario: Cut-In Scenario (Large Vehicle) — Point Cloud Level

Validation Method

- In a cut-in scenario involving a large vehicle, compare, between measured results and simulation results, the temporal changes in:
  azimuth,
  range,
  number of detection points, and
  size,
  at the point-cloud level.
- Example condition: ego-vehicle velocity 60 km/h, lead-vehicle longitudinal velocity 40 km/h, lateral velocity 1.0 m/s during the cut-in maneuver.



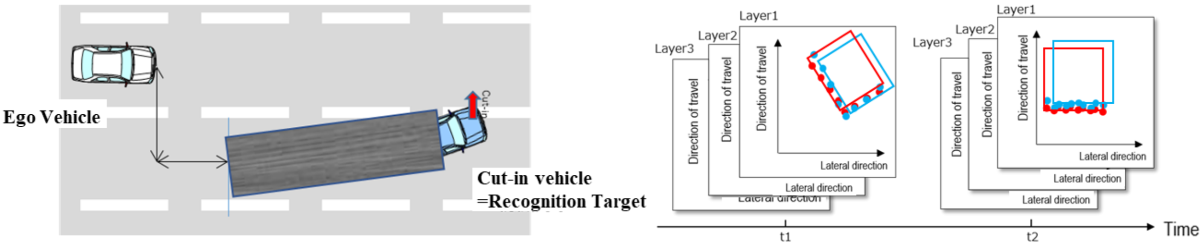
Acceptance Criteria

- At each time step, range, number of detection points, and size shall satisfy the criteria defined in F.2.3.2.2, F.2.3.2.4, and F.2.3.2.5.

F.2.3.2.10. Basic Traffic-Flow Scenario: Cut-In Scenario (Large Vehicle) — Object Level

Validation Method

- In a cut-in scenario involving a large vehicle, compare, between measured results and simulation results, the temporal changes in:
  range (longitudinal and lateral directions), and
  size,
  at the object level.
- Example condition: ego-vehicle velocity 60 km/h, lead-vehicle longitudinal velocity 40 km/h, lateral velocity 1.0 m/s during the cut-in maneuver.



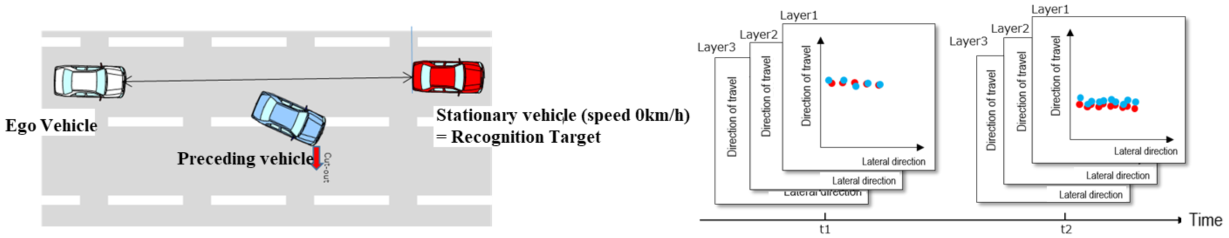
Acceptance Criteria

- At each time step, range (longitudinal and lateral) and size shall satisfy the criteria defined in F.2.3.2.2 and F.2.3.2.5.

F.2.3.2.11. Basic Traffic-Flow Scenario: Cut-Out Scenario — Point Cloud Data

Validation Method

- After a lead vehicle performs a cut-out maneuver, approach a stationary vehicle and compare, between measured results and simulation results, the temporal changes in:
  azimuth,
  range,
  number of detection points, and
  size,
  at the point-cloud level.
- Example condition: ego vehicle follows at 40 km/h, the lead vehicle cuts out, and the ego vehicle approaches the recognition target.



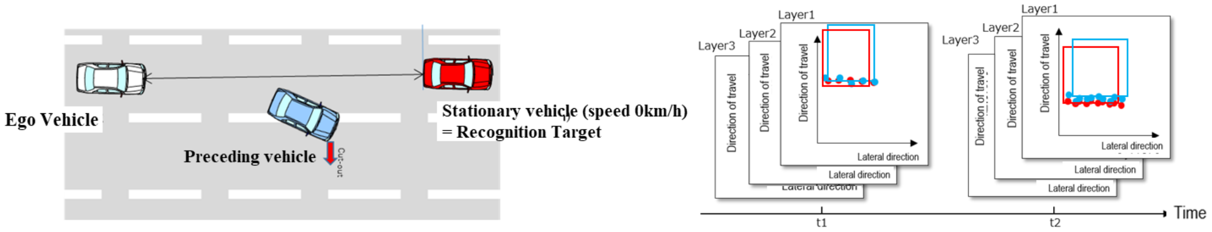
Acceptance Criteria

- At each time step, range, number of detection points, and size shall satisfy the criteria defined in F.2.3.2.2, F.2.3.2.4, and F.2.3.2.5.

F.2.3.2.12. Basic Traffic-Flow Scenario: Cut-Out Scenario — Object Level

Validation Method

- After a lead vehicle performs a cut-out maneuver, approach a stationary vehicle and compare, between measured results and simulation results, the temporal changes in:
- range (longitudinal and lateral directions), and
- size,
- at the object level.
- Example condition: ego vehicle follows at 40 km/h, the lead vehicle cuts out, and the ego vehicle approaches the recognition target.



Acceptance Criteria

- At each time step, range (longitudinal and lateral) and size shall satisfy the criteria defined in F.2.3.2.2 and F.2.3.2.5.

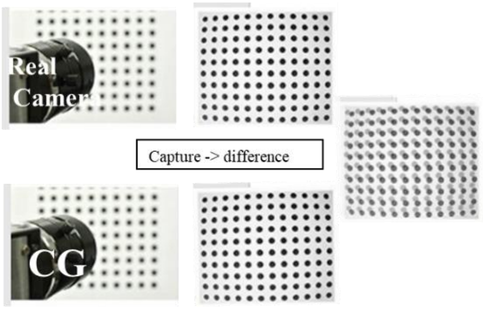
F.2.3.3. Validation Methods for Common Requirements of Cameras

This subsection describes the validation methods for verifying the common requirements of camera sensors, as defined in Section F.2.2.

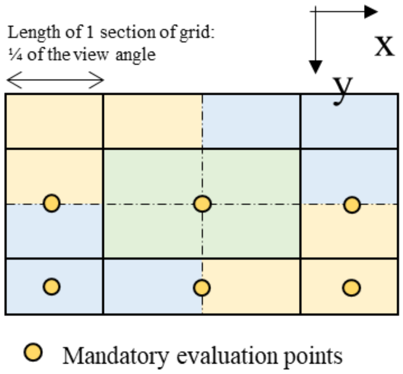
F.2.3.3.1. Standalone Camera: Module Calibration — FOV / Optical Axis / Distortion

Validation Method

- Using a test chart (grid lines or grid dots), calibrate distortion and resolution so that discrepancies between the real camera images and the simulation-generated images is minimized. Calibration is performed using RAW image data.
- For the real camera, capture images while keeping the grid chart level, and align the center point of the chart with the center point of the imaging device.
- For the simulated camera, align the center point in the same manner and adjust camera-related parameters so that the surrounding grid becomes positionally equivalent to that in the real image.
- Examples of calibration parameters include:
  distortion characteristics over the entire screen;
  resolution characteristics;
  lens focal length;
  distortion characteristics and various aberrations; and
  assembly offsets between the lens and imaging device, such as center offset and angular offset.



Source: https://www.seika-di.com/measurement/qanda/qanda_material/Effectoflensdistortion.html



[Measurement Conditions]

- Darkroom environment
- Use a known test chart
- Use a known light source
- Light sources used in validation include headlights and sunlight

Acceptance Criteria

- Visual overlap: the real and simulated images shall almost overlap over the entire image. Evaluation is performed from the viewpoints of visual resolution, spatial frequency response (SFR), and limiting resolution.

- Pixel-level accuracy: for grid coordinates near the evaluation points, the positional difference between the real image and the simulated image shall be within ±2 pixels.

F.2.3.3.2. Standalone Camera: Module Calibration — Color and Luminance

Validation Method

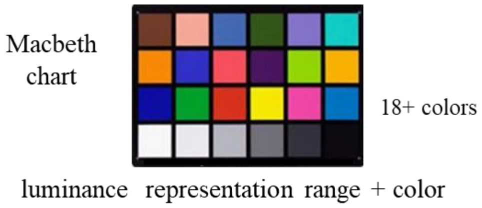
- Using a color test chart, calibrate luminance and color reproduction so that discrepancies between real camera images and simulation-generated images are minimized, based on RAW image data.
- Perform measurements at each color block in the chart.
- At the target image positions, compute statistics over 16 pixels or more, including the mean and standard deviation of luminance and saturation.
- Adjust camera-related parameters so that the luminance expression and color reproducibility of the simulated camera become equivalent to those of the real camera.

Examples of calibration parameters include:

- photoelectric conversion characteristics of the imaging device;
- transmittance characteristics of the lens and imaging-device filters.

The following parameters are treated as verification parameters, which are assumed to match between the real camera and the simulation:

- exposure control characteristics of the imaging device;
- HDR (high dynamic range) characteristics;
- various ISP (image signal processing) setting values.

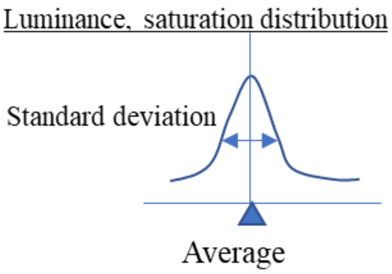


[Measurement Conditions]

- Darkroom environment
- Use a known test chart
- Use a known light source
- Light sources used in validation include headlights and sunlight

Acceptance Criteria

- F For each evaluation item, the difference between the real camera and the simulation shall be within ±5%.



F.2.3.3.3. Standalone Camera: Module Calibration — Dynamic Range

Validation Method

- Stepwise vary the luminous intensity (luminance) of a known illumination source and measure the camera dynamic range as a function of intensity. Calibration is performed so that discrepancies between the real camera and the simulation images are minimized, based on RAW image data.
- Measure the relationship between illumination intensity and pixel value (brightness value) until saturation (white clipping) occurs.
- Normalize the intensity at white clipping to 1, and compare the response down to the intensity at black clipping using at least six intensity levels.
- Prefer geometrically spaced levels (e.g., 1/2, 1/4, 1/8, …).
- Adjust camera-related parameters so that the dynamic-range characteristics of the simulated camera match those of the real camera.

Examples of calibration parameters include:

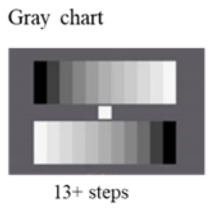
- exposure-control characteristics of the imaging device;
- HDR (high dynamic range) characteristics.

The following parameters are treated as verification parameters, which are assumed to match between the real camera and the simulation:

- various ISP (image signal processing) setting values.

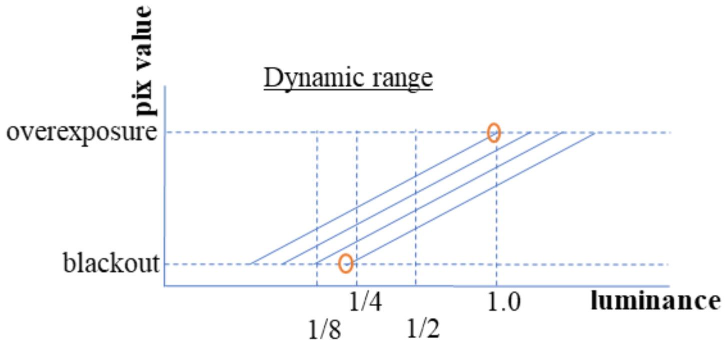
[Measurement Conditions]

- Darkroom environment
- Use a known test chart
- Use a known light source
- Light sources used in validation include headlights and sunlight



Acceptance Criteria

- Intensity at white clipping: difference from the real camera within ±5%
- Intensity at black clipping: difference from the real camera within ±5%



F.2.3.3.4. In-Vehicle Camera: Front-Side Adjustment — Optical Axis

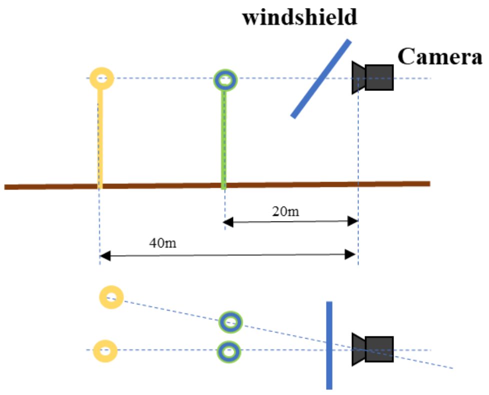
Validation Method

Assuming the real camera optical axis is mounted horizontally to the road surface and parallel to the vehicle longitudinal axis, apply an aiming and adjustment method to minimize the impact of installation errors.

- Install and adjust the camera according to the mounting specifications such that:
  - ➢ target points at different distances on the optical axis align with the center point of the imaging device; and
  - ➢ target points at different distances shifted laterally to the right align along the same line passing through the imaging-device center point.
- For the simulated camera, adjust the corresponding parameters so that its configuration becomes positionally equivalent to that of the real camera.

Examples of calibration parameters:

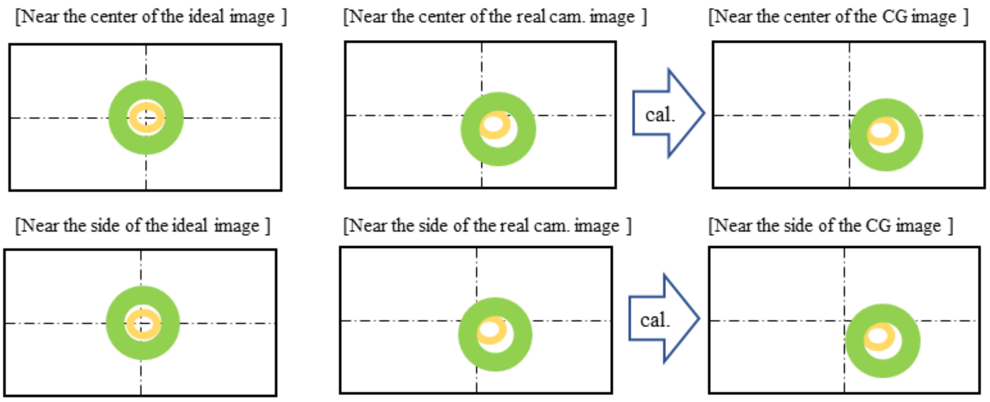
1. camera mounting height and orientation (vehicle yaw, pitch, roll);
2. windshield thickness, including thickness, curvature, tilt angle, and refractive index.



[Measurement Conditions]
- On-vehicle installation
- Use known target points
- Use a known light source
- Skylight (sunlight)
- Known road surface (asphalt, level)

Acceptance Criteria

- For the image positions of the target points, the difference between the real camera and the simulation shall be within ±5 pixels.



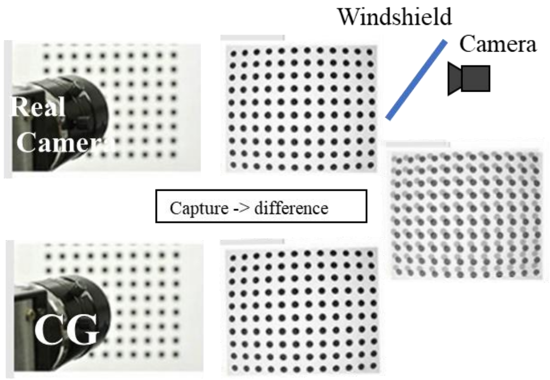
F.2.3.3.5. In-Vehicle Camera: Front-Side Adjustment — Distortion

Validation Method

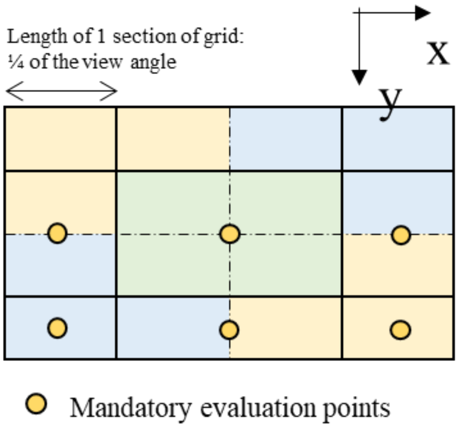
- Using a test chart (grid lines or grid dots), calibrate distortion and resolution so that the discrepancies between real camera images captured through the windshield and simulation-generated images are minimized, based on RAW image data.
- For the real camera, capture images while keeping the chart level and aligning the chart center point with the center point of the imaging device.
- For the simulated camera, align the center point in the same manner and adjust camera-related parameters so that the surrounding grid becomes positionally equivalent to that in the real image.

Examples of calibration parameters include:

- distortion characteristics over the entire image and resolution characteristics;
- camera mounting height and orientation (vehicle yaw, pitch, roll);
- windshield characteristics, including thickness, curvature, tilt angle, and refractive index.



Source: https://www.seika-di.com/measurement/qanda/qanda_material/Effectoflensdistortion.html



[Measurement Conditions]

- Darkroom environment
- Use a known test chart
- Use a known light source
- Light sources used in validation include headlights and sunlight

Acceptance Criteria

- Visual overlap: the real and simulated images shall almost overlap over the entire image. Evaluation is performed from the viewpoints of visual resolution, spatial frequency response (SFR), and limiting resolution.
- Pixel-level accuracy for grid coordinates near evaluation points:
  near the image center: within ±5 pixels;
  near the image periphery: within ±30 pixels.

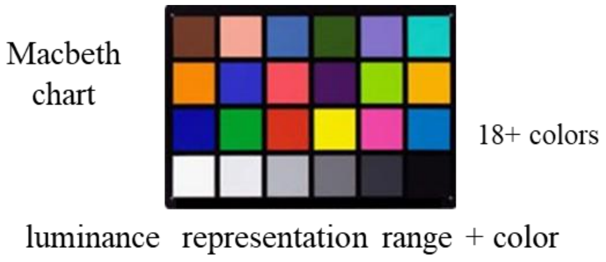
F.2.3.3.6. In-Vehicle Camera: Front-Side Adjustment — Color and Luminance

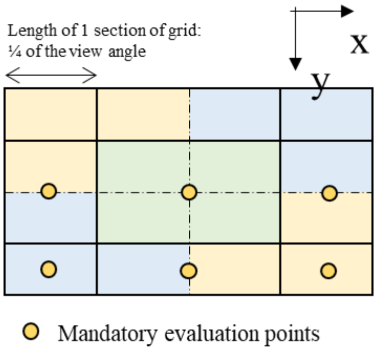
Validation Method

- Using a color test chart, calibrate luminance and color reproduction so that discrepancies between real camera images captured through the windshield and simulation-generated images are minimized, based on RAW image data.
- Perform measurements at each color block of the chart.
- At target image positions, compute statistics over 16 pixels or more, including the mean and standard deviation of luminance and saturation.
- Evaluate performance using general camera metrics for luminance expression and color reproducibility.

Examples of calibration parameters include:

- wavelength-dependent reflectance and transmittance characteristics of the windshield.



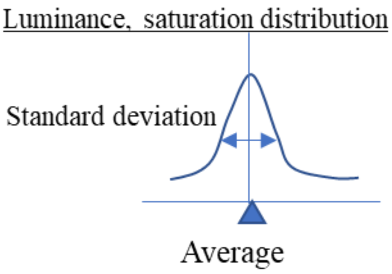


[Measurement Conditions]

- Darkroom environment
- Use a known test chart
- Use a known light source
- Light sources used in validation include headlights and sunlight

Acceptance Criteria

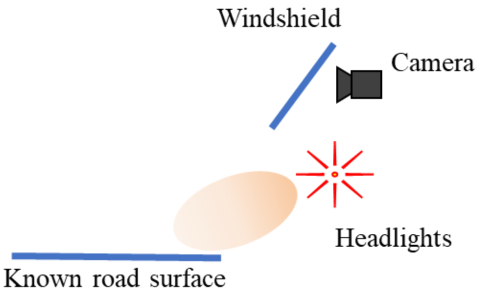
- For each evaluation point and each evaluation item, the difference between the real camera and the simulation shall be within ±5%.

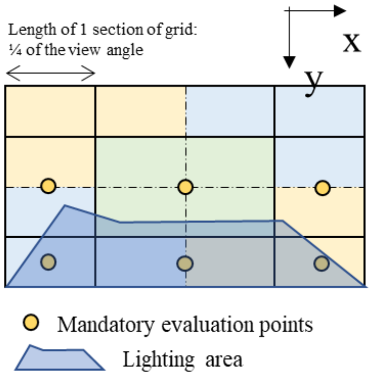


F.2.3.3.7. In-Vehicle Camera: Front-Side Adjustment — Color and Luminance (Headlights)

Validation Method

- For the headlight light-distribution pattern, perform a two-step calibration using a known reflector and a known road surface to minimize discrepancies in color and luminance between the real system and computer-generated (simulation) images at observation points:
  within the illuminated area: 5 points or more;
  outside the illuminated area: 3 points or more.
- At the target image positions, compute statistics over 16 pixels or more, including the mean and standard deviation of luminance and saturation.
- Examples of calibration parameters include:
- for the known reflector: color and luminance of light rays emitted in each direction from the headlights;
- for the known road surface: road-surface reflectance characteristics.

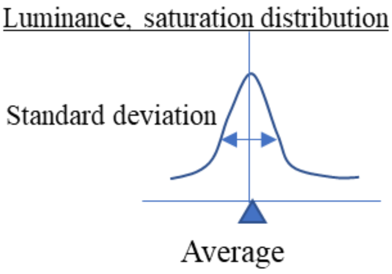




[Measurement Conditions]
- Darkroom environment
- Known light source (headlights)
- Known reflector (Lambertian reflector, vertical)
- Known road surface (asphalt, level)

Acceptance Criteria

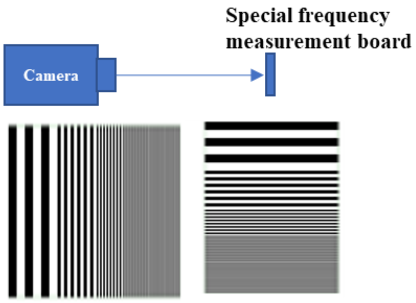
- For each evaluation point and each evaluation item, the difference between the real system and the simulation shall be within ±5%.



F.2.3.3.8. In-Vehicle Camera: Reproduction of Spatial Frequency

Validation Method

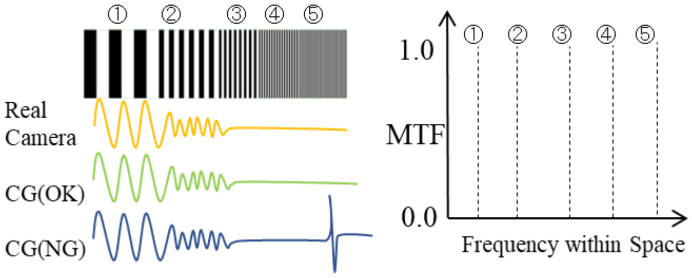
- Using a spatial-frequency measurement board, calibrate the system so that the spatial-frequency characteristics of the real camera images and the simulation images satisfy the acceptance criteria. Calibration is performed using RAW image data.
- For the real camera:
  keep the board level;
  align the center point of the chart with the center point of the imaging device;
  capture images and derive horizontal and vertical MTF curves.
- For the simulated camera:
  align the center point in the same manner;
  adjust vehicle attitude and camera mounting-position parameters so that the positions of the black reference lines become positionally equivalent to those in the real images;
  capture images and derive horizontal and vertical MTF curves.



[Measurement Conditions]
･Darkroom environment
･Use of a known light source (the entire board must maintain appropriate contrast)
･Use of a spatial-frequency board capable of measuring a resolution appropriate to the camera specifications
･Placement of the board at a distance where proper focus can be achieved

Acceptance Criteria

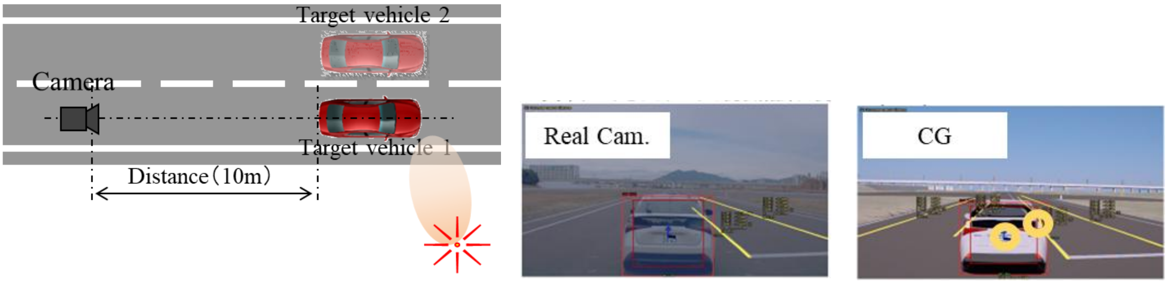
- In regions where the MTF is non-zero, the difference in MTF between the real camera and the simulation shall be within ±5%.
- In regions where the MTF is close to zero, the simulation shall not produce contrast exceeding that of the real camera.



F.2.3.3.9. Asset/Scenario: Recognition Target (Vehicle) — Placement

Validation Method

- Confirm that the placement of recognition targets is equivalent between the real system and the simulation environment.
- Set the following conditions:
  - Ego vehicle velocity: stopped, or approximately 5 km/h or 10 km/h;
  - Target vehicle velocity: stopped, or approximately 5 km/h or 10 km/h;
  - Drive on known roads (straight road, constant-radius circle road, e.g., R100);
  - Target vehicle 1: passenger car;
  - Target vehicle 2: large vehicle;
  - Initial headway to target 1: approximately 10 m or 30 m;
  - Initial headway to target 2: approximately 10 m;
  - Target 1: stopped or maintains headway;
  - Target 2: maintains headway;
  - Target 1: maintains ego lane;
  - Target 2: initial lane is ego lane or adjacent lane; maintaining lane or performing lane change.
- Acquire time-series data and real video of distance (position) and relative velocity to targets 1 and 2 ahead in the ego lane.
- Generate simulation video for the same scenario.
- Measure and compare the image positions of three or more salient feature points on the vehicle (e.g., body gaps).



[Measurement Conditions]

- On-vehicle testing
- Use known target points
- Known light source: skylight (sunlight, new moon)
- Known road surface (asphalt, level)

※Reference information for judgement criteria near center of image

- Measure error of distance to target vehicle: 1%
- Image sensor horizontal pixels：2880 [pixel]
  size: 8.64 *10^-3[m]
- Lens parameter focal length: 7.9*10^-3[m]
  distortion ratio：15%
- Vehicle width：1.745[m]

Acceptance Criteria

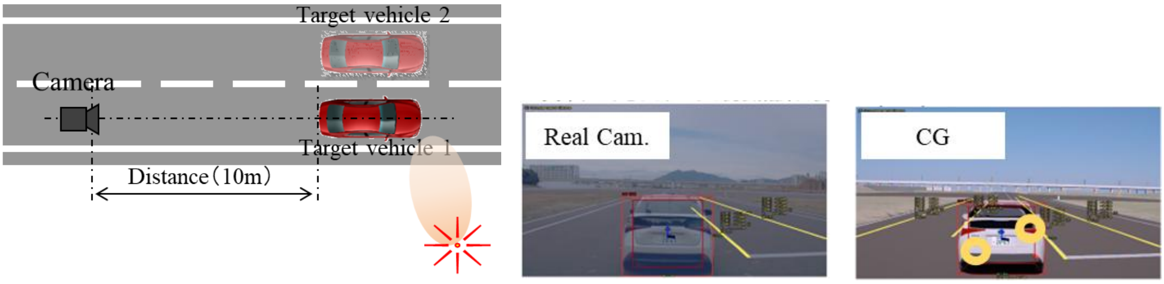
For the correlation distance of salient points, the allowable difference from the real system depends on image position:

- Near the image center: within ±5 pixels
- Near the image periphery: within ±30 pixels

F.2.3.3.10. Asset/Scenario: Recognition Target (Vehicle) — Color and Luminance

Validation Method

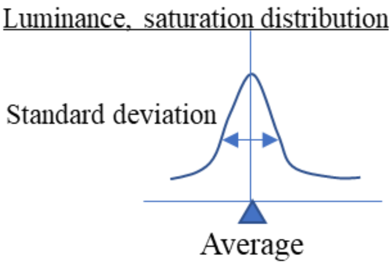
- Confirm that the color and luminance of recognition targets are equivalent between the real system and simulation environment.
- Set the same vehicle, road, and motion conditions as described in F.2.3.3.9.
- Acquire time-series data and real video of distance (position) and relative velocity to targets 1 and 2 ahead in the ego lane.
- Generate simulation video for the same scenario.
- Measure luminance and color representation for the vehicle body, bumper, and ─where possible—tail lamps, under both sunlit and shaded conditions.
- At target image positions, compute statistics over 16 pixels or more, including the mean and standard deviation of luminance and saturation, and compare the results.



[Measurement Conditions]
･On-vehicle testing
･Use known target points
･Known light source: skylight (sunlight, new moon)
･Known road surface (asphalt, level)

Acceptance Criteria

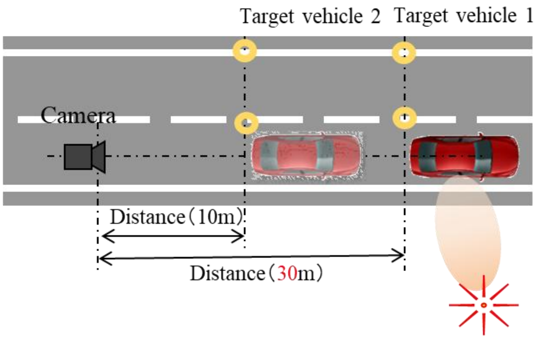
- For each evaluation item, the difference between the real system and the simulation shall be within ±20%.



F.2.3.3.11. Asset/Scenario: Recognition Target (Lane Boundaries) — Placement

Validation Method

- Confirm that the placement of lane-boundary recognition targets is equivalent between the real system and the simulation environment.
- Ego vehicle velocity: stopped, or approximately 5 km/h or 10 km/h
- Target vehicle velocity: stopped, or approximately 5 km/h or 10 km/h
- Set the same vehicle, road, and motion conditions as described in F.2.3.3.9.
- Acquire time-series data and real video of distance (position) and relative velocity to targets 1 and 2 ahead in the ego lane.
- Generate simulation video for the same scenario.
- Measure and compare the image coordinates at selected comparison points on the lane-boundary lines.



[Measurement Conditions]

- On-vehicle testing
- Use known target points
- Known light source: skylight (sunlight, new moon)
- Known road surface (asphalt, level)

※Reference information for judgement criteria near center of image

- Measure error of distance to target vehicle: 1%
- Image sensor horizontal pixels：2880 [pixel]
  size: 8.64 *10^-3[m]
- Lens parameter focal length: 7.9*10^-3[m]
  distortion ratio：15%
- Vehicle width：1.745[m]

Acceptance Criteria

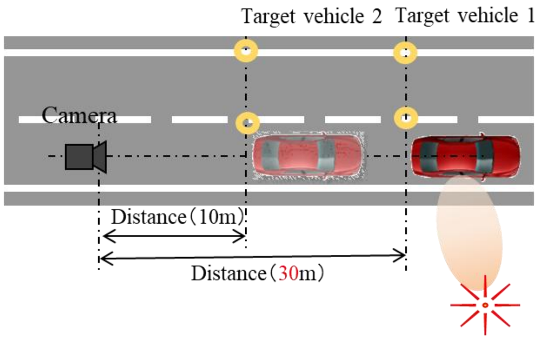
For each evaluation item, the allowable difference from the real system depends on image position:

- Near the image center: within ±5 pixels
- Near the image periphery: within ±30 pixels

F.2.3.3.12. Asset/Scenario: Recognition Target (Lane Boundaries) — Color and Luminance

Validation Method

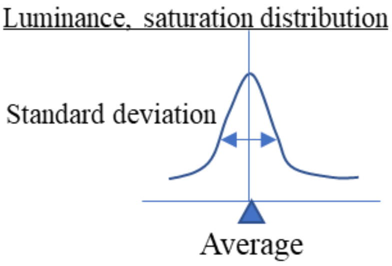
- Confirm that the color and luminance of lane-boundary recognition targets are equivalent between the real system and the simulation environment.
- Use the same vehicle, road, and motion conditions as defined in F.2.3.3.9.
- Acquire time-series data and real video of distance (position) and relative velocity to targets 1 and 2 ahead in the ego lane.
- Generate simulation video for the same scenario.
- For lane-boundary lines and the road surface, measure luminance and color representation under both sunlit and shaded conditions.
- At the target image positions, compute statistics over 16 pixels or more, including the mean and standard deviation of luminance and saturation, and compare the results.



[Measurement Conditions]
･On-vehicle testing
･Use known target points
･Known light source: skylight (sunlight, new moon)
･Known road surface (asphalt, level)

Acceptance Criteria

- For each evaluation item, the difference between the real system and the simulation shall be within ±20%.

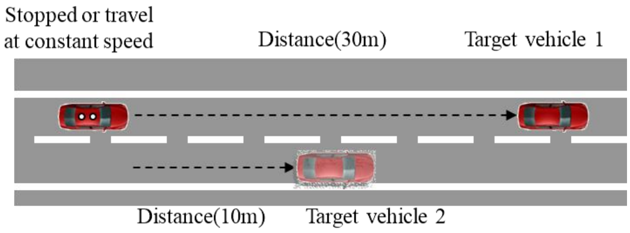


F.2.3.3.13. Asset/Scenario: Recognition Target (Vehicles) — Distance / Velocity

Validation Method

- Confirm that vehicle-recognition outputs are equivalent between the real system and simulation environment.
- Set the following conditions:
  - Ego-vehicle velocity: stopped, or approximately 5 km/h or 10 km/h;
  - Target-vehicle velocity: stopped, or approximately 5 km/h or 10 km/h;
  - Drive on known roads (straight road, constant-radius circle road, e.g., R100);
  - Target vehicle 1: passenger car;
  - Target vehicle 2: large vehicle;
  - Initial headway to target 1: approximately 10 m or 30 m;
  - Initial headway to target 2: approximately 10 m;
  - Target vehicle 1: stopped or maintains headway;
  - Target vehicle 2: maintains headway;
  - Target vehicle 1: maintains ego lane;
  - Target vehicle 2: initial lane is ego lane or adjacent lane; maintains lane or performing lane change.
- Measure time-series data of distance (position) and relative velocity to targets vehicles 1 and 2 ahead of the ego vehicle.

- If a steady offset is observed, estimate it using a correlation-based method and cancel it out as necessary before comparison.



Acceptance Criteria

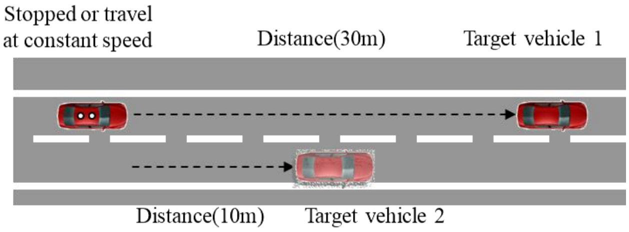
- Distance: within ±5% of the real-system values
- Velocity: within ±10% of the real-system values

F.2.3.3.14. Asset/Scenario: Recognition Target (Vehicles) — Size / Orientation

Validation Method

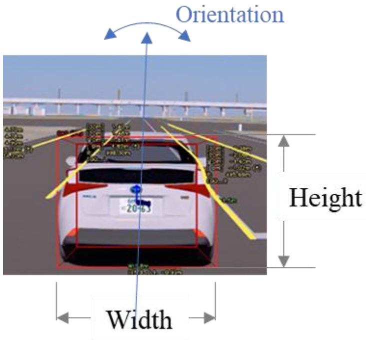
- Confirm that vehicle-recognition outputs related to size and orientation are equivalent between the real system and the simulation.
- Use the same vehicle, road, and motion conditions as defined in F.2.3.3.13.
- Measure time-series data of the target vehicle's height, width, and orientation ahead of the ego vehicle.

- If a steady offset is observed, estimate it using a correlation-based method and cancel it out as necessary before comparison.



Acceptance Criteria

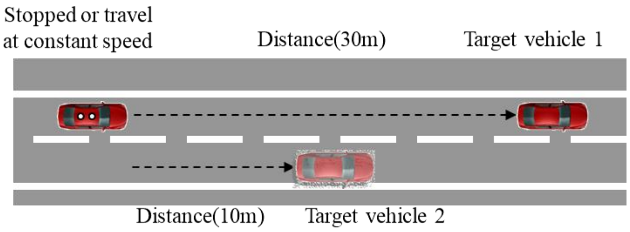
- Size: within ±5% of the real-system values
- Orientation: within ±5% of the real-system values



F.2.3.3.15. Asset/Scenario: Recognition Target (Vehicles) — Classification

Validation Method

- Confirm that vehicle-recognition outputs are equivalent between the real system and simulation.
- Use the same vehicle, road, and motion conditions as defined in F.2.3.3.13.
- Measure and compare time-series classification outputs for the target vehicles ahead in the ego lane.
- Target classes include: four-wheeled vehicles, pedestrians, and any other output classes defined by the recognition module.



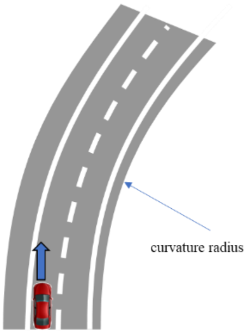
Acceptance Criteria

- The classification labels obtained in the simulation shall match those obtained in the real system.

F.2.3.3.16. Asset/Scenario: Recognition Target (Lane Boundaries) — Curvature

Validation Method

- Confirm that lane-boundary recognition outputs are equivalent between the real system and the simulation.
- Set the following conditions:
  - Ego-vehicle velocity: stopped, or approximately 5 km/h or 10 km/h;
  - Drive on known roads (straight road, constant-radius circle road, e.g., R100).
- Measure time-series data of the lane-boundary curvature radius on the constant-radius section, up to approximately 40 m ahead of the ego vehicle.
- If a steady offset is observed, estimate it using a correlation-based method and cancel it out as necessary before comparison.



Acceptance Criteria

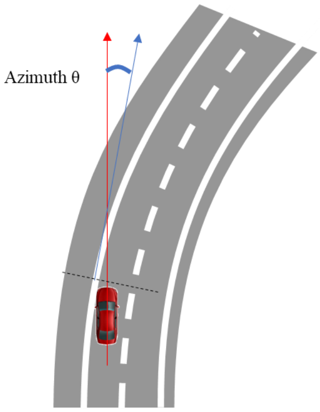
- Curvature radius: within ±15% of the real-system values.

F.2.3.3.17. Asset/Scenario: Recognition Target (Lane Boundaries) — Heading Angle

Validation Method

- Confirm that lane-boundary recognition outputs are equivalent between the real system and the simulation.
- Set the following conditions:
  - Ego-vehicle velocity: stopped, or approximately 5 km/h or 10 km/h;
  - Drive on known roads (straight road, constant-radius circle road, e.g., R100)
- Measure time-series data of the lane-boundary heading angle relative to the ego vehicle (e.g., at the lane boundary tip).

- If a steady offset is observed, estimate it using a correlation-based method and cancel it out as necessary before comparison.



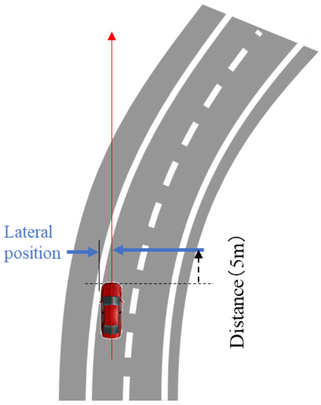
Acceptance Criteria

- Heading angle: within ±10% of the real-system values.

F.2.3.3.18. Asset/Scenario: Recognition Target (Lane Boundaries) — Lateral Position

Validation Method

- Confirm that lane-boundary recognition outputs are equivalent between the real system and the simulation.
- Set the following conditions:
    - Ego-vehicle velocity: stopped, or approximately 5 km/h or 10 km/h;
    - Drive on known roads (straight road, constant-radius circle road, e.g., R100).
- Measure time-series data of the lateral position of the lane boundary boundaries relative to the ego vehicle (e.g., at approximately 5 m ahead).
- If a steady offset is observed, estimate it using a correlation-based method and cancel it out as necessary before comparison.
- Evaluate both left and right lane boundaries of the ego lane.



Acceptance Criteria

- Lateral position: within ±5% of the real-system values.

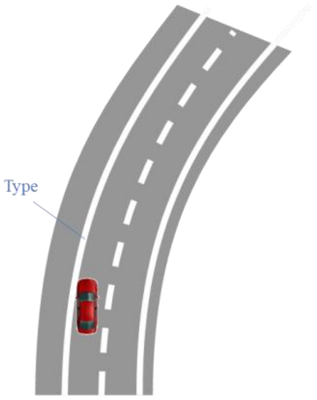
F.2.3.3.19. Asset/Scenario: Recognition Target (Lane Boundaries) — Type

Validation Method

- Confirm that lane-boundary type recognition outputs are equivalent between the real system and the simulation.
- Set the following conditions:
  - Ego-vehicle velocity: stopped, or approximately 5 km/h or 10 km/h;
  - Drive on known roads (straight road, constant-radius circle road, e.g., R100).
- Measure and compare time-series data of the lane-boundary type for each lane marking.

Lane-boundary types include, but are not limited to:

- dashed or solid lines;
- color; and
- any other output classes defined by the recognition module.



Acceptance Criteria

- The lane-boundary types labels obtained in the simulation shall match those obtained in the real system.

F.3.Reproducibility Requirements for Perception Disturbances and Validation Methods

This chapter describes the reproducibility requirements that must be verified for perception disturbances, together with the corresponding validation methods. The overall approach follows the same structure as that used for the common requirements described in the preceding sections.

First, the underlying concept for selecting items to defined as reproducibility requirements for perception disturbances is summarized. Next, based on this concept, validation methods are organized for each sensor type. Because these validation methods are defined in accordance with the perception principles of each sensor, when dealing with sensors based on different underlying principles, it is necessary to organize and verify the validation items using the same conceptual framework. It should be noted that the validation methods described in this chapter may be replaced by other methods capable of verifying equivalent content.

In addition, for each sensor, if adjustments equivalent to calibration are required, validation is assumed to be performed after such adjustments have been completed.

F.3.1. Concept for Defining Reproducibility Requirements for Perception Disturbances

This section summarizes the concept used to define the items to be treated as reproducibility requirements for perception disturbances.
As in the case of the common requirements, the causes of perception disturbances are classified into the following three categories:

1. The sensor and the vehicle itself,
2. The space through which the signal propagates, and
3. The perception target object (Figure F-3).

For each category, the items to be verified and their corresponding acceptance criteria (evaluation criteria) are organized under environments in where perception disturbances are applied. In addition, to confirm these items in an integrated manner, a method is defined to verify whether the perception target can be correctly recognized under disturbance-applied conditions within basic traffic-disturbance scenarios.

F.3.2. Concept of Reproducibility Requirements for Perception Disturbances for Each Sensor

This section describes the conceptual approach to defining reproducibility requirements for perception disturbances for each sensor type, based on the sensing principles specific to that sensor.

F.3.2.1. Concept for Millimeter-Wave Radar

For millimeter-wave radar, based on its perception principles, verification is performed—under environments in which perception disturbances are applied—to determine whether fundamental physical quantities are correctly reproduced. These quantities include range, azimuth, relative velocity, and received signal power (Figure F-4).
By confirming that these quantities are reproduced with sufficient fidelity under disturbance conditions, it becomes possible to verify the reproducibility of perception disturbances in the virtual environment for millimeter-wave radar.

A summary of the specific reproducibility requirements for millimeter-wave radar is provided in Table F-4.

Table F- 4.　Reproducibility Requirements for Perception Disturbances for Millimeter-Wave Radar

								Perception process																			Recognition process					
								Signal from perception target (S)								Signal from others											Processing ability	Processing performance				
									Phase			Strength				Noise (N)				Undesired signal (U)								Detection (Output of reflected point cloud of target)		Clustering (grouping of reflected points)	Tracking (tracking of target)	Classification (Identification of target)
									Change of DOA				High intensity			Low S/N				Low D/U						Increasing of U						
			Items	Paramters	Requirements	Method of Validation No.	not a disturbance	Frequency	Reflection (indirect wave)	Refraction	Change of propagation delay	No signal (partial)	Aliasing	Harmonic	Large differnce of signal	Low S/N (change of angle)	Low S/N (attenuation at the sensor surface)	Low S/N (attenuation in space)	Low S/N (low retroreflection)	Low D/U (change of angle)	Low D/U (road surface reflection)	Low D/U (surrounding structures)	Low D/U (floating objects in space)	Low D/U (sensors on other cars)	Low D/U (sensors on ego cars)	Increasing of U (road surface reflection)	Lack of points to be processed Lack of calculating ability	False detection of undesired signal	No detection of required signal	Unexpected distribution of point cloud	Unexpected movements (between frames)	Unexpected objects
Validation of Disturbance Reproducibility	Simulating Large Difference of Signals	Simulating the Disturbance Phenomena	Signal Intensity Ratio	Distance/Angle	Signal intensity ratio of target 1 and 2 is equivalent to the actual environment.	3-1									○																	
			HMFW Ratio	Distance/Angle	HMFW ratio of target 1 and 2 is equivalent to the actual environment.	3-2									○																	
			Buried Signals	Distance/Angle	The signal from a motorcycle is obscured by the signal of a large vehicle in the same way as the actual environment.	3-3									○																	
	Simulating Low D/U due to Road Surface Multipath	Simulating the Disturbance Phenomena	Received Power	Distance	Envelope line in received power is equivalent to the actual environment.	4-1															○											
		Road Surface Material/Road Surface Condition	Received Power	Distance	Envelope in received power of the reflected wave from C/R is equivalent to the actual environment.	4-2															○											
			Null points	Distance	Null points distances in received power of the reflected wave from C/R is equivalent to the actual environment.	4-3															○											
	Simulating Low D/U Due to Change of the Angle	Simulating the Disturbance Phenomena	Buried Signals	Distance/Angle	The phenomenon, whereby the signal from the recognition target becomes buried in the signal from the signage board, occurs in the same way as the actual environment.	5-1														○												
		Reflective Properties of Overhead Structures	Signal Intensity Ratio	Distance/Angle	signal intensity ratio of the target and signage board is equivalent to the actual environment.	5-2														○												
			HMFW Ratio	Distance/Angle	HMFW ratio of the target and signage board is equivalent to the actual	5-3														○												
	Simulating Low S/N Due to Vehicle Orientation	Simulating the Disturbance Phenomena	Cumulative distribution of the received power	Vehicle orientation	The cumulative distribution of the received power within a certain distance range is equivalent to the actual environment.	6-1													○													

F.3.2.2. Concept of Reproducibility Requirements for Perception Disturbances for LiDAR

For LiDAR, based on its perception principles, verification is performed—under environments in which perception disturbances are applied—to determine whether fundamental physical quantities are correctly reproduced in the virtual environment. These quantities include range, azimuth, received intensity, number of detection points, and object size (Figure F-5).

By confirming the reproducibility of these quantities under disturbance conditions, it becomes possible to evaluate whether perception disturbances affecting LiDAR are appropriately reproduced in the virtual environment.

A summary of the specific reproducibility requirements for LiDAR is presented in Table F-5.

Table F- 5. Reproducibility Requirements for Perception Disturbances for LiDAR

										Perceptual part																
										Signal from recognition target (S)												Signal from non-recognition target				
										Scan timing		S strength							S Propagation direction		S speed	N factor		U factor		
									No disturbance	Misalignment of overall spatial position	Misalignment of position of recognition target	Saturation of S	Attenuation of S					No S due to occlusion	Reflection	Refraction	Arrival time of S	Pulsed noise	DC noise	Multiple reflections	Signal from non-recognition target (Reflection)	Signal from non-recognition target (Refraction)
	Verification perspective		Explanation	target	item	Parameters	request	Validation Method No.					Low reflection of the recognition target	Adhesion to the recognition target	Rain/Snow/Fog	Exhaust gas/Hoisting	Adhesion to the sensor									
Disturbance Reproducibility verification	Noise	Error mean and variation	A standard reflector is installed in front of LiDAR, the error average and variance are measured by changing the distance, and it is verified that the difference from the actual measurement is within the judgment criteria.	Standard reflector	light source	Altitude	Being able to detect after changing the position from 0 to 90 degrees	F.2.4.2.1														○	○			
						Direction	Being able to detect after changing the position from 0 to 360 degrees	F.2.4.2.1														○	○			
						Brightness	The brightness can be detected by changing the brightness from 0 to XX mW/mmˆ2. (Since the wavelength range differs depending on LiDAR, set it within the range that can be taken according to the wavelength that Lidar emits.)	F.2.4.2.1														○	○			
		Reception strength and detection probability	A standard reflector is installed in front of LiDAR, the reception intensity and detection probability are measured by changing the distance, and it is verified that it is within the judgment criteria.	Standard reflector	light source	Altitude	Being able to detect after changing the position from 0 to 90 degrees	F.2.4.2.2														○	○			
						Direction	Being able to detect after changing the position from 0 to 360 degrees	F.2.4.2.2														○	○			
						Brightness	The brightness can be detected by changing the brightness from 0 to XX mW/mmˆ2. (Since the wavelength range differs depending on LiDAR, set it within the range that can be taken according to the wavelength that Lidar emits.)	F.2.4.2.2														○	○			
			Install the asset in front of LiDAR and change the distance to verify the difference in the number of received points.	Asset (Vehicles, Motorcycles, People, Installations, Falling objects)	light source	Altitude	Being able to detect after changing the position from 0 to 90 degrees	F.2.4.2.3														○	○			
						Direction	Being able to detect after changing the position from 0 to 360 degrees	F.2.4.2.3														○	○			
						Brightness	The brightness can be detected by changing the brightness from 0 to XX mW/mmˆ2. (Since the wavelength range differs depending on LiDAR, set it within the range that can be taken according to the wavelength that Lidar emits.)	F.2.4.2.3														○	○			
	Attenuation of S	Reproducibility of cognitive disturbances	Install the asset in front of LiDAR and change the distance to verify the difference in the number of received points.	Vehicle	Reflector	Shape	It can be detected by vehicles with high ground clearance, vehicles with low vehicle height, motorcycles, bicycles, angular vehicles, and rounded vehicles.	F.2.4.2.4					○													
					Mirror reflector	Color, Material	What can be detected by black paint and specular reflection	F.2.4.2.4					○													

F.3.2.3. Concept of Reproducibility Requirements for Perception Disturbances for Camera Sensors

As described in the section on common requirements, camera sensors differ fundamentally from active sensors in that they do not acquire distance information at the perception stage, while they are capable of acquiring color and luminance information. These characteristics are therefore particularly important in consistency validation of camera sensors under disturbance conditions.
Accordingly, reproducibility requirements for camera sensors focus on verifying whether image-level characteristics and recognition outputs affected by perception disturbances are appropriately reproduced in the virtual environment.

A summary of the specific reproducibility requirements for camera is presented in Table F-6.

Table F- 6. Reproducibility Requirements for Perception Disturbances for Camera Sensors

Verification								Perception																	Recognition									
								Optics					Imager									Image			Feature			Detection,			Positioning		Tracking	
								Refraction	Reflection	Scattering	Diffraction	Absorption	Noise	Color filter	Exposure time	Exposure period	Time rag for exposure	Overexposure		Underexposure	Lack of Gradation	Brightness	Hue	Chroma	Hidden	Low spatial frequency	Low contrast	No classification	Detection or classification error		Base-position error	Target-position error	Tracking error	Velocity error
Items/ Target Parts		Measurement items	Parameters	Requirement	Requirement ID	Normal condition(Day)	Normal condition(Night)	Blur, Dislocation, Distortion	Flare, Artifact, Mirrored Objects	Flare	Linear Flare	Vignetting	Random, Fixed-pattern	Fade	Shaked Image	Flicker	Distortion depended on Rolling-shutter	Clipped whites (Too long exposure time)	Clipped whites + Flare (Backlight)	Crushed shadows	Crushed shadows	Out of correct exposure	WB deviation		(Invisible)	(Solid color)(Flattish surface)	(Weak edge)(Similar colors)	(No classification)	(False positive detection)	(False negative detection, or classification error)	(Self-position) (Target-position)	(Size, position, or direction error(s))	(Lost) (Change to another object)	(Orientation error) (Magnitude error)
perception disturbance reproducing requirement	shielding (Shelter: mud, water droplets) (passenger cars, large vehicles) (boundary lines: white, solid, dashed) (surface: curved, asphalt)	Placement verification (shield)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-1-1	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	—
		color luminance verification(shield)	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-1-2	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	—
		Placement verification (landmarks)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-2-1	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	—
		color luminance verification	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-2-2	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	—
		Recognition result (Object)	Relative distance	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-3-1	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	○	—
			Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-3-2	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	○	—
			Relative velocity	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-3-3	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	○	—
			Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-3-4	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	○	—
		Placement verification(boundary line)	Shape, Size	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-4	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	—
		color luminance verification(boundary line)	Luminance, Hue, Color	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-5	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	—
		Recognition result (boundary line)	Curvature	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-6-1	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	○	—
			Azimuth	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-6-2	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	○	—
			Lateral position	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-6-3	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	○	—
			Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-1-6-4	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	○	—
	Low contrast (Fog) (passenger cars, large vehicles) (boundary lines: white, solid, dashed) (surface: curved, asphalt)	Spatial frequency	MTF	Adjust spatial frequency characteristics to meet judgement criteria based on RAW images of real and virtual (CG) environment	B-2-1	✓	—	○	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—
		Recognition result (Object)	Relative distance	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-1	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	○	—
			Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-2	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	○	—
			Relative velocity	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-3	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	○	—
			Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-4	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	○	—
		Recognition result (Boundary line)	Curvature	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-5	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	○	—
			Azimuth	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-6	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	○	—
			Lateral position	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-7	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	○	—
			Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-8	✓	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	○	—
	Too much (saturation) (Tunnel) (passenger cars, large vehicles) (boundary lines: white, solid, dashed) (Road surface: straight, asphalt)	Dynamic range	Histogram	Parameters in virtual environment (CG) are similar to ones in real environment	B-3-1	✓	—	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	○	—	—	—	—	○	—	—	—	—	—	—	—
		Duration time	Number of clipped whites pixels, Time	Parameters in virtual environment (CG) are similar to ones in real environment	B-3-2	✓	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	○	—	—	—	—	○	—	—	—	—	—	—	—
		Recognition result (Object: Vehicles)	Relative distance	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-3-1	✓	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—
			Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-3-2	✓	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—
			Relative velocity	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-3-3	✓	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—
			Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-3-4	✓	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—
		Recognition result (Object)	Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-3-5	✓	—	—	—	—	—	—	—	—	—	—	—	◎	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—
		Recognition result (Boundary line)	Curvature	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-5-1	✓	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—
			Azimuth	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-5-2	✓	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—
			Lateral position	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-5-3	✓	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—
			Classification	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-5-4	✓	—	—	—	—	—	—	—	—	—	—	◎	◎	—	—	—	—	—	—	—	○	—	—	—	—	—	—	—

F.3.3. Validation Methods for Reproducibility Requirements of Perception Disturbances

This subsection describes the validation methods used to verify the reproducibility requirements for perception disturbances of millimeter-wave radar, as defined in Section F.3.2.1.
Each validation item corresponds to a specific perception-disturbance principle, and reproducibility is verified by comparing results obtained in the real-world environment with those obtained in the virtual environment..

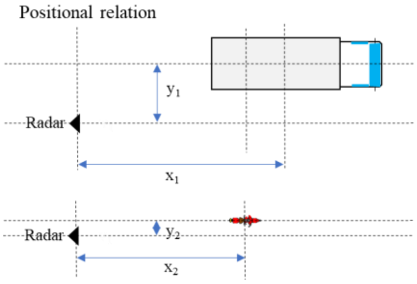
F.3.3.1. Reproducibility Requirements and Validation Methods for Millimeter-Wave Radar

■ Reproduction of Large Signal-Strength Difference (S)
Reproduction of Disturbance Phenomenon — Signal-Intensity Ratio / Half-Width Ratio

Validation Method

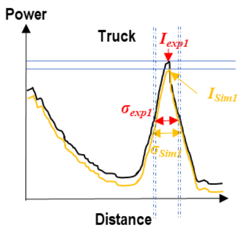
- Perform evaluation using:
    - a large vehicle with high reflectivity (Recognition Target 1), and
    - a small vehicle with lower reflectivity, such as a motorcycle (Recognition Target 2).
- Place both recognition targets on a horizontal straight road and evaluate them in a stationary condition (0 km/h).
- Evaluate Recognition Target 1 and Recognition Target 2 individually.
- Reference relative positions for evaluation:
    - x_1= 150(m), x_2= 140(m)
    - y_1= 3.5(m), y_2= 1(m)

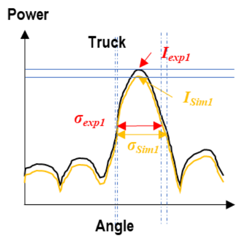
- Compare following ratios between the real-world environment and the virtual environment (exp: real-system experiment, sim: virtual environment):
    - signal-intensity ratios: I_{exp1}/I_{exp2} I_{sim1}/I_{sim2} ;
    - half-width ratios: $\sigma_{exp1}/\sigma_{exp2}$ $\sigma_{sim1}/\sigma_{sim2}$

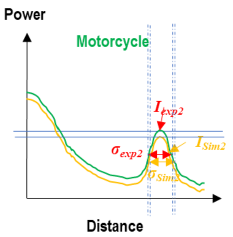


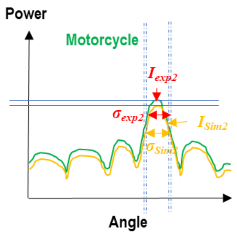
Acceptance Criteria

- The differences between the real-world and virtual environments for both the signal-intensity ratios and half-width ratios shall be within ±5%.





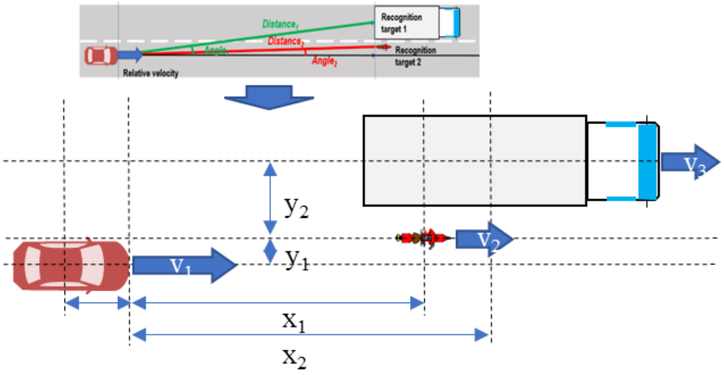




■ Reproduction of Large Signal-Strength Difference (S)
Reproduction of Disturbance Phenomenon — Signal Burial

Validation Method

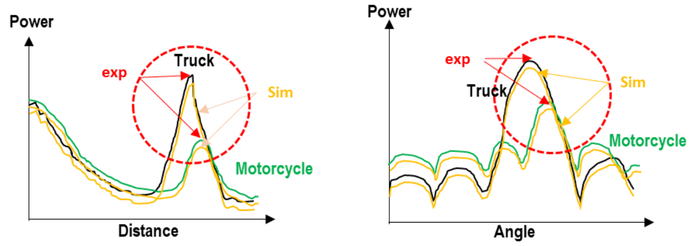
- Perform evaluation using:
  - a large vehicle with high reflectivity (Recognition Target 1), and
  - a small vehicle with lower reflectivity, such as a motorcycle (Recognition Target 2).
- Conduct the evaluation while driving on a horizontal straight road.
- Have Recognition Target 1 and Recognition Target 2 travel side by side in adjacent lanes, approaching the ego vehicle.
- Evaluate the following two cases:
  1. Recognition Target 1 and Recognition Target 2 have the same relative velocity with respect to the ego vehicle;
  2. Recognition Target 1 and Recognition Target 2 have different relative velocities.
- Reference initial positions and velocities:
  - x1= 140(m), x2= 150(m)
  - y1=1(m), y2= 2.5(m)
  - Relative velocity:
    v1-v2 ≈ 10(km/h)
    v2-v3≈ 0-10(km/h)
- Verify whether Recognition Target 2, which has weaker signal intensity, becomes buried in the signal of Recognition Target 1 in both environments.



Phenomenon (Parameter)	Cause (Parameter)	Disturbance (Parameter)	Disturbance	Parameter Range	Explanation	Cause Category
Strength of signal	Distance to subject of recognition	←	←	Distance to subject (r_n) minimum detectable distance to maximum detectable distance	To evaluate the perceptual device of the radar, test using the range determined by the given radar's specs	Cause other than disturbance
	Antenna gain	←	←	Within subject angle (θ_n) FOV range	Evaluate by varying the parameter within the FOV range determined by the radar's specs	
		Sensor angle	Sensor misalignment	Misalignment angle 0 to ±X deg	Minimum angle where auto-misalignment detection will activate	Disturbance factor
	Retroreflectance RCS value (σ_n)	Shape of subject of recognition	Shape of subject of recognition (3D)	Subjects of recognition are persons or motor vehicles as classified in the Road Traffic Act First step is large-sized motor vehicles and ordinary two-wheeled motor vehicles	Take into account vehicles which can travel on expressways +persons walking by the side of a stationary vehicle stopped for an emergency	
		Size of subject of recognition	Size of subject of recognition	Vehicle: Motorized bicycle (equivalent) to large-sized motor vehicle (equivalent) Person: ----	Take into account vehicles which can travel on expressways +persons walking by the side of a stationary vehicle stopped for an emergency	
		Vehicle material	Color	Define using data on rate of reflection/transmittance in millimeter waveband	Require database as there is no correlation between detectable colors and physical property values in millimeter waveband	
			Material	Define using data on physical property values in millimeter waveband	Require database for physical property values in millimeter waveband	
	Combination of subjects of recognition	←	←	Subjects of recognition are persons or motor vehicles as classified in the Road Traffic Act	Take into account vehicles which can travel on expressways +persons walking by the side of a stationary vehicle stopped for an emergency	

Acceptance Criteria

- Confirm that the phenomenon in which Recognition Target 2 becomes undetectable due to signal burial by Recognition Target 1 is reproduced in the same manner in both the real-world and virtual environments.

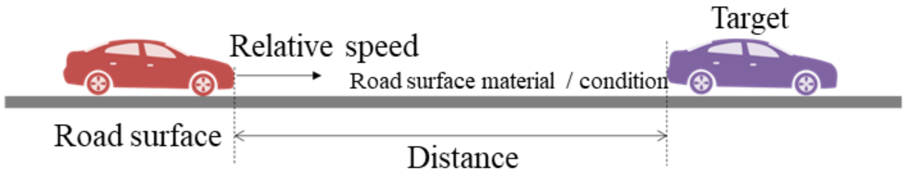


The red frame is an example of this situation, where the signal of motorcycles is buried in the signal of heavy vehicles.

■ Reproduction of Low D/U Due to Road-Surface Multipath
Reproduction of Disturbance Phenomenon — Received Power

Validation Method

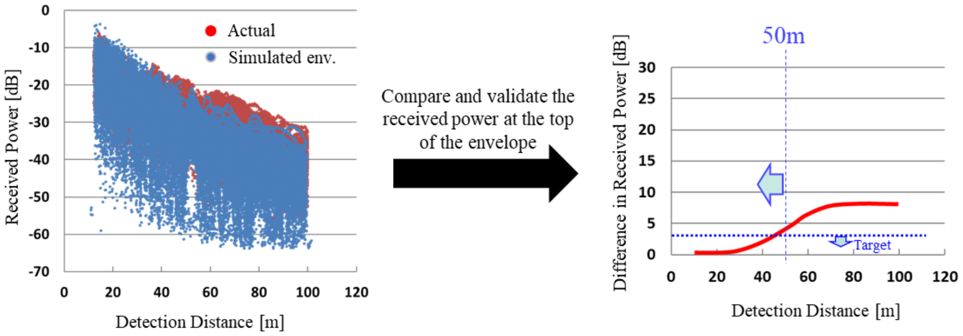
- Reproduce the “Low D/U (road-surface multipath)” evaluation scenario:
  - approach a stationary recognition target located ahead in the ego lane.
- Evaluation conditions:
  - distance to target: from the sensor’s minimum to maximum detection range;
  - relative velocity: e.g., approximately 20 km/h;
  - target types: passenger car, large trailer, etc;
  - road-surface material: asphalt, steel plate, etc;
  - road-surface condition: normal, wet.



Parameter Item	Variable/Fixed	Range	Explanation
Distance to target	Variable	Min to Max detection Range	Min to max range detectable by the sensor
Relative speed	Fixed	Max speed within ODD	
Target type	Fixed	Large-sized vehicle (height：high) Normal vehicle (height：medium) Small-sized vehicle (height：low)	Three levels of representative examples such as large-sized vehicles, normal vehicles, and small-sized vehicles
Road surface material	Fixed	Asphalt / Metal plate(TBD)	Typical road surface material / highly reflective road surface material
Road surface condition	Fixed	Dry / Wet	Normal road surface condition / highly reflective road surface condition

Acceptance Criteria

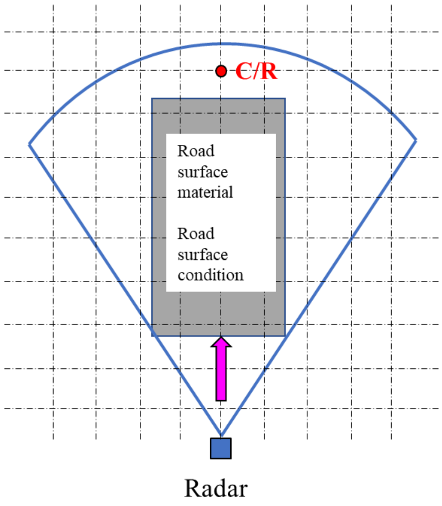
- For relative distances of 50 m or less, the difference in the received-power envelope shall be within 3 dB.



■ Reproduction of Low D/U Due to Road-Surface Multipath
Road-Surface Material and Condition — Received Power / Null Point

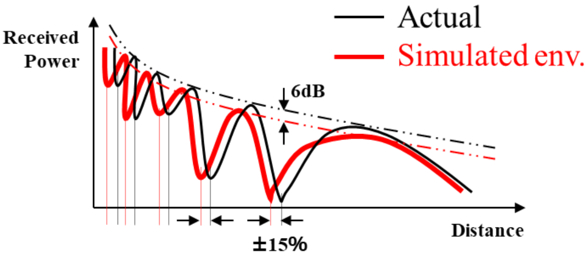
Validation Method

- Install a corner reflector (C/R) directly in front of the radar and move the radar toward the C/R.
- Evaluation parameters:
  - road-surface material: asphalt, steel plate, etc;
  - road-surface condition: normal, wet.



Acceptance Criteria

- Difference in received-power envelope: within 6 dB
- Difference in null-point distance: within ±15%



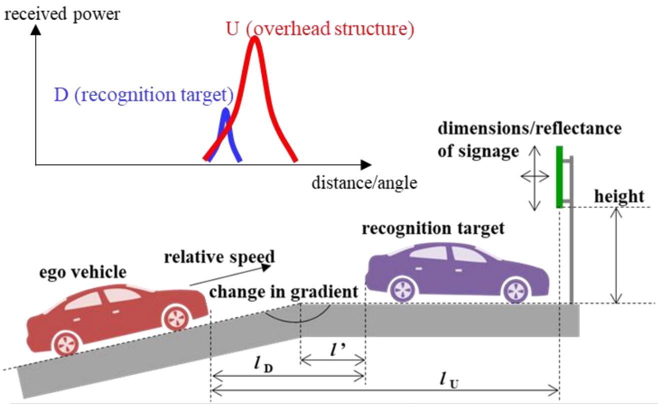
■ Reproduction of Low D/U Due to Elevation-Angle Variation

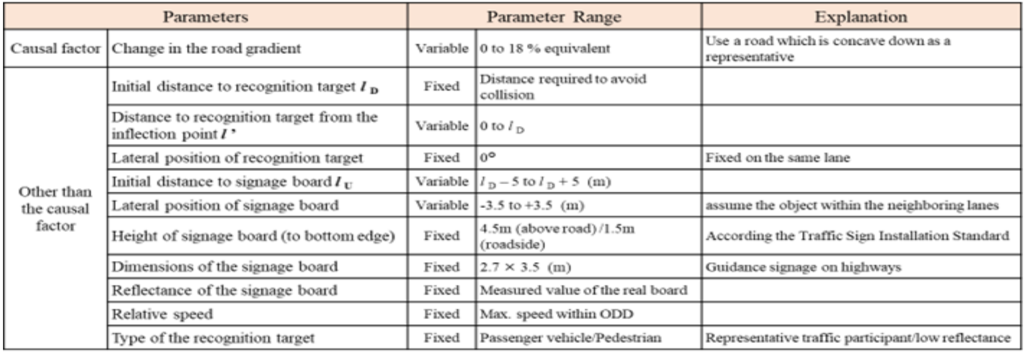
Reproduction of Disturbance Phenomenon — Signal Burial

Validation Method

- Reproduce the “Low D/U due to elevation-angle variation” evaluation scenario:
  - drive on a road with an upward convex gradient change;
  - place a metallic signboard ahead beyond the gradient-change point;
  - approach a stationary vehicle located ahead in the ego lane near the signboard.

  Note: Equivalent conditions (e.g., adjusting the radar mounting angle) may be used as substitutes.
- Evaluation parameters:
  - gradient change: two points within 3° to 10°;
  - l' = 5 m (fixed);
  - Initial lD= 15 m;
  - Initial lU= 20 m;
  - recognition target type: passenger car.
- Compare the peak intensity ratio ID/IU between environments.





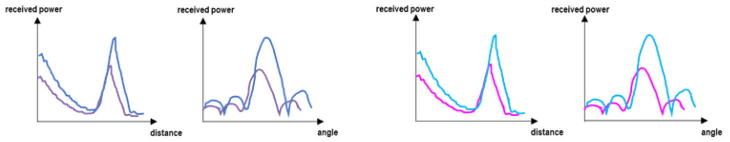
Parameters		Parameter Range		Explanation
Causal factor	Change in the road gradient	Variable	0 to 18 % equivalent	Use a road which is concave down as a representative
Other than the causal factor	Initial distance to recognition target l_D	Fixed	Distance required to avoid collision	
	Distance to recognition target from the inflection point l'	Variable	0 to l_D	
	Lateral position of recognition target	Fixed	0°	Fixed on the same lane
	Initial distance to signage board l_U	Variable	$l_D - 5$ to $l_D + 5$ (m)	
	Lateral position of signage board	Variable	-3.5 to +3.5 (m)	assume the object within the neighboring lanes
	Height of signage board (to bottom edge)	Fixed	4.5m (above road) /1.5m (roadside)	According the Traffic Sign Installation Standard
	Dimensions of the signage board	Fixed	2.7 × 3.5 (m)	Guidance signage on highways
	Reflectance of the signage board	Fixed	Measured value of the real board	
	Relative speed	Fixed	Max. speed within ODD	
	Type of the recognition target	Fixed	Passenger vehicle/Pedestrian	Representative traffic participant/low reflectance

Acceptance Criteria

- Confirm that the phenomenon in which the signal from the recognition target becomes buried in the signal from the signboard occurs in the same manner in both environments.

Actual Environment

Simulated Environment

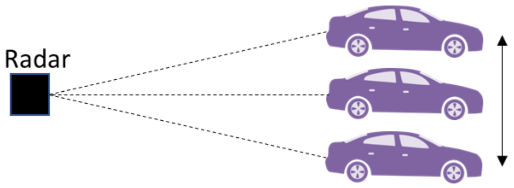


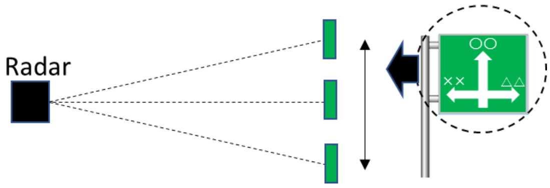
■ Reproduction of Low D/U Due to Elevation-Angle Variation

Reflective Characteristics of Overhead Structures — Signal-Intensity Ratio / Half-Width Ratio

Validation Method

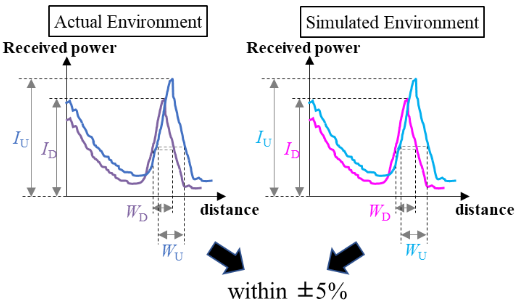
- Irradiate radar electromagnetic waves onto:
  - a passenger car, and
  - a flat surface of a road sign.
- Vary the vertical-plane angle between the radar and the targets:
  - angles: 0°, ±5°, ±10°.
- Measurement distances: 15 m and 20 m.
- Compare:
  - peak intensity ratio I_D/I_U ;
  - peak half-width ratio W_D/W_U.

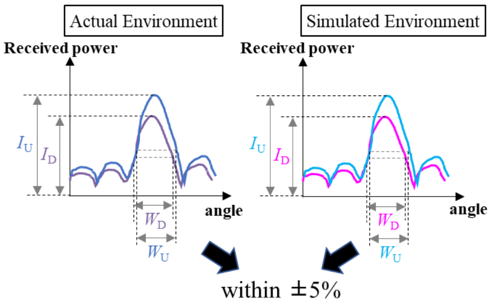




Acceptance Criteria

- Differences in both I_D/I_U and W_D/W_U between the real-world and virtual environments shall be within ±5%.

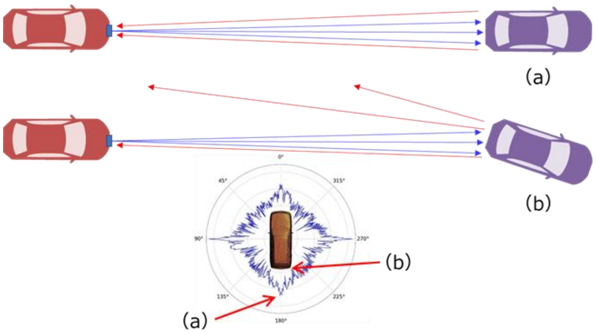




■ Low S/N Due to Vehicle Orientation

Validation Method

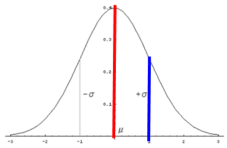
- Reproduce the “Low S/N due to vehicle orientation” evaluation scenario:
  - place a stationary vehicle ahead on a straight road;
  - approach the vehicle at low velocity.
  - vary the installation angle of the vehicle ahead.
- Evaluation parameters:
  - installation angles: 0°, 10°, 30°;
  - Initial headway: 150 m;
  - Vehicle velocity: ≤ 20 km/h;
  - recognition target type: passenger car (standard vehicle)
- Record and compare the received power in both environments.



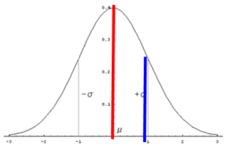
Parameter Item	Variable/ Fixed	Range	Explanation
Type of recognition target	Variable	• Projected area (large/mid/small) • Contribution rate to scattering= Reflectance (heavy use of metal / heavy use of non- metal / in-between) • Directivity of scattered waves (uniform/biased)	• 3 levels of projected area generally • 3 levels (no vehicle has zero metal used) • 3 levels (relying on concentration of normal vectors in microparts of the vehicle)
Orientation of the target	Variable	0 to 30 deg.	According to the line of the road (curve R)
Distance to the target	Variable	5 to 150 m	
Relative speed	Fixed	20 km/h and below	constant

Acceptance Criteria

- For a given headway range (e.g., 10–20 m), plot the cumulative distribution of received power (dBm)
- Differences in both the mean and variance between environments shall be within ±10%.



Cumulative Distribution of the Received power (ACTUAL)



Cumulative Distribution of the Received power (SIM)

F.3.3.2. Reproducibility Requirements and Validation Methods for LiDAR

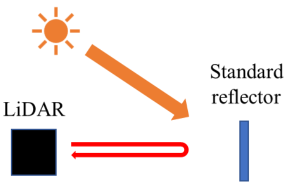
This subsection describes the validation methods used to verify the reproducibility requirements for perception disturbances of LiDAR, as defined in Section F.3.2.2.
Each validation item corresponds to a specific perception-disturbance principle described in Annex E, and reproducibility is verified by comparing results obtained in the real-world environment with those obtained in the virtual environment.

■ Noise: Mean Error and Variability of Measured Range

This validation corresponds to the evaluation of “disturbance light due to reflected light” described in Annex E, Section 3.2.2.2.

Validation Method

- Place a standard reflective plate directly in front of the LiDAR
- Vary the distance to the reflective plate and measure the mean error and variance of the measured range.
- Confirm that the difference between the real-world measurements and the virtual-environment results fall within the acceptance criteria.

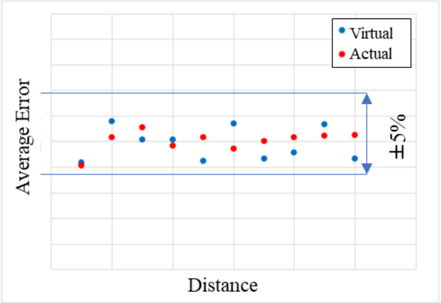


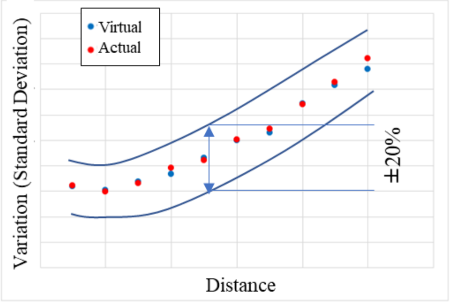
Causal Factors			Causal Factor Parameter	Range	Basis (or reasons)
Space	Light source	Halogen lights, etc.	Altitude	20 to 90 degrees	i.q. Annex.E
			Azimuth	-180 to -150, 150 to 180 degrees	± 30 deg in the rear of the ego vehicle (traveling direction ≡ 0 deg)
			Brightness	XX～YY W/mm²	The irradiance value on the target surface within the angular condition of the sun above is used in case of using a Halogen light etc. The parameter range is set within the LiDAR’s wavelength range.

From the parameter ranges defined above, select conditions under which the irradiance on the target is near its maximum and perform the validation.
If the noise level can be appropriately reproduced, it is acceptable to perform the validation using irradiance as the sole parameter, with the incidence angle fixed.

Acceptance Criteria

- Mean error: within ±5% of the distance to the target
- Standard deviation (σ): within ±20%



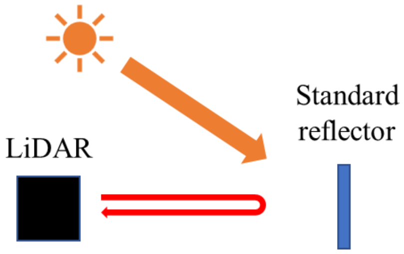


■ Noise: Received Intensity and Detection Probability

This validation corresponds to the evaluation for “disturbance light due to reflected light” described in Annex E, Section 3.2.2.2.

Validation Method

- Place a standard reflective plate directly in front of the LiDAR.
- Vary the distance to the plate and measure the received intensity and detection probability.
- Confirm that the results obtained in the virtual environment satisfy the acceptance criteria when compared with measured values.

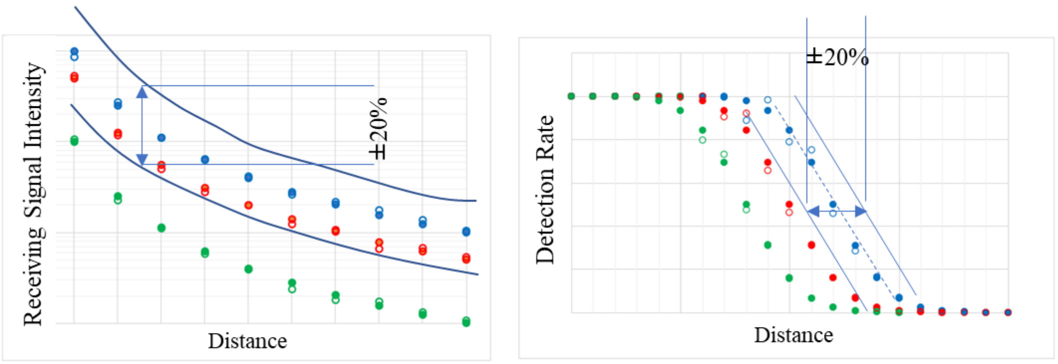


Causal Factors			Causal Factor Parameter	Range	Basis (or reasons)
Space	Light source	Halogen lights, etc.	Altitude	20 to 90 degrees	i.q. Annex.E
			Azimuth	-180 to -150, 150 to 180 degrees	±30 deg in the rear of the ego vehicle (traveling direction ≡ 0 deg)
			Brightness	XX～YY W/mm^2	The irradiance value on the target surface within the angular condition of the sun above is used in case of using a Halogen light etc. The parameter range is set within the LiDAR’s wavelength range.

From the parameter ranges defined above, select conditions under which the irradiance on the target is near its maximum and perform the validation.
If the noise level can be appropriately reproduced, it is acceptable to perform the validation using irradiance as the sole parameter, with the incidence angle fixed.

Acceptance Criteria

- Intensity error relative to measured values: within ±20%
- Difference in detection probability relative to measured values at:
  - 90% detection probability: within ±20%
  - 50% detection probability: within ±20%
  - 10% detection probability: within ±20%



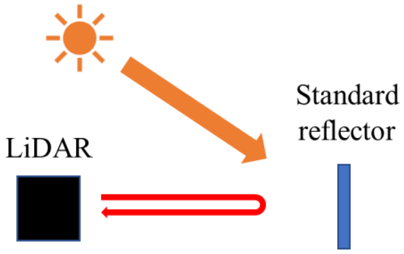
※Blue: reflectivity xx% Red: reflectivity xx% Green: reflectivity xx% ※● Actual ○Virtual

■ Noise: Number of Received Points

This validation corresponds to the evaluation of “disturbance light due to reflected light” described in Annex E, Section 3.2.2.2.

Validation Method

- Place a recognition-target asset directly in front of the LiDAR.
- Vary the distance to the asset and verify the difference in the number of received points between environments.

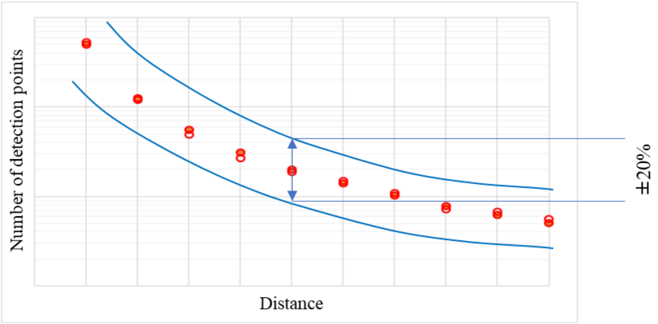


Causal Factors			Causal Factor Parameter	Range	Basis (or reasons)
Space	Light source	Halogen lights, etc.	Altitude	20 to 90 degrees	i.q. Annex.E
			Azimuth	-180 to -150, 150 to 180 degrees	±30 deg in the rear of the ego vehicle (traveling direction ≡ 0 deg)
			Brightness	XX～YY W/mm^2	The irradiance value on the target surface within the angular condition of the sun above is used in case of using a Halogen light etc. The parameter range is set within the LiDAR’s wavelength range.

From the parameter ranges defined above, select conditions under which the irradiance on the target is near its maximum and perform the validation.

Acceptance Criteria

- Error relative to the measured number of points: within ±20%,
  excluding long-distance ranges where the number of received points becomes inherently small.



■ Signal Attenuation (S): Reproducibility of Attenuation Disturbance

Reproduction of Attenuated Recognition Targets

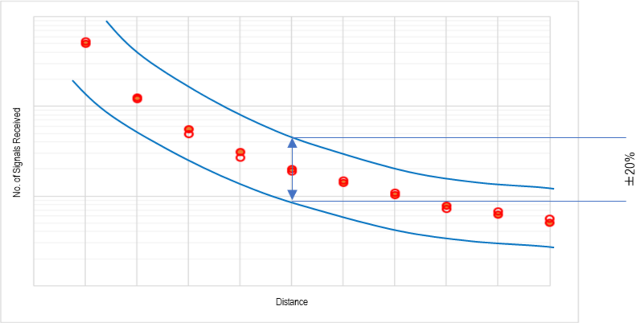
Validation Method

- Place a recognition-target asset directly in front of the LiDAR.
- Vary the distance to the asset and verify the difference in the number of received points between the real-world environment and the virtual environment.

Causal Factors	Causal Factor Parameter	Range	Basis (or reasons)
Vehicle	Shape	• Vehicles with high ground clearance • Low height vehicle • Motorcycles, bicycles • Angular vehicles • Rounded vehicles	• Clears bottom of body and only receives reflection from tires • The top layer of the beam has difficulty hitting the roof rack • Number of reflection points in horizontal direction is minimal • Depending on orientation, it may be difficult for the direction of the normal vector to align with the LiDAR • It may be difficult for the direction of the normal vector to align with the LiDAR
	Color, material properties	• Black paint • Specular reflection	• Does not diffuse reflection well • Depending on the orientation, the specular reflection will occur and not return

Acceptance Criteria

- Error relative to the measured number of points: within ±20%,
  excluding long-distance ranges where the number of received points becomes inherently small.



F.3.3.3. Reproducibility Requirements and Validation Methods for Camera Sensors

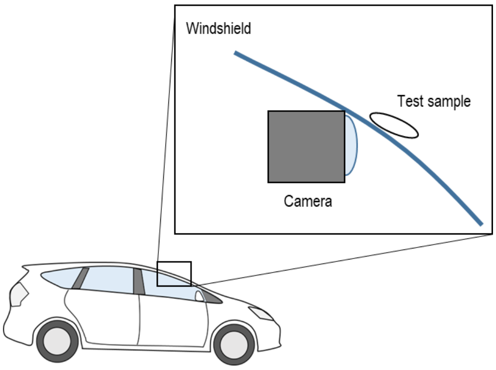
This subsection describes the validation methods for verifying the reproducibility requirements of perception disturbances for camera sensors, as defined in Section F.3.2.3.
The validation items are organized according to the type of occlusion-related disturbance and the processing stage affected, namely the perception module (image-level consistency) and the recognition results (object-level outputs).

■ Occlusion: Placement Verification (Occluding Objects) and Color/Luminance Verification (Occluding Objects)

1. Deposits on the Sensor Front Surface — Consistency of the Perception Module

Validation Method

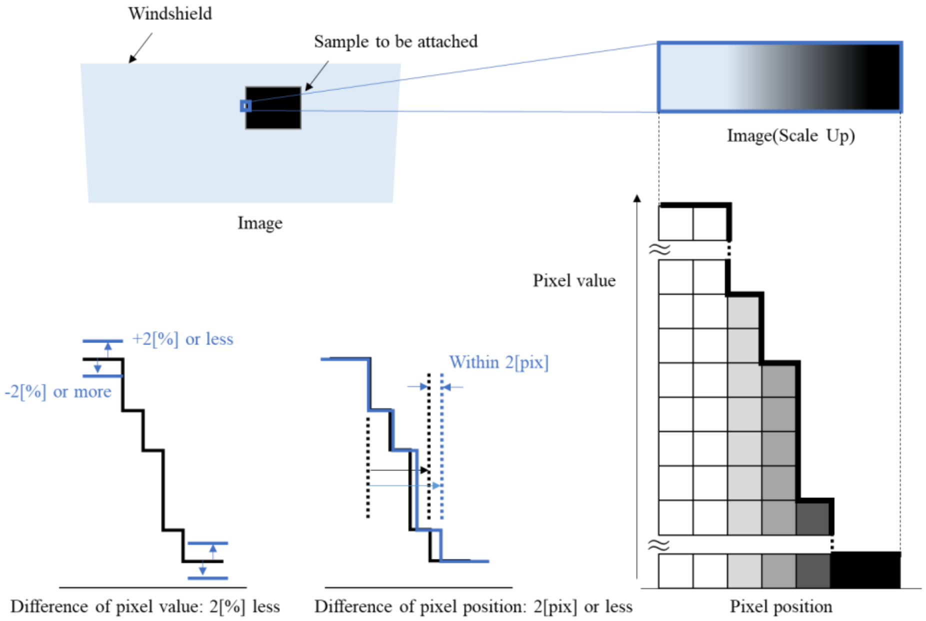
- With the vehicle stationary, apply a sample material to the windshield and perform validation.
- The evaluation method is the same as that used for the common requirements.
- If precise physical alignment of the sample is difficult, comparison may alternatively be performed using the pixel-value profile at the edge of the occluding object.
- Refer to:
  - F.2.3.3.1 Standalone Camera: Module Calibration — FOV / Optical Axis / Distortion, and
  - F.2.3.3.2 Standalone Camera: Module Calibration — Color and Luminance.
- The applied sample shall be a fully occluding material (opaque, non-transmissive).



Acceptance Criteria

- For both the occluded region and the non-occluded region, the difference in pixel values between the real system and the simulation shall be within ±2%, and
- the difference in image-plane distance between the occluded and non-occluded regions shall be within ±2 pixels.

Supplementary note:

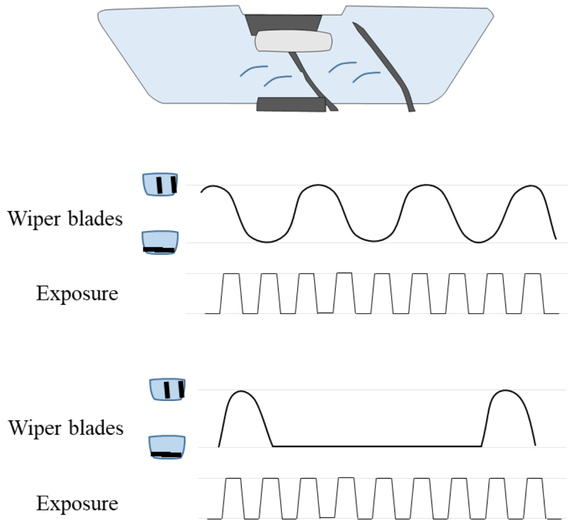


2. Obstructions on the Sensor Front Surface — Consistency of the Perception Module

Validation Method

- Verify the reproduction of wiper intrusion as a time-varying element.
- Evaluate time-dependent characteristics such as wiper motion and shutter timing.

Wiper blades：intermittent, continuous



Acceptance Criteria

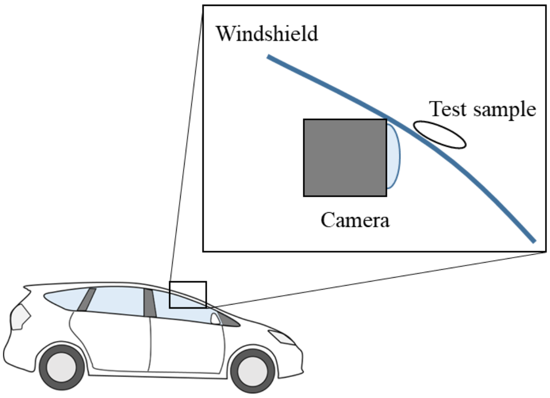
- The exposure timing and the temporal behavior of the wiper motion shall match between the real system and the simulation.
- The difference in pixel values for images under the same condition shall be within 5%.

■ Occlusion: Placement Verification (Targets) and Color/Luminance Verification (Targets)

1. Deposits on the Sensor Front Surface — Consistency of the Perception Module

Validation Method

- With the vehicle stationary, apply a sample material to the windshield and perform validation using the same methods as those defined for the common requirements.
- Refer to F.2.3.3.9 and F.2.3.3.10.



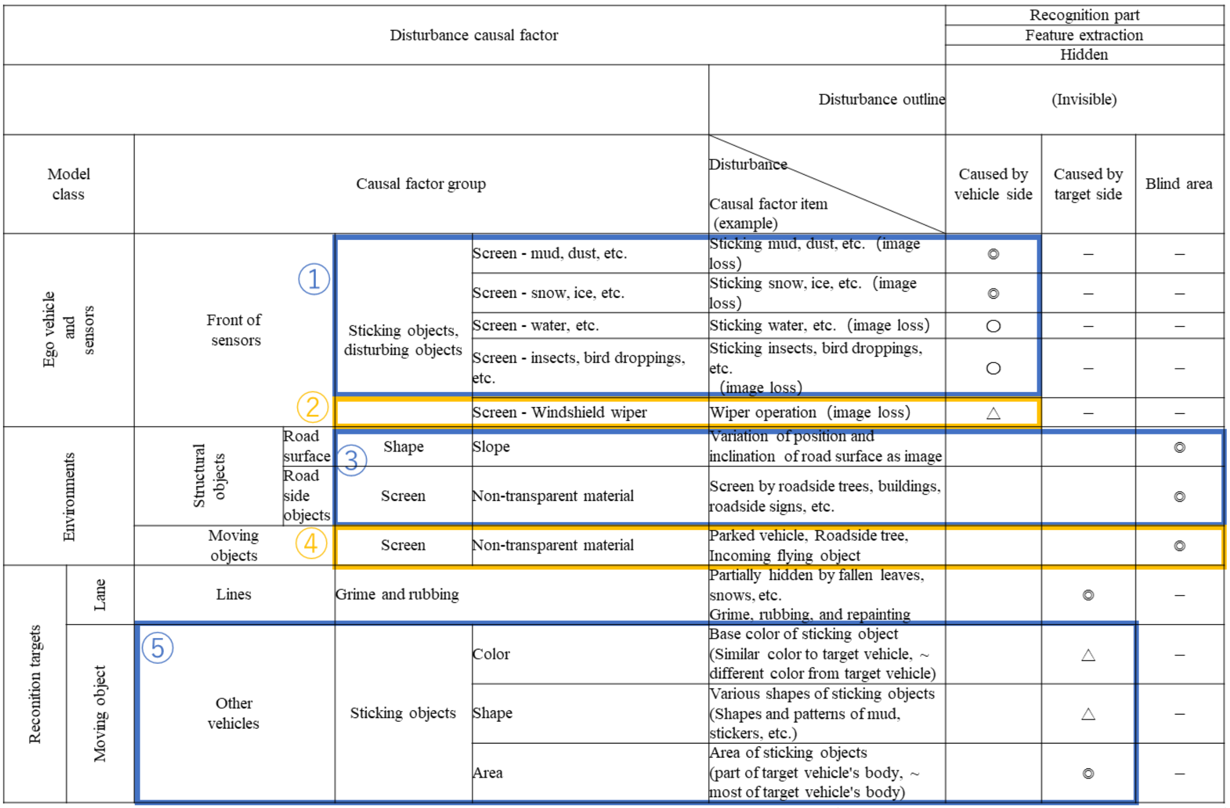
Acceptance Criteria

- For both the occluded region and the non-occluded region, the difference in pixel values between the real system and the simulation shall be within ±2%, and
- the difference in image-plane distance between the occluded and non-occluded regions shall be within ±2 pixels.

■ Occlusion: Recognition Results (Targets)

For occlusion-related disturbances affecting recognition results, validation methods are defined individually for the following five categories.

(◎: large impact, ○: middle impact, △: small impact)



Disturbance causal factor								Recognition part Feature extraction Hidden		
							Disturbance outline	(Invisible)		
Model class		Causal factor group					Disturbance Causal factor item (example)	Caused by vehicle side	Caused by target side	Blind area
Ego vehicle and sensors		Front of sensors		①	Sticking objects, disturbing objects	Screen - mud, dust, etc.	Sticking mud, dust, etc. (image loss)	◎	–	–
						Screen - snow, ice, etc.	Sticking snow, ice, etc. (image loss)	◎	–	–
						Screen - water, etc.	Sticking water, etc. (image loss)	○	–	–
						Screen - insects, bird droppings, etc.	Sticking insects, bird droppings, etc. (image loss)	○	–	–
				②		Screen - Windshield wiper	Wiper operation (image loss)	△	–	–
Environments		Structural objects	Road surface	③	Shape	Slope	Variation of position and inclination of road surface as image			◎
			Road side objects		Screen	Non-transparent material	Screen by roadside trees, buildings, roadside signs, etc.			◎
		Moving objects		④	Screen	Non-transparent material	Parked vehicle, Roadside tree, Incoming flying object			◎
Reconition targets	Lane	Lines			Grime and rubbing		Partially hidden by fallen leaves, snows, etc. Grime, rubbing, and repainting		◎	–
	Moving object	Other vehicles		⑤	Sticking objects	Color	Base color of sticking object (Similar color to target vehicle, ~ different color from target vehicle)		△	–
						Shape	Various shapes of sticking objects (Shapes and patterns of mud, stickers, etc.)		△	–
						Area	Area of sticking objects (part of target vehicle's body, ~ most of target vehicle's body)		◎	–

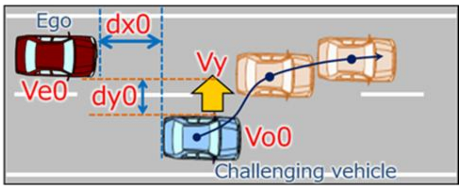
(Taken from Phenomenon and Cause Matrix)

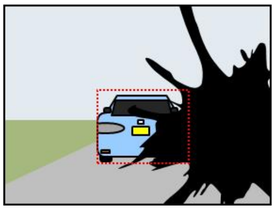
1. Deposits on the Sensor Front Surface

Scenario F-1: Cut-In Scenario on a Straight Road

Validation Method

- With the field of view restricted by deposits, a recognition target enters the ego lane ahead with a constant lateral velocity.





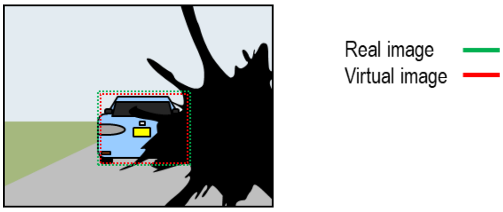
Reference: Parameters of Validation Scenario

Parameter	Variable／Fexed	Range
Distance to the target	Variable	Longitudinal position dx0 [m]
		Lateral position y0 : 3.5m
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph] Lateral velocity Vy [kph]
Type of the target	Fixed	Shape: sedan Color: White
Degree of shielding of the detection-target due to adherence of foreign object	Variable	In relation to the bounding box of the detection-target ① Initial50% → Final0% ② Initial100% → Final50%*

Acceptance Criteria

- Longitudinal distance difference: ≤ 5%
- Lateral distance difference: ≤ 5%
- Longitudinal relative-velocity difference: ≤ 10%
- Lateral relative-velocity difference: ≤ 10%
- Width and height difference: ≤ 5%

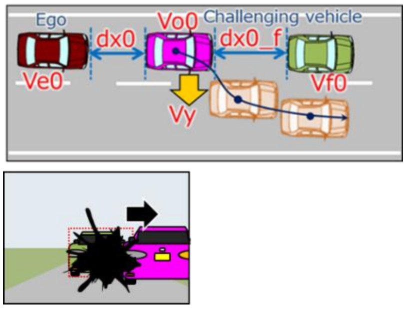
Evaluation shall be performed only on frames in which the target is successfully recognized.



Scenario F-2: Cut-Out Scenario on a Straight Road

Validation Method

- A leading vehicle performs a cut-out maneuver from an occluded position.
- Recognition targets include both the leading vehicle and the vehicle ahead of it.



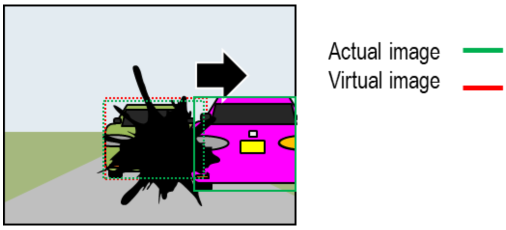
Reference: Parameters of Validation Scenario

Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 [m]
		Longitudinal position dx0_f [m]
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph]
		Longitudinal velocity Vo0-Vf0 [kph]
		Lateral velocity Vy [kph]
Type of the target	Fixed	Shape: sedan Color: White
Degree of shielding of the detection-target due to adherence of foreign object	Variable	In relation to the bounding box of the detection-target ① Initial50% → Final0%

Acceptance Criteria

- Longitudinal distance difference: ≤ 5%
- Lateral distance difference: ≤ 5%
- Longitudinal relative-velocity difference: ≤ 10%
- Lateral relative-velocity difference: ≤ 10%
- Width and height difference: ≤ 5%

Evaluation shall be performed only on frames in which the target is successfully recognized.

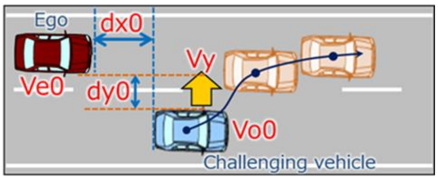


2. Obstructions on the Sensor Front Surface

Scenario F-1: Cut-In Scenario on a Straight Road

Validation Method

- While the wipers are operating, a recognition target enters the ego lane ahead with a constant lateral velocity.

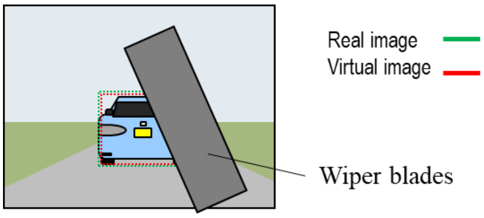


Reference: Parameters of Validation Scenario

Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 [m]
		Lateral position y0 : 3.5m
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph] Lateral velocity Vy [kph]
Type of the target	Fixed	Shape: sedan Color: White
Wiper blade movement	Fixed	1. Intermittent 2. Continuous

Acceptance Criteria

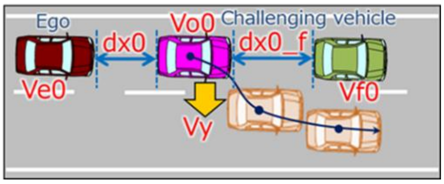
- Longitudinal distance difference: ≤ 5%
- Lateral distance difference: ≤ 5%
- Longitudinal relative-velocity difference: ≤ 10%
- Lateral relative-velocity difference: ≤ 10%
- Width and height difference: ≤ 5%



Scenario F-2: Cut-Out Scenario on a Straight Road

Validation Method

- While the wipers are operating, a recognition target performs a cut-out maneuver.

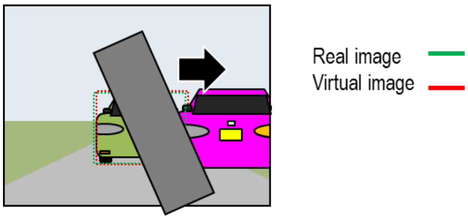


Reference: Parameters of Validation Scenario

Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 [m]
		Longitudinal position dx0_f [m]
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph] Longitudinal velocity Vo0-Vf0 [kph] Lateral velocity Vy [kph]
Type of the target	Fixed	Shape: sedan Color: White
Wiper blade movement	Fixed	1. Intermittent 2. Continuous

Acceptance Criteria

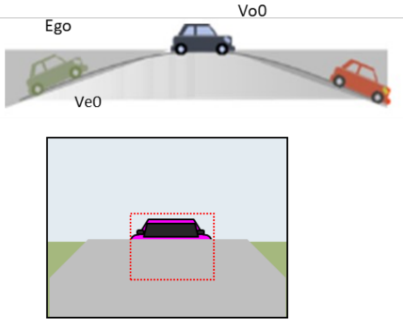
- Longitudinal distance difference: ≤ 5%
- Lateral distance difference: ≤ 5%
- Longitudinal relative-velocity difference: ≤ 10%
- Lateral relative-velocity difference: ≤ 10%
- Width and height difference: ≤ 5%



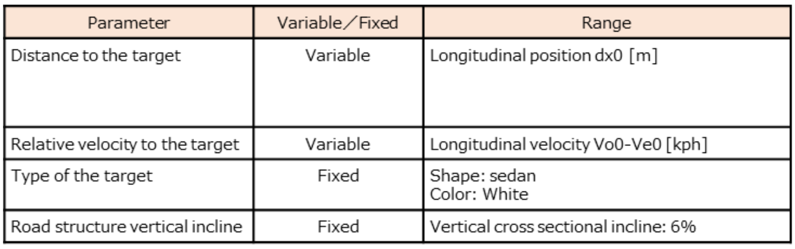
3. Road-Gradient Obstructed-View Scenario (Vertical)

Validation Method

- Drive on a road surface with a convex longitudinal gradient and approach a recognition target ahead in the ego lane at a constant velocity.



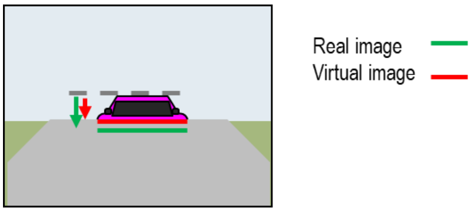
Reference: Parameters of Validation Scenario



Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 [m]
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph]
Type of the target	Fixed	Shape: sedan Color: White
Road structure vertical incline	Fixed	Vertical cross sectional incline: 6%

Acceptance Criteria

- Difference in image height from vehicle top to occluding road surface: ≤ 10 pixels
- Longitudinal distance difference: ≤ 5%
- Lateral distance difference: ≤ 5%
- Longitudinal relative-velocity difference: ≤ 10%
- Lateral relative-velocity difference: ≤ 10%
- Width and height difference: ≤ 5%

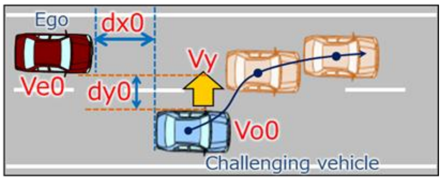


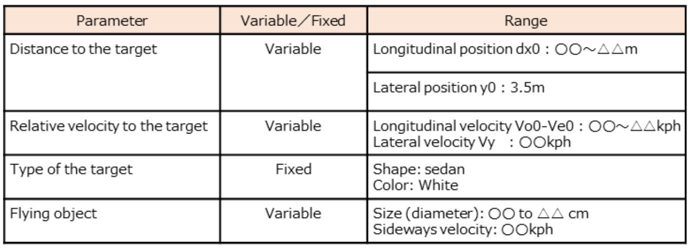
4. Occlusion by Surrounding Moving Objects (Flying Objects): Cut-In Scenario

Validation Method

- While a recognition target enters the ego lane ahead with a constant lateral velocity, a flying object crosses in front of the ego vehicle.
- Flying objects are defined as moving objects other than traffic participants. They may be in contact with the ground, provided that they can move so as to occlude part of the recognition target.

Reference: Parameters of Validation Scenario

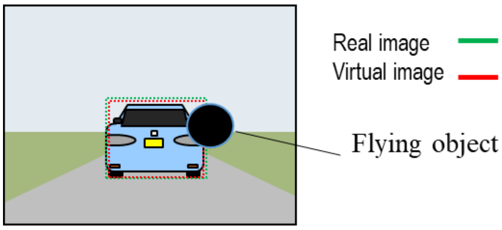




Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0：〇〇~△△m
		Lateral position y0：3.5m
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0：〇〇~△△kph Lateral velocity Vy　：〇〇kph
Type of the target	Fixed	Shape: sedan Color: White
Flying object	Variable	Size (diameter): 〇〇 to △△ cm Sideways velocity: 〇〇kph

Acceptance Criteria

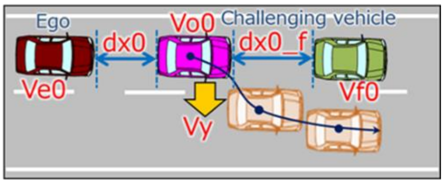
- Longitudinal distance difference: ≤ 5%
- Lateral distance difference: ≤ 5%
- Longitudinal relative-velocity difference: ≤ 10%
- Lateral relative-velocity difference: ≤ 10%
- Width and height difference: ≤ 5%

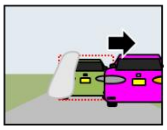


5. Deposits on Other Vehicles: Cut-Out Scenario

Validation Method

- A vehicle traveling behind a recognition target covered with a cover performs a cut-out maneuver.



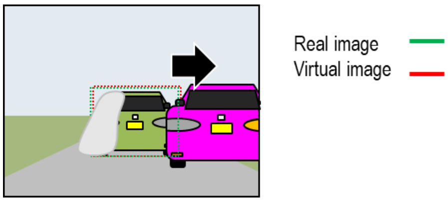


Reference: Parameters of Validation Scenario

Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 : ○○～△△m
		Longitudinal position dx0_f : ○○～△△m
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 : ○○～△△kph Longitudinal velocity Vo0-Vf0 : ○○～△△kph Lateral velocity Vy : ○○kph
Type of the target	Fixed	Shape: sedan Color: White
Degree of shielding of the detection-target due to partial shielding by a cover	Variable	30% to 70% shielding in relation to the vehicle width of the detection-target

Acceptance Criteria

- Longitudinal distance difference: ≤ 5%
- Lateral distance difference: ≤ 5%
- Longitudinal relative-velocity difference: ≤ 10%
- Lateral relative-velocity difference: ≤ 10%
- Width and height difference: ≤ 5%

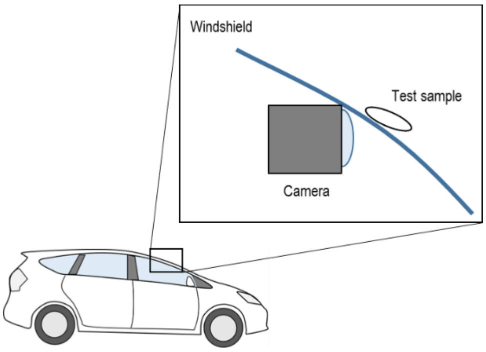


■ Occlusion: Placement Verification (Lane Boundaries) and Color/Luminance Verification (Lane Boundaries)

1. Deposits on the Sensor Front Surface — Consistency of the Perception Module

Validation Method

- With the vehicle stationary, apply a sample material to the windshield and perform validation using signal intensity and color-evaluation methods.
- Refer to:
  - F.2.3.3.11 Asset/Scenario: Recognition Target (Lane Boundaries) — Placement, and
  - F.2.3.3.12 Asset/Scenario: Recognition Target (Lane Boundaries) — Color and Luminance.

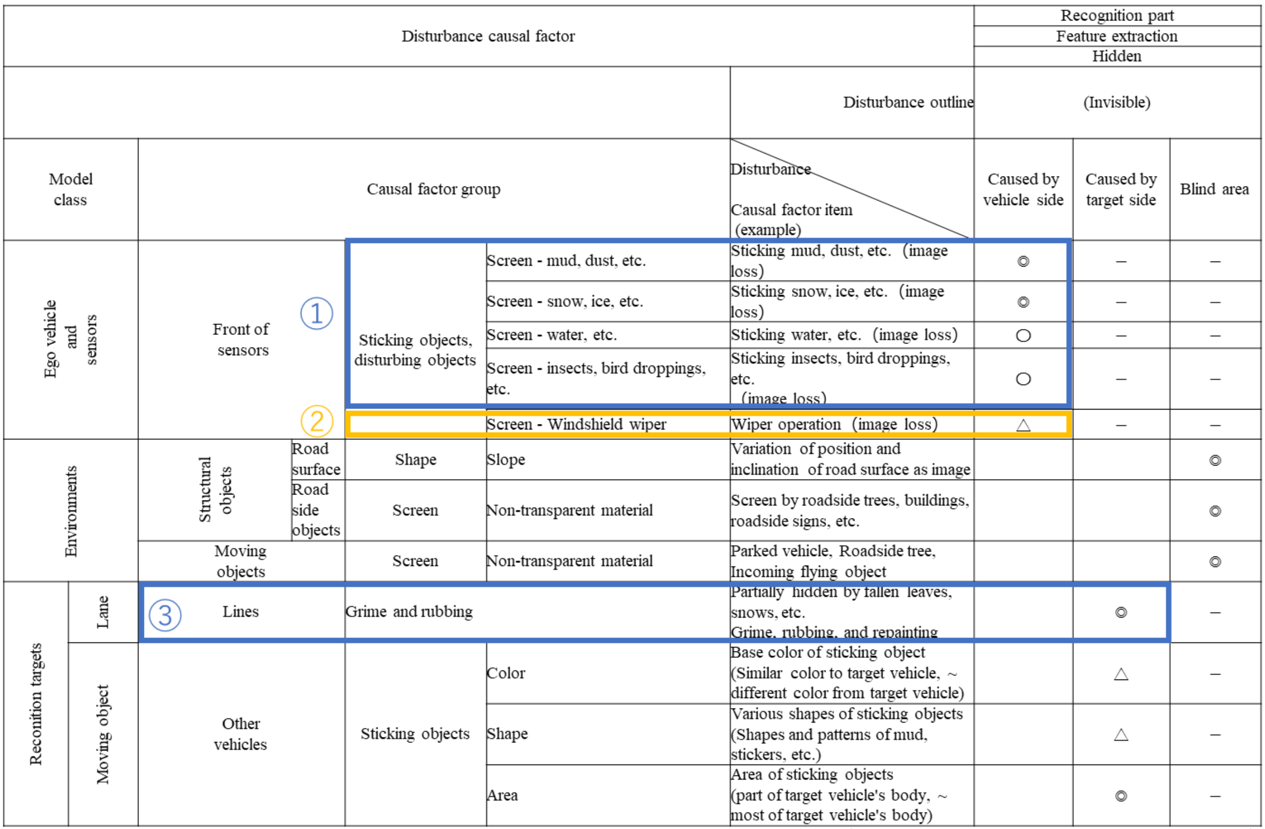


Acceptance Criteria

- For both the occluded region and the non-occluded region, the difference in pixel values shall be within ±2%, and
- the difference in image-plane distance between occluded and non-occluded regions shall be within ±2 pixels.

■ Occlusion: Recognition Results (Lane Boundaries)

For occlusion-related disturbances affecting lane-boundary recognition results, validation methods are defined individually for the following three categories.



Disturbance causal factor							Recognition part Feature extraction Hidden		
						Disturbance outline	(Invisible)		
Model class		Causal factor group			Causal factor item (example)	Disturbance	Caused by vehicle side	Caused by target side	Blind area
Ego vehicle and sensors		Front of sensors ①		Sticking objects, disturbing objects	Screen - mud, dust, etc.	Sticking mud, dust, etc. (image loss)	◎	–	–
					Screen - snow, ice, etc.	Sticking snow, ice, etc. (image loss)	◎	–	–
					Screen - water, etc.	Sticking water, etc. (image loss)	○	–	–
					Screen - insects, bird droppings, etc.	Sticking insects, bird droppings, etc. (image loss)	○	–	–
		②			Screen - Windshield wiper	Wiper operation (image loss)	△	–	–
Environments		Structural objects	Road surface	Shape	Slope	Variation of position and inclination of road surface as image			◎
			Road side objects	Screen	Non-transparent material	Screen by roadside trees, buildings, roadside signs, etc.			◎
		Moving objects		Screen	Non-transparent material	Parked vehicle, Roadside tree, Incoming flying object			◎
Reconition targets	Lane	③ Lines		Grime and rubbing		Partially hidden by fallen leaves, snows, etc. Grime, rubbing, and repainting		◎	–
	Moving object	Other vehicles		Sticking objects	Color	Base color of sticking object (Similar color to target vehicle, ~ different color from target vehicle)		△	–
					Shape	Various shapes of sticking objects (Shapes and patterns of mud, stickers, etc.)		△	–
					Area	Area of sticking objects (part of target vehicle's body, ~ most of target vehicle's body)		◎	–

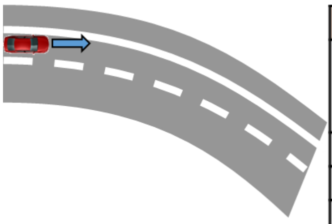
（Taken from Phenomenon and Cause Matrix）

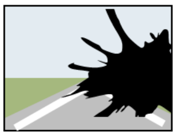
1. Deposits on the Sensor Front Surface — Lane-Keeping Scenario

Validation Method

- Drive along the ego lane at a constant velocity under conditions where the field of view is restricted by deposits.

Reference: Parameters of Validation Scenario





Parameter	Variable／Fixed	Range
Velocity of ego vehicle	Fixed	Ve0 : 120kph
Width of driving lane	Fixed	3.5m
Curvature of lane	Fixed	R〇〇
Type of the target	Variable	Shape: solid line, dotted line Color: white, yellow
Amount which the ego vehicle’s driving lane marking lines are shielded due to the adherence of a foreign object (disturbance)	Fixed	Amount of shielding: 50%

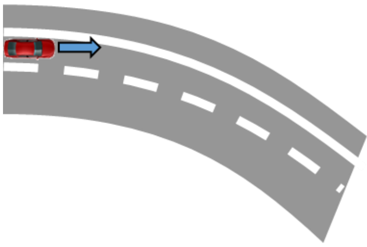
Acceptance Criteria

- Curvature-radius difference: ≤ 5%
- Heading-angle difference: ≤ 5%
- Position difference: ≤ 5%
- Target type matches

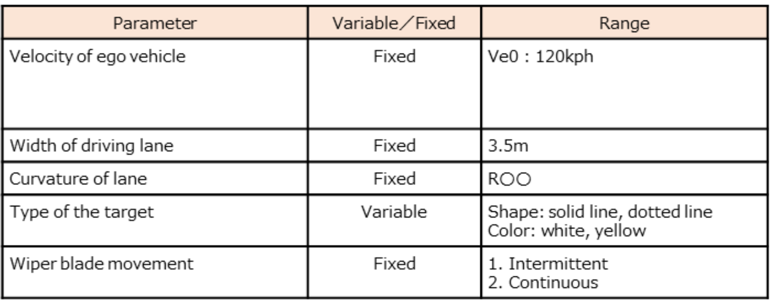
2. Obstructions on the Sensor Front Surface — Lane-Keeping Scenario

Validation Method

- Drive along the ego lane at a constant velocity while the wipers are operating.



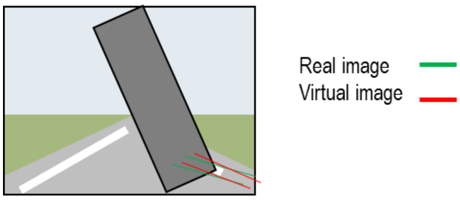
Reference: Parameters of Validation Scenario



Parameter	Variable／Fixed	Range
Velocity of ego vehicle	Fixed	Ve0 : 120kph
Width of driving lane	Fixed	3.5m
Curvature of lane	Fixed	R〇〇
Type of the target	Variable	Shape: solid line, dotted line Color: white, yellow
Wiper blade movement	Fixed	1. Intermittent 2. Continuous

Acceptance Criteria

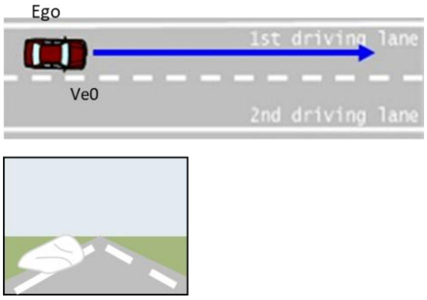
- Curvature-radius difference: ≤ 5%
- Heading-angle difference: ≤ 5%
- Position difference: ≤ 5%
- Target type: matches



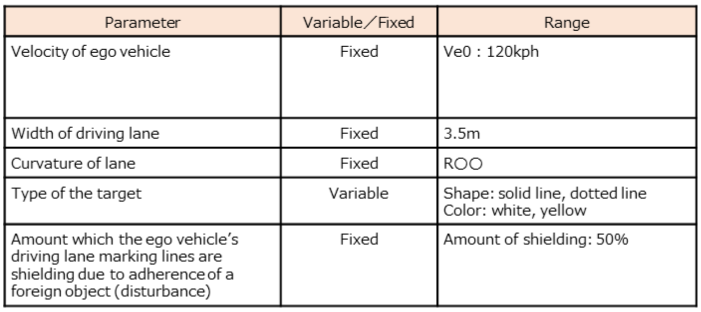
3. Lane-Marking Contamination — Lane-Keeping Scenario

Validation Method

- Drive along the ego lane at a constant velocity under conditions where lane markings are partially occluded by fallen leaves, snow accumulation, or similar factors.
- The occlusion ratio of the lane markings shall be up to a maximum of 50%.



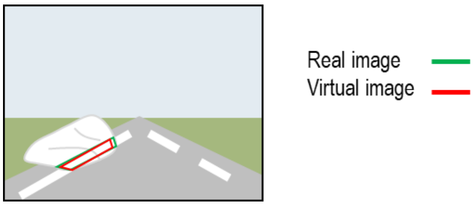
Reference: Parameters of Validation Scenario



Parameter	Variable／Fixed	Range
Velocity of ego vehicle	Fixed	Ve0 : 120kph
Width of driving lane	Fixed	3.5m
Curvature of lane	Fixed	ROO
Type of the target	Variable	Shape: solid line, dotted line Color: white, yellow
Amount which the ego vehicle's driving lane marking lines are shielding due to adherence of a foreign object (disturbance)	Fixed	Amount of shielding: 50%

Acceptance Criteria

- Difference in occlusion amount of lane markings: ≤ 5% (pixel count)
- Curvature-radius difference: ≤ 5%
- Heading-angle difference: ≤ 5%
- Position difference: ≤ 5%
- Target type: matches



■ (Due to Spatial Obstacles) Low Spatial Frequency and Low Contrast

Validation Method

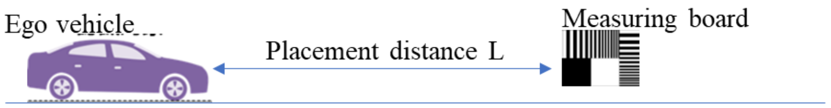
- In the evaluation scenarios, vary the causal-factor parameters to create conditions near the performance limits, and perform validation.
- Confirm disturbance reproduction using combinations of causal-factor parameters that are supported by tools are measurable in real systems.

Verification 1: Perception-Module Perspective

  - Place a dedicated measurement board, vary the causal-factor parameters, and verify spatial frequency and contrast.
  - Verification shall be performed using RAW data that are linear with respect to luminance.

Verification 2: Recognition -Module Perspective

  - Vary the causal-factor parameters, approach a stationary recognition target with the ego vehicle, and verify the recognition results.



Object of obstruction is not present in space

Object of obstruction present in space

Object of obstruction present in space

Acceptance Criteria

(Verification 1)

- Differences in spatial frequency and contrast between the simulation and the real systems shall be within ±5%.
- Measurement condition: the difference between the mean measured value and the theoretical value shall be within ±5%.

(Verification 2)

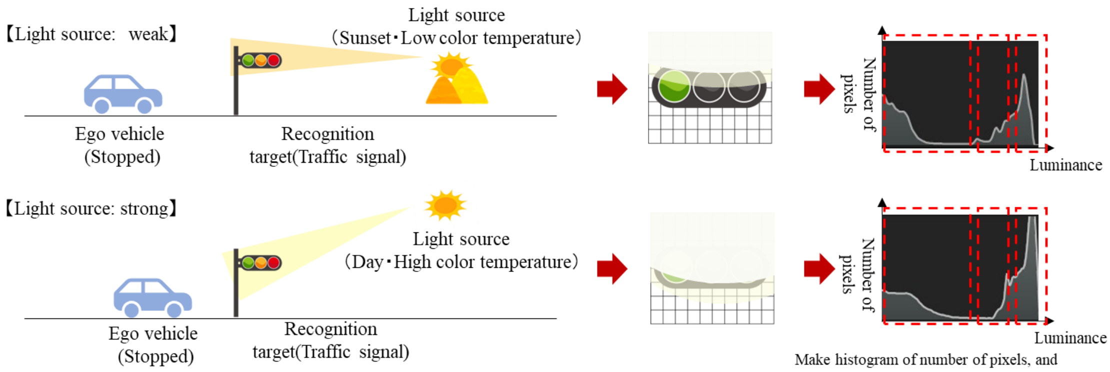
- The difference in recognition distance for vehicles between the simulation and the real systems shall be within ±5%.

-

■ Excess (Saturation): Dynamic Range

Validation Method

- For a light source located directly ahead, evaluate image changes such as blown highlights within the sensor field of view using histograms.

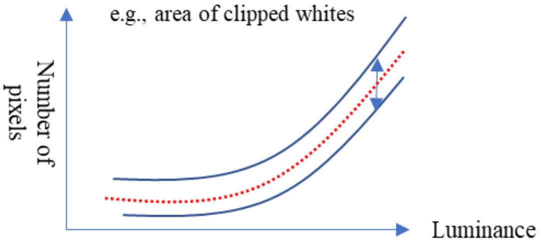


※Prior condition: Simulation environment can reproduce the light source

Make histogram of number of pixels, and
compare for each range of “clipped whites”, “high key”,
and “proper exposure” between real and virtual image.

Acceptance Criteria

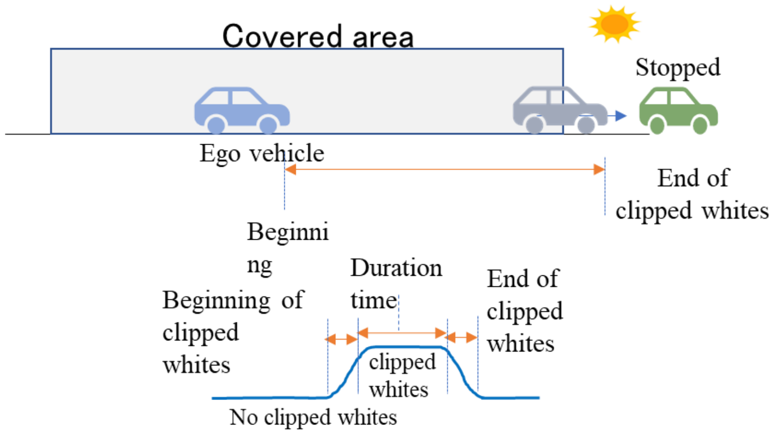
- Perform verification N times (e.g., 3 times) for each region, and confirm that the difference in pixel count from measured values is within ±5%.
- Where possible, validation under multiple light-source intensities is desirable.



■Excess (Saturation): Duration

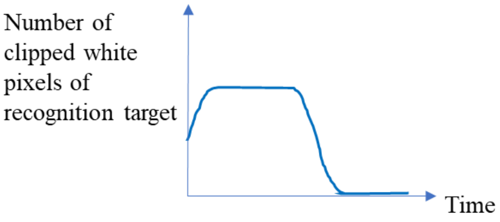
Validation Method

- Definition of blown highlights:
  A condition in which pixel values exceed 80% of the maximum capture value, or blown highlights occur within a recognition-critical occlusion space (including cases suppressed by HDR processing), evaluated from onset to termination.
- Evaluation conditions:
  - Ego-vehicle velocity: approximately 10 km/h or 30 km/h;
  - Target vehicle type: large vehicle, etc.; target velocity: stationary.
- Place the target vehicle outside a known road segment with an occluding space (e.g., tunnel), and approach it at a constant velocity.
- Perform validation N times (e.g., 3 times) for each combination of light-source intensity (e.g., clear weather, light cloudiness) and vehicle velocity.
- Acquire time-series data and real images of the distance (position) and relative velocity to the target vehicle ahead in the ego lane.
- Generate simulation images for the same scenario.
- Measure and compare the number of blown-highlight pixels over the time interval from the point where no blown highlights are present until the end of the blown-highlight condition.



Acceptance Criteria

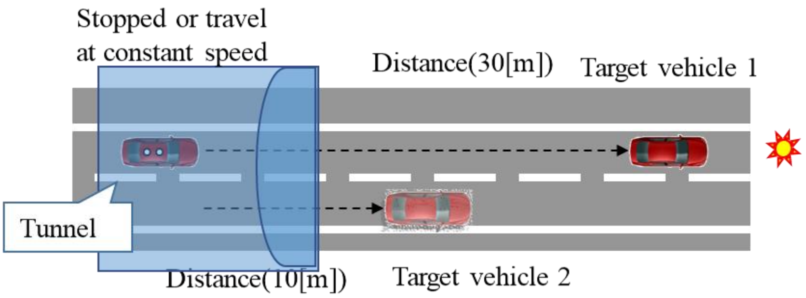
- For both elapsed time and number of blown-highlight pixels, the difference from the real system shall be within ±5 pixels.



■ Scenario: Recognition Target (Vehicle) — Distance / Velocity

Validation Method

- Verify that the recognition results are equivalent between the real camera system and the simulation images.
- Properly place the degradation factors (e.g., tunnel, light sources) that cause the phenomenon in the real-world test.
- Evaluation conditions:
  - Ego-vehicle velocity: standstill, or approximately 5 km/h, or approximately 10 km/h;
  - Target-vehicle velocity: standstill, or approximately 5 km/h, or 10 km/h;
  - Drive on a known road (straight road or steady-state circular path, e.g., R ≈ 100 m);
  - Target vehicle 1: passenger car;
  - Target vehicle 2: heavy-duty vehicle;
  - Initial distance to target vehicle 1: approximately 10 m or 30 m;
  - Initial distance to target vehicle 2: approximately 10 m;
  - Target vehicle 1: stationary or maintaining headway;
  - Target vehicle 2: maintaining headway;
  - Target vehicle 1: maintains ego lane;
  - Target vehicle 2: initial lane is the ego lane or adjacent lane; maintains lane or performs lane change.
- Measure time-series data of distance (position) and relative velocity to target vehicles 1 and 2 ahead of the ego vehicle.
- If a steady offset is observed, estimate it using a correlation-based method, cancel it out as needed, and then compare.



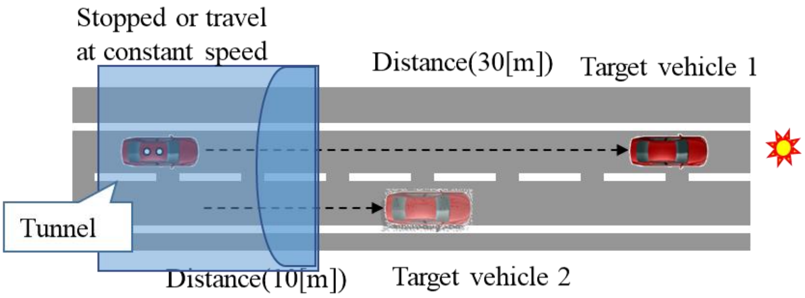
Acceptance Criteria

- Distance: difference from the real-world measurement is within ±5%
- Velocity: difference from the real-world measurement is within ±10%

■ Scenario: Recognition Target (Vehicle) — Size / Orientation

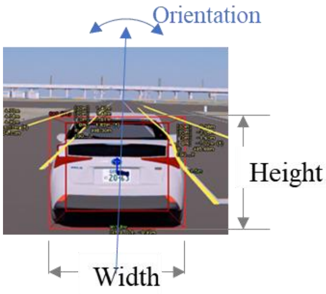
Validation Method

- Verify that the recognition outputs related to size and orientation are equivalent between the real camera system and the simulation images.
- Properly place degradation factors (e.g., tunnel, light sources) so that the disturbance phenomenon occurs in the real-world test.
- Evaluation conditions:
  - Ego-vehicle velocity: standstill, or approximately 5 km/h, or 10 km/h;
  - Target-vehicle velocity: standstill, or approximately 5 km/h, or 10 km/h;
  - Drive on a known road (straight, or steady-state circular path, e.g., R ≈ 100 m;
  - Target vehicle 1: passenger car;
  - Target vehicle 2: heavy-duty vehicle;
  - Initial distance to target vehicle 1: approximately 10 m or 30 m;
  - Initial distance to target vehicle 2: approximately 10 m;
  - Target vehicle 1: stationary or maintaining headway distance;
  - Target vehicle 2: maintaining headway distance;
  - Target vehicle 1: maintains ego lane;
  - Target vehicle 2: initial lane is the ego lane or an adjacent lane; maintaining lane or performing lane change.
- Measure time-series data of height, width, and orientation of the target vehicle ahead in the ego lane.
- If a steady offset is observed, estimate it using a correlation-based method, cancel it out as necessary, and then compare the results.



Acceptance Criteria

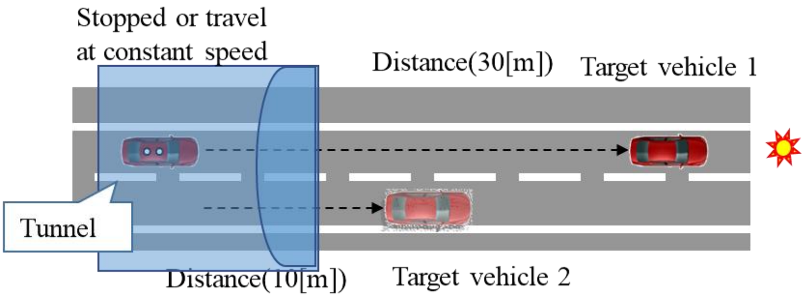
- Size: difference from the real-world measurement is within ±5%
- Orientation: difference from the real-world measurement is within ±5%



■ Scenario: Recognition Target (Vehicle) — Class

Validation Method

- Verify that vehicle-class recognition outputs are equivalent between the real camera system and the simulation images.
- Properly place the degradation factors (e.g., tunnel, light sources) such that the disturbance phenomenon occurs in the real-world test.
- Evaluation conditions:
  - Ego-vehicle velocity: standstill, or approximately 5 km/h, or 10 km/h;
  - Target-vehicle velocity: standstill, or approximately 5 km/h, or10 km/h;
  - Drive on a known road (straight road or steady-state circular path, e.g., R ≈ 100 m);
  - Target vehicle 1: passenger car;
  - Target vehicle 2: heavy-duty vehicle;
  - Initial distance to target vehicle 1: approximately 10 m or 30 m;
  - Initial distance to target vehicle 2: approximately 10 m;
  - Target vehicle 1: stationary or maintaining headway distance;
  - Target vehicle 2: maintaining headway distance;
  - Target vehicle 1: maintains ego lane;
  - Target vehicle 2: initial lane is the ego lane or adjacent lane; maintaining lane or performing a lane change.
- Measure and compare time-series data of the recognized class for the target vehicle ahead in the ego lane.
- Classification categories shall include:
- four-wheeled vehicles;
- pedestrians, and
- any other output classes defined by the recognition algorithm.



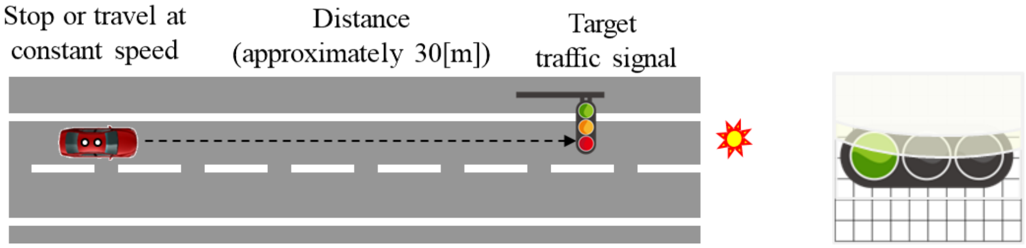
Acceptance Criteria

- The recognized class labels shall match between the real system and the simulation.

■ Scenario: Recognition Target (Traffic Signal) — Class

Validation Method

- Verify that traffic-signal classification outputs are equivalent between the real camera system and the simulation images.
- Properly place the degradation factors, particularly light sources, such that the disturbance phenomenon occurs in the real-world test.
- Evaluation conditions:
  - Ego-vehicle velocity: standstill or approximately 5 km/h;
  - Stop or drive on a known straight road;
  - Target: traffic signal located ahead in the ego lane;
  - Ego vehicle maintains the ego lane.
- Measure and compare time-series data of the recognized traffic-signal color class ahead in the ego lane.
- Classification categories shall include:
  - green, yellow, red, and
  - any other output classes defined by the recognition algorithm.



Validation shall include scenes in which, from the ego vehicle’s viewpoint, the traffic signal and the light source (sun) are aligned or overlapped, resulting in partial or complete overexposure (blown-out regions) of the target.

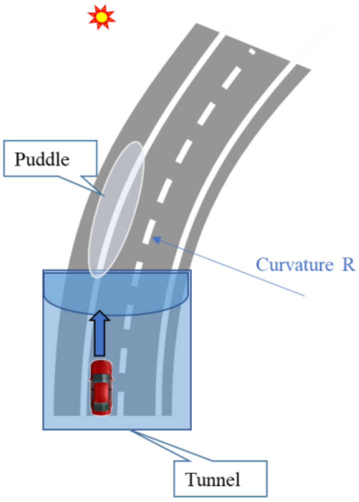
Acceptance Criteria

- The recognized traffic-signal class shall match between the real system and the simulation.

■ Scenario: Recognition Target (Lane Boundary) — Curvature

Validation Method

- Verify that lane-boundary recognition outputs related to curvature are equivalent between the real camera system and the simulation images.
- Properly place the degradation factors (e.g., tunnel, light sources, puddles) so that the phenomenon occurs in the real-world test.
- Evaluation conditions:
  - Ego-vehicle velocity: standstill, or approximately 5 km/h, or 10 km/h;
  - Drive on a known road (straight road or steady-state circular path, e.g., R ≈ 100 m).
- Measure time-series data of the lane-boundary curvature radius on the steady-state circular section (up to approximately 40 m ahead of the ego vehicle).
- If a steady offset is observed, estimate it using a correlation-based method, cancel it out as necessary, and then compare.



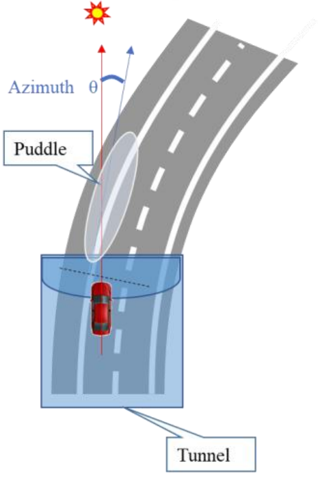
Acceptance Criteria

- Curvature radius: difference from the real-world measurement is within ±15%.

■ Scenario: Recognition Target (Lane Boundary) — Heading Angle

Validation Method

- Verify that lane-boundary recognition outputs related to heading angle are equivalent between the real camera system and the simulation images.
- Evaluation conditions:
  - Ego-vehicle velocity: standstill, or approximately 5 km/h, or 10 km/h;
  - Drive on a known road (straight road or steady-state circular path, e.g., R ≈ 100 m).
- Measure time-series data of the lane-boundary heading angle Evaluation conditions:
- Ego-vehicle velocity: standstill, or approximately 5 km/h, or 10 km/h;
- Drive on a known road (straight road or steady-state circular path, e.g., R ≈ 100 m).
- If a steady offset is observed, estimate it using a correlation-based method, cancel it out as necessary, and then compare.



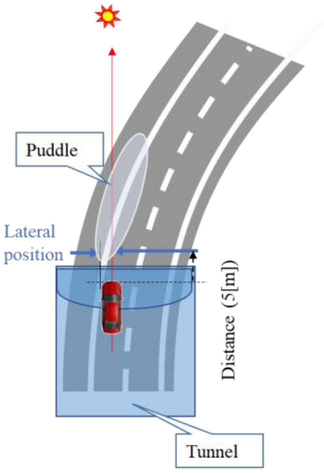
Acceptance Criteria

- Heading angle: difference from the real-world measurement is within ±10%

■ Scenario: Recognition Target (Lane Boundary) — Lateral Position

Validation Method

- Verify that lane-boundary recognition outputs related to lateral position are equivalent between the real camera system and the simulation images.
- Evaluation conditions:
  - Ego-vehicle velocity: standstill, or approximately 5 km/h, or 10 km/h;
  - Drive on a known road (straight road or steady-state circular path, e.g., R ≈ 100 m).
- Measure time-series data of the lateral position of the lane boundaries relative to the ego vehicle (e.g., at approximately 5 m ahead).
- If a steady offset is observed, estimate it using a correlation-based method, cancel it out as necessary, and then compare.
- Evaluate both the left and right lane boundaries of the ego lane.



Acceptance Criteria

- Lateral position: difference from the real-world measurement is within ±5%.

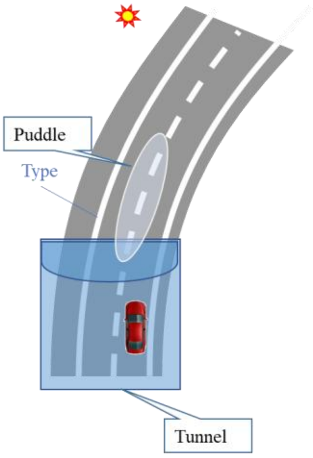
■ Scenario: Recognition Target (Lane Boundary) — Class

Validation Method

- Verify that lane-boundary type recognition outputs are equivalent between the real camera system and the simulation images.
- Evaluation conditions:
  - Ego-vehicle velocity: standstill, or approximately 5 km/h, or 10 km/h;
  - Drive on a known road (straight road or steady-state circular path, e.g., R ≈ 100 m).
- Measure and compare time-series data of the recognized class for each lane boundary.

Classification categories shall include, but are not limited to:

- dashed line,
- solid line,
- color, and
- any other output classes defined by the recognition algorithm.



Acceptance Criteria

- The recognized lane-boundary class labels shall match between the real system and the simulation.

Annex G Validation of Simulation Tools and Simulation Test Methods related to UN Regulation No. 157

G.1. Purpose and Scope

This Annex summarizes the conceptual approach to the validation of simulation tools and the simulation-based test methods used in certification tests for traffic-disturbance scenarios (ALKS lane keeping) specified in UN Regulation No. 157. In this annex, it is assumed that the perception module operates with 100% recognition capability, and that perception malfunctions are not considered. Accordingly, the evaluation targets are limited to:

- the main Automated Driving (AD) control module (behavior planning) , and
- the vehicle motion control module.

These evaluation targets are illustrated in Figure G- 1.

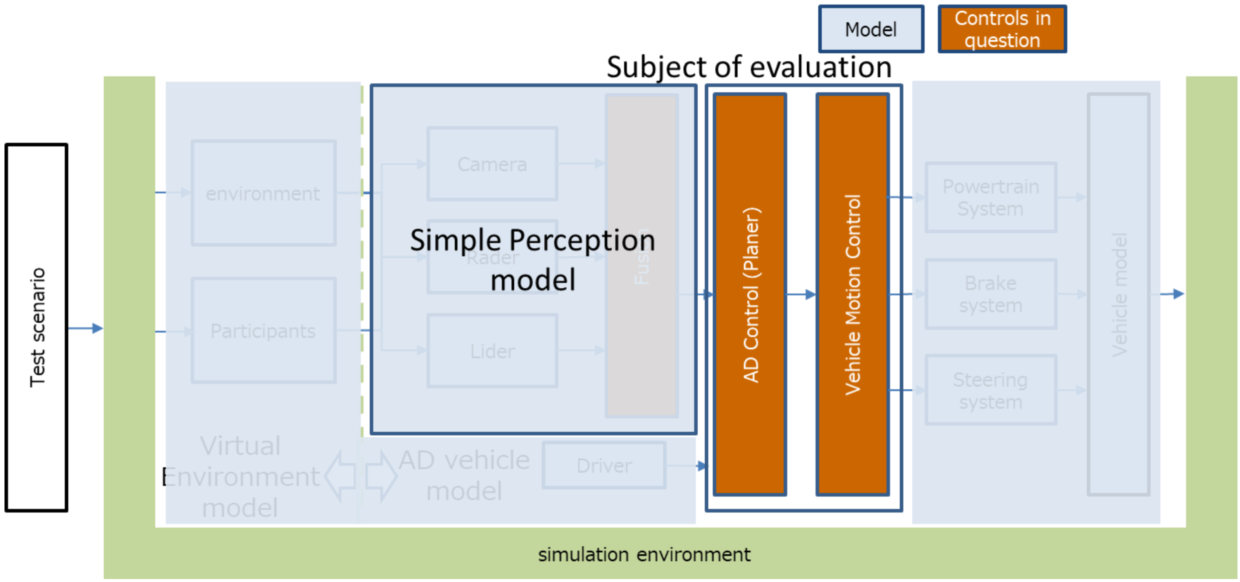


Figure G- 1. Control Modules Subject to Evaluation in Traffic-Disturbance Scenarios

G.2. Terms and Definition

The terms used in this chapter are defined as follows.

(a) ADS (Automated Driving System)
A system that performs part or all of the Dynamic Driving Task (DDT) through automatic perception of the driving situation, decision-making, and vehicle control, thereby substituting for part or all of the driving functions normally required of a human driver.

(b) Parameter
A physical quantity used for data measurement or execution of simulations (e.g., vehicle velocity, distance).

(c) Calculated Value
A value obtained as a result of calculations performed by a simulation tool.

(d) Provided Value
A value given as part of a scenario definition.

(e) Scenario

A sequential description of a scene and its interactions, integrating one or more ADSs and one or more subject vehicles, during the execution of a specific DDT.

In this annex, a scenario refers to a description composed of evaluation conditions used when conducting real-vehicle tests and simulations, including, but not limited to:

- initial conditions of the ego vehicle and other vehicles (e.g., vehicle velocity, inter-vehicle distance);
- behaviors of other vehicles (e.g., cut-in); and
- road conditions (e.g., number of lanes, lane width).

(f) Preventable Boundary

The boundary shown in the graph referenced in UN Regulation No. 157, Appendix 3, "*Guidance on Traffic Disturbance Critical Scenarios for ALKS,*" Section 5 (Reference), which separates "no collision" outcomes from outcomes other than no collision (e.g., collision).

G.3. Validation Method for Simulation Tools

G.3.1. Purpose of This Section

Before conducting simulation-based tests, it is necessary to confirm that the simulation tools used can appropriately substitute for real-vehicle tests. This section describes the validation method for simulation tools and the corresponding acceptance criteria required to demonstrate such suitability.

G.3.2. Validation Method and Acceptance Criteria

This section presents the validation method for simulation tools, the acceptance criteria, and the underlying rationale supporting them.

Validation Method

For the selected scenarios, provide the same environmental information to the simulation tool as that used in the real-vehicle tests, and compare the relative distance between the ego vehicle and other vehicles (hereinafter referred to as the inter-vehicle distance).

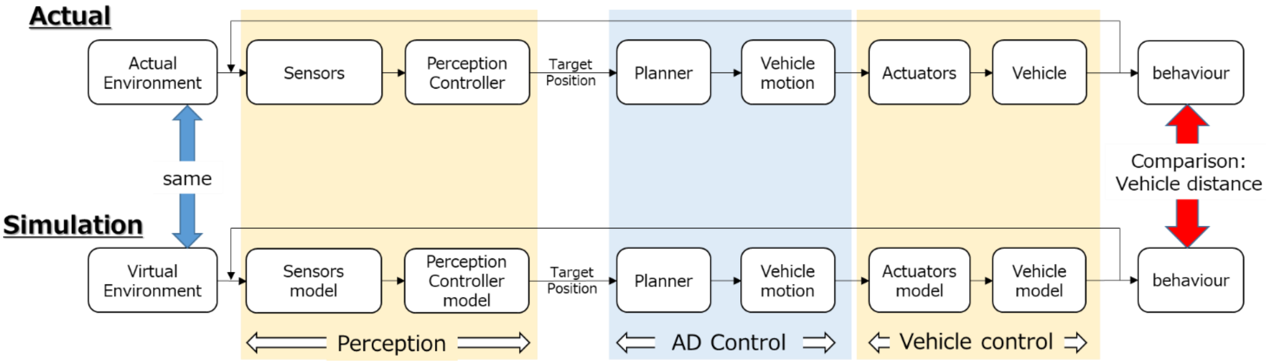


Figure G- 2. ADS Configuration Diagram

Underlying Rationale:

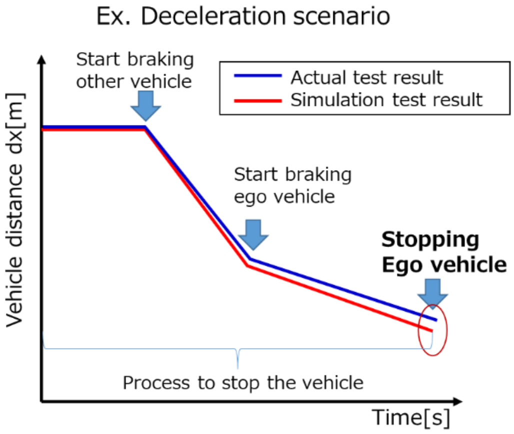
In certification test, UN Regulation No. 157, the primary determination is whether a collision or non-collision occurs between the ego vehicle and other vehicles.
Accordingly, the simulation tool is required to accurately reproduce the inter-vehicle distance, which is the physical quantity used to determine collision or non-collision.
Furthermore, in order to appropriately compare the results of real-vehicle tests and simulations, the environmental information provided as input—such as the position and motion of the preceding vehicle—must be equivalent in both cases.
Based on these considerations, applying the validation method described above makes it possible to demonstrate the validity of the simulation tool for use in certification tests under UN Regulation No. 157.

Acceptance Criteria

At the point when the ego vehicle comes to a stop or reaches a steady state [1], the inter-vehicle distance [2] between the ego vehicle and the vehicle subject to collision avoidance shall be greater in the real-vehicle test results than in the simulation-tool results.
The comparison shall be performed within the non-collision (Preventable) region. The process leading up to the ego vehicle's stop or steady state shall be treated for reference purposes only. In addition, as a prerequisite to demonstrating compliance with the above acceptance criteria, the simulation tool shall satisfy the requirements defined in G.4 Simulation Tool Requirement.

[1] "Steady state" refers to a condition in which, as a result of the ego vehicle's avoidance maneuver, there is no longer a speed difference between the ego vehicle and the target vehicle.

[2] Inter-vehicle distance refers to the perpendicular distance measured between the front end of the ego vehicle and the rear end of the target vehicle.



Underlying Rationale:

The objective of the certification test is to confirm that the collision / non-collision outcomes achieved by an ADS are entirely superior to those defined by the regulatory criteria.
Accordingly, the method used to evaluate differences between real-vehicle tests and simulations is critical. If the real-vehicle test results consistently exhibit greater performance (i.e., larger inter-vehicle distance at stop or steady state) than the simulation results, then demonstrating that the simulation results satisfy the regulatory criteria in all cases enables a valid determination of the pass/fail outcome for the real-vehicle avoidance performance in the test scenario.

This acceptance-criteria structure therefore establishes a conservative validation principle, ensuring that simulation-based certification does not overestimate real-vehicle performance.

G.3.3. Requirements for Simulation Tools

For the purpose of validity verification, the simulation tool shall satisfy the following requirements.

Requirement 1:

The simulation tool shall be capable of calculating and outputting all parameters that contribute to the determination of collision or non-collision outcomes.
(For the contributing parameters applicable to each scenario, refer to Attachment 1: Contributing Parameters for Each Scenario.)

Requirement 2:

To enable comparison of calculation results, there shall be correlation [1] between the parameters output by the simulation tool and the parameters measured in real-vehicle tests.

[1] "Having correlation" does not require the calculated parameter values to exactly match the measured values. Rather, it means that the variations and trends of the parameter values behave in a similar manner.

G.4. Validation Procedure for Simulation Tools

G.4.1. Purpose of This Section

This section defines the procedure for validating the simulation tool, using the validation methods described in the preceding sections.

G.4.2. Validation Procedure for Simulation Tools

(1) Selection of Validation Scenarios and Parameters

From among the scenarios required for certification (refer to "G.5 ADS Safety Performance Evaluation Simulation Method"), select the validation scenarios and parameters sets to be used.

INPUT: Scenarios and parameter ranges defined in "G.5 ADS Safety Performance Evaluation Simulation Method"

OUTPUT: Selected validation scenarios and parameter sets

NOTE:
For low-speed ALKS lane-keeping, the ADS avoidance maneuver consists solely of deceleration (no steering-based avoidance). Accordingly, it is sufficient to select scenario parameters that allow correlation of ADS deceleration performance between real-vehicle tests and simulations. It is desirable that the comparison of deceleration performance cover a range that includes the maximum deceleration (G) of the ADS.

(2) Pre-Test Real-Vehicle Experiments

Before validation, conduct real-vehicle tests to measure the parameters that will be set and adjusted in the simulation tool.

INPUT: Identification of performance characteristics affecting simulation outputs

OUTPUT: Real-vehicle measurement data for vehicle-model characteristic calibration

(3) Configuration and Calibration of the Simulation Tool and Environment

Configure and calibrate the simulation tool using the vehicle specifications (e.g., vehicle mass) and the data obtained from the pre-test real-vehicle experiments in Step (2) (e.g., brake performance).

INPUT: Real-vehicle measurement data for calibration

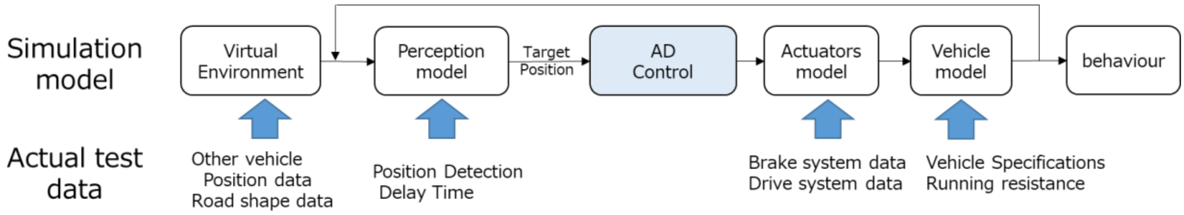
OUTPUT: Configured and calibrated simulation tool and environment

NOTE:
Calibration refers to adjusting perception-model and vehicle-model parameters, starting from the pre-calibration state, so as satisfy:

- the validation acceptance criteria, and
- the simulation tool requirements defined in this annex.

Examples of configuration and calibration:

- Use measured data from Step (2) to configure and calibrate the perception model and vehicle dynamics model.



Additional Note:
If the response characteristics of the perception module are modeled using a "delay time", correlation shall be verified by matching the temporal alignment of:

- changes in the longitudinal and lateral position and velocity of the target vehicle as perceived by the real vehicle's perception module, and
- the corresponding changes measured for the actual target vehicle.

(4) Real-Vehicle Tests for Validation

Conduct real-vehicle validation tests using the scenarios selected in Step (1).

INPUT: Validation scenarios and parameter sets

OUTPUT: Real-vehicle measurement data for validation, for each scenario

(5) Simulation for Validation

Perform simulation-based validation tests using the same scenarios.

INPUT: Real-vehicle measurement parameters and the configured/calibrated simulation environment

OUTPUT: Simulation data for validation, for each scenario

NOTE:

Information for other vehicles in the simulation may be generated using, for example, GNSS-based position data obtained during the real-vehicle tests in Step (4).

(6) Validation of the Simulation Environment

Validate the simulation environment by comparing the results obtained in Steps (4) and (5).

INPUT: Real-vehicle measurement data and simulation data

OUTPUT: Validation results for the simulation environment

NOTE:
Steps (1) - (5) need not be performed strictly sequentially.
Steps (2) - (5) may be iteratively repeated until the acceptance criteria are satisfied.

G.5. ADS Safety Performance Evaluation Simulation Method

G.5.1. Purpose of This Section

This section defines the simulation-based test method used to confirm—by means of a simulation tool whose validity has been verified—that the certification pass/fail criteria are satisfied, namely:
“The collision/non-collision test results obtained using the ADS are superior, in all cases, to the outcomes defined by the criteria.”

G.5.2. Test Method

Using the simulation tool and execution environment specified in G.6 Submission Documents–3, the simulation inputs shall be combining the following two elements.

1. Scenarios

Scenarios consist of the configuration and behavior of
- the ego vehicle equipped with an ADS, and
- surrounding vehicles (hereinafter referred to as other vehicles).

The applicable scenarios are:

(a) Cut-in scenario [No. 1]

(b) Cut-out scenario [No. 2]

(c) Deceleration scenario [No. 4]

Note: The numbers in brackets [ ] correspond to the scenario numbers defined in “Attachment 2: Hazardous Scenarios.”

2. Parameters of the Ego Vehicle and Other Vehicles in the Scenario

The parameters of the ego vehicle and other vehicles used in the scenarios are defined as follows:

(a) Vehicle velocity of the ego vehicle and other vehicles

(b) Acceleration and deceleration of the ego vehicle and other vehicles

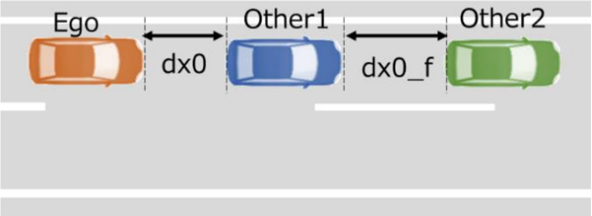
© Inter-vehicle distance between the ego vehicle and other vehicles

The scenarios used above and the corresponding vehicle parameters are defined in detail in the following sections.

G.5.3. Definition of Parameters for the Ego Vehicle and Other Vehicles

(1) Initial Longitudinal Inter-Vehicle Distance (dx_0)
The initial longitudinal inter-vehicle distance is defined as the perpendicular distance between the front end and rear end of two vehicles.
Let:

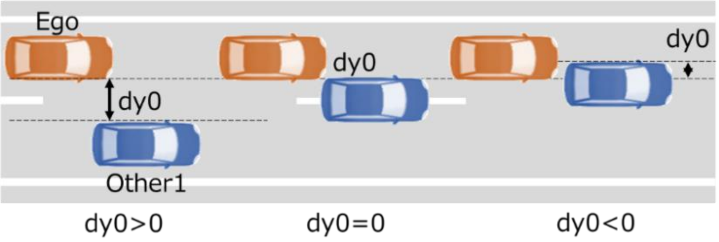
- dx_0 (m) denote the inter-vehicle distance between the ego vehicle and the preceding other vehicle 1, and
- dx_0_f (m) denote the inter-vehicle distance between other vehicle 1 and the preceding other vehicle 2.



(2) Initial Lateral Inter-Vehicle Distance (dy_0)
The lateral inter-vehicle distance is defined as the distance between the adjacent side edges of the side surfaces of two vehicles.
The sign convention is defined as follows:

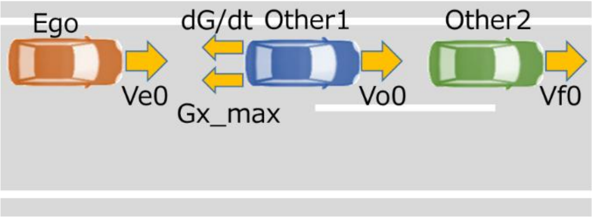
- The distance is positive when there is no overlap between the ego vehicle and other vehicle 1 as viewed from the ego vehicle.
- The distance is negative when there is an overlap.

Accordingly, a value of zero indicates that the two perpendicular distances overlap.



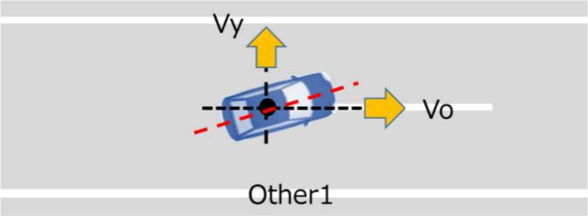
(3) Initial Velocity

- Ve_0 (km/h): Initial velocity of the ego vehicle
- Vo_0 (km/h): Initial velocity of the preceding other vehicle 1 in the same or an adjacent lane
- Vf_0 (km/h): Initial velocity of other vehicle 2
- Gx_max (G): Maximum deceleration of other vehicle 1
- dG/dt: Rate of change of the deceleration of other vehicle 1



(4) Lateral Velocity

- Vy (m/s): Lateral velocity of other vehicle 1, defined as the velocity perpendicular to the lane direction

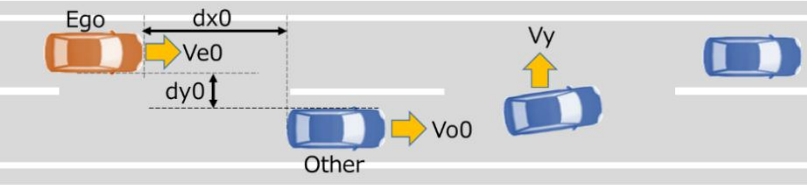


Note: For details, refer to Attachment 3: Definition of Other-Vehicle Behavior.

G.5.4. Definition of Each Scenario

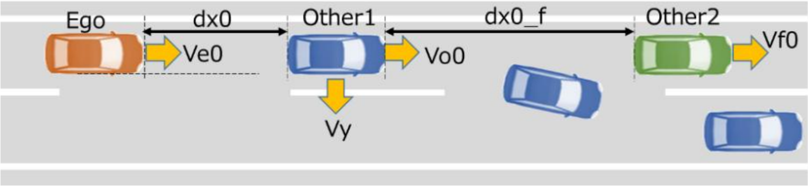
(a) Cut-In Scenario

The parameters of the ego vehicle and other vehicles defined in G.5.3 are used as specified below.



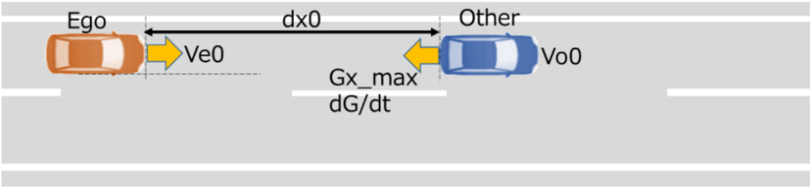
(b) Cut-out Scenario

The parameters of the ego vehicle, other vehicle 1, and other vehicle 2 defined in G.5.3 are used as specified below.



(c) Deceleration Scenario

The parameters of the ego vehicle and other vehicles defined in G.5.3 are used as specified below.



G.5.5. Pass/Fail Criteria

No collision shall occur within the preventable range (the “no collision” region) defined in UN Regulation No. 157, Appendix 3, “Guidance on Traffic Disturbance Critical Scenarios for ALKS,” Section 5 (Reference).

G.5.6. Parameter Ranges Used in Simulation

① Parameter Values and Ranges Common to All Scenarios

(1) Road parameter values

Road Parameters	Value	Unit
Number of lanes	2	-
Road width	3.5	m
Road friction coefficient	1.0	μ
Horizontal gradient	0	%
Vertical gradient	0	%
Curve radius	∞	%

(2) Vehicle parameter values

Vehicle Parameters	Ego Vehicle	Other Vehicle 1	Other Vehicle 2
Vehicle width	(According to the application)	1.9 m	1.9 m
Vehicle length	(According to the application)	5.3 m	5.3 m
Shape	Rectangular	Rectangular	Rectangular
Position of travel	Middle of lane	Middle of lane	Stationary in middle of lane

② Scenario-Specific Parameter Ranges

The parameter ranges shall be defined using items (1) through (3) below as a baseline, and shall be individually specified according to the operating-environment conditions intended by the applicant.

(1) Parameter Ranges for the Cut-In Scenario

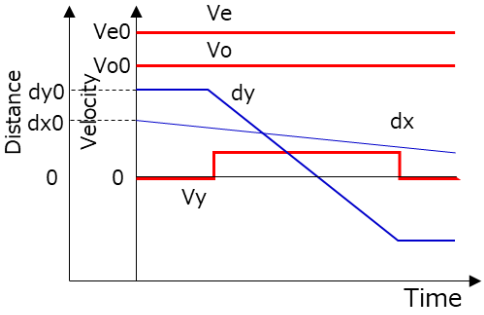
Parameter	Range
Ve0 [Initial velocity of ego vehicle]	20 ≦ Ve0 ≦ [60] km/h
Ve0 − Vo0 [Relative velocity]	0 ≦ Ve0 − Vo0 ≦ 40 km/h *[1]
dx0 [Initial longitudinal distance]	0 ≦ dx0 ≦ 60 m
dy0 [Initial lateral distance]	{(3.5-ego vehicle width)/2＋0.8 (other vehicle side)} m
Vy [Lateral velocity]	0 < Vy ≦ 3.0 m/s

[ ] Design maximum velocity of the ego vehicle

[1] Scenarios in which the cut-in vehicle velocity exceeds the ego vehicle velocity are excluded.

Note :
Physically infeasible parameter combinations (e.g., very low longitudinal speed combined with excessive lateral velocity) shall be excluded.
If the ODD is limited to following a preceding vehicle, scenarios in which the cut-in vehicle interferes with or collides with the preceding vehicle shall be excluded.

Example: Temporal variation of cut-in parameters



※For time-series parameters, refer to Attachment 1(a).

(2) Parameter Ranges for the Cut-Out Scenario

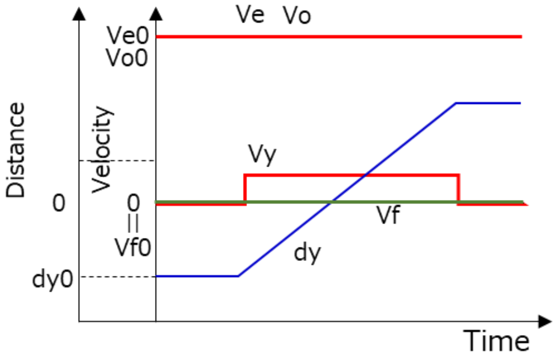
Parameter	Range
Ve0 [Initial velocity of ego vehicle]	10 ≦ Ve0 ≦ [60] km/h
Vo0 [Velocity of preceding vehicle]	10 ≦ Vo0 ≦ [60] km/h [*2]
Vf0 [Initial velocity of other vehicle]	0 km/h
dx0_f [Initial longitudinal distance]	0 < dx0_f ≦ 100 m
Vy [Lateral velocity]	0 < Vy ≦ 3.0 m/s

[ ] Design maximum velocity of the ego vehicle

[2] Velocity of preceding vehicle equals ego vehicle velocity.

Note:
Physically infeasible parameter combinations shall be excluded.
Inter-vehicle distance conditions that would cause collision with a stationary vehicle shall be excluded.

Example: Temporal variation of cut-out parameters



※For time-series parameters, refer to Attachment 1(b).

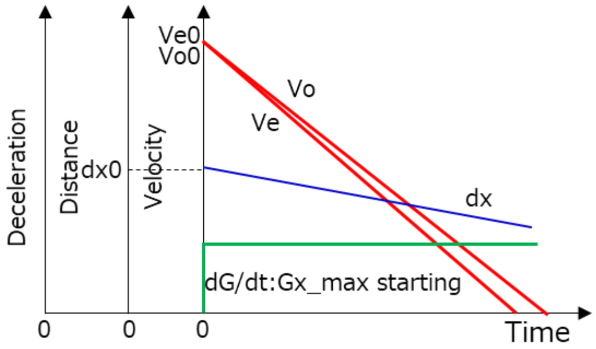
(3) Parameter Ranges for the Deceleration Scenario

Parameter	Range
Ve0 [Initial velocity of ego vehicle]	10 ≦ Ve0 ≦ [60] km/h
Vo0 [Velocity of preceding vehicle]	10 ≦ Vo0 ≦ [60] km/h ^{*3}
Gx_max [Deceleration velocity of preceding vehicle]	0 < Gx_max ≦ 1.0G
dG/dt [Rate of change in the deceleration velocity of other vehicles]	Limitless

[ ] Design maximum velocity of the ego vehicle

[3] Velocity of the preceding vehicle equals ego vehicle velocity.

Example: Temporal variation of deceleration parameters



※For time-series parameters, refer to Attachment 1(c)

G.5.7. Execution of Simulations

Simulations shall be conducted by dividing the evaluation space into the following three regions, based on the relationship between the preventable / unpreventable boundary and the inter-vehicle distance.

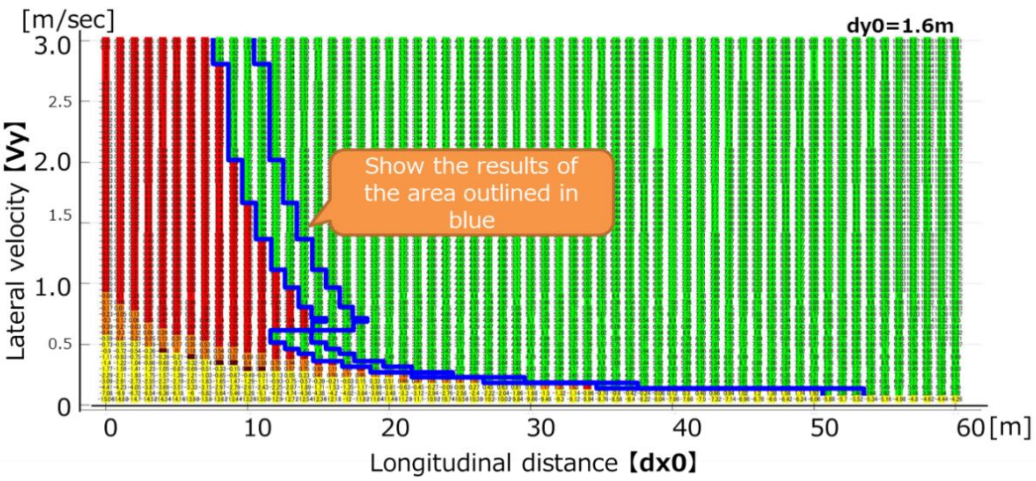
(1) Preventable / Unpreventable Boundary Region

In order to verify collision-avoidance behavior over a sufficiently wide range in the vicinity of the preventable/unpreventable boundary, simulations shall be conducted not only on the boundary line itself, but also at positions +1 m and +2 m on the side where the inter-vehicle distance increases from the boundary.

This requirement applies to both the Cut-in and Cut-out scenarios.

NOTE: The lateral velocity shall be varied using a minimum increment of 0.1 m/s.

Example (Cut-in scenario):
Ego vehicle velocity [Ve_0]: 30 km/h
Other vehicle velocity [Vo_0]: 10 km/h



(2) Non-Collision Region (Preventable Region Away from the Boundary)

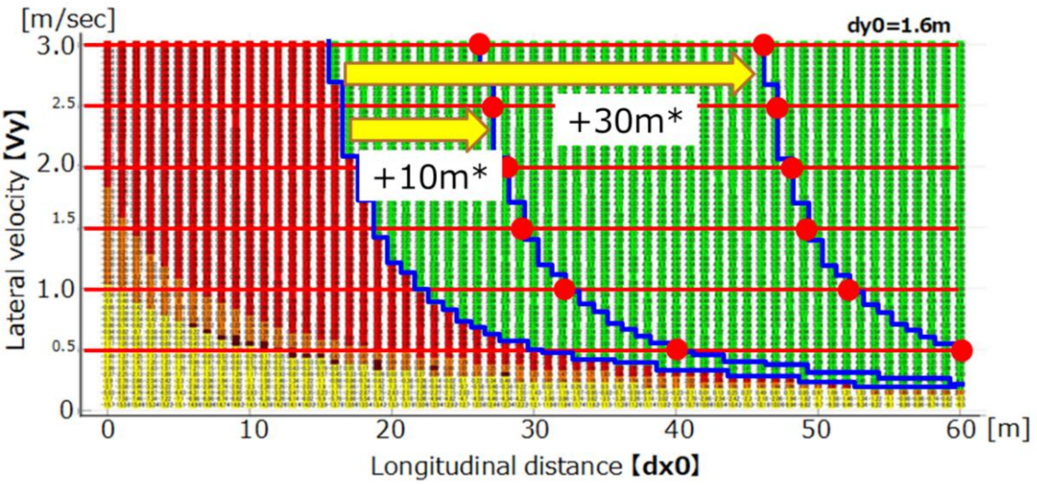
For coverage purposes, and to confirm by sampling that no collision occurs in preventable regions sufficiently far from the boundary, simulations shall be conducted for Cut-in and Cut-out scenarios at positions progressively farther from the boundary, specifically at:
+10 m, and
+30 m
from the preventable / unpreventable boundary.

The rationale for selecting "+10 m" and "+30 m" is to confirm not only the center area of the preventable region but also regions with larger inter-vehicle distances, using a limited number of representative test points.

All combinations of ego-vehicle velocity and relative velocity within the ODD range shall be tested.

NOTE: The lateral velocity shall be varied in 0.5 m/s increments. If the specified increment cannot be achieved, testing shall be conducted within the achievable range.

Example (Cut-in scenario):
Ego vehicle velocity [Ve_0]: 60 km/h
Other vehicle velocity [Vo_0]: 30 km/h



(3) Collision Region (Unpreventable Region)

Within the unpreventable region, it shall be confirmed that the ADS operates in a Best Effort manner, meaning that it does not discontinue control actions intended for collision avoidance, even though collision avoidance may not be achievable.

This verification applies only to the Cut-in scenario.

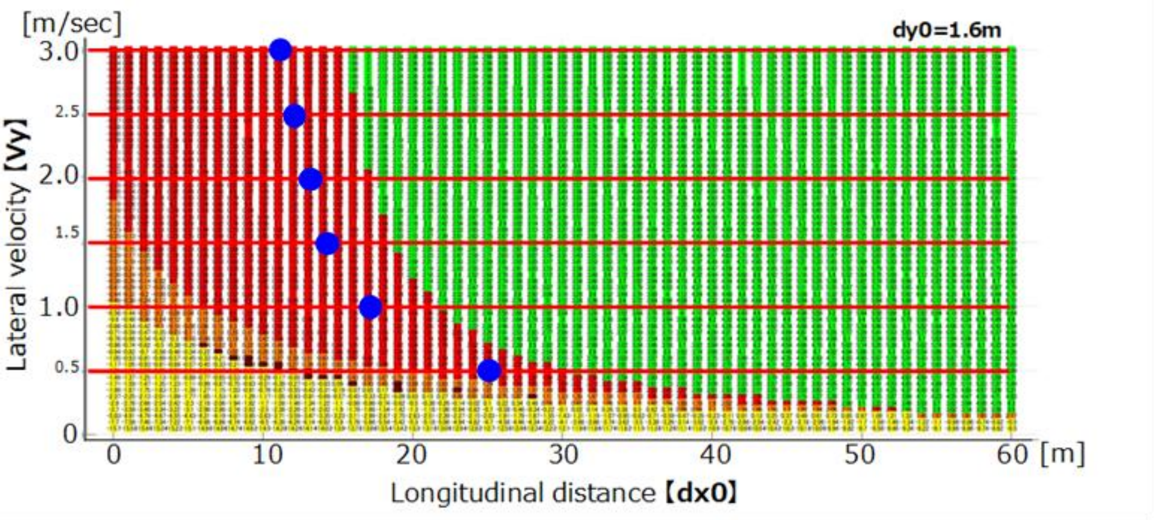
The inter-vehicle distance within the unpreventable region shall be selected arbitrarily by the applicant, subject to the conditions described below.

All combinations of ego-vehicle velocity and relative velocity within the ODD range shall be tested.

NOTE: The lateral velocity shall be varied in 0.5 m/s increments. Collision avoidance is permitted, even though collision may occur.

Example (Cut-in scenario):
Ego vehicle velocity [Ve_0]: 60 km/h
Other vehicle velocity [Vo_0]: 30 km/h

If the selected test point is too far from the preventable/unpreventable boundary, the likelihood of a side collision or a collision occurring before deceleration becomes effective increases. Therefore, as a reference, a value of 5 m─corresponding approximately to the overall length of a standard passenger car─is used, and the inter-vehicle distance is selected as uniformly 5 m shorter than the boundary distance.



G.6. Submission Documents

The following documents shall be submitted at the time of certification:

1. Results of simulation-tool validation tests (refer to Chapter G.4)
2. Results and judgments of simulation tests for ADS safety performance evaluation (refer to Chapter G.5)
3. Information on the simulation tool and execution environment, including:
   - hardware and software configuration, and
   - configuration of the simulation test tools and models.

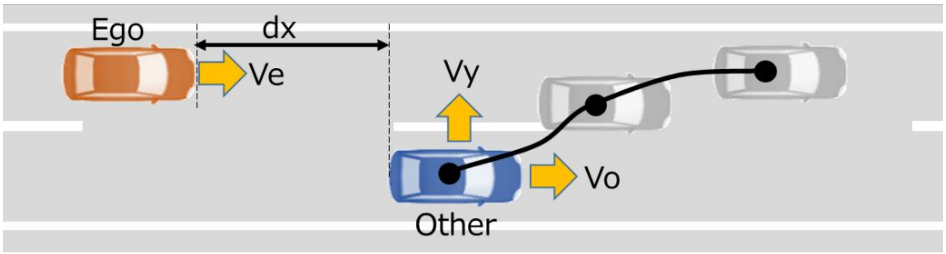
NOTE：Detailed information on the test vehicle is provided in TRIAS 48-J122-01 and TRIAS 48-R157-01, Appendix Table 1, “1. Test Vehicle and Test Conditions.”

Attachment 1: Contributing Parameters for Each Scenario

This attachment defines the parameters that contribute to the determination of collision or non-collision outcomes for each scenario, together with their attributes.

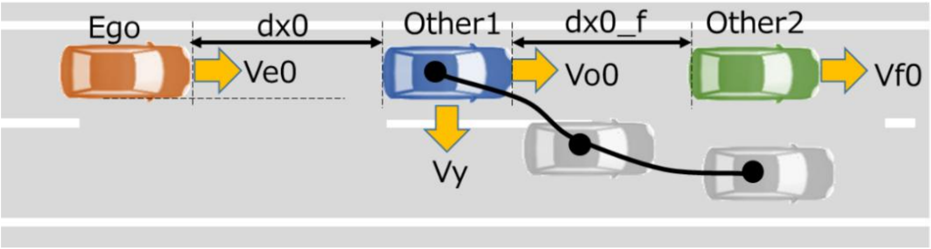
（a）Cut-in Scenario

Parameter	Attribute
Ego vehicle velocity [Ve]	Calculated value
Longitudinal distance between the ego and other vehicles [dx]	Calculated value
Lateral velocity of the other vehicle [Vy]	Provided value
Velocity of the other vehicle [Vo]	Provided value



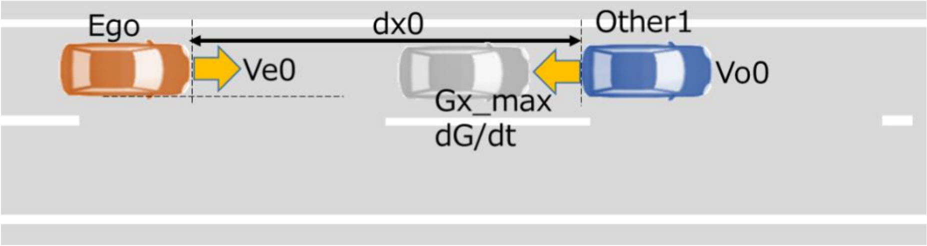
（b）Cut-out Scenario

Parameter	Attribute
Longitudinal distance between the ego vehicle and other vehicle 1 [dx]	Calculated value
Longitudinal distance between the other vehicle 1 and 2 [dx_f]	Calculated value
Ego vehicle velocity [Ve]	Calculated value
Lateral velocity of the other vehicle 1 [Vy]	Provided value
Velocity of the other vehicle 1 [Vo]	Provided value



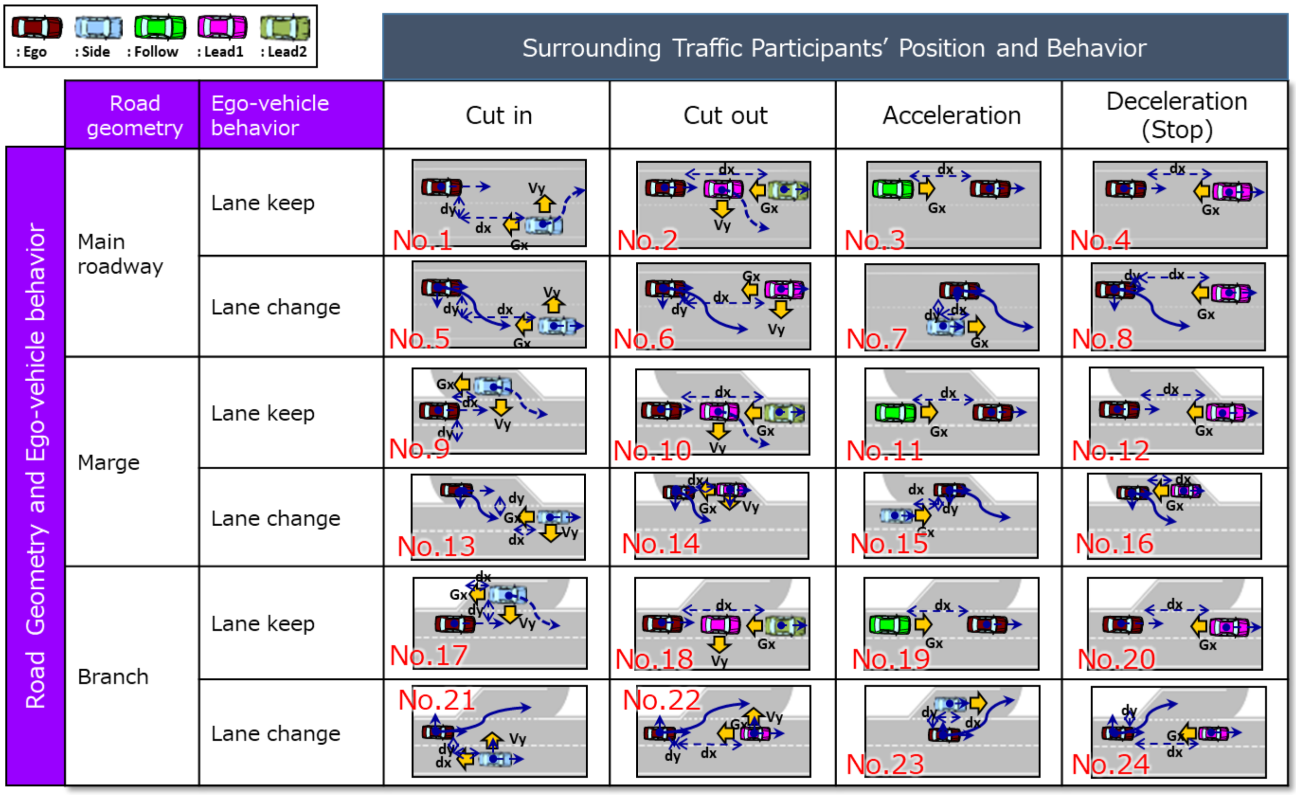
（c）Deceleration Scenario

Parameter	Attribute
Longitudinal distance between the ego and other vehicles [dx]	Calculated value
Ego vehicle velocity [Ve]	Calculated value
Deceleration of the other vehicle [Gx_max]	Provided value
Velocity of the other vehicle [Vo]	Provided value



The simulation tool shall be equipped with the necessary simulation components required to calculate and output all of the above parameters.

Attachment 2: Hazardous Scenarios



Road geometry	Ego-vehicle behavior	Surrounding Traffic Participants' Position and Behavior			
		Cut in	Cut out	Acceleration	Deceleration (Stop)
Main roadway	Lane keep	No.1	No.2	No.3	No.4
	Lane change	No.5	No.6	No.7	No.8
Marge	Lane keep	No.9	No.10	No.11	No.12
	Lane change	No.13	No.14	No.15	No.16
Branch	Lane keep	No.17	No.18	No.19	No.20
	Lane change	No.21	No.22	No.23	No.24

Attachment 3: Definition of Other-Vehicle Behavior

The purpose of this evaluation is to compare the ADS's capability to respond to the behavior of other vehicles that interfere with the ego vehicle, using collision/non-collision criteria. Accordingly, the definition of other-vehicle behavior shall be identical under the same conditions, regardless of whether the evaluation is conducted using real-vehicle tests or simulations.

To ensure consistency with the graphs described in UN Regulation No. 157, Appendix 3, Section 5 (Reference), the other-vehicle model and behavior are defined as follows:

- Other vehicles shall be modeled as point-mass models.
- During cut-in and cut-out maneuvers, the lateral velocity shall be given as a step function.
- During cut-in and cut-out maneuvers, the longitudinal velocity shall remain at the initial velocity (V_{O0}).

- In the deceleration scenario, the deceleration shall be given as a step function and the jerk [dG/dt] shall be assumed to be infinite.
- During cut-in and cut-out maneuvers, the vehicle orientation shall be aligned with the direction of travel, which is defined by the resultant vector composed of Vo and Vy.