Automated Driving Safety Evaluation Framework

Ver 3.0

Japan Automobile Manufacturers Association, Inc.

Sectional Committee of AD Safety Evaluation,

Automated Driving Subcommittee

December 2022

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Contents

Main changes and additions to Ver. 3

- Traffic disturbance scenarios
  The motorway-specific content has been revised to include general roads, and a traffic disturbance scenario for general vehicles that includes general roads has been added along with the addition of ITARDA data to Annex D.
- Perception disturbance scenarios
  The content of Annex E and F has been added.
- Vehicle motion disturbance scenarios
  Preventability/unpreventability boundary conditions have been added for general roads.

1. Positioning of this Paper

【Background】

The realization and deployment of autonomous driving (AD) is expected to bring forth an even safer society which is also more efficient and with a freer mobility. The fulfillment of these expectations is a major global challenge that stands on the sufficient safety assurance and verification of the autonomous vehicles both in terms of performance and technology.

In this document, the Japan Automobile Manufacturers Association Inc. (JAMA) has summarized the best practice on safety argumentation structuring, safety evaluation, and safety assessment methods needed to enable logical completeness, practicability, and transparency of AD safety.

The safety assessment and the technical judgment may be revised according to the practical implementation and evolution of the AD safety assurance dialogue, along with technical content modifications.

【Aims】

①To enhance safety and efficiency of AD systems development by providing guidelines that serve as a common ground for each JAMA member at each product development stage, from planning and design, to evaluation.

② To gain a common technical understanding when international regulations and standards are formulated.

③ To clarify JAMA position when cooperating with international projects.

2. Automated Driving System Safety Argumentation Structure

An overview of the safety argumentation structure for AD systems with SAE automation level 3 through to level 5 is provided in this chapter.

2.1. Issues with existing approaches

2.1.1. Safety evaluation through long-distance/ long-duration driving tests

Long-distance/long-duration driving test strategies aim at ensuring safety by randomly indentifying malfunctions and unintended disengagements in a black box-type manner, until a certain value for a probabilistic metric is guaranteed. These strategies, applied as a safety evaluation process, present issues both in terms of ‘evaluation scope sufficiency’ and of ‘explainability in emergencies’.

The main issue related to "evaluation scope sufficiency" relates to the stochastical increase of factors and associated hazards with driving distance and time. In other words, it is not possible to ensure that hazards due to factors not identified in long-distance/long-duration runs will not occur after release.

Further, within a contex in which there is neither legal nor social consensus on criteria based on driving distance or time, the issue on "explainability in emergencies" relates to the impossibility of clarifying social responsibility for emergency interventions when hazards are encountered by the system. Probabilistic safety criteria based on long-distance/long-time driving also present problems from a technical development point of view, due to the inefficiency of identifying factors that dependend on the environmental conditions in which the driving was conducted, as well as on the characteristics of the vehicle.

2.1.2. Data storage/classification scenario-based approach

A number of countries are actively developing data driven scenario-based approaches to address the challenges of applying previous ADAS development processes for safety assurance of AD systems of SAE automation level 3 through to level 5. These approaches incorporate normal traffic and accident data, process the data, and systematically categorize the processed information into formats known as ‘scenarios’ which are stored in a database.

The collection, storage and creation of such scenarios and database in the public domain, free from manufacturers’ intellectual property and bias, may enable the development a safety evaluation ecosystem, that both certification bodies and manufacturers could incorporate for the benefit of the general public through safer vehicles.

However, the scenario based approach does not resolve per se the aboved mentioned issue concerning ‘evaluation scope sufficiency’ before release. When the obtained data is tagged and "categorized", the compensation for the phenomenon that may occur in the future still depends on the distance and time or the amount of data, so the previously mentioned issue related to evaluation scope sufficiency remains unresolved. Further, if the driving data shared in the public domain is only comprised of "images" and "vehicle trajectories" this will lead to insufficient safety verification range, as such data may exclude factors related to autonomous vehicles’ misinterpretaion of both the surroundings and its own conditions, as well as factors possibly affecting vehicle stability.

2.2. Overview of ‘Physics Principles Approach Process’

In order to address the limitations of existing approaches concerning evaluation scope suffciency and explainability in emergencies, a ‘Physical Principles Approach Process’ for safety evaluation is proposed. This proposal essentially incorporates physics principles into a scenario-based approach.

The number of safety-relevant situations that an AD system may encounter in real traffic is infinite. Therefore, if scenarios are structuralized by solely combining traffic factors without further considerations, the unlimited number of variables that need to be considered will prevent from a complete scope verification. In contrast with the infinite number of safety-relevant situations that an AD system may encounter in traffic, the number of physics principles that the system can apply for safely handling such situations is limited. AD systems decompose all DDT into perception, judgement and operation subtasks, and each of these subtasks is associated with one or several specific physics principles. Therefore, if scenarios are decomposed and structuralized logically in consideration of the physics of the AD system, then it is possible to provide a complete coverage of all the safety-relevant root causes for given DDT. This motivates the incorporation of perception, traffic situation, and operation related disturbances, and the corresponding scenario structures introduced in the following table, in Figure 1 and Figure 2, and elaborated in detail in following chapters.

Task	Processing results	Disturbance	Governing physics principles
Perception	Own position, surrounding traffic environment positional information and other traffic information	Perception disturbance	Light, radio wave, infrared light propagation principles that affect camera, mili-wave radar and LiDAR sensors, respectively
Judgement	Path, speed plan instructions	Traffic disturbance	Kinematics describing the motion of traffic participants, objects and systems of groups of objects, without reference to the causes of motion.
Operation	Movement instruction allocation for each ACT for achieving path and speed plan instructions	Vehicle control disturbance	Dynamics, concerned with forces applied on the vehicle’s body and tires, and their effects on motion.

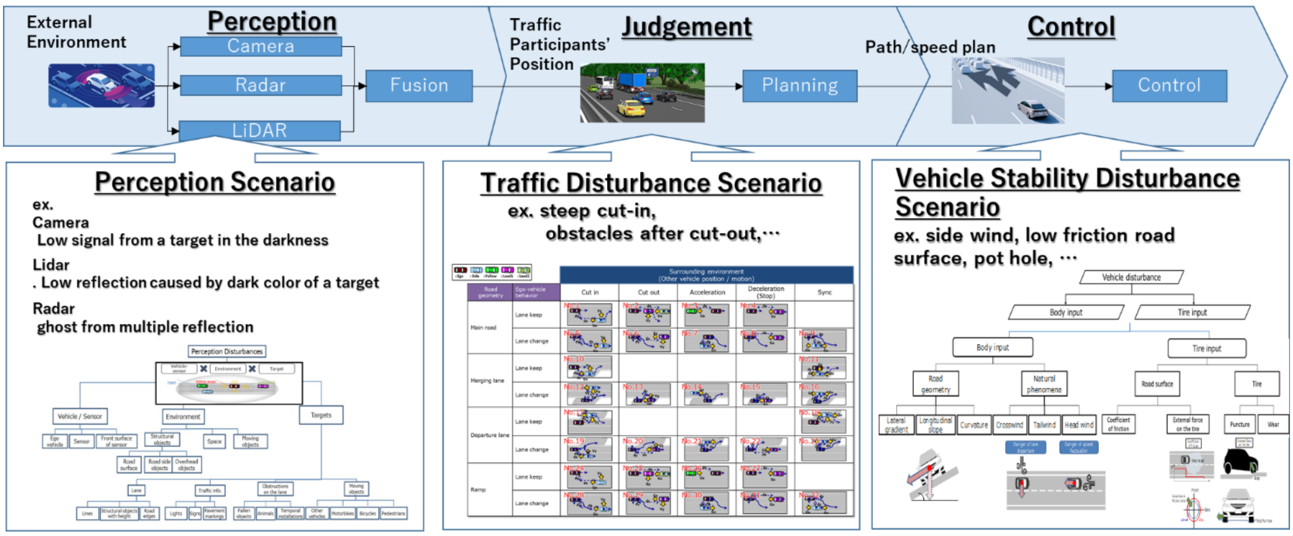


Figure 1. different categories of structuralized scenarios considering physics principles for each corresponding perception, judgement and control tasks

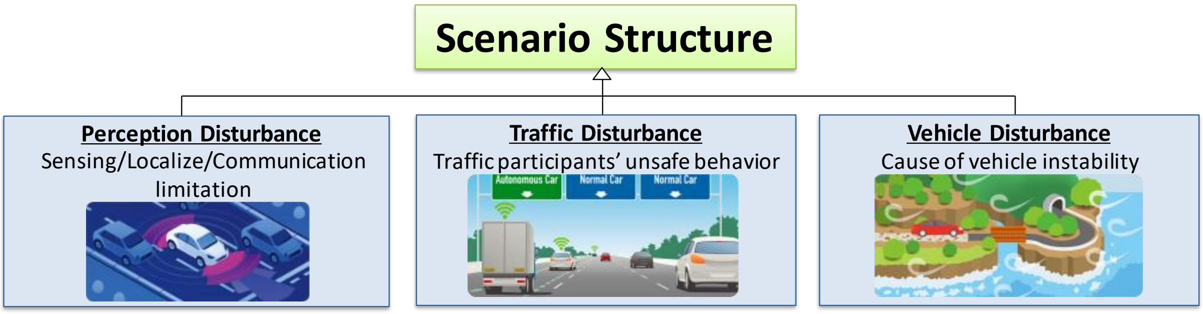


Figure 2. Schematic of the three disturbance categories considered to logically structuralize scenarios

Perception disturbance refers to conditions in which the sensor system may fail to correctly judge a hazard or a non-hazard for sensor or vehicle intrinsic or extrinsic reasons. Examples of intrinsic reasons include part mounting (e.g. unsteadiness related to sensor mounting or manufacturing variability), or vehicle conditions (e.g. vehicle inclination due to uneven loading that modifies sensor orientation, or sensor shielding with external attachments such as bicycle racks). External reasons include environmental conditions (e.g. sensor cloudiness, dirt, light, etc.) or blind spots induced by surrounding vehicles.

Traffic disturbance refers to traffic conditions that may lead to a hazard resultant of a combination of the following factors: road geometry (e.g., branch), ego-vehicle behaviour (e.g., lane change), and surrounding vehicle location and action (e.g. cut-in from a near side vehicle).

Vehicle disturbance refers to situations in which perception and judgement work correctly but where the subject vehicle may fail to control its own dynamics. This can be due to intrinsic vehicle factors (e.g. total weight, weight distribution, etc.) or extrinsic vehicle factors (e.g. road surface irregularities and inclination, wind, etc.).

Collected normal traffic and accident data can be used to confirm possible gaps in terms of whether situations actually occurring in real traffic are being missed by the logically created scenario systems. Further, by assigning probabilistic ranges to physical parameters for each qualitative scenario category, the data and scenarios can also be used to show in a downscaled manner, to what extent certain situations actually occur.

2.3. Safety Argumentation Structure Framework

2.3.1. Automated driving safety principles

The WP29 document for the harmonisation of international regulations on automated driving reads "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" (UN/WP29, 2019, WP29-177-19, Framework document on automated/autonomous vehicles).

These definitions allow to contextualize the safety philosophy of the current methodology proposed, with respect to safety principles that international policy makers are applying in the form of a matrix (Figure 3). Considering the two conditions of foreseeability and preventability together generates a 4 quadrant matrix that better contextualises the philosophy of this document. Scenario based safety evaluation, can be found in the top left quadrant of the matrix where no accidents are acceptable. This quadrant accounts for all scenarios for which an accident is foreseeable and preventable. The bottom left quadrant of the matrix depicts the traffic situations that can not be foreseen but that can be prevented. The cases that fall under this category form the basis for learning and serve as a precedent for future generation AD system developments. The top right quadrant of the matrix introduces cases that are foreseeable but not preventable. The situations that fall under this category are situations for which mitigation is the only option. Measures to reduce the damage resultant of these unpreventable (yet foreseeable) cases constitutes the main area of focus in this section. The final quadrant (bottom right) accounts for crashes that are neither foreseeable nor preventable. In these situations, resilience support in the form of legalities, the division of responsibilities, health support, insurance and other such areas need to be the focus of attention.

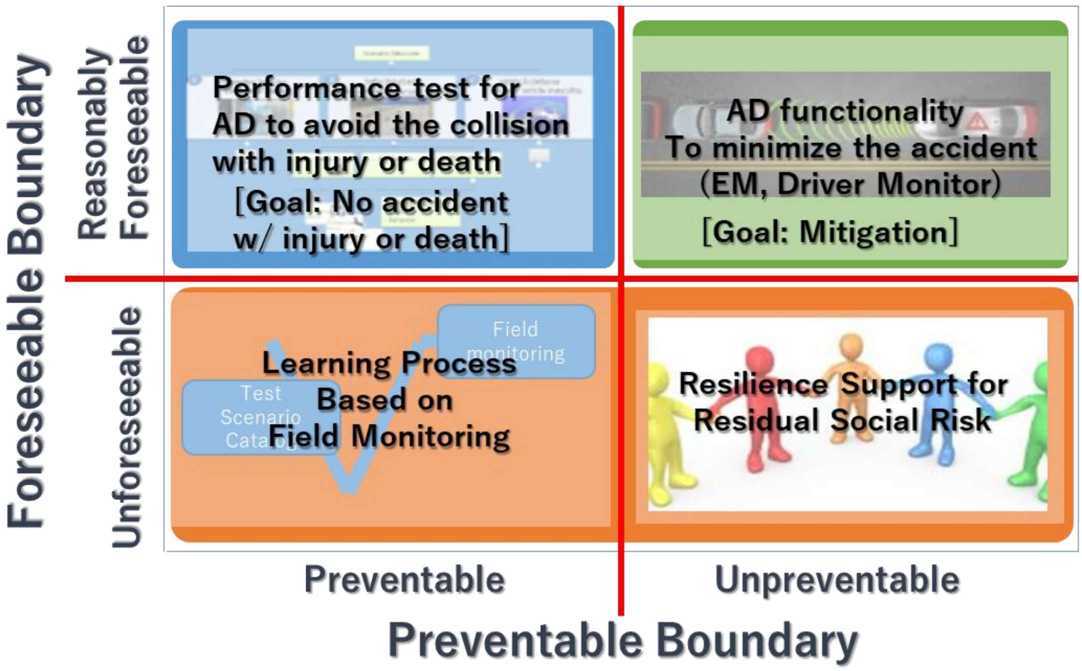


Figure 3. Safety approach in context with foreseeability and preventability matrix

2.3.2. Scope of safety evaluation

Figure 4 presents a summary of the safety aspects described in the WP29 framework document organized hierarchically. With the common top level safety goal of achieving systems free of unreasonable safety risks, the scope of the current proposal is limited to Validation for System Safety (highlighted in pink).

The validation for system safety according to the safety vision framework can be further decomposed as shown in Figure 5. The scope of the current proposal is limited to critical conditions, and excludes 'Pre critical conditions'. The reason for this exclusion is that, in situations in which there may be a potential risk (e.g. frontal vehicle carrying a load that may fall on the road), may induce many actuations that are not motivated by real risks and that alter traffic imposing risks on other participants (e.g. braking frequently despite not being a real risk). Therefore, to address pre-critical situations, rather than applying physics principles approach processes, other means to verify if the vehicle follows traffic rules and keeps sufficient distance with surrounding objects

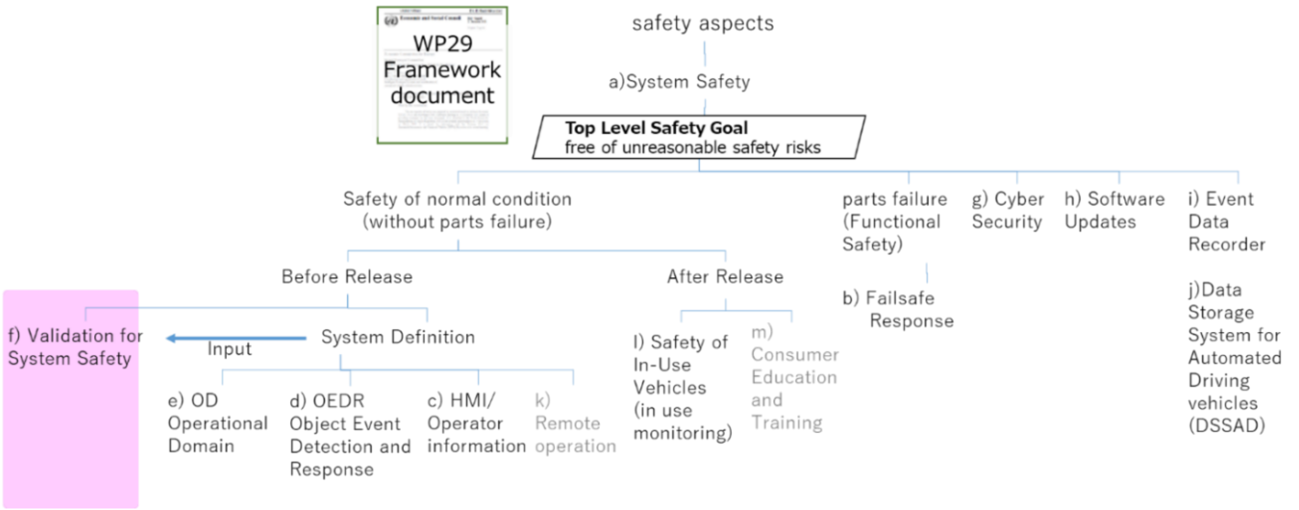


Figure 4. Safety Aspects Hierarchy Diagram

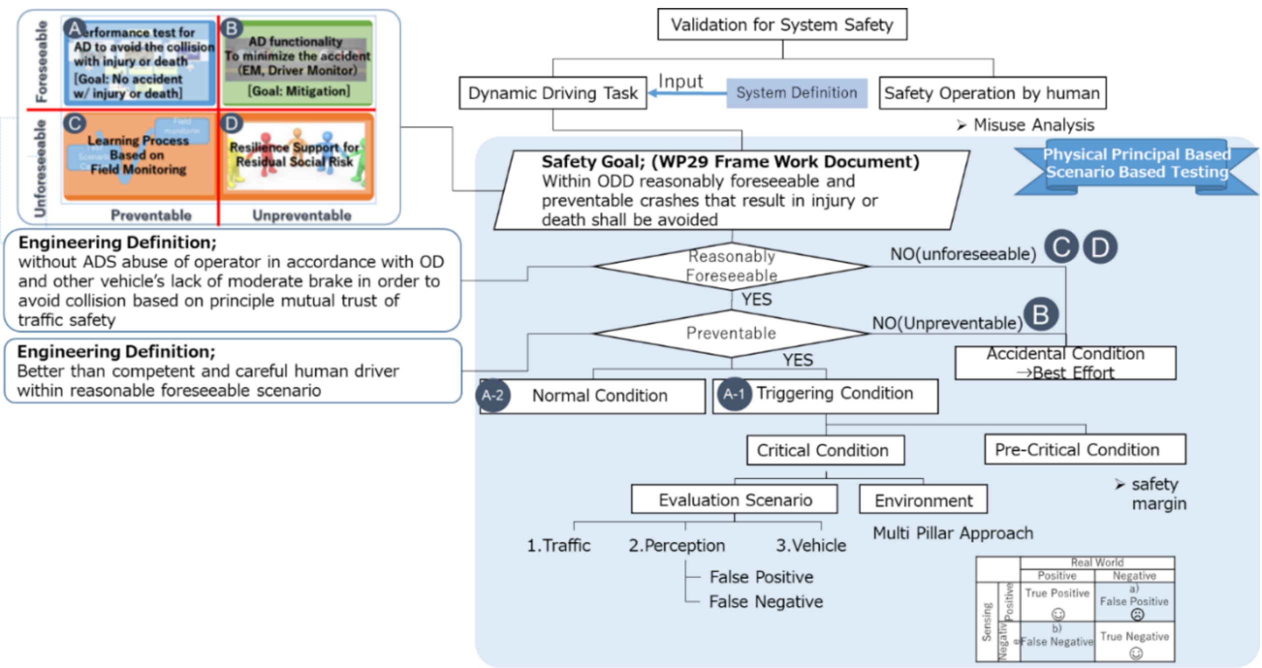


Figure 5. Safety argumentation structure diagram

2.3.3. Method of evaluating safety

The main DDT safety risk is to collision with the surrounding traffic participants or obstacles, which is systematized through traffic disturbance scenarios. By defining quantified ranges of reasonable foreseeability and preventability for each of these traffic disturbance scenarios, quantitative criteria associated to each test are defined. Based on these traffic related hazardous scenarios, it is then possible to expand the evaluation to incorporate perception- and vehicle stability-related hazardous scenarios into the assessment which will enable a comprehensive safety evaluation (Figure 6).

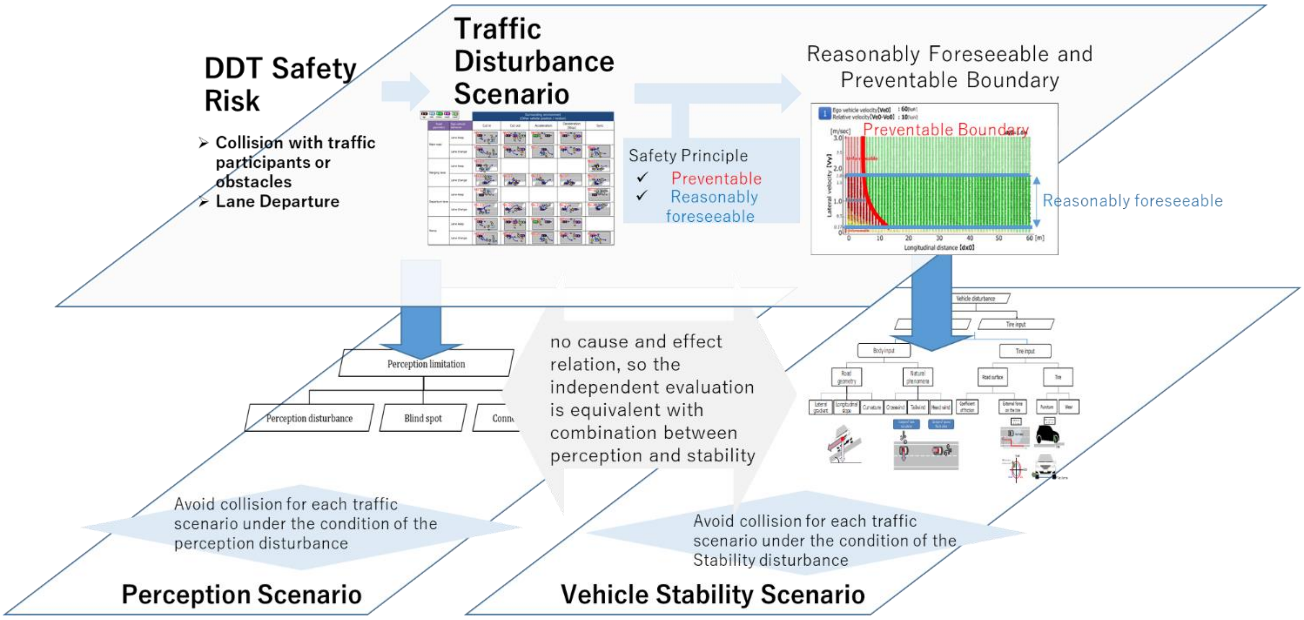


Figure 6. Overview of method of judging safety

2.3.3.1. Traffic disturbance safety evaluation method

Traffic disturbance is the position and actions of traffic participants existing around your own vehicle that prevent safe driving by your own vehicle. As previously described, the basic thinking behind safety principles is ‘to equip the automated driving system with higher level avoidance performance than a competent and careful human driver within a foreseeable range.’ For this thinking, we need to define and model the performance of a competent and careful drive applied to traffic disturbances. By implementing this defined model in a simulation program and deriving the actual scope avoidable for a competent and careful human driver, it is possible to define safety standards in relation to traffic disturbances.

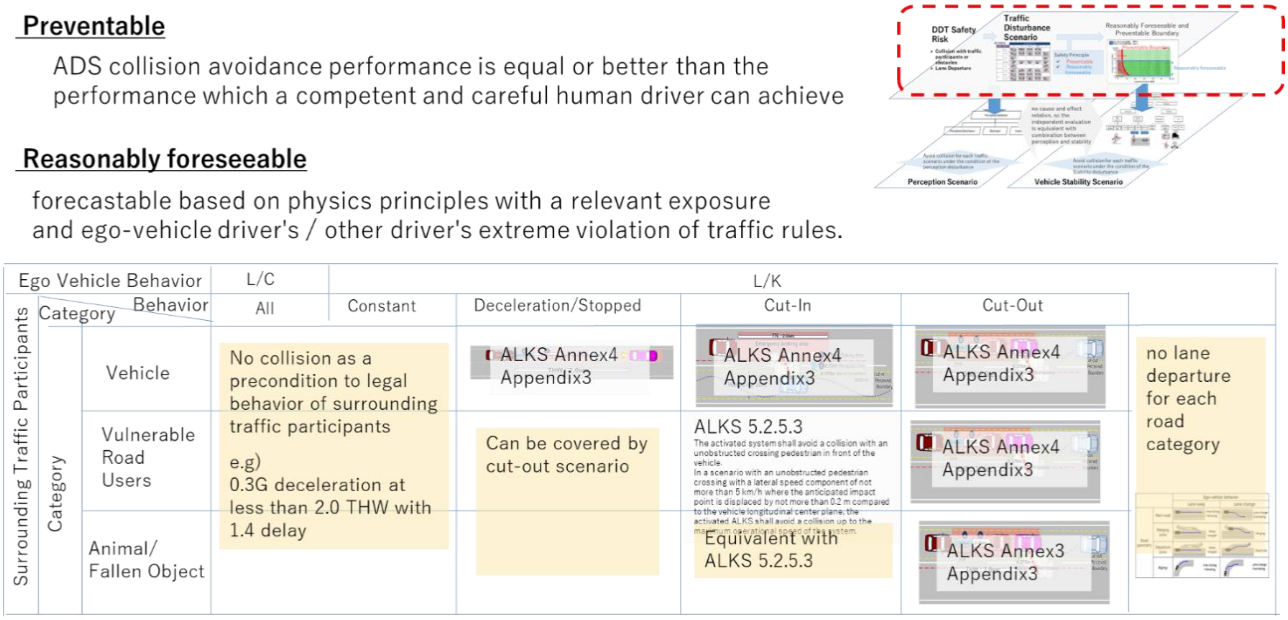


Figure 7. Overview of traffic disturbance safety judgement method

The competent and careful human driver performance model definition (Figure 8) is able to define the three elements of ‘perception’, ‘judgement’, and ‘operation.’ It is important to have objective grounds for defining parameter coefficients related to performance shown in the respective segments.

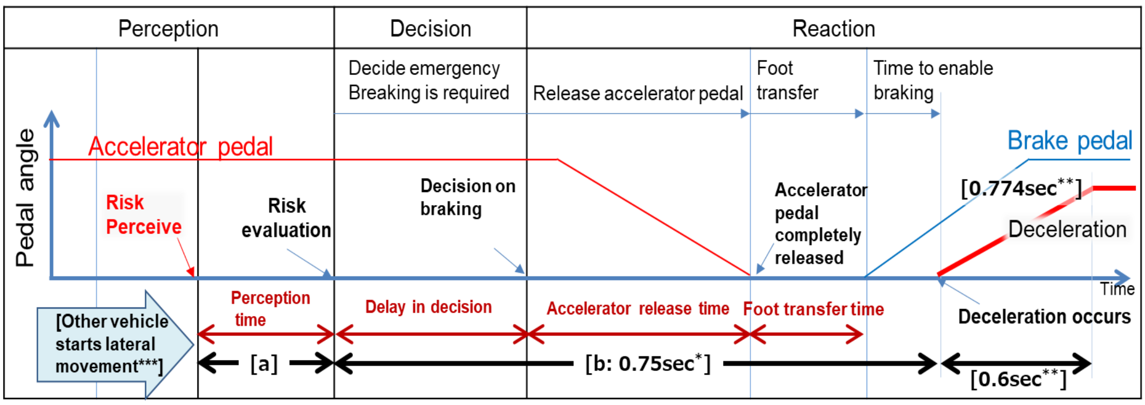


Figure 8. Competent and careful human driver model

Here, the driving action elements of ‘judgement’ and ‘operation’ are explained. The main avoidance actions of automatic driving in relation to traffic disturbances are considered to be the brake operation (deceleration action) and, regardless of the type of traffic disturbance (position and action of the traffic participants surrounding the ego vehicle), this is fulfilled by defining the performance of a competent and careful human driver. Figure 9 shows a diagram which demonstrates the brake operation of a competent and careful human driver. The model on the left shows the braking operation made by a competent and careful human driver. The model on the right is a functional model of the collision damage mitigation braking system (AEB: Advanced Emergency Braking), it considers the amount of improvement in avoidance performance when equipped with AEB.

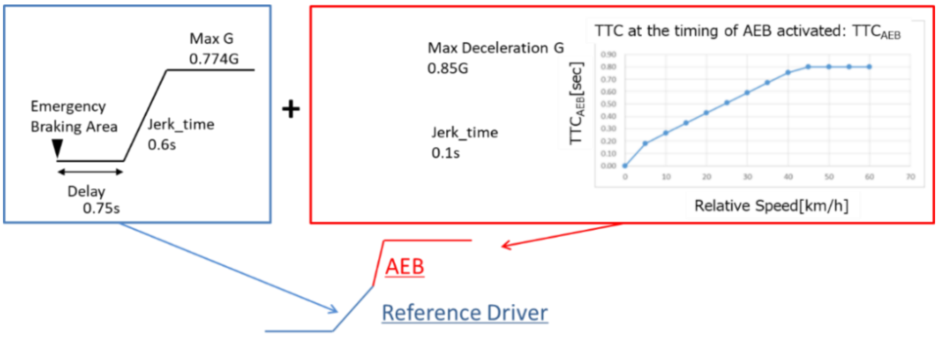
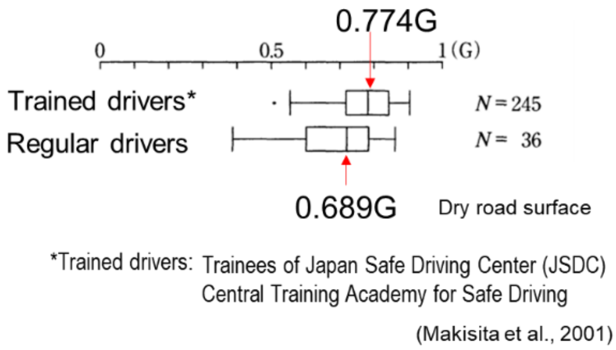


Figure 9. Competent and careful human driver brake model

Perception response time, the time delay from the moment when a competent and careful human driver perceives risk to the time that deceleration braking force occurs is set at 0.75 s. This time set is used by police and domestic courts in Japan when establishing a driver's "perception response time".

In terms of maximum deceleration force, quoting the Japanese test data shown in Figure 10, is 0.774G. Whereas the brake force generated by normal drivers in emergencies is 0.689G, normal drivers who have received training in driving techniques have a braking force of 0.774G; albeit this is defined as a higher skill value compared to ordinary drivers.

Furthermore, from the accident statistics data from NHTSA (Figure 11), 0.74G is the peak value; therefore, the maximum deceleration of 0.774G applied to the competent and careful human driver model can be considered appropriate.



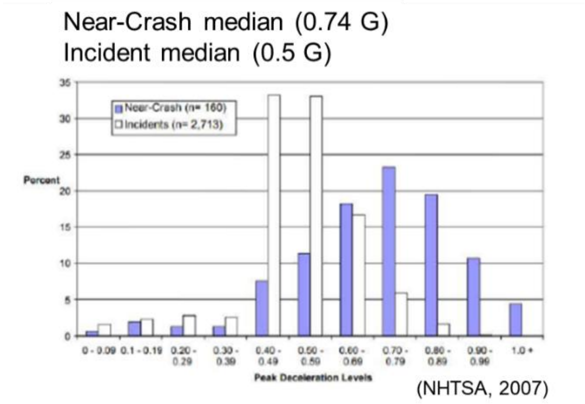


Figure 10.Emergency brake characteristic

Figure 11Maximum deceleration due to deceleration of the preceding vehicle

Figure 12 shows a waveform diagram of deceleration braking for drivers who have received driver skill training. This quotes the Japanese test data previously described. In this waveform diagram, the time for reaching the maximum deceleration is demonstrated, and the maximum deceleration arrival of a competent and careful human driver is defined as 0.6 s.

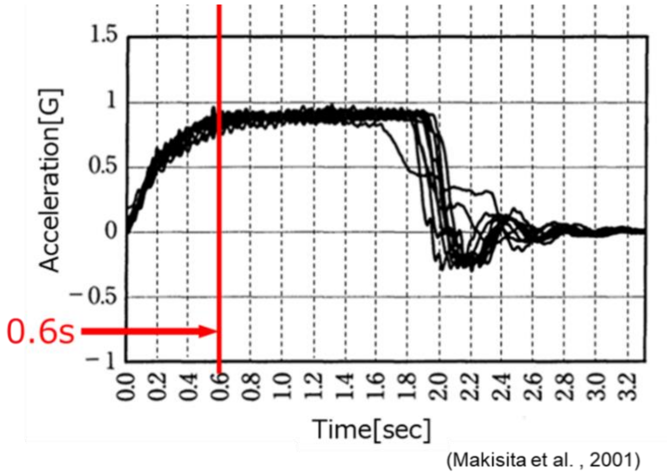


Figure 12. Emergency brake characteristics study example (arrival time until maximum deceleration)

2.3.3.1.1. Cut-in scenarios

Cut-in scenarios are scenarios in which vehicles travelling in an adjacent lane to the ego vehicle cuts in front of it.Figure 13 shows a schematic expressing boundary conditions where a competent and careful human driver judges it risky when another vehicle cuts in in front of the ego vehicle.

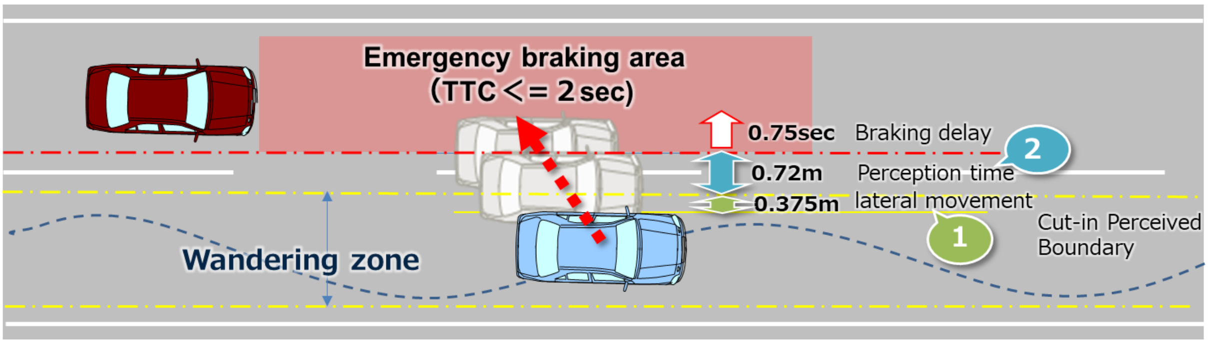
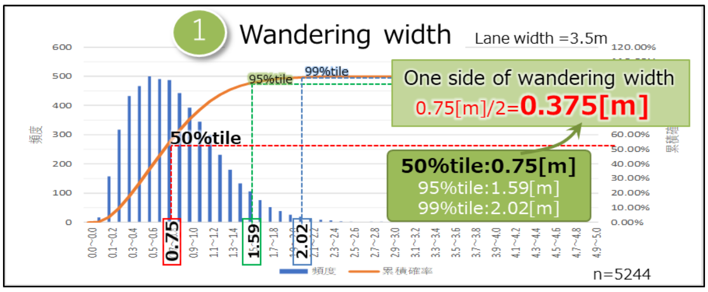


Figure 13. Cut-in judgement conditions and danger judgement boundaries

The boundary conditions when it is judged that a vehicle travelling in the adjacent lane has cut in front of the ego vehicle are defined as the cut-in vehicle lateral movement distance (wander amplitude). In an actual driving environment, vehicles driving while maintaining their lane will wander a little to the left or right while driving. In the scope of the wander lateral movement distance, it is unlikely that the vehicle traveling in the adjacent lane of the ego vehicle travels whith a recognition that it will cut in. Therefore, the cut-in perception boundary conditions were defined from the lateral distance movement (wander amplitude) distribution (Figure 14) of vehicles changing lanes based on the data observed in the actual traffic environments.

After the cut-in judgment, the boundary conditions for perceiving risk for the ego vehicle and perceives a need for the emergency brake (risk perception boundaries) can be defined by multiplying the maximum lateral velocity derived from the actual traffic observation data by the risk perception response time.



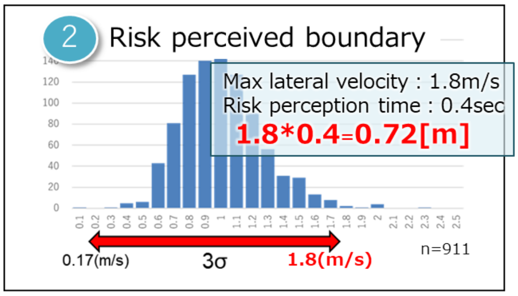


Figure 14. Actual observation statistics for ‘stagger amplitude’

Figure 15. ‘Maximum lateral velocity’ observation data statistics

When calculating the ‘risk perception response time, test data using a driving simulator carried out in Japan was utilised and analysed. The prerequisites for the test are shown in Figure 16.

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 16. Assumptions for driving simulator tests

The tests measured the driver's response (reaction time, avoidance operation) for cut-ins from 20 other regular drivers (Table 1). The measurements were performed twice on each participant; by comparing the respective average values of the first and second time, we derived the time until risk was perceived.

Table 1. Test participant attributes

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 test results are shown in Figure 17. The results demonstrated that the time from the start of the cut-in from the other driver to when risk was perceived was ~0.8 s for the first time and 0.4 s for the second time. Based on these test results, with the first time perception, the cut-in time is required by the other driver and the time for risk to be perceived, whereas the second time because they were driving while being wary of the cut-in, the time for identifying the cut-in from the other vehicle was not required. However, even when the driver was aware, time was still required for determining risk (Figure 18), and the 'time until risk was perceived' was defined as 0.4 s.

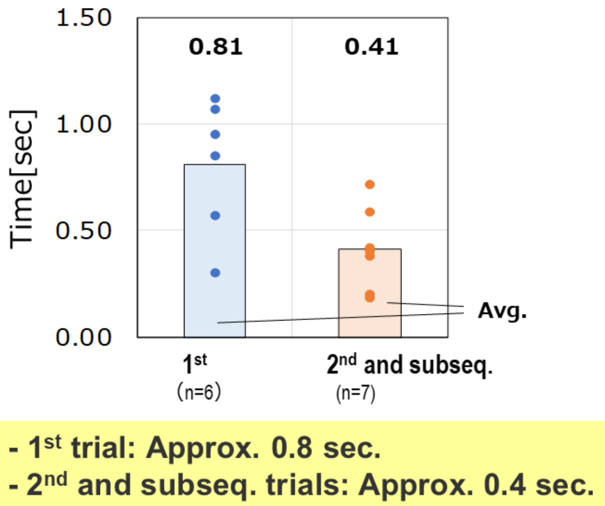


Figure 17. Driving simulator test results

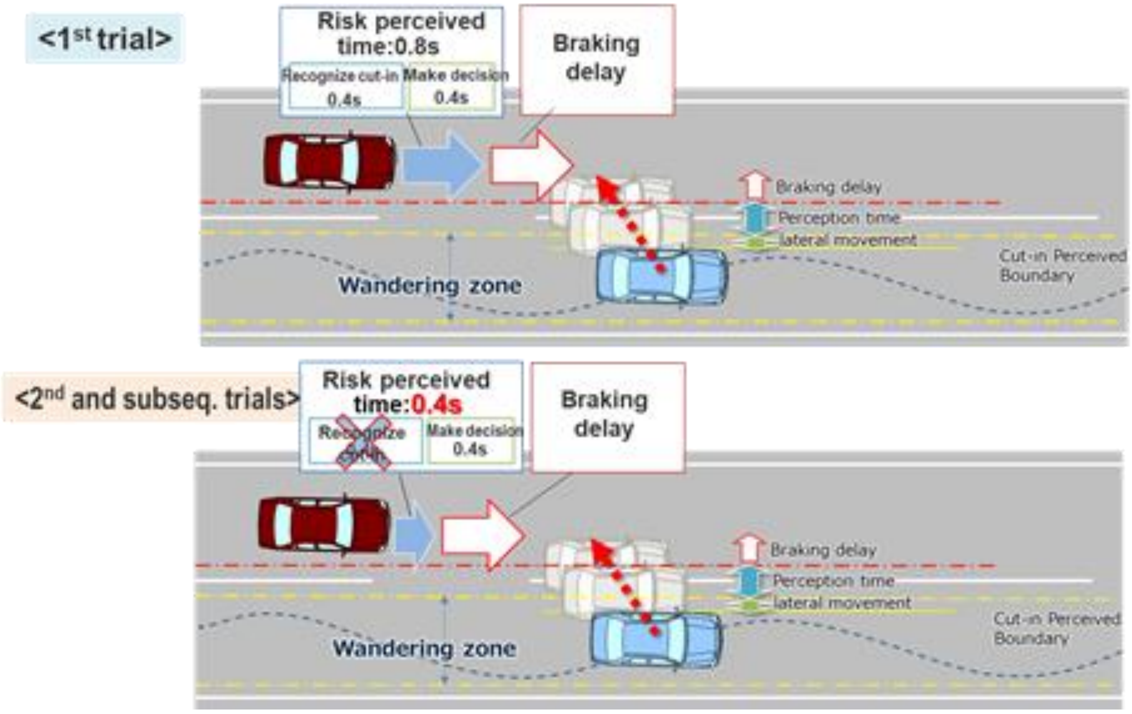


Figure 18. Relationship between cut-in identification time and danger judgement time

As described above, the risk judgement boundary is defined as the time when multiplying the maximum lateral velocity, and the time until perceiving risk. The maximum lateral velocity of 1.8 m/s calculated from the actual traffic observation data and the time until risk is perceived and calculated from the driving simulator test results of 0.4 s are multiplied. Therefore, the risk perception boundary is defined as 1.8 × 0.4＝0.72 m.

When the cut-in perception condition and risk evaluation boundary area applied to the diagram in Figure 8, it results in Figure 19.

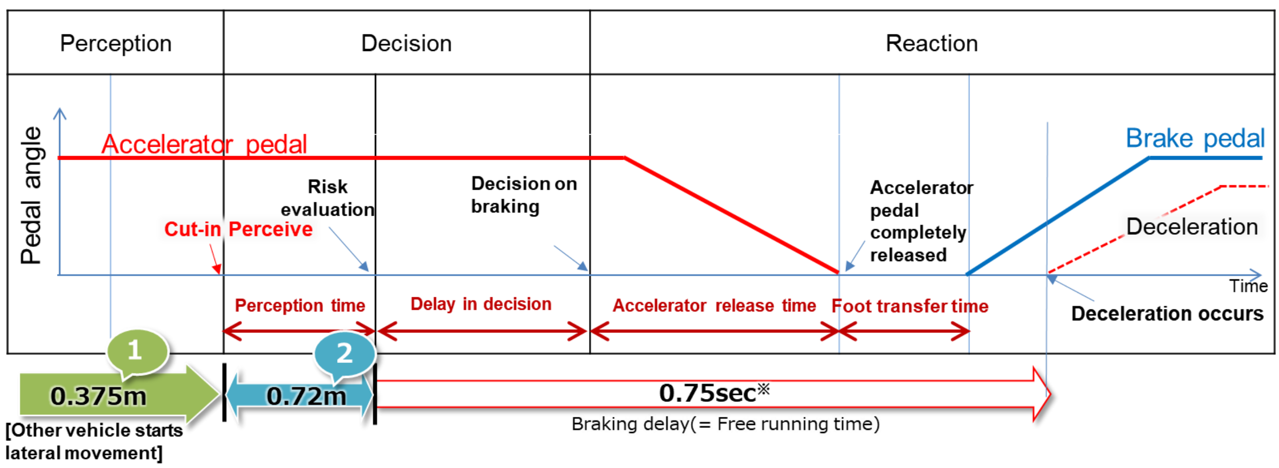


Figure 19. Competent and careful human driver model (Cut In)

According to the UNR collision warning guidelines, the boundary that requires emergency action is defined as TTC※ = 2.0 s regarding the longitudinal (distance from the other vehicle) risk evaluation boundary (Figure 2). This is cited to define the longitudinal risk evaluation boundary as TTC = 2.0 s.

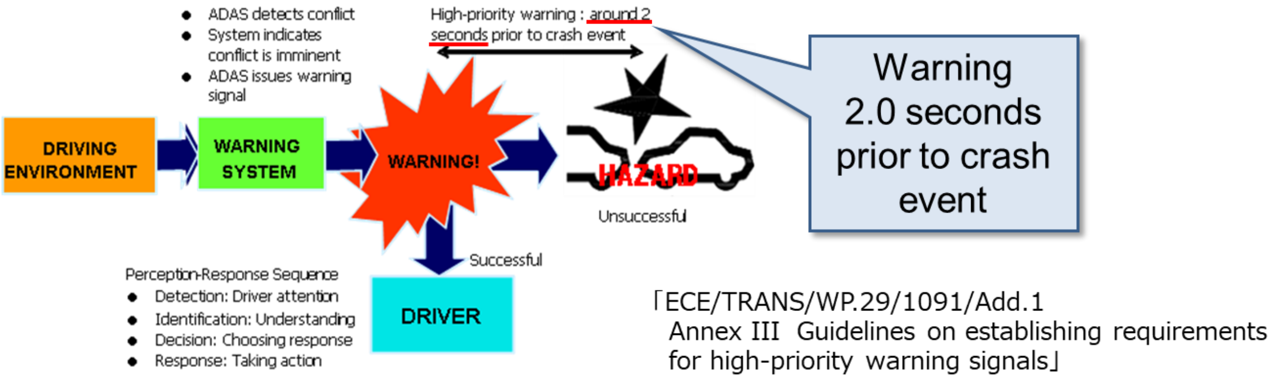


Figure 20. UNR collision warning guidelines (Citation)

2.3.3.1.2. Cut-out Scenario

The cut-out scenario is a scenario in which the leading vehicle that the ego vehicle is following suddenly changes its lane to the adjacent lane (cut-out). This scenario evaluates safety in relation to the sudden appearance of a decelerating or stopped vehicle (such as broken-down car and the tail end of a traffic jam) in front of the ego vehicle due to the preceding vehicle's cut-out. Figure 21 shows the schematic that represents the boundary condition for the competent and careful human driver who perceives the situation to be risky when the preceding vehicle performs a cut-out.

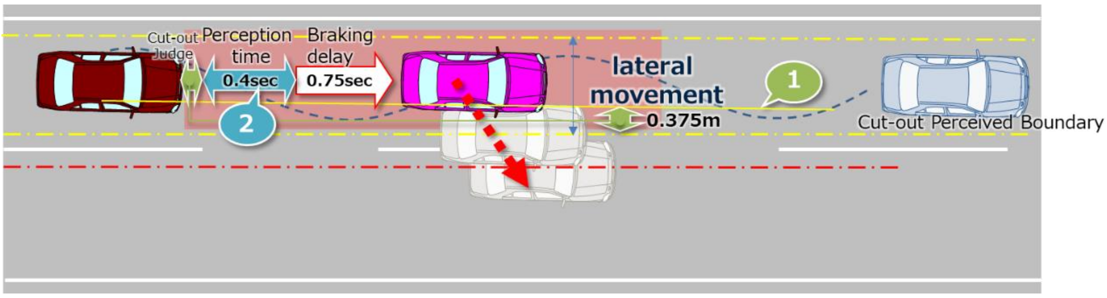


Figure 21. Cut-out perception condition and risk evaluation boundary

The cut-out perceived boundary condition to perceiving the preceding vehicle's cut-out manoeuvre is defined by the amount of lateral movement (drifting amplitude), which is similar to the case with the aforementioned cut-in perception condition. Both the cut-in and cut-out are maneuvres to change lanes. Similar to the case of cut-in, the boundary condition using the distribution of drifting amplitude from the observation data of real traffic is applied to the perception condition of cut-out.

Moreover, the time from the cut out perception to the recognition of the vehicle ahead that appears and the risk perception is defined as 0.4 sec based on the experimental data (Figure 17 and 18).

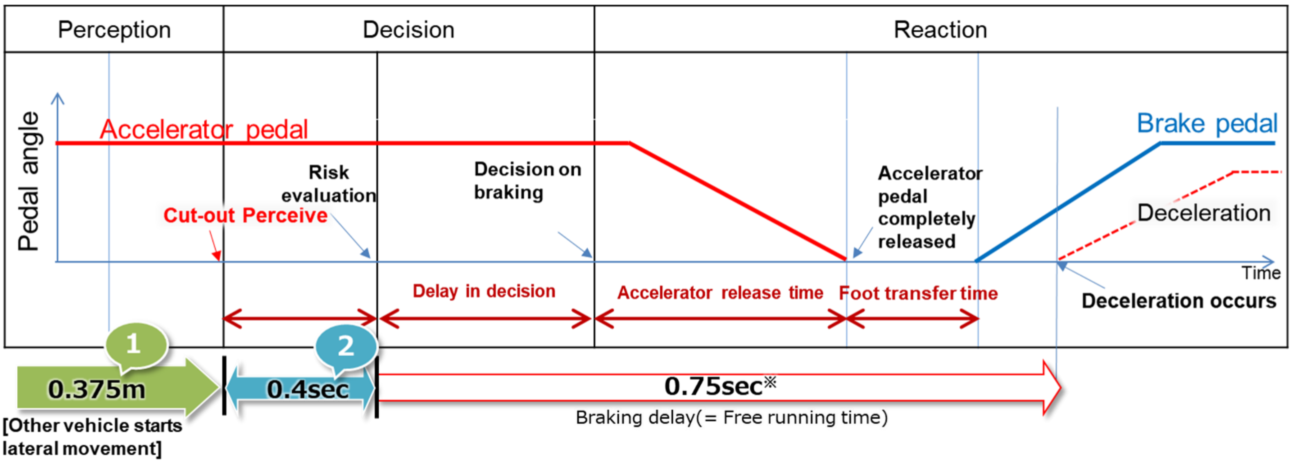


Figure 22. Competent and careful human driver model (cut out)

2.3.3.1.3. Deceleration Scenario

A deceleration scenario takes into consideration the sudden deceleration of the leading vehicle that the ego vehicle is following. Although the previous cut-in and cut-out scenarios required the perceived lane change boundaries from the following or leading vehicle, the deceleration scenario only involves the longitudinal behaviour. Therefore, it is only necessary to define the deceleration perception time by the leading vehicle to evaluate the risk boundary. Similar to the preceding case, 0.4 s can be applied as the time required to evaluate the risk.

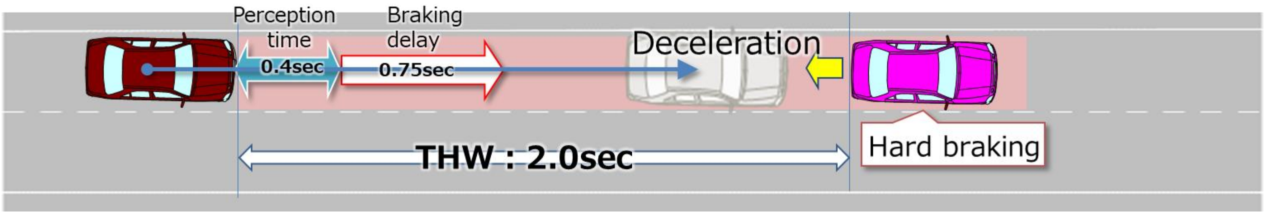


Figure 23. Risk evaluation boundary in deceleration scenario

When the risk evaluation condition of the deceleration scenario is applied to the diagram in Figure 8, it results in Figure 24.

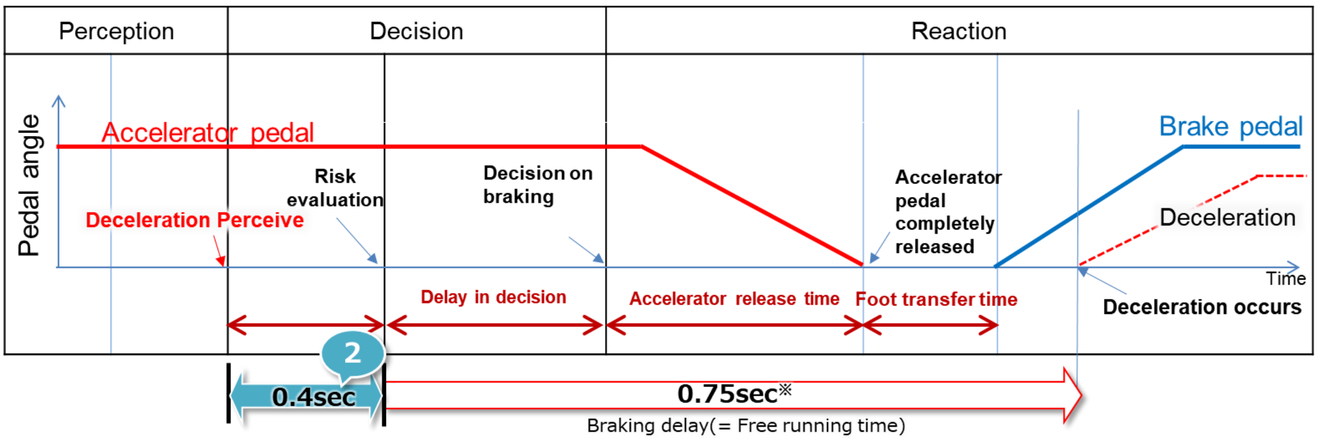


Figure 24. Competent and careful human driver model (Deceleration)

Definition of Parameters for Deriving Standard

The following table lists the parameters required for deriving the safety standards for traffic disturbances. The evaluation scenarios related to traffic disturbances are generated by defining road geometry, the ego vehicle's behaviour, and locations and motions of the surrounding traffic participants. The parameter items required in the evaluation scenario are categorized in a specific numerical range, and the Pass / Fail boundary is derived within that range.

Table 2. List of traffic disturbance parameters.

Operating conditions	Roadway	#of lanes = The number of parallel and adjacent lanes in the same direction of travel Lane Width = The width of each lane
Initial condition	Initial velocity	Ve0 = Ego vehicle
		Vo0 = Leading vehicle in lane or in adjacent lane
		Vf0 = Vehicle in front of leading vehicle in lane
	Initial distance	dx0 = Distance in longitudinal direction between the front end of the ego vehicle and the rear end of the leading vehicle in ego vehicle's lane or in adjacent lane
		dy0 = Inside Lateral distance between outside edge line of ego vehicle in parallel to the vehicle's median longitudinal plane within lanes and outside edge line of leading vehicle in parallel to the vehicle's median longitudinal plane in adjacent lines.
		dy0_f = Inside Lateral distance between outside edge line of leading vehicle in parallel to the vehicle's median longitudinal plane within lanes and outside edge line of vehicle in front of the leading vehicle in parallel to the vehicle's median longitudinal plane in adjacent lines.
		dx0_f = Distance in longitudinal direction between front end of leading vehicle and rear end of vehicle in front of leading vehicle
		dfy = Width of vehicle in front of leading vehicle
		doy = Width of leading vehicle
		dox = Length of the leading vehicle
Vehicle motion	Lateral motion	Vy =Leading vehicle lateral velocity
	Deceleration	Gx_max = Maximum deceleration of the leading vehicle in G
		dG/dt = Deceleration rate (Jerk) of the leading vehicle

2.3.3.1.4. Calculation of Boundary

As discussed above, the specific standard value can be derived by the numerical calculation of the competent and careful human driver model. The parameter region for the standard value derivations are set to allow combinations of every parameter within the maximum vehicle velocity region allowed by the ADS to be targeted.

2.3.3.1.4.1. Derivation result of the preventable boundary of cut-in scenario

The safety standard of the cut-in is derived for every relative velocity between the ego vehicle and the counter vehicle. Collision with the cut-in vehicle is not allowed in the parameter region indicated by the green area in Figure 26.

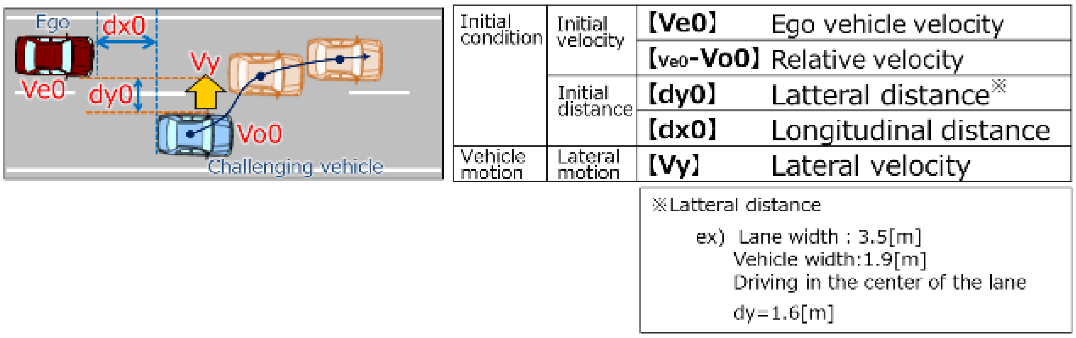


Figure 25. Conceptual diagram of cut-in scenario parameters

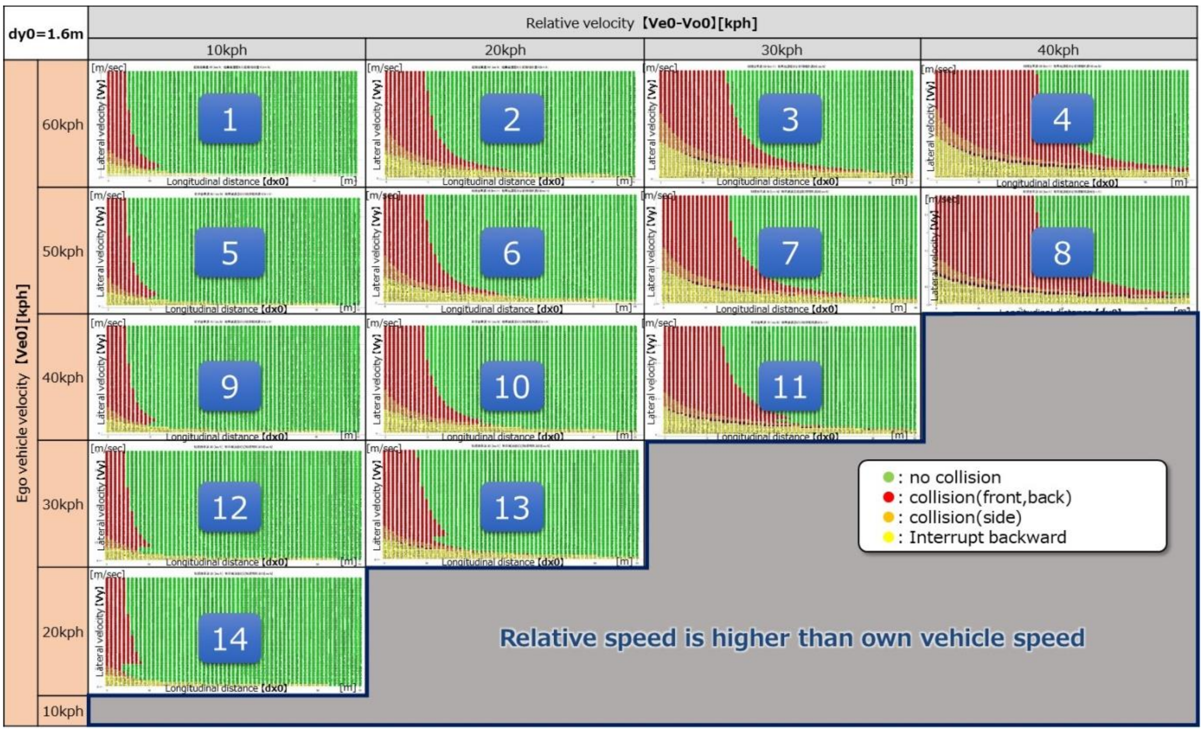
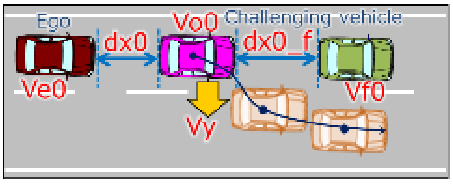


Figure 26. Preventable boundary data sheet of cut-in scenario

2.3.3.1.4.2. Derivation result of cut-out scenario standard

The cut-out safety standard requires that all decelerating (stopped), vehicles located ahead of the vehicle cut-out, must be able to avoid collisions. This standard is derived by making the aforementioned competent and careful human driver model follow the leading vehicle at THW = 2.0 s. This value, i.e., THW=2.0 s, is applied by referring to the laws and instructions of each country.



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 27. Conceptual diagram of cut-out scenario parameters

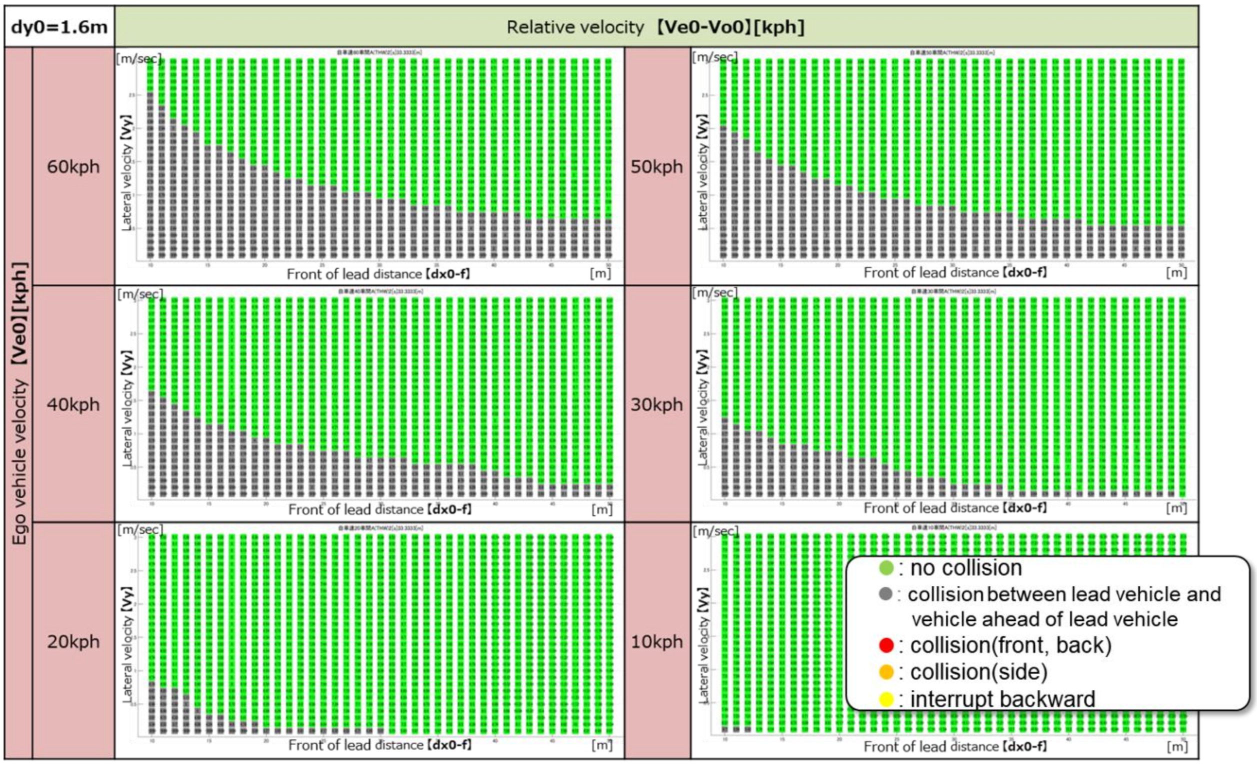
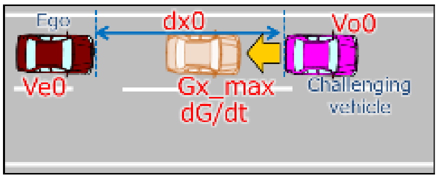


Figure 28. Preventable boundary data sheet of cut-out scenario

2.3.3.1.4.3. Derivation result of preventable boundary of deceleration scenario

The safety standards for deceleration scenarios are required to enable avoidance of collision with the suddenly decelerating vehicle at −1.0 G or less or by stopping the vehicle. This standard is derived by making the aforementioned competent and careful human driver model follow the leading vehicle at THW = 2.0 s. This value, THW = 2.0 s, is applied by referring to the laws and instructions of each country.



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 29. Conceptual diagram of decelerating scenario parameters

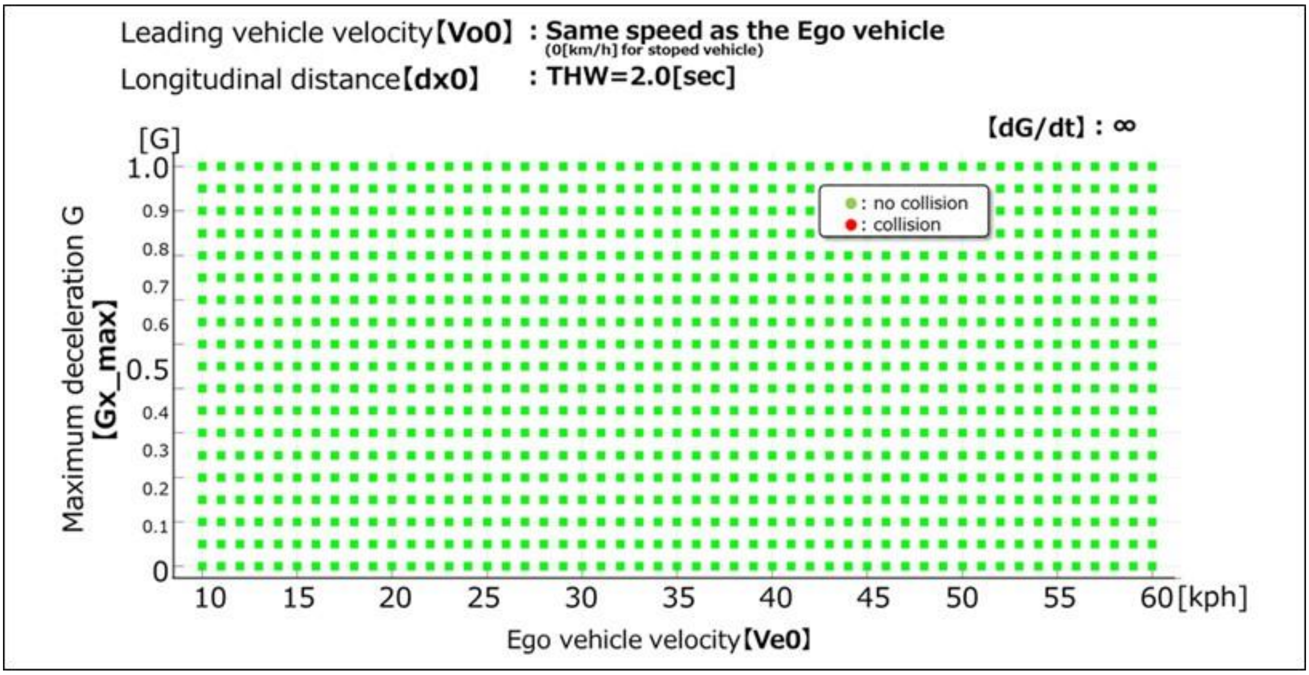


Figure 30. Preventable boundary data sheet of decelerating scenario

NOTE: Preventable boundary does not show up at 60 km/h or less because the braking force is sufficient.

2.3.4. Safety evaluation method for perception disturbance

The basic conception of safety standard is as follows: ‘To avoid collisions in any of the traffic disturbance scenarios, even when experiencing perception disturbances.’

When considering that lane deviation can also contribute to collisions, the perception of objects is necessary to avoid collisions with objects on the runway (Fig. 31). Moreover, there are two types of phenomena that result from the perception disturbance, namely, a false negative where the existing objects are not correctly detected, and a false positive where objects that do not exist are falsely detected (Figure32).

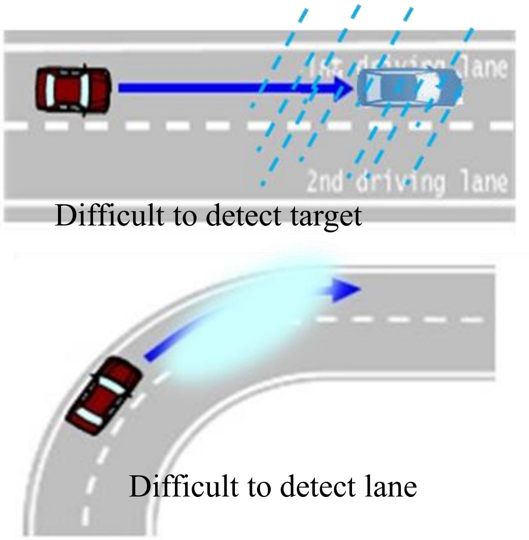


Figure 31. Types of detection target

		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 ☺

Figure 32. Detection result caused by disturbance

When these are combined, evaluations based on the concept of safety standards become necessary for four categories of situations in total (Figure 33).

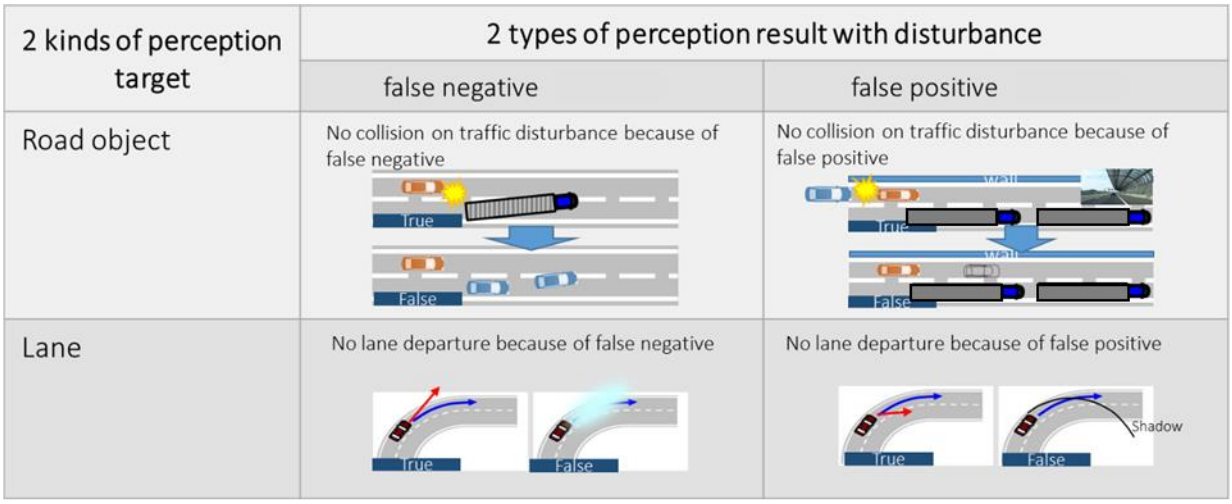


Figure 33. Four categories of detection disturbance situation

The following is considered within the ODD region as the parameter region of perception disturbance to define an appropriate region for each disturbance factor.

1: Road structure, Road Traffic Law and other regions defined by laws and regulations.
(e.g.: When visibility is 50 m or less, the road is closed, i.e., a level difference of >15 cm on the road surface must be repaired)
2: Region that is determined to be possible at certain probability based on statistical data.
(e.g., precipitation, brightness, and sun altitude, etc)

Moreover, this safety standard is not the performance standard allocated to an individual sensor. Instead, it should complement the entire recognition system installed. The above flow of safety perception can be summarized as follows.

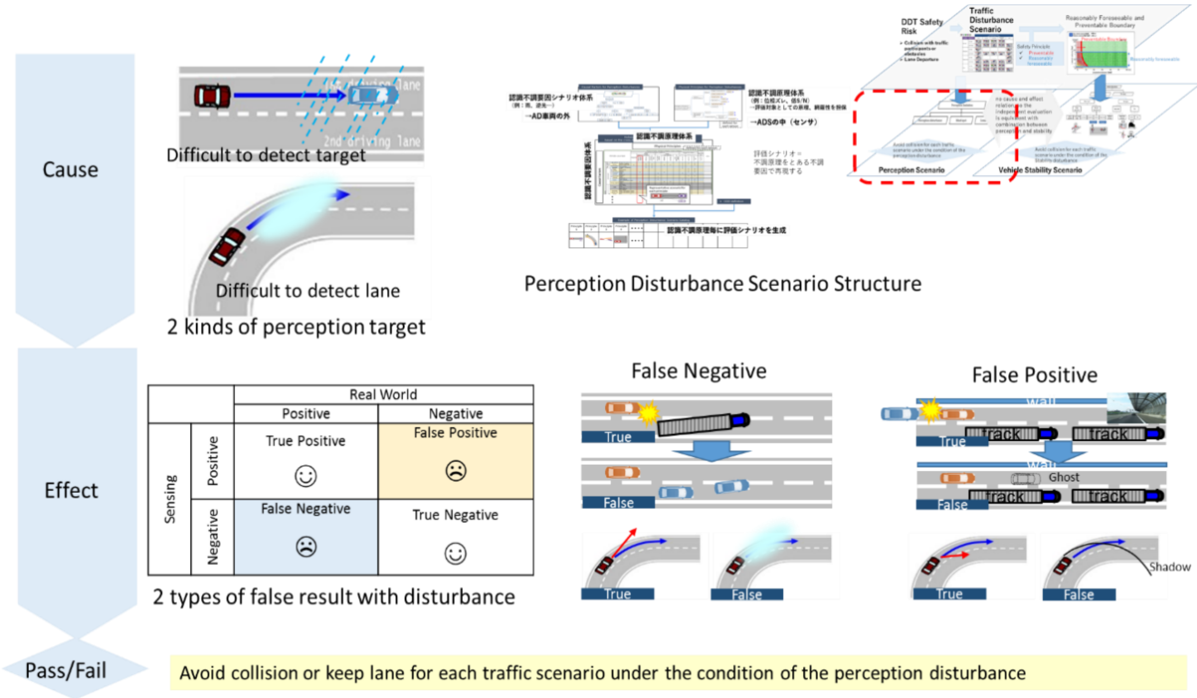


Figure 34. Safety assessment of perception disturbance detection flow

2.3.5. Safety evaluation method for vehicle disturbance

A vehicle disturbance indicates sudden disturbances (e.g. puddles or sudden gust of wind). Although these are unpredictable phenomena, drivers can safely drive by following common sense related to road design, road maintenance/management and road environmental conditions. Thus, the premise of driving on common roads is that the roads are constructed by responsible public or private organisations which follow basic principles such as legality, ethics and engineering and are always maintained and managed. Most countries have road structure ordinances and guidelines for road maintenance and repair to ensure that the road geometry design enables safe driving by every person with a valid driving license (regardless of their driving skill, reflexes, or age). Moreover, when there is a risky situation, such as freezing or a sinkhole, that can hinder driving, the road administrator is obliged to warn the drivers in advance, e.g., with a traffic sign. Based on these preconditions, a technical safety approach for foreseeable vehicle disturbances is introduced.

As shown in Figure 6, ‘collisions must be avoided in any of the traffic disturbance scenarios, even when experiencing vehicle disturbance.’ In the current standards, the collision avoidance strategy under the foreseeable and avoidable scenarios and collision mitigation strategies for predictable but unavoidable scenarios are of particular consideration. Henceforth, when a vehicle behaviour changes because of a vehicle disturbance within the scope of avoidable conditions, the AD vehicle is required to possess a controllability that can stabilise the vehicle without halting driving. However, when these disturbances cause instability that cannot be avoided, the AD vehicle must adapt to the ‘best effort’ strategy to mitigate the possible collision.

Figure 35 shows a specific example of the safety approach for foreseeable vehicle disturbances. The upper section of the figure represents an example of the AD vehicle experiencing a rapid decrease of sliding friction while staying within the avoidable conditions on a wet road; in such a state, the vehicle must be able to be safely controlled without interrupting the driving process. However, the lower section of the figure represents an example involving an AD vehicle equipped with summer tires encountering a frozen road, which causes a rapid decrease of sliding friction and generates a vehicle state that was defined to be unavoidable in advance (e.g., maximum deceleration). Therefore, the safety approach toward vehicle disturbances is based on the principle and clear definitions of vehicle motion engineering related to the definitions of the states where the vehicle is controllable and the states where the vehicle is uncontrollable. (Section 4.3.3 for detail).

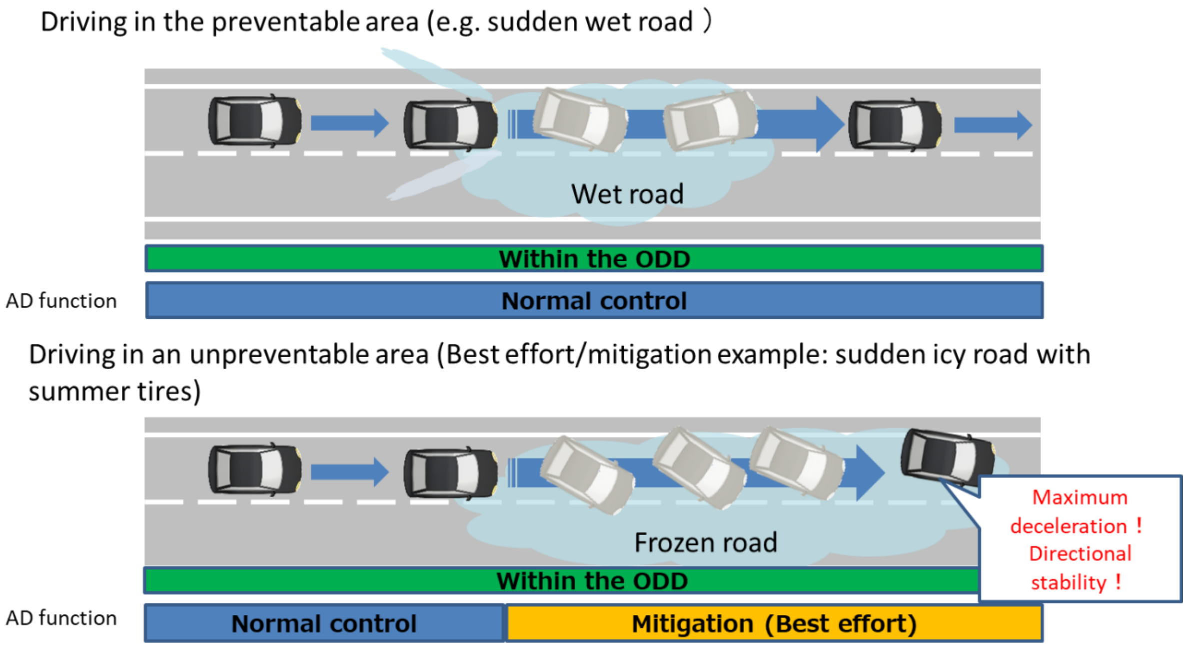


Figure 35. Safety approach for avoidable (above) and unavoidable (below) vehicle disturbance

When these considerations are combined with traffic disturbances, the safety of the AD vehicle does not affect the test result if the stability of the vehicle is maintained. Moreover, while wind affects other vehicles, it only influences the lateral velocity as with cut-in, and it is included in the original traffic flow parameters. The safety standards for vehicle motion disturbances are evaluated relatively without including the vehicle disturbance to the traffic flow scenario. Therefore, the safety standards for vehicle disturbances only need to set the most strict condition under the premise that the Road Traffic Act is strictly adhered. Drivers are responsible for the maintenance of their vehicles, the road administrator is appointed as per the Road Traffic Act, and roads are managed and operated according to the Road Structure Ordinance and guidelines for road maintenance and repair, and perception standards 'do not departing from the road surface.' As an example, the disturbance factors and conditions for motorways in Japan (refer to 4.3.3.8 for general roads) are listed below:

- Road surface state: Friction coefficient is 0.3 (lock μ) or more, external force on the tires is at the set point of the road maintenance and repair or less (e.g.: rut: 25 mm, level difference: 30 mm, pothole: 20 cm)

- Road geometry: Curve within the regulation of the road structure ordinance, i.e., R = 460 m, vehicle velocity is 100 km/h

- Natural phenomena: Wind speed of lateral wind without speed control is <10 m/s, i.e., vehicle velocity is 100 km/h

As the most difficult condition here is when the abovementioned disturbances all simultaneously occur, these three factors are added up for evaluation (Figure 36).

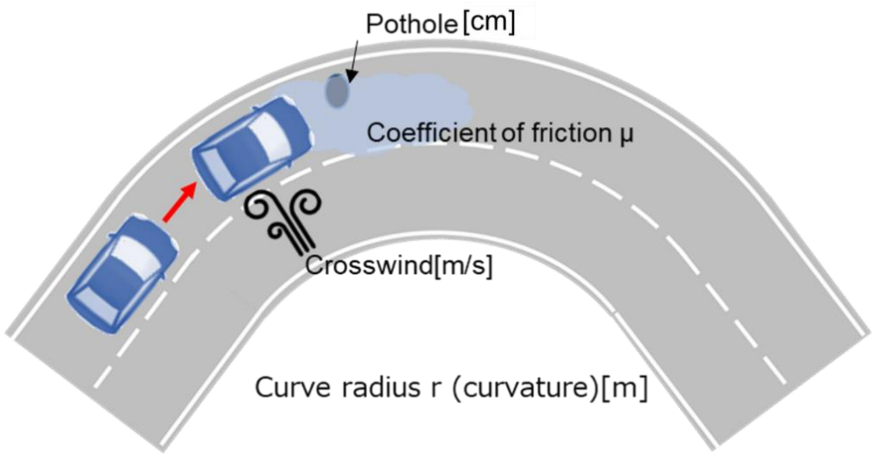


Figure 36. Vehicle motion disturbance evaluation conditions

The perception condition under this situation is to avoid departure from the lane. Here, the cases where the vehicle cannot drive under these conditions (e.g., when lateral wind is 5 m/s or more, i.e., driving is not possible) must be defined in advance as ODD by the manufacturer.

Furthermore, as a functional requirement, the slow puncture that occurs while driving should be managed before the vehicle becomes uncontrollable (before the rim touches the surface of the road).

The summary of the flow of safety perception discussed to date is listed below.

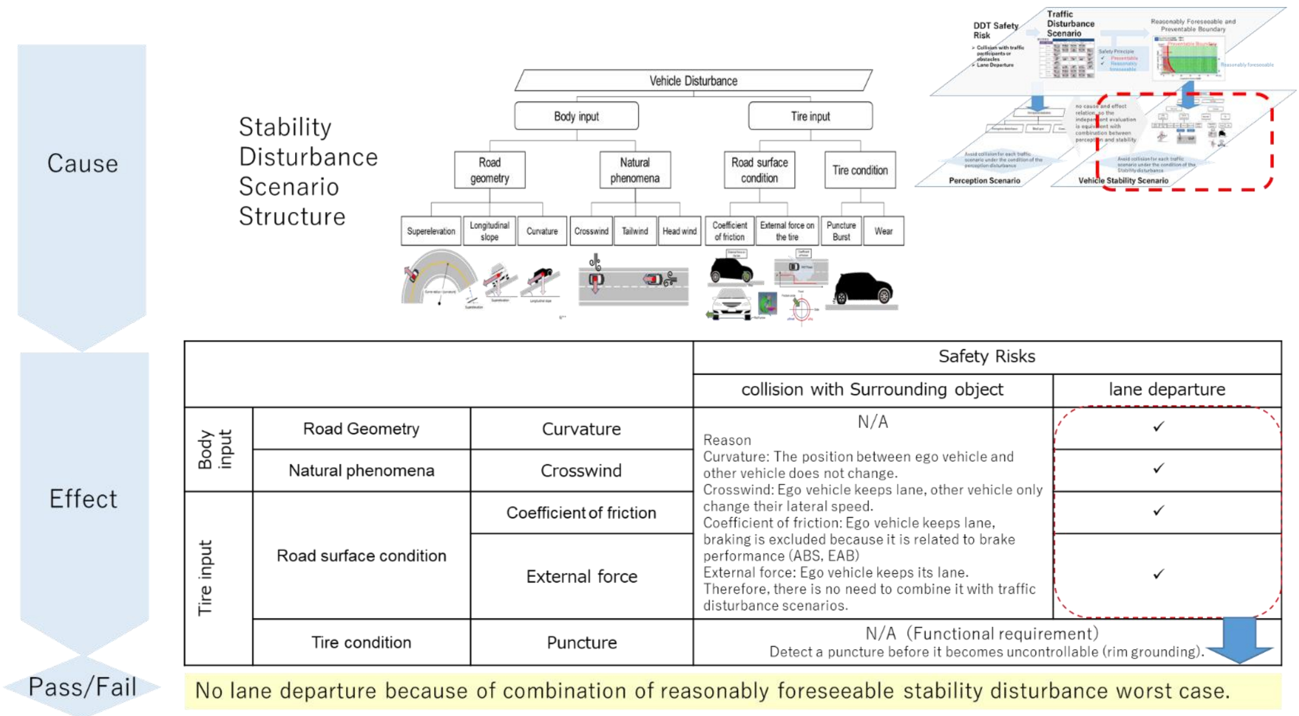


Figure 37 Safety perception flow of vehicle motion disturbance

3. Scenario-Based Safety Assurance Process

Figure 38 shows the schematics for the overall safety argumentation system in development and production cycle based on the V-shaped model, which is the project management commonly appointed to the development of advanced driving assistance systems (ADAS) and AD systems. By integrating verification to the sensor setup assessment and software agility basement processes from the planning phase in the first half of development, rather than conducting it only during the latter half of development represented by the right side of the V-shape, it can contribute to the optimisation of the development.

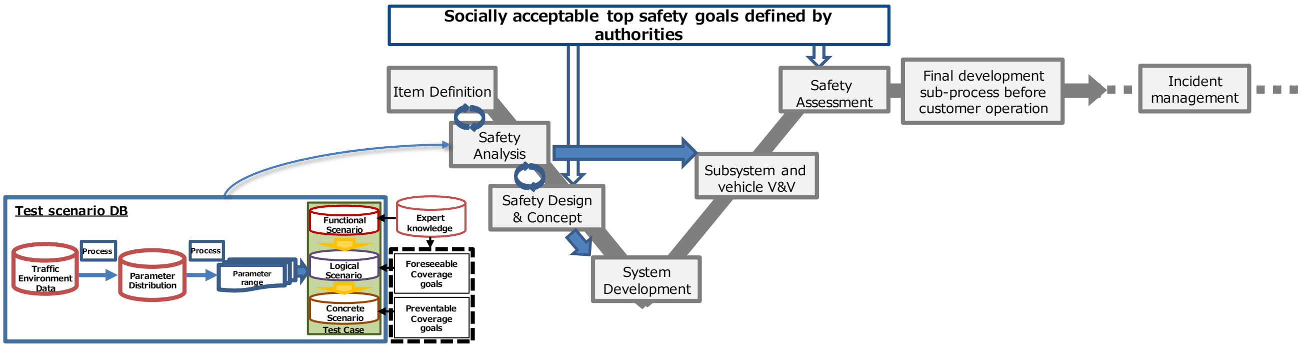


Figure 38. Overall scheme of safety assurance process

3.1. Safety argumentation scheme (Steps of the V-shaped model)

3.1.1. Item definition

The safety argumentation process is for making the vehicle compatible with the safety target within the operation scope of the automatic driving vehicle that was determined in advance. The operation scope of automatic driving vehicles is defined at the initial stage as the operation design scope (ODD). The contents of the ODD must include, at a minimum, information such as the road type, position on the road, vehicle velocity scope and environmental condition. Moreover, a fallback strategy for transition to outside the ODD boundary must be designed; moreover, the AD system must detect whether it is operating within the defined ODD. The definition of OD must be structured in such a manner as to enable notification to the users, as well as allow them to understand, trust and operate the AD system (Khastgir, Birrell, Dhadyalla, & Jennings, 2018).

Note that by mapping the ODD system and the scenario system as shown in Figure 39, it becomes possible to select the evaluation scenario following the ODD range.

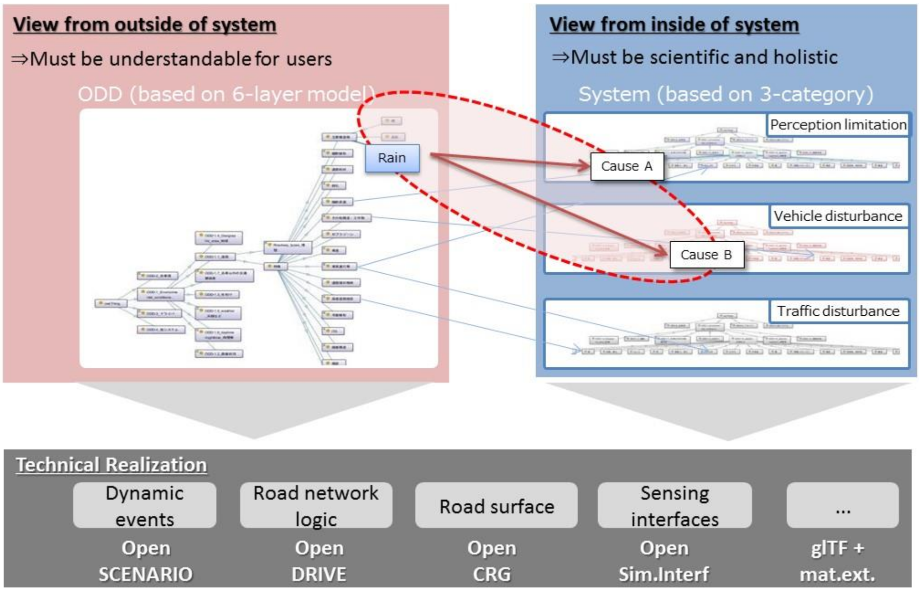


Figure 39. ODD scenario classification and relationship diagram of the system level classification based on the three category scenario level

3.1.2. Safety Analysis

It is important to determine as many foreseeable scenarios as possible, as well as systematise detailed scenario-related information on the operation design scope (ODD), vehicle and its surrounding, technically comprehensive definition of ODD based on the system physics, in addition to the overall definition of ODD that employs the systematic combination approach. For instance, the word 'rain' is enough for communicating with the user if rainfall conditions are included in the ODD; however, the AD system itself cannot interpret such a concept in the same manner. This scenario is able to consider the influence of rain from the perspective of system physics instead such as the possibility of the influence of raindrops on the sensor performance or the influence of rain on the vehicle dynamics (e.g., decrease in friction coefficient between the tire and the wet road surface). To describe ODD in a technical and system-oriented way, it is classified into three categories related to the system physics in order. These categories cover the respective perception, traffic flow and vehicle disturbances that can potentially occur within the AD system safety analysis (Figure 2).

3.1.3. Safety Design and Safety Concept

The system requirements should be produced based on the safety analysis steps. The safety target defined by our association is integrated into the development cycle during this process, as well as confirmed during the system design. As layers of different complexity are added to the safety design, the safety analysis cycle can be unified as per necessity between this process and the preceding process as long as their outputs follow the safety analysis steps. It is important to ensure compatibility between the ODD and the system requirements to avoid unnecessary specification changes in the system development process. This indicates the importance of the role of the safety analysis step.

3.1.4. System development

When the system design is complete and its safety is analysed, the actual system that includes the component elements of both software and hardware is developed.

3.1.5. Examination and validation of the sub-system and the vehicle

At this point, the strategy for safety examination and validation of the system and the vehicle is defined without interaction with the driver. The examination and validation are conducted by combing concentrated virtual evaluations and a relatively limited amount of physical tests in real traffic environments and at test courses.

The mathematical and physical accuracy of the system, development functions, and employed safety measures are verified in the sub-process of the examination. Moreover, verification is performed in regard to whether all the safety specifications and requirements drawn up during the safety analysis process (sufficiency of sensors, algorithm and actuator-related measures) have been satisfied.

For the validation sub-process, verification is performed in terms of whether the system and components, including the employed safety measures, pose an irrational risk to the traffic participants. Moreover, the safety of the AD system is substantiated by confirming that the defined validation targets were met.

3.1.6. Safety assessment

The test for determining whether the end product is acceptable is conducted during this step, which includes the related inspections, document checks and certifications.

3.1.7. Final check process before release

In the final check before release, verification is performed in terms of whether the safety of the AD system can be explained, in addition to whether the remaining risk is within the permissible range. This can be conducted by, e.g., using technologies such as the behaviour safety assessment (BSA), which focuses on the evaluation of the AD system at each test case by applying different measurement standards and confirms the compatibility of AD with predefined behaviour standards. Finally, a determination is made in terms of whether the system can be released during the review of the result, and then the post-release incident management strategy is designed.

3.1.8. Incident management

During the incident management process, the performance data is fed back into the safety argumentation process. This enables the improvement of the AD technology and reduces the number of ‘unforeseeable’ situations as time passes. It is expected that, because of this reduction, the threshold between two left quadrants shifts, as well as the boundary between them will be lesser in the way that is beneficial to the foreseeable scenarios (Figure 40). Following the same logic, it is expected that the boundary between the preventable scenarios and unpreventable scenario shifts rightward, and the quadrant on the upper left will expand. It is highly possible that this will occur as more scenarios become preventable.

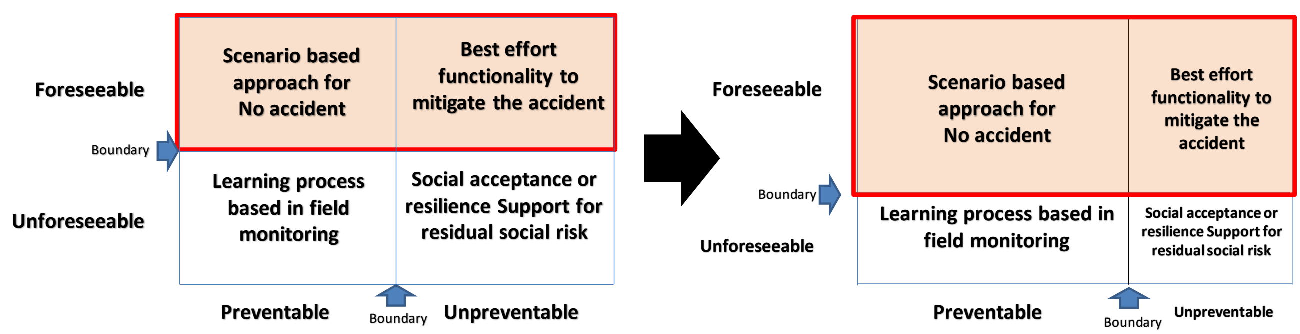


Figure 40. Expansion of foreseeable and preventable scopes following the evolution of the AD system

4. Scenario structure

Every approach is constructed by applying the systematic combination approach for defining the combinations derived from all possible factors. This approach requires significant specialized effort for defining all the factors and their interdependency as was the case by examining the safety coverage target. Therefore, it requires a systematic standardization methodology for structuring every factor related to the information. As mentioned earlier, the structures of the scenarios are the possible disturbances that can occur in three different categories related to the physics of the system, namely, the perception disturbance, traffic disturbance and vehicle motion disturbance.

4.1. Traffic disturbance scenario

Traffic disturbance scenarios are classified as general vehicle scenarios (including automobile and motorcycles), motorcycle-specific scenarios, and vulnerable road user scenarios (Figure 41). These three scenario classifications are further generated by systematically analyzing and classifying the combinations of different factors, namely the road geometry, ego-vehicle behavior, and the locations and motions of the surrounding traffic participants (Figure 42).

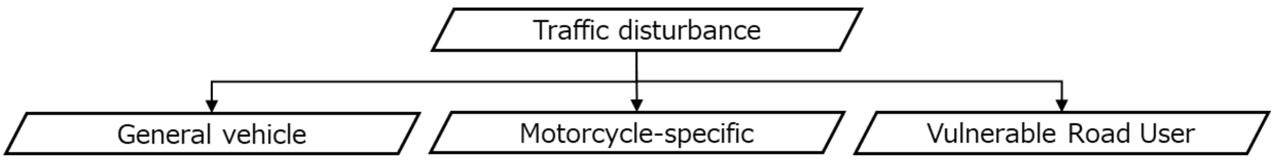


Figure 41. Traffic disturbance scenario classification

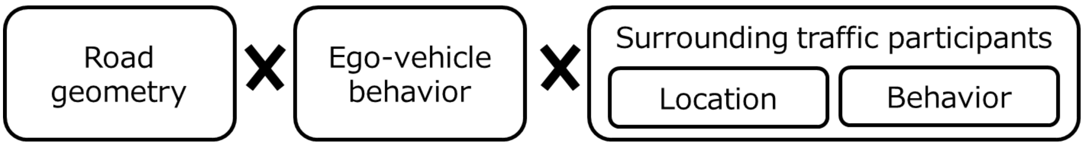


Figure 42. Structure of a traffic disturbance scenario

NOTE：The vulnerable road user scenario will be included in the next version.

4.1.1. General vehicle scenario

For traffic disturbance scenarios involving general vehicles, we provide specific explanations for the road geometry, ego-vehicle behavior, and the locations and motions of the surrounding traffic participants.

4.1.1.1. Road geometry category

The standard road is a non-intersection road (a). Merge zones (b) are formed when another road merges into a single road. When a single road splits, a branch zone (c) is formed. Furthermore, when one straight road intersects another straight road, an intersection (d) is formed (Figure 43). These roads are combined to form various types of roads. Motorways are classified into three categories: main roads (non-intersection), merge zones, and branch zones, with intersections being excluded. The road scenario classification for scenario generation must be also discussed to make it applicable to highways internationally (Association, 2004) (Transportation, 2008; UK, 2006).

NOTE : Another type of road shape is a roundabout. For this, we must either consider a combination of merging and branching roads or prepare a separate scenario. In addition, we intend to include another Annex that considers parking lots and trams, among other scenarios.

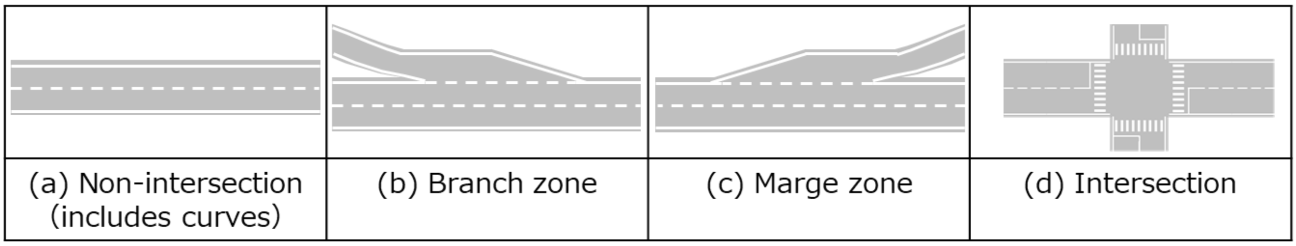


Figure 43. Road geometry classifications

4.1.1.2. Vehicle behavior category

Vehicles move in a straight line along the lanes of road geometry (a) (also known as lane keeping). In addition, vehicles move between lanes from an adjacent and merging lane (b) (lane change). Here, while a lane change from an adjacent lane and a merging lane have different road geometry categories, as vehicle behaviors, both are considered to be lane changes. At intersections, the vehicle turns without changing lanes (right or left turn). Therefore, the possible vehicle behaviors are classified into three categories: going straight, lane change, and turning. This vehicle behavior category is expressed using a combination of the road geometry information discussed above (Figure 44).

NOTE : In addition to right and left turns, there is also the U-turn as a turning behavior, but the ADS will not perform a typical U-turn; however, if a road is designed for U-turns, it is treated as a merge zone.

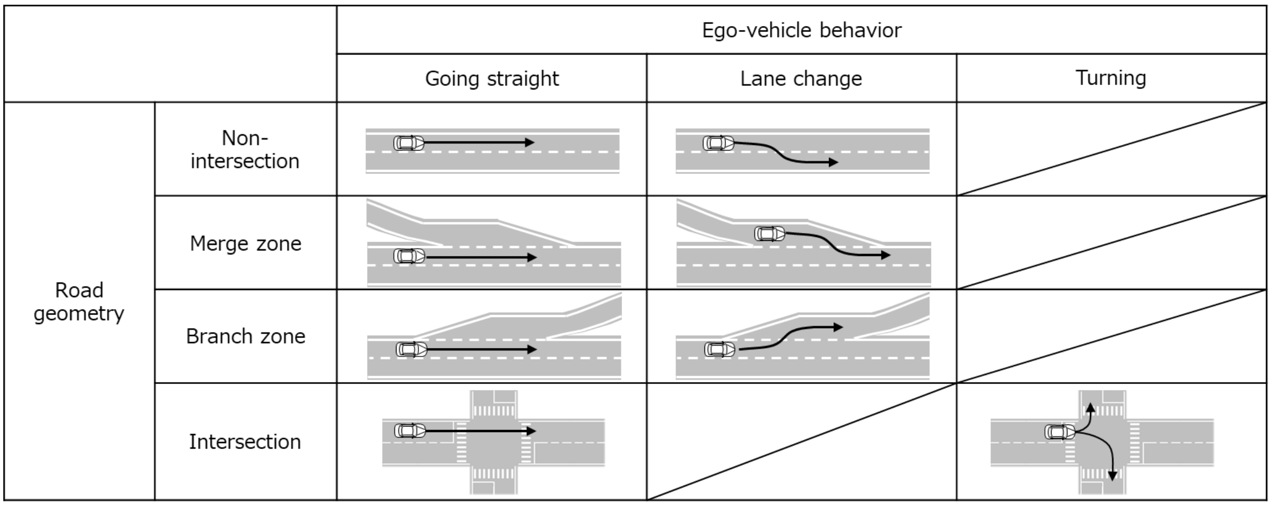


Figure 44. Parameters of road geometry and vehicle behavior

4.1.1.3. Categories of positions and motions of surrounding vehicles

Moreover, when there is a significant difference between the speeds of the leading vehicle and the vehicle in front of it, the leading vehicle might perform cut-out to avoid a collision. When a cut-out suddenly occurs, the ego vehicle might be required to take action to avoid a collision. To consider this scenario, the position of the vehicle in front of the leading vehicle is indicated as “+1” (Figure 45).

The neighboring positions in six directions around the ego vehicle that have a possibility of entering the driving trajectory of the ego vehicle, the left and right when entering from an intersection, and three oncoming directions, for a total of eleven directions, define the surrounding vehicles positions that must be considered in a scenario structure. Moreover, if the speed difference between the leading vehicle and the vehicle in front of it is significant, the leading vehicle may perform a lane change (cut-out*1: Figure 46) to avoid a collision. If there is a sudden lane change, the ego vehicle may need to take action to avoid a collision. To account for such a scenario, the position of the vehicle in front of the leading vehicle is considered and indicated as "+1" (Figure 45). An oncoming vehicle may also enter the lane of the ego vehicle by performing a lane change (✓ mark under cut-in*2: Figure 46).

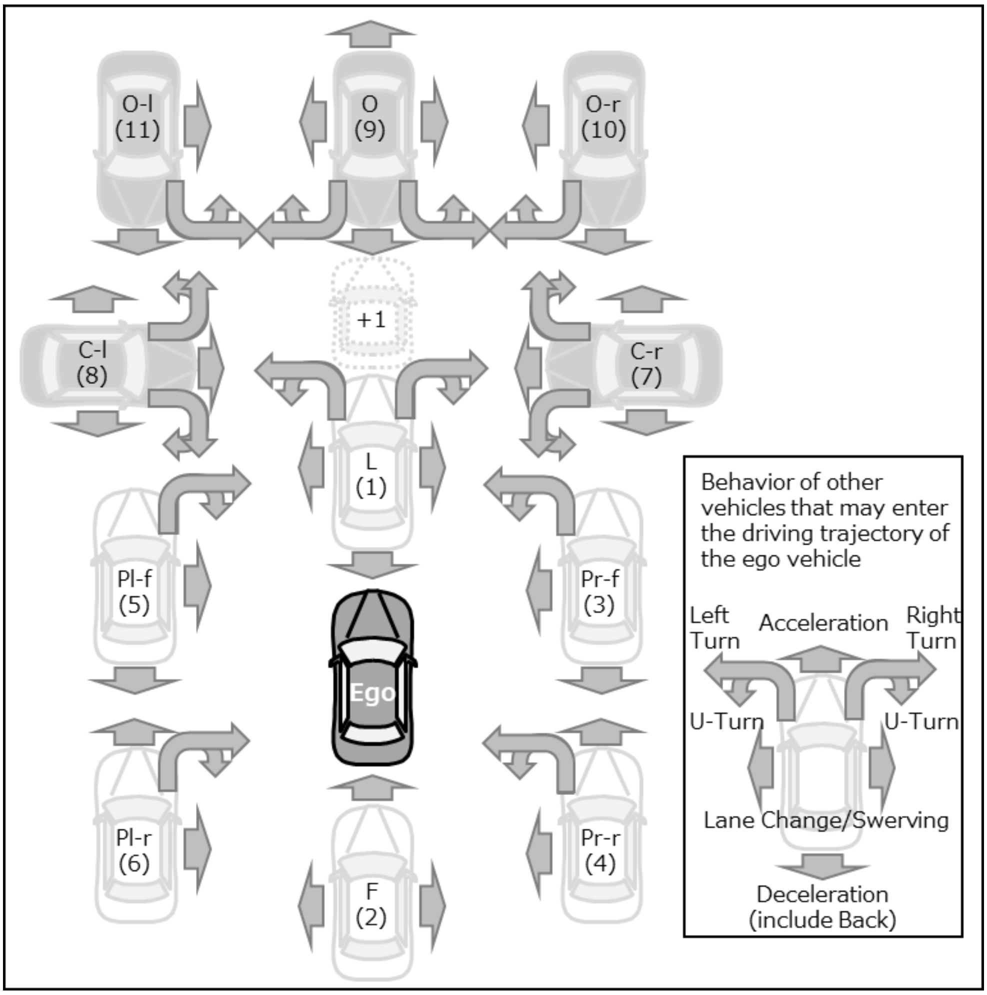


Figure 45. Positions of surrounding vehicles

	Surrounding traffic participants behavior							
	Going straight		Lane change / swerving			Turning		
Surrounding traffic participants location / Vehicle location	Acceleration	Deceleration	Cut-in	Cut-out	swerving	Right turn	Left turn	U-turn
1. Lead (L)		✓		✓*1	✓	✓	✓	✓
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)	✓	✓	✓*2		✓	✓	✓	✓
10. Opposite (O-r)	✓		✓*2		✓	✓		✓
11. Opposite (O-l)	✓		✓*2		✓		✓	✓

✓: have impact, blank: no impact

Figure 46. The combination of the surrounding vehicle positions and the motions that can potentially obstruct the ego vehicle

NOTE: In Ver 2.0, we placed other vehicles next to the ego vehicle; however, it has been eliminated. The reason for this is that the positions next to the ego vehicles would be covered depending on the initial positions of the vehicles in the front and rear (e.g., positions 3 and 4),.

The behaviors of the surrounding vehicles are classified into three categories: going straight (acceleration/deceleration), lane change (cut-in/cut-out) and swerving (e.g., behavior to avoid a stopped vehicle), and turning (right and left turn, U-turn). From a safety evaluation perspective, it is possible to minimize the number of evaluations by focusing on the behaviors of other traffic participants that have the potential to obstruct the behavior of the ego vehicle (Figure 46). For instance, the turning of the vehicle in position 2 does not interfere with the ego vehicle; thus, it can be excluded from the safety analysis. The check mark in the figure indicates cases where the corresponding combinations of the surrounding vehicle positions and motions can potentially impact the driving of the ego vehicle, which must be considered in the safety analysis.

4.1.1.4. Resulting traffic disturbance scenarios

As a result of the systematization process discussed thus far, a methodology for structuring scenarios as a combination of the road geometry, the behavior of the ego vehicle, and the position and motion of the surrounding vehicles is proposed herein. This structure consists of a matrix that contains 58 possible combinations in total (Figure 47). When limited to motorways as an example, there are three categories for the road geometry: “straight roads,” “merging zones,” and “branching zones;” two categories for the ego-vehicle behavior: “going straight” and “lane change;” and two categories each (total four) for the positions and motions of the surrounding vehicles: “going straight (acceleration/deceleration)” and “lane change (cut-in/cut-out).” The motorway scenarios consist of a matrix with 24 possible combinations that could occur in a real traffic flow (Figure 48). Based on the similar accident categories, the sufficiency of these 58 cases, which cover all the dangerous cases that can lead to an accident, can be evaluated (Annex D). This matrix deals with comprehensive coverage of traffic disturbances resulting from interactions between two vehicles.

The scenarios described here as traffic disturbance scenarios (Figures 47 and 48) are representative and must be able to consider a combination of the surrounding vehicle positions and behaviors that could obstruct the ego vehicle (Figure 46). For example, Figure 49 presents the results of a scenario developed for Figure 48 (Nos. 5, 6, 7, and 8) where the road geometry consists of a single road, the ego vehicle behavior involves a lane change, and the motion of surrounding vehicles involves going straight and performing a lane change. To elaborate on No. 5, when the ego vehicle makes a lane change, cases where the surrounding vehicle is in front, situations in which the surrounding vehicle is in the front, the rear, or the side (i.e., the vehicle in the front or rear is beside the ego vehicle) must be considered. The routes that could lead to obstructions will differ when the number of lanes is different, even if the positions of the nearby vehicles remain the same. As a result, it is important to consider the positions of the surrounding vehicles and the number of lanes, as well as identify combinations of behaviors that could obstruct the ego vehicle.

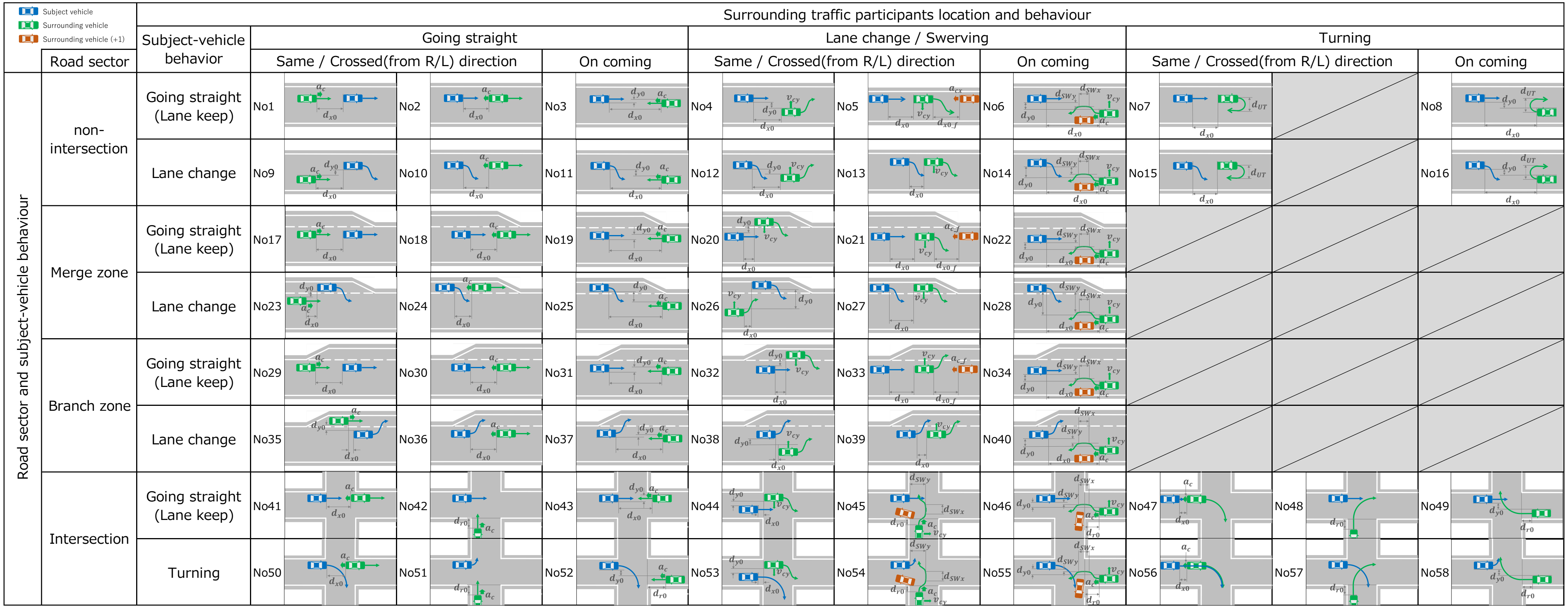


Figure 47. Traffic disturbance scenarios for general vehicles

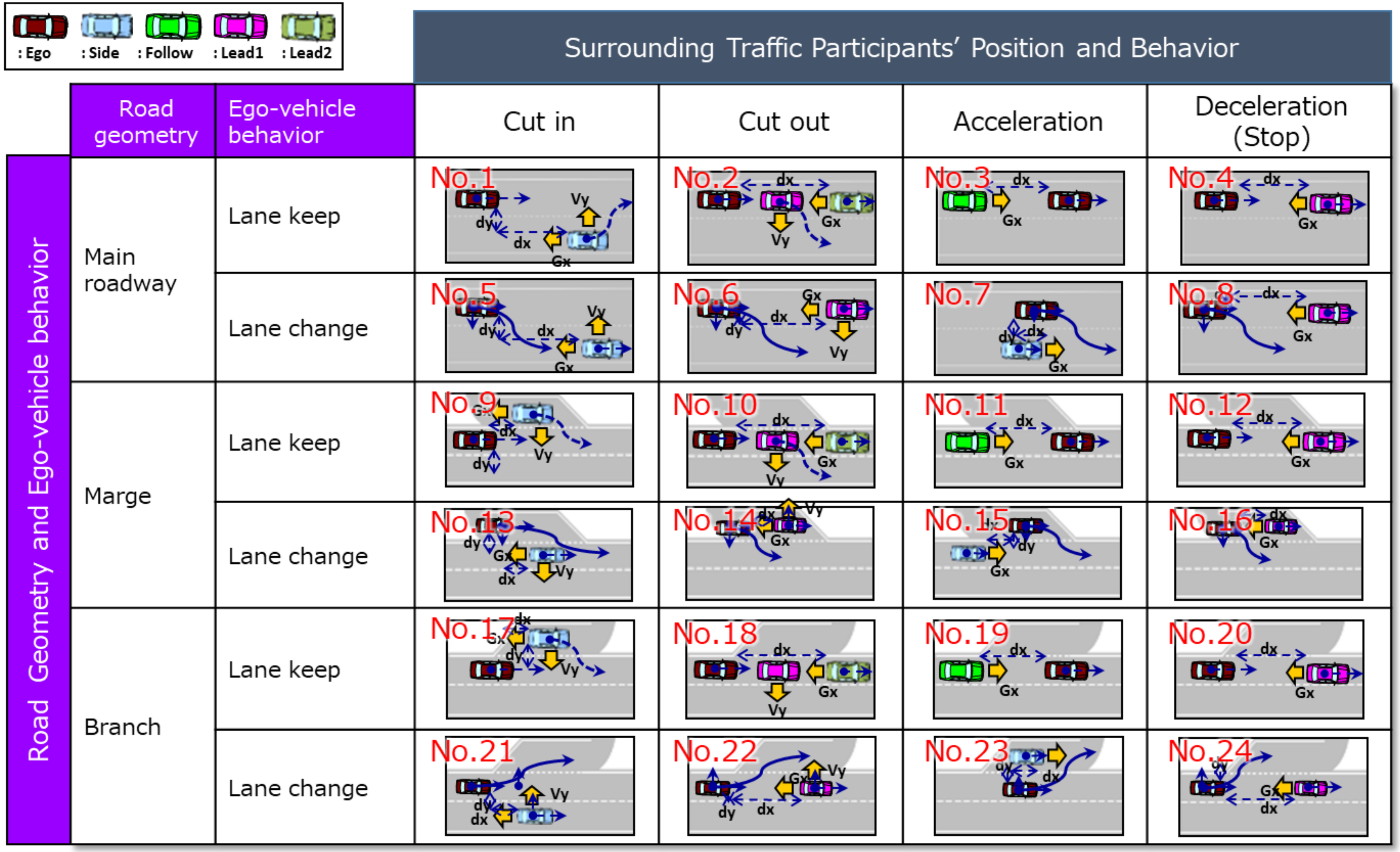


Figure 48. Traffic disturbance scenarios for general vehicles on motorways

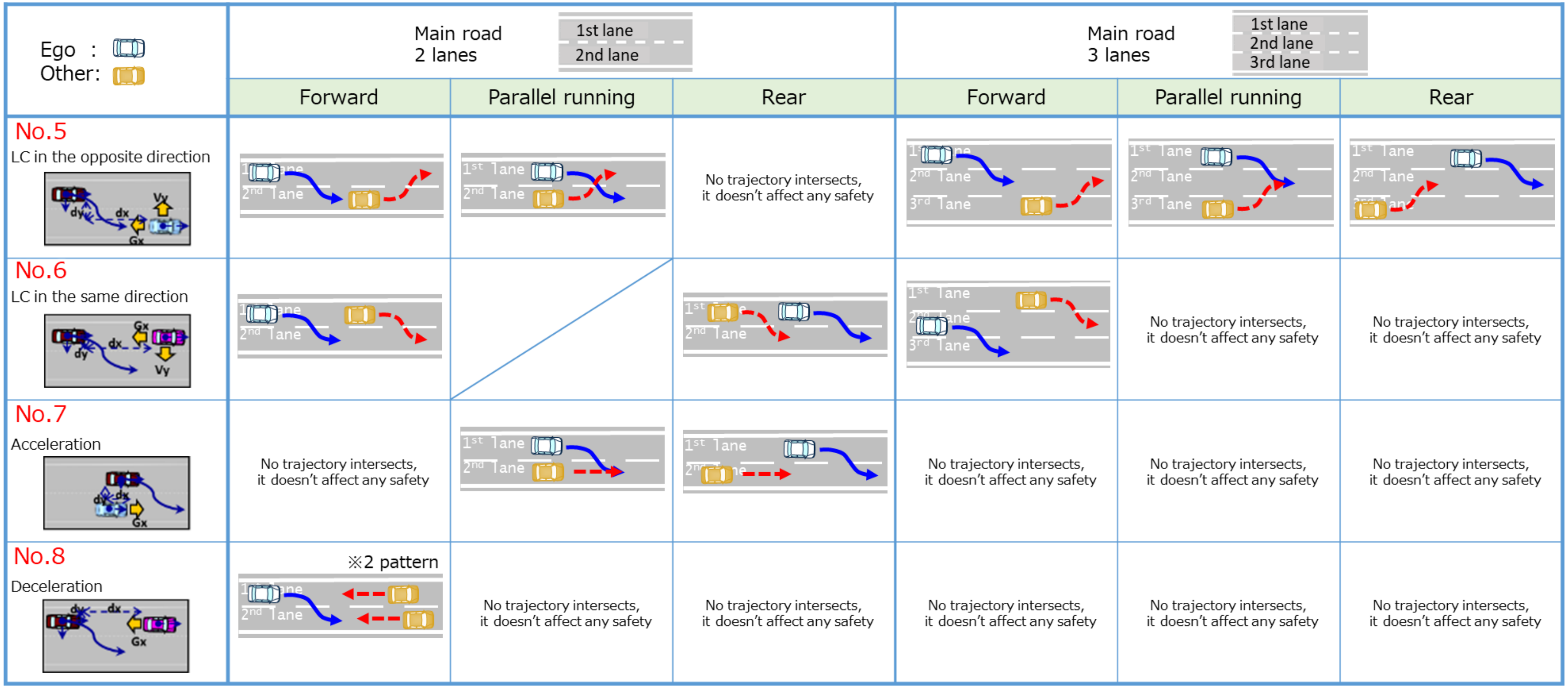


Figure 49. Scenarios with various combinations of positions of the surrounding vehicles and behaviors that could obstruct the ego vehicle

4.1.2. Scenarios unique to motorcycles

In general, the categories of aforementioned positions and motions of surrounding vehicles (Figure 44) are applied to both four-wheeled vehicles and motorcycles. However, there are situations where motorcycles may drive in the narrow space in the same lane as the ego vehicle, which requires additional safety evaluation scenarios. Because these scenarios only have the potential to occur in countries where such driving is legally allowed, an approach including detailed examples is shown in Annex B.

4.1.3. Scenarios resulting from the combination of behaviours by several vehicles

The proposed traffic disturbance scenario structure covers the relationship between the ego vehicle and one or two surrounding vehicles. However, in real traffic, multiple traffic participants take diverse actions at various moments. The current methodology covers these complex cases by extracting scenarios where the sudden motions by surrounding vehicles trigger the sequence of avoidance motions. By dividing these scenario types into a sequence of behaviours, multiple combinations of the positions and motions of the ego vehicle and the surrounding vehicles can be covered by safety analysis. Moreover, this can be realized by considering the influence of the road environment on the cut-in scenario by other vehicles that can potentially appear in this sequence. For instance, when the leading vehicle performs sudden deceleration (the first behaviour of the sequence), the avoidance motion by the ego vehicle occurs (the second behaviour) and the ego vehicle retreats into the surrounding avoidance area. The detail of the approach to the complex scenarios that include detailed examples is included in Annex C.

4.2. Perception disturbance scenarios

Perception disturbance scenarios include blind spot scenarios and connectivity disturbance scenarios, in addition to perception disturbances (Figure 50).

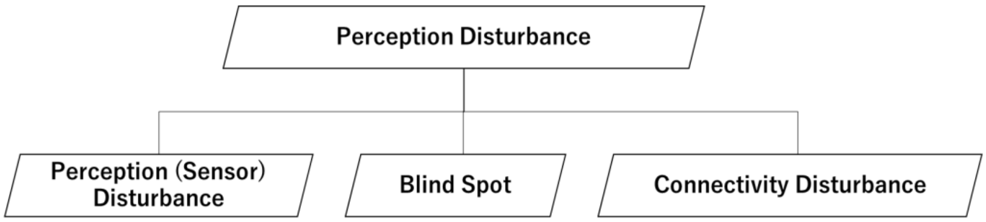


Figure 50. Categories of perception disturbance scenarios

4.2.1. Perception disturbance scenarios

Perception disturbance refers to a negative effect on perception performance during a situation in which the automatic driving system detects objects. The perception disturbance scenario is generated by disturbance-triggering factors and based on the principle of the sensors where disturbance occurs. While the factors of disturbances are diverse, it is possible to select the scenario group that contains the perception disturbance overall by classifying the factors based on the generation principle and then selecting a representative factor among those in the same category. Moreover, by considering the necessary combinations based on the generation principle of each disturbance factor, it is possible to create a perception disturbance combination evaluation scenario. In this study, the disturbance scenarios of three types of sensors, namely, millimetre wave radar, LiDAR and camera (Figure 51).

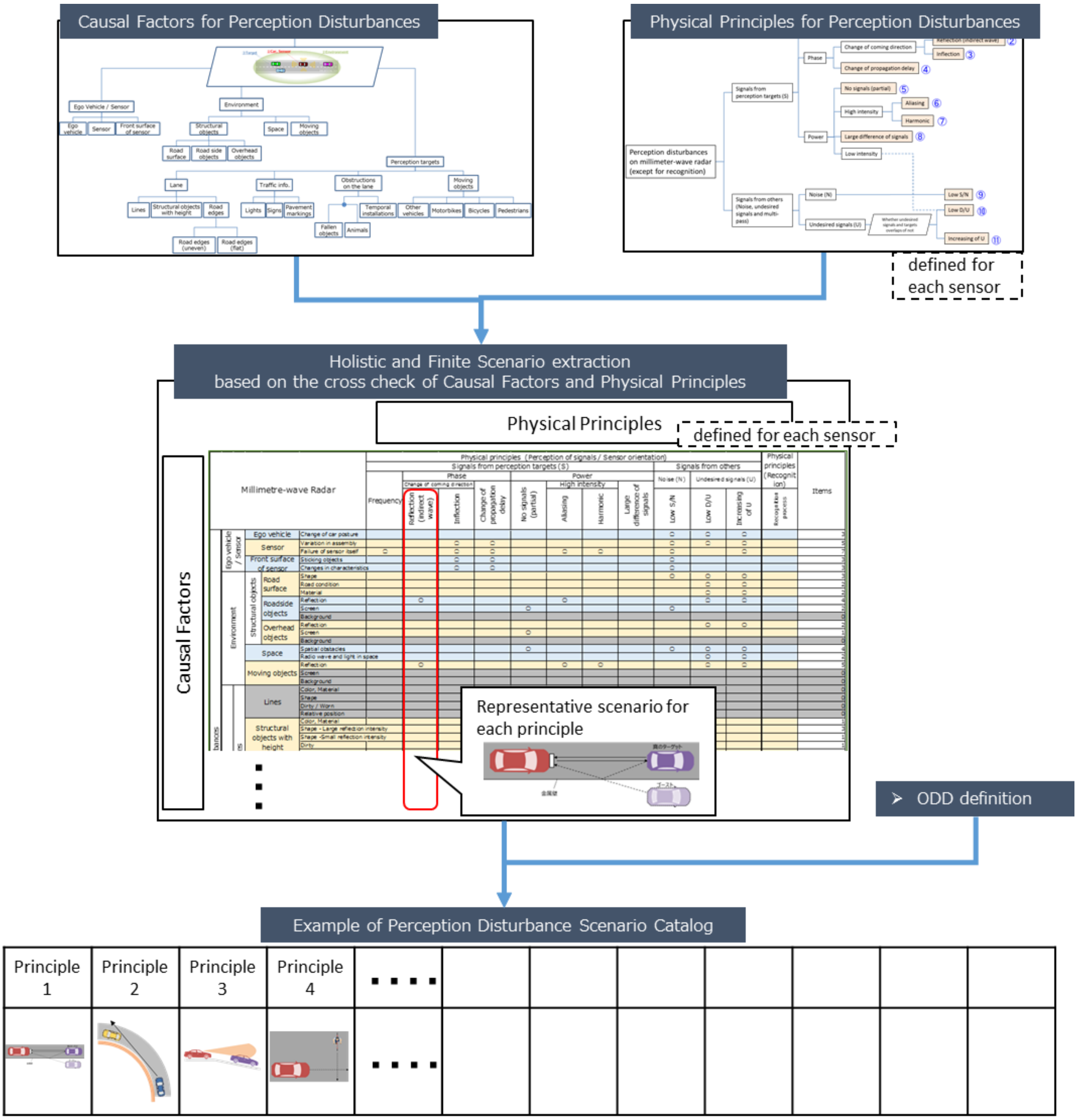


Figure 51. Scenario derivation process based on perception disturbance factors and sensor principle

4.2.1.1. Perception disturbance factors

The factors of perception disturbance can be broadly classified into "vehicle/sensor," "surrounding environment" and "perception target" in relation to the ego vehicle, which are then broken down and comprehensively classified at each layer to compose the perception disturbance factors system. Here, e.g., a factor is broken down from the perspectives of structure, relative position and types, and continues to be categorized to layers such as colour, shape, material and behaviour.

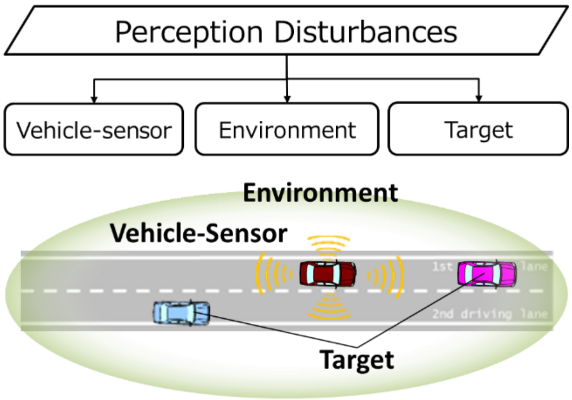


Figure 52. Broad categories of perception disturbance factors according to the positional relationship with the ego vehicle

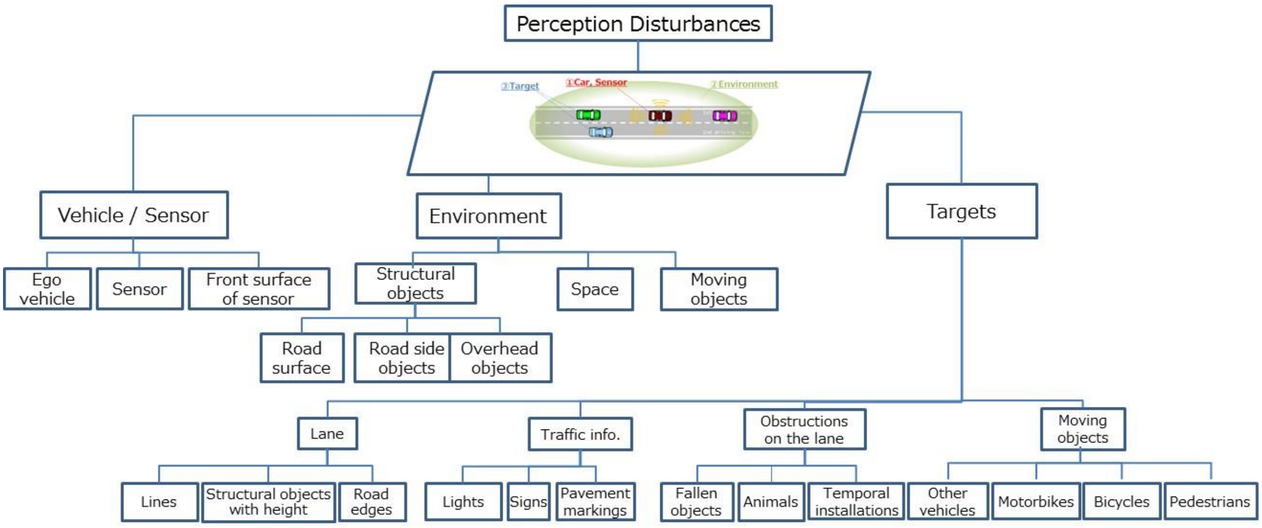


Figure 53. System diagram of perception disturbance factors

4.2.1.1.1. Perception Disturbance Factors: Vehicle/Sensor

The perception factors classified into “vehicle/sensor” are divided into three categories according to the positions of these factors, namely, “a. ego vehicle”, “b. sensor” and “c. in front of the sensor”.

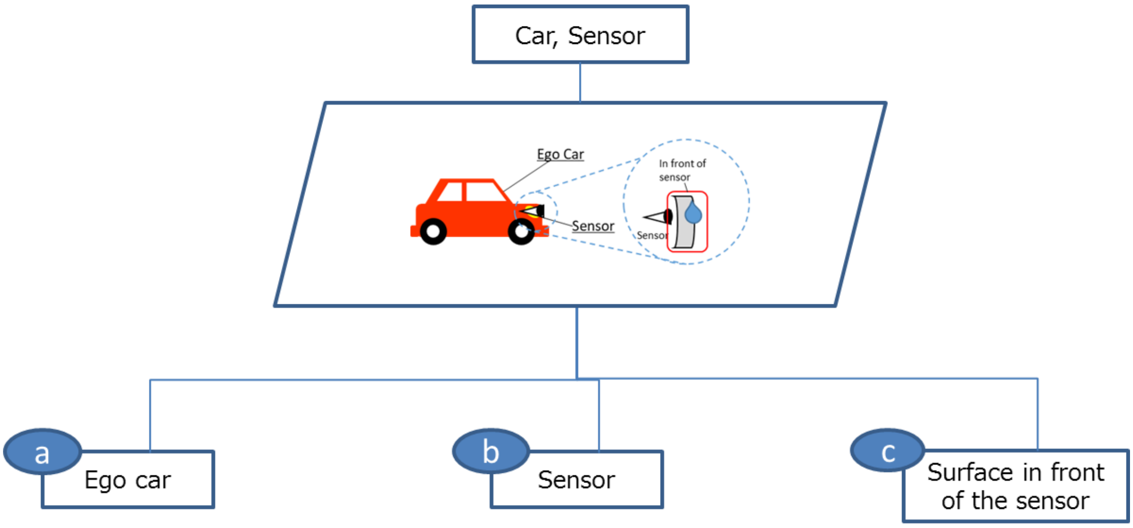
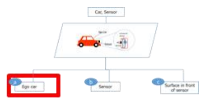


Figure 54. Vehicle/sensor categories

Tables 3–5 show the details of the perception disturbance factors categorized into a, b and c. These tables describe the detailed categorization, impact on the perception performance, and the generation principle of perception disturbance of the perception disturbance factors for each sensor.

Table 3. “a. Ego Vehicle” disturbance factors

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 4. “b. Sensor” disturbance factors

b Sensor

	Class.	Millimeter waves: Variation in assembly	Millimeter waves: Failure of sensor itself	LiDAR: Variation in assembly	LiDAR: Failure of sensor itself	Camera: Variation in assembly	Camera: Failure of sensor itself
Influence on sensor principle	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 5. “c. In front of sensor” disturbance factors

c Surface in front of the sensor

	Class.	Millimeter waves: Sticking objects	Millimeter waves: Changes in characteristics	LiDAR: Sticking objects	LiDAR: Changes in characteristics	Camera: Sticking objects	Camera: Changes in characteristics	Camera: Reflection on windshield
Influence on sensor principle	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

4.2.1.1.2. Perception disturbance factors: Surrounding environment

The perception factors classified into “surrounding environment” are divided into three categories according to the characters of the objects existing around the ego vehicle, namely, “d. surrounding structure”, “e. space” and “f. surrounding moving objects”. “d. Surrounding structure” is further divided into the following three categories: “d-1. road surface”, “d-2. structure by the road” and “d-3. structure above the road”.

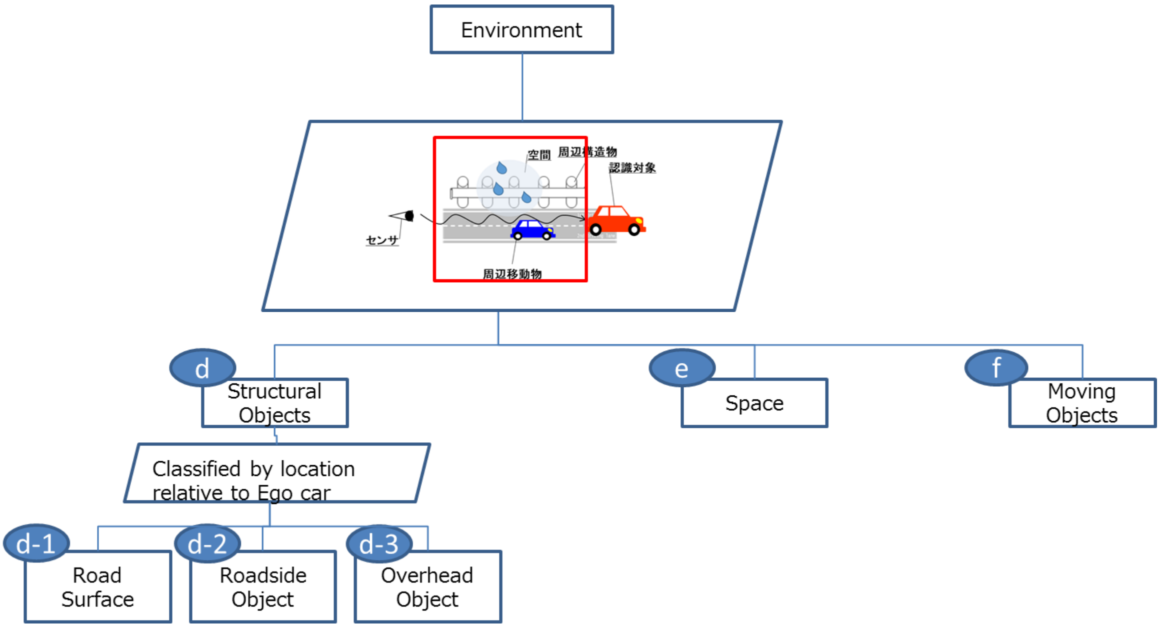


Figure 55. Surrounding environment categories

Tables 6–8 show detailed categorization, impact on the perception performance, and the generation principle of perception disturbance of the perception disturbance factors classified into d-1, d-2, d-3, e and f.

Table 6. “d-1. Road surface” disturbance factors

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 7. “d-2. Structures by the road” disturbance factors

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 8. “d-3. Structures above the road” disturbance factors

d-3 Overhead Object

	Class.	Millimeter waves			LiDAR			Camera		
		Reflection	Screen	Background	Reflection	Screen	Background	Reflection	Screen	Background
Influence on sensor principle	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)

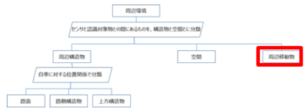
Table 9. “e. Space” disturbance factors

e Space

	Class.	Millimeter waves		LiDAR		Camera	
		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 10. “f. Surrounding moving objects” disturbance factors

f Moving Object



Influence on sensor principle		Millimeter waves			LiDAR			Camera		
	Class.	Reflection	Screen	Background	Reflection	Screen	Background	Reflection	Screen	Background
	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)

4.2.1.1.3. Perception Disturbance Factors: Perception Targets of Sensors

The perception disturbance factors categorized as “perception targets of sensors” are broadly classified into “g. route”, “h. traffic information”, “j. obstacles” and “k. moving object” (Figure 56).

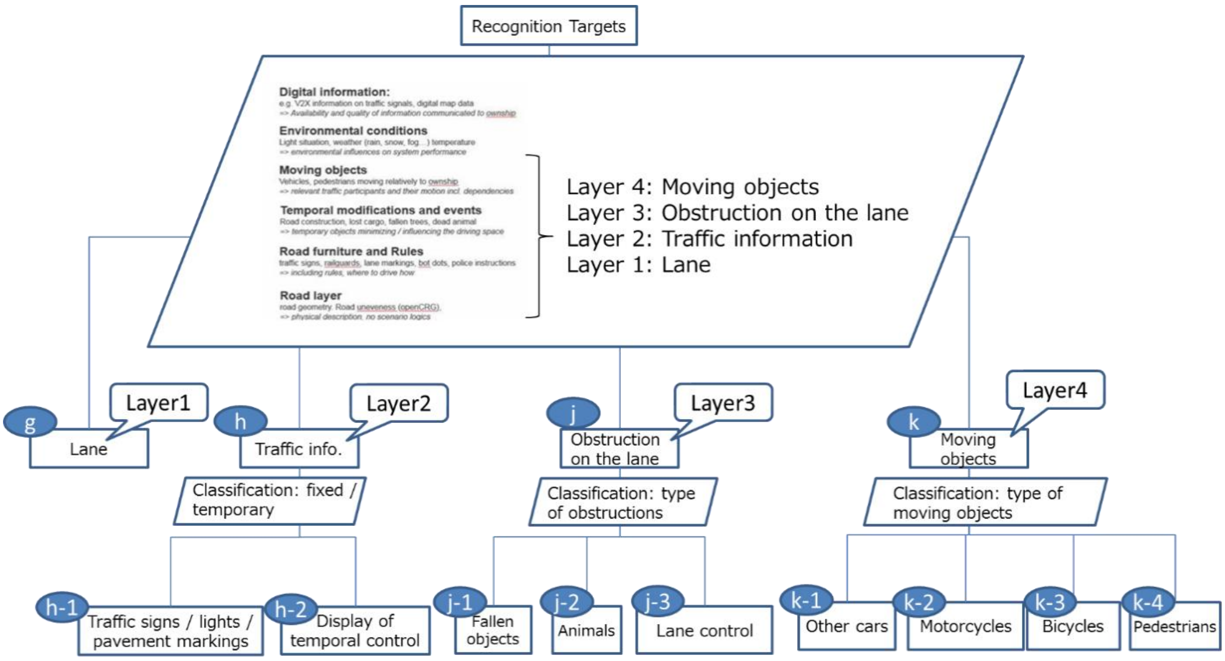


Figure 56. Categories of perception targets of sensor

“g. Route” is classified into “g-1. lane maker”, “g-2. structure with height” and road edge as per the object that indicates a given place is a driving route. Moreover, road edge is divided further into g-3 and g-4 depending on whether there is a level difference or not (Figure 57).

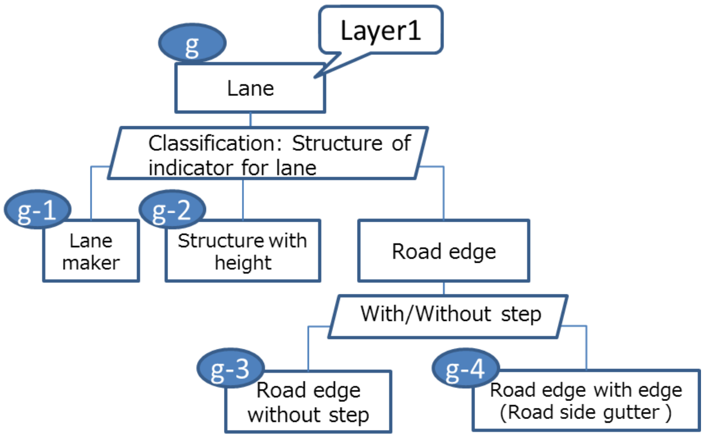


Figure 57. Categories of "g. route"

"h. Traffic information" is classified into "h-1. traffic light", "h-2. traffic sign" and "h-3. road marking" as per their display style (Figure 58).

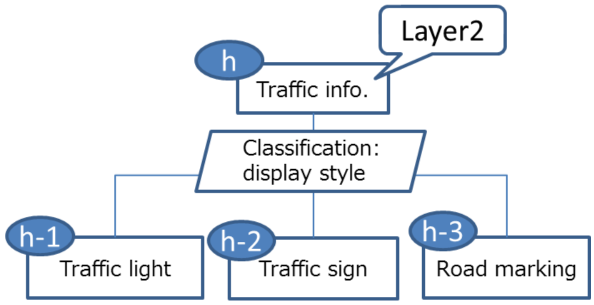


Figure 58. Categories of "h. traffic information"

"j. Obstacle" is classified into "j-1. falling object", "j-2. animal" and "j-3. installed object" according to whether it moves or not and the degree of impact when colliding with the vehicle (Figure 59).

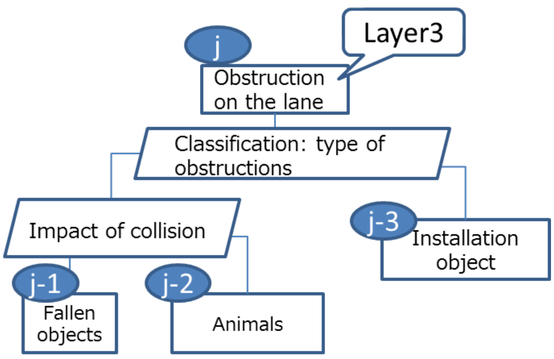


Figure 59. Categories of "j. obstacle"

“k. Moving objects” are classified into “k-1. other vehicles”, “k-2. motorcycle”, “k-3. bicycle” and “k-4. pedestrian” as per the type of traffic participant (Figure 60).

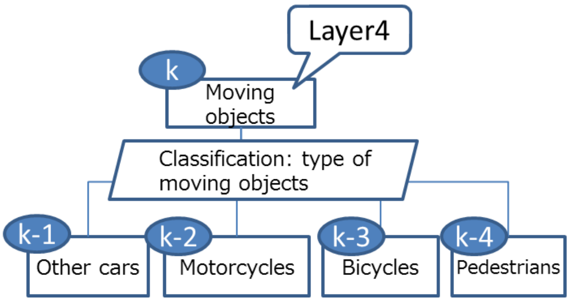
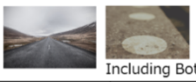


Figure 60. Categories of “k. moving objects”

Tables 11–14 show the detailed categorization, impact on the perception performance, and the generation principle of perception disturbance for the perception disturbance elements classified into g-1 to k-4, respectively.

Table 11. “g-1. Lane marker” disturbance elements

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 12. "g-2. Structure (with height)" disturbance elements

g-2 Structure with height

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

Influence on sensor principle	Millimeter waves				LiDAR				Camera			
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 13. "g-3. Road edge without level difference" disturbance elements

g-3 Road edges without a step

Break of a road, etc.

Influence on sensor principle	Millimeter waves				LiDAR				Camera			
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 14. "g-4. Road edge with a step" disturbance elements

g-4 Road edges with a step

Gutters, etc.

Influence on sensor principle	Millimeter waves				LiDAR				Camera			
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 15. “h-1. Traffic lights” disturbance elements

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 16. **“h-2. Traffic sign” disturbance elements**

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 17. “h-3. Road marking” disturbance elements

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 18. “j-1. Falling object” disturbance elements

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 19. “j-2. Animal” disturbance elements

j-2 Animals

Influence on sensor principle	Millimeter waves			LiDAR			Camera		
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 20. “j-3. Installation object” disturbance elements

j-3 Installation object

Influence on sensor principle	Millimeter waves				LiDAR				Camera			
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 21. “k-1. Other vehicles” disturbance elements

k-1 Other cars

Influence on sensor principle	Millimeter waves				LiDAR				Camera				
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 22. "k-2. Motorcycle" disturbance elements

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 23. "k-3. Bicycle" disturbance elements

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 24. "k-4. Pedestrian" disturbance elements

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

4.2.1.2. Generation principle of sensor perception disturbance

The sensor can potentially experience perception disturbance when detecting objects because of the factors discussed in the preceding section. While the principle of perception disturbance generation is different for each sensor, they can be categorized as per the following common perspectives.

・The sensor disturbance principles are classified into "those occurring due to perception processing", "those occurring due to cognitive processing" and "others".

・The disturbances occurring because of perception processing are classified into those related to the signal from the perception target (S) and those that hinder the signals from the perception target (noise N, unnecessary signal U).

・List the disturbances that can occur on signals individually related to S, N and U.

The examples of categories of generation principles of perception disturbances that could occur on each sensor based on these perspectives are as follows.

- Generation principle of perception disturbance of millimetre-wave radar.

  The perception disturbances that occur on millimetre-wave radar includes those caused by the direction of the sensor, those occurring because of perception processing and those occurring because of cognitive processing (Figure 61).

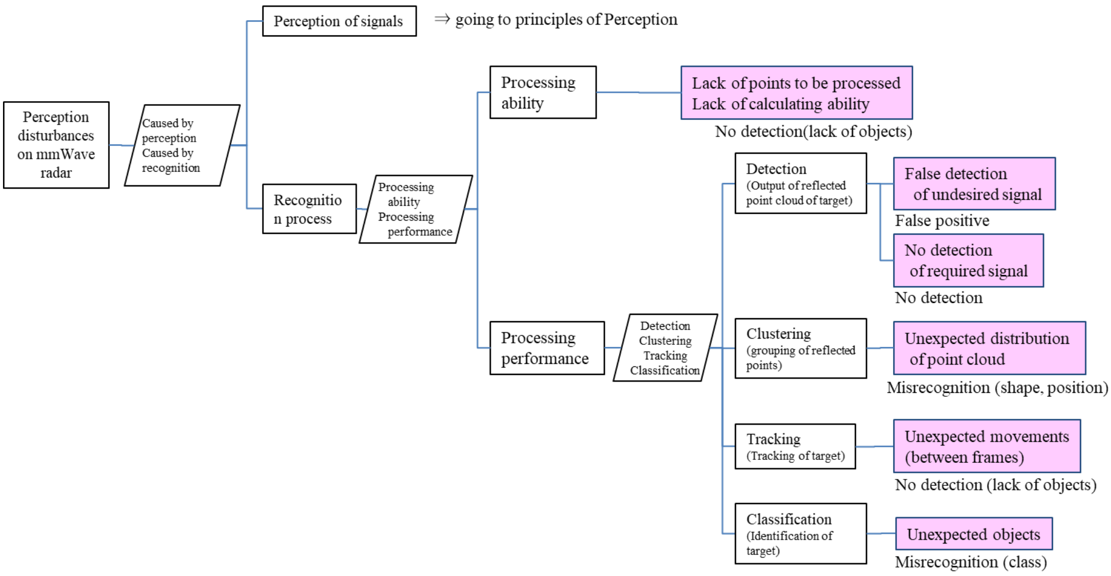


Figure 61. Categories of perception disturbances for millimetre-wave radar

In particular, the physical quantities that characterize the signal S in perception processing of millimetre-wave radar are the following three: frequency, phase and strength (Figure 62).

- Frequency: Problem with the signal frequency can be cited as a disturbance originating from the sensor itself.

- Phase: There are cases where the direction the signal is arriving from changes and cases where the amount of propagation delay changes, and the changes in signal arrival direction are attributed to reflection and refraction.

- Signal strength: The conceivable situations include partial signal loss, a signal that is too strong, a large difference in signal strengths, and the signal being too weak.

Furthermore, possible disturbances in regard to the noise N and the unnecessary signal S in perception processing include low S/N, low D/U (ratio of strength between the necessary signal D and unnecessary signal U) and increase of U.

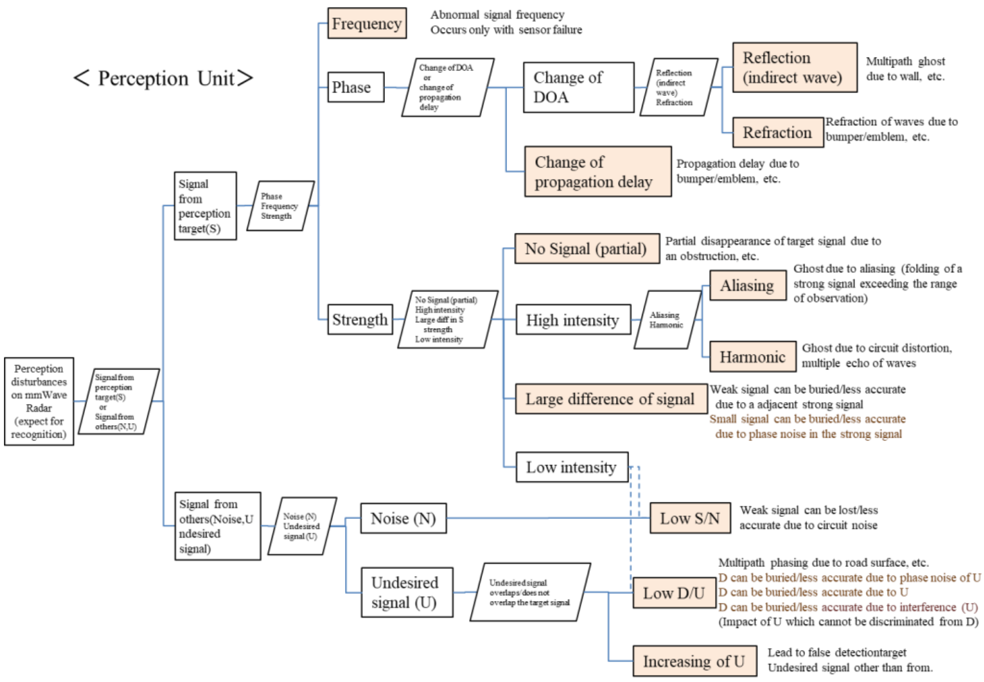


Figure 62. Generation principle of disturbance in millimetre-wave radar perception processing

- Generation principle of LiDAR perception disturbance
The physical quantities that characterize the signal S in perception processing of LiDAR are the scan timing, strength, propagation direction and velocity.

  - Scan timing: The time difference because of the movement of the ego vehicle leads to positional shifts in the overall space; moreover, the time difference caused by the movement of the perception target leads to its positional shift.

  - Strength: Phenomena include saturation, attenuation and shielding.

  - Propagation direction change: There are those caused by reflection and those caused by refraction.

  - Velocity: While it affects the arrival time of signals, there are no corresponding items in perception disturbance of LiDAR.

Furthermore, the noise N and unnecessary signal U include reflection and refraction from objects other than the perception target, in addition to DC noise, pulse-like noise and multiple reflections (Figure 63).

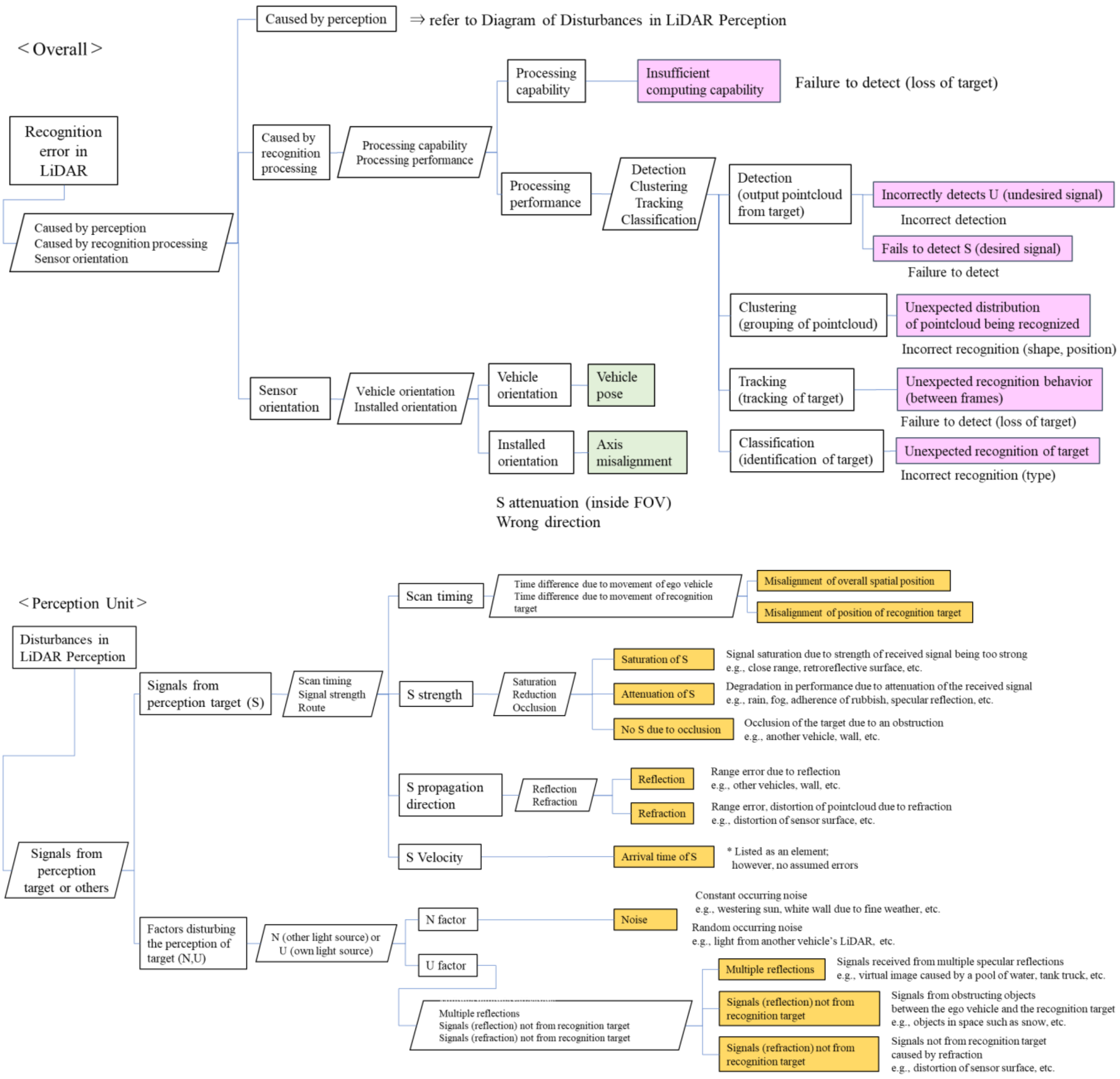


Figure 63. Generation principle of disturbance at perception of LiDAR

- Generation principle of perception disturbance at the camera
  The physical quantities that characterize the signal S in perception processing of the camera are the strength, direction/range signal change and acquisition time.

  - Strength: There are cases where the signal is too weak, the signal is too strong, the difference in signal strength is large and the signal is partially lost.
  - Direction/range: There are changes caused by refraction and changes caused by reflection.
  - Changes in the signal S.
  - Acquisition time: The possible cases of disturbances caused by blinking of the perception target and changes in relative positions include flickering and image blur/ deletion.

Furthermore, the noise N and unnecessary signal U include low D/U and low S/N (Figure 64).

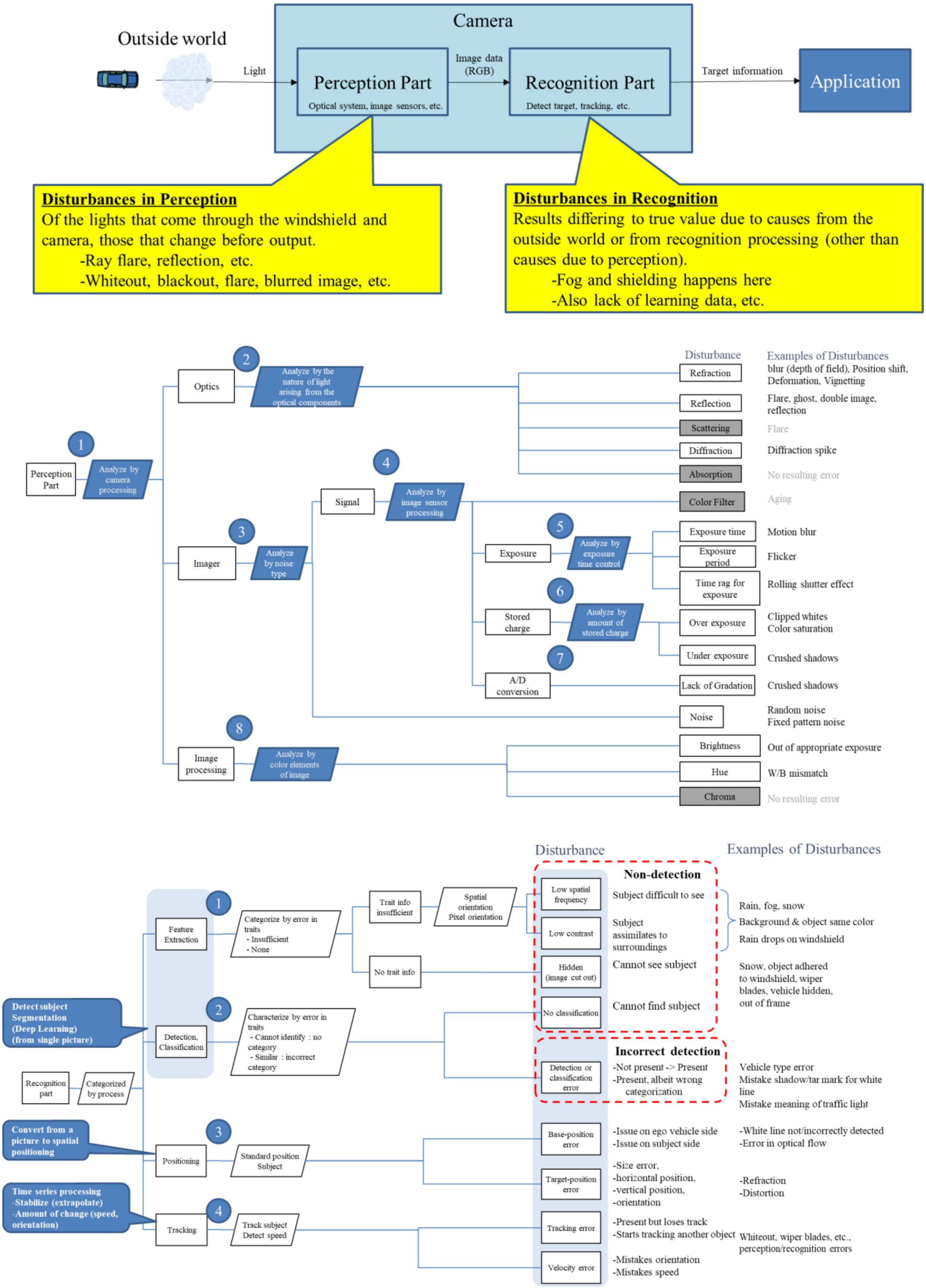


Figure 64. Generation principle of disturbance in camera perception

Scenario selection through cross-checking of perception disturbance elements and generation principle

The relationship between the elements of perception disturbance at each sensor and the generation principles can be represented in the matrixes shown in Tables 25–27. These matrixes list the perception disturbance elements vertically and generation principles horizontally, which makes it possible to understand the elements (= line) that can potentially cause the generation principle (= column). The several disturbance elements that can be reported in the same column are generated by the same principle. However, from the perspective of a system safety evaluation, it is possible to select the elements whose degree of influence on the perception performance of each sensor and encounter probability in the market are high, as well as prioritize them as evaluation scenarios.

When there are several elements that have the equal priority, one or several elements are selected while taking the reproducibility of the evaluation environment of that scenario into account and evaluating the same. Moreover, when there are disturbance elements that do not match the given sensor among the items represented in the vertical axis because of the specifications of the ADS under evaluation (such as ODD and perception target), exclude them and select the representative scenario among the remaining elements.

Table 25. Perception disturbance elements and generation principle matrix of millimetre-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												
Classification			Classification of Causal Factors		Items	Variable Parameters	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	
							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 coefficient(RCS), 3D shape, target combination, relative position	change of angle, change of vehicle posture, road gradient, misalignment,	transmittivity, range, failure of sensor itself	attenuation rate in space	retroreflection coefficient(RCS), 3D shape, target combination, relative position	change of angle, change of vehicle posture, road gradient, misalignment,	retroreflection coefficient, 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 coeffiecen	retroreflection coefficient, target position	retroreflection coeffiecen	type of sensors on other vehicle, position	type of sensors, mounting position, surrounding environment							
Vehicle motion			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 surface	(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 performance	(a level of fault detection failure)					△	△																			○	○	false positive, false negative	←	←	2
Mounted place / status				Variation in assembly	misalignment (within adjustment)	(failure of misalignment detection)		○	○					△				△						△							○	○	false positive, false negative	←·○	←	5
					misalignment (out of adjustment)	(untill detection of misalignment)		◎	◎					○				○						○							○	○	false positive, false negative	←·○	←	5
Front surface of the sensor	Car / 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 blizzard)										◎																	○	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 vehicle	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	linearly, after fixing of convex region													△						△						○	○	false positive, false negative	←·○	←·○	2
					rut	concave surface paranell 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
		Lane	Structure with height	color, material									○				○															○	false negative	←·○	←	2
				shape	large reflection	large signal intensity					○	○	◎																		○	○	false positive, false negative	←·○	←	3
				shape	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
	Recognition targets	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
				Shape, size	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
				Shape, size	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 26. Perception disturbance elements and generation principle matrix of LiDAR

Small impact △
Medium impact ○
Great impact ◎

						Perception Error / Signals from recognition target (S) / Scan Timing: Misalignment of overall spatial position	Perception Error / Signals from recognition target (S) / Scan Timing: Misalignment of position of recognition target	Perception Error / Signals from recognition target (S) / S strength: Saturation of S	Perception Error / Signals from recognition target (S) / S strength: Attenuation of S	Perception Error / Signals from recognition target (S) / S strength: No S due to occlusion	Perception Error / Signals from recognition target (S) / S propagation direction: Reflection	Perception Error / Signals from recognition target (S) / S propagation direction: Refraction	Perception Error / Signals from recognition target (S) / S Speed: Arrival time of S	Perception Error / Signals not from recognition target (N,U) / N factor: Noise	Perception Error / Signals not from recognition target (N,U) / U factor: Multiple reflections	Perception Error / Signals not from recognition target (N,U) / U factor: Signals not from recognition target (reflection)	Perception Error / Signals not from recognition target (N,U) / U factor: Signals not from recognition target (refraction)	Recognition Error / Processing capability: Insufficient number of processing points	Recognition Error / Processing capability: Insufficient computing capability	Recognition Error / Processing performance / Detection: Incorrectly detects U (undesired signal)	Recognition Error / Processing performance / Detection: Fails to detect S (desired signal)	Recognition Error / Processing performance / Clustering: Unexpected distribution of pointcloud being recognized	Recognition Error / Processing performance / Tracking: Unexpected recognition behavior (between frames)	Recognition Error / Processing performance / Classification: 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		○	○															○	←	←

Table 27. Perception disturbance elements and generation principle matrix of the camera (element: vehicle/sensor, surrounding environment)

Small effect △
Medium effect ○
Large effect ◎

Model class	Causal factor group			Causal factor item	Causal factor item (example)	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	0 0	3 3
				Sensing - direction - Single vibration	Bump over	- -	- -	0 0	0 0	1 5
				Sensing - direction - Periodic vibration	Using tire chains	- -	- -	0 0	0 0	1 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 1	- -	0 1	1 0	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 Out)	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 28. Perception disturbance elements and generation principle matrix of the camera (element: perception target – route/traffic information/obstacle)

Small effect △
Medium effect ○
Large effect ◎

Disturbance causal factor – Perception part (Optics: Refraction, Reflection, Scattering, Diffraction, Absorption; Imager: Noise, Color filter, Exposure time, Exposure period, Time lag for exposure, Over exposure, Under exposure, Lack of Gradation; Image processing: Brightness, Hue, Chroma) – Recognition part (Feature extraction: Low spatial frequency, Low contrast, Hidden; Detection and classification: No classification, Detection or classification error; Positioning: Base position error, Target position error; Tracking: Tracking error, Velocity error) – Others

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
Recognition targets	Lane	Lines	Color and material		Line color is NOT covered by recognition process. Color of botts dots is similar to color of road surface. Color of target is changed by lighting environment. (Mark in 'Target color variation' because of difficulty to distinguish yellow line from white line under sodium vapor lamp.)	1	-	1	0	0
			Shape		Pattern of line (single, double, etc.)	-	-	0	1	1
					Pattern of line (broken, dotted, etc.)	1	-	0	0	2
			Grime and rubbing		Partially hidden by fallen leaves, snows, etc. Grime, rubbing, and repainting	-	-	1	0	0
			Relative position	Distance - Far side	Far target	1	-	1	0	0
						-	-	1	0	0
				Distance - Near side	Near target ("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)	1	-	0	0	1
				Direction	Fail to recognize target by large motion blur of peripheral part of image. Fail to recognition caused by deformation of image of objects located diagonally in front of ego vehicle.	1	-	0	0	1
		Structural objects (with height)	Color and material		Color	-	-	1	0	0
			Shape		Broken Fail to detect stick, chain, and rope which show boundary	-	-	1	0	0
			Grime		False recognition of pattern made by grime Fail to detect target caused by grime or cut out by structural objects.	-	-	1	0	0
			Relative position	Distance - Far side	Far target	-	-	1	0	0
				Distance - Near side	Near target (Especially periphery of image) Fail to recognize target because of large motion blur at periphery of image ("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)	1	-	0	0	1
				Direction	Fail to recognition caused by deformation of image of objects located diagonally in front of ego vehicle.	1	-	1	0	0
		Road edges – without step	Color and material		Similar colors between inside and outside of road edge False recognition of road repair trace as road edge	-	-	1	0	0
			Shape		Outside of track is as flat as inside. (Difficult to detect boundary because of similar colors between inside and outside of track)	-	-	1	0	0
			Grime		Grime, or hidden by objects except spatial obstacles Fail to detect road edge covered by snow, leaves, etc.	-	-	1	0	0
			Relative position	Distance - Far side	Far target	-	-	1	0	0
				Distance - Near side	Near target (Especially periphery of image) Fail to recognize target because of large motion blur at periphery of image ("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)	1	-	0	0	1
				Direction	Fail to recognize target located diagonally in front of ego vehicle because of deformation of image, etc.	1	-	1	0	0
		Road edges – with step	Color and material		Fail to detect because of similar colors between road surface and gutter	-	-	1	0	0
			Shape		Fail to detect narrow gutter Fail to detect small step	-	-	1	0	0
			Grime		Fail to detect road edge covered by snow, leaves, etc.	-	-	1	0	0
			Relative position	Distance - Far side	Far target	-	-	1	0	0
				Distance - Near side	Near target (Especially periphery of image) Fail to recognize target because of large motion blur at periphery of image ("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)	1	-	0	0	1
				Direction	Fail to recognize target located diagonally in front of ego vehicle because of deformation of image, etc.	1	-	1	0	0
	Traffic information	Traffic lights	Color and material		Color of traffic light is out of expected color by recognition process. Back panel of traffic light is similar color to background color	-	-	1	0	0
			Shape		Shape of whole traffic light, shape of lighting parts, and size	-	-	1	0	0
			Light source	Continuous lighting	Light bulb, Fluorescent light (inverter type)	1	-	1	0	0
				Blinking (include scanning, etc.)	LED (scan type), Fluorescent light (no inverter type)	1	-	1	0	0
			Grime		Grime, blurred, or covered by snow, etc. (except spatial obstacles)	-	-	1	0	0
			Relative position	Distance - Far side	Far target	-	-	1	0	0
				Distance - Near side	Near target ("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)	1	-	0	0	1
				Direction	Difficult to detect status of lighting because of directivity of traffic light	1	-	1	0	0
					Parts of traffic light is out of FOV	-	-	1	0	0
				Vertical position	Installed at very high position	-	-	1	0	0
		Traffic signs	Color and material		Background is similar color to target	-	-	1	0	0
					Large variation apparent color because of reflective material with light source (Mark in 'Target color variation' because of larger effect to target using reflective material from light source than effect to other object)	1	-	1	0	0
					Color of traffic sign Differences among countries or regions	-	-	1	0	0
			Shape		Shape of traffic sign Differences among countries or regions	-	-	1	0	0
			Light source	Continuous lighting	Light bulb, Fluorescent light (inverter type (high frequency blinking))	1	-	1	0	0
				Blinking (include scanning, etc.)	LED (scan type), Fluorescent light (no inverter type (low frequency blinking like 50 or 60Hz))	1	-	1	0	0
			Grime		Grime, blurred, or covered by object (except spatial obstacles)	-	-	1	0	0
			Relative position	Distance - Far side	Far target	-	-	1	0	0
				Distance - Near side	Near target ("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)	1	-	0	0	1
				Direction	Target's direction	-	-	1	0	0
				Vertical position	Installation height	-	-	1	0	0
		Pavement markings	Color		Similar to apparent color of road surface	-	-	1	0	0
					Color of marking Differences among countries or regions	-	-	1	0	0
			Shape		Shape of marking Differences among countries or regions	-	-	1	0	0
			Grime		Grime, blurred, or covered by object (except spatial obstacles)	-	-	1	0	0
			Relative position	Distance - Far side	Far target	-	-	1	0	0
				Distance - Near side	Near target ("Motion blur" is caused by both relative distance and direction. The darker case causes that the effect is larger.)	1	-	0	0	1
				Direction	Target's direction	-	-	1	0	0
	Obstructions on the lane	Fallen objects	Color and material	Color	・Color and pattern of object (cardboard boxes, tires, blue tarp, carpet, etc.)	-	-	1	0	0
					・Similar to background color	-	-	1	0	0
				Reflection	・Reflectors, metals, glass, mirrors, etc. (those object attached to fallen object)	-	-	1	0	0
				Transparency	・Transparent materials	-	-	1	0	0
				Lighting device	・Smoke pots (LED type)	1	-	1	0	0
			Shape and size	Shape	・Shape of each kind of object	-	-	1	0	0
				Size	・Size (width, length, height)	-	-	1	0	0
				Direction	・Target's direction	-	-	1	0	0
			Relative position and motion	Velocity	・Speed of moving object (ball, etc.)	1	-	0	0	1
				Moving direction	・Moving direction of object (ball, etc.)	1	-	0	0	1
				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
				Relative position - Vertical position	・Height of target (vertical FOV＋α) (require +α to check recognition process when target exists in FOV partially) (need to consider flying plastic bag, etc.)	-	-	1	0	0
		Animals	Color and material	Color	・Color and pattern of each type of object	-	-	1	0	0
				Reflection	・Reflector attached to collar, clothes, etc.	-	-	1	0	0
				Lighting device	・Lighting device attached to collar, clothes, etc.	1	-	1	0	0
			Shape and size	Shape	・Posture (walk, run, stand, sit, lie down) ・Adult or child	-	-	1	0	0
				Size	・Figure ・Adult or child	-	-	1	0	0
				Orientation	・Orientation of body and face	-	-	1	0	0
			Relative position and motion	Velocity	・Moving speed ・Speed of motion of body, legs, etc.	1	-	0	0	1
				Moving direction	・Moving direction (crossing, approaching, etc.)	1	-	0	0	1
				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)	-	-	1	0	0
					・Fail to recognize near object because of motion blur ("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
				Relative position - Vertical position	・Height of target (vertical FOV＋α) (require +α to check recognition process when target exists in FOV partially) (birds may locate at upside of image) (difficult to recognize small animals moving fast)	-	-	1	0	0
		Installations	Color and material	Color	・Fail to recognize target because of lack of contrast ・Fail to detect or recognize target because of unexpected brightness, chroma, or hue.	-	-	1	0	0
				Reflection	・False recognition caused by image reflected in transparent board, etc. ・False recognition caused by bright spot created by reflector, etc.	-	-	1	0	0
				Lighting device	・False recognition caused by flicker of lighting	1	-	1	0	0
					・Failed exposure because of large difference of brightness caused by lighting device which illuminate partially. (balloon light, etc.)	1	-	1	0	0
			Shape and size	Shape	・Unexpected shape of each type of target object for recognition process ・Fail to detect stick, chain, pillar, poll, etc. because of insufficient information from those image	-	-	1	0	0
				Size	・Fail to recognize large target because only part of target can be captured in FOV ・Fail to recognize target because of insufficient information from part of small target in FOV.	-	-	1	0	0
				Orientation	・Fail to recognize target object because of variation of apparent shape depended on orientation of the object	-	-	1	0	0
			Grime		・Fail to recognition because of grimed pattern large different from original pattern	-	-	1	0	0
			Relative position and motion	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
				Relative position - Vertical position	・Height of target (vertical FOV＋α) (require +α to check recognition process when target exists in FOV partially)	-	-	1	0	0

Table 29. Perception disturbance elements and generation principle matrix of the camera (element: perception target – moving object)

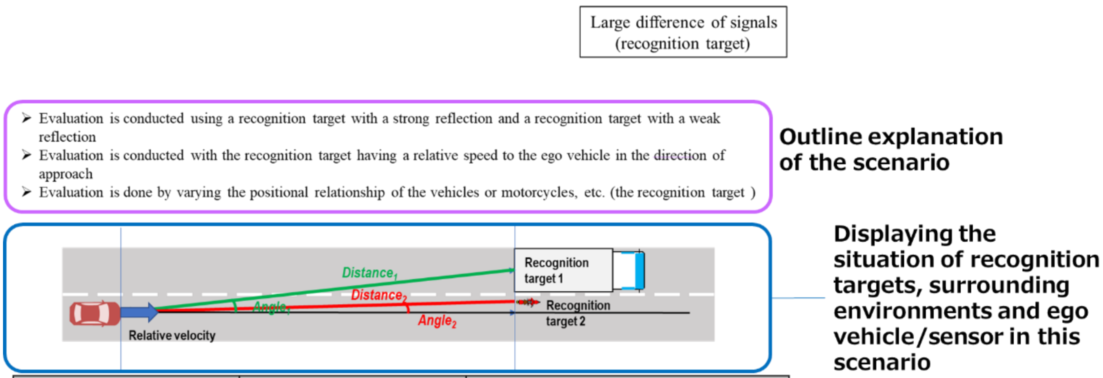
Small effect △
Medium effect ○
Large effect ◎

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																																	○	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–			-	-	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 recognize 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) (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) (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	~Reflection, 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) (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) (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) (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) (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) (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) (to check recognition process when target exists in FOV partially)																																								◎	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–			-	-	1	0	0

The following are examples of scenarios selected as the perception disturbance representative scenarios of the millimetre-wave radar, LiDAR, as well as the camera by taking the degree of influence on the sensor perception performance and encounter probability as per the abovementioned conception (Figures 61, 62 and 63).

As an example, Fig. 61 shows one of the scenarios selected by the abovementioned conception. The scenario illustration should include the following elements: See ANNEX for details.

- ✓ Outline explanation of the scenario
- ✓ Illustration of the recognition target, surrounding environment, own vehicle / sensor status in the scenario
- ✓ List of parameter items and ranges



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 65. Example of recognition disturbance evaluation scenario explanatory diagram

4.2.1.3. Evaluation of Perception Disturbance Combination

It is possible for multiple elements of perception disturbance to occur in one sensor at once. When these several elements strengthen the influence on the perception performance of each other, a perception performance evaluation that combines these elements becomes necessary. Whether the elements strengthen each other must be considered based on the generation principles of perception disturbance; the influence must be determined as per the principles among different columns in the matrixes from the preceding section. The principles that weaken or do not influence each other as per the result of verification are excluded from the combination evaluation (Figure 66).

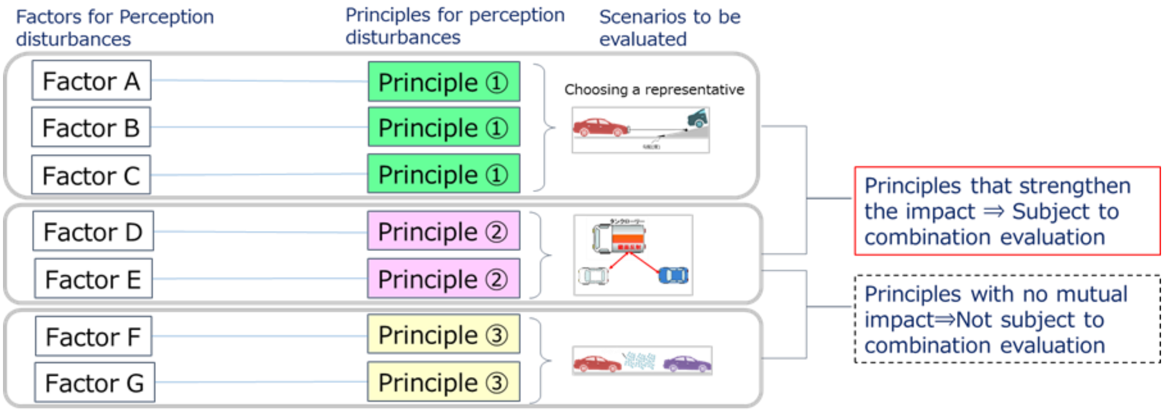


Figure 66. Perception disturbance generation principles that are the subjects of combination evaluation

4.2.1.4. Perception disturbance evaluation of automatic driving system equipped with several sensors

Commonly, ADS construct sensor fusion systems that combine several sensors. When evaluating the perception performance of the system as a whole, a unified scenario based on the sensor composition that gathers the evaluation scenarios of each individual sensor selected through the aforementioned process is used, and the system as a whole under each disturbance condition is evaluated.

4.2.2. Blind Spot Scenarios

The premise of the aforementioned (Chapter 3.1) traffic disturbance scenario structure is that the surrounding vehicles are detectable. However, in an actual traffic environment, certain surrounding vehicles or road components can sometime cover other surrounding vehicles (hereafter referred to as peripheral vehicles). Therefore, it is necessary to consider safety-related scenarios that include the peripheral vehicles in blind spots and integrate them into the safety analysis.

The blind spot scenarios are classified into three sub-categories, namely, the peripheral vehicles, the road structure and the road shape (Figure 67).

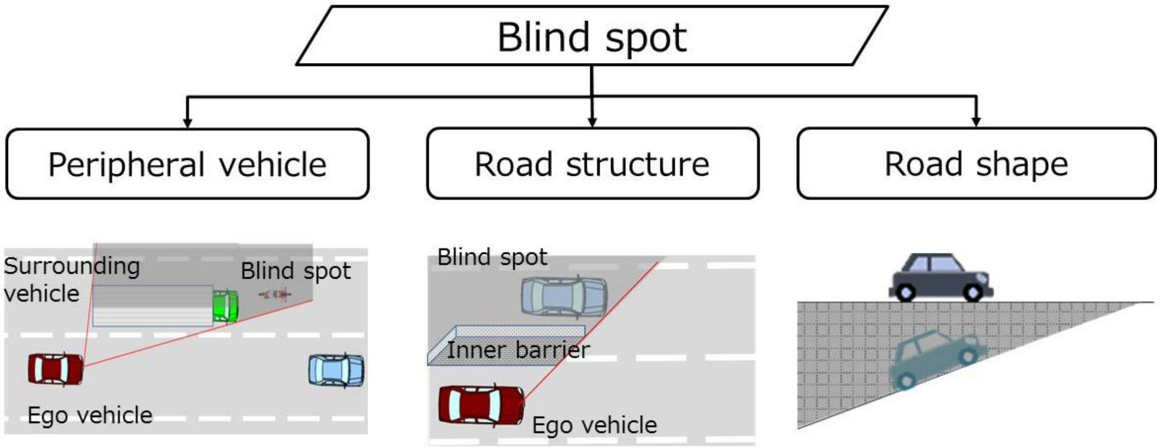


Figure 67. Perception disturbance categories related to blind spot

4.2.2.1 Blind spot scenarios caused by peripheral vehicles

Sixteen new position definitions were added to the eight surrounding vehicle positions to date defined to structure the blind spot scenarios caused by the peripheral vehicles (Figure 68). Beware that each peripheral vehicle can create blind spots that affect other peripheral vehicles, in additon to the vehicle immediately behind it. This is particularly true when the blind spot area and the positions of the vehicles inside that area change, e.g., when the ego vehicle and the surrounding vehicles are driving on a curve.

To elucidate this dynamic phenomenon, an additional figure and explanation are presented as follows. Figure 69 shows the process to explain the blind spots of peripheral vehicles derived as the combination of the ego vehicle, curvature of the roads in the same lane, and the peripheral vehicles. Similarly, Figure 70 and Figure 71 show the blind spots related to the peripheral vehicles at lateral or diagonal positions to the ego vehicle.

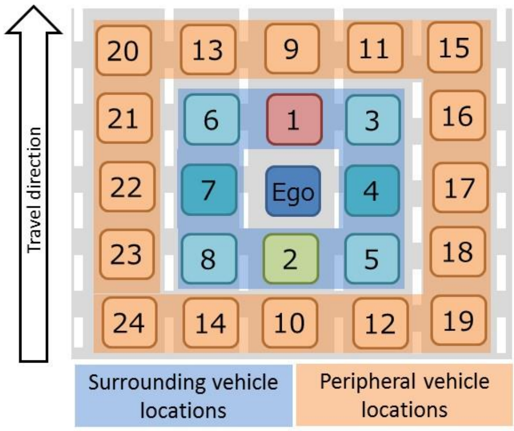


Figure 68. Vehicle positions applied to define the peripheral vehicles-related blind spot scenarios

Figure 67 shows the blind spot positions that are generated when the peripheral vehicle is at postion 1. In the figure, a picture of a truck is used to make it more understandable. The only blind spot position generated by the truck on a straight road is position 9. However, when both the ego vehicle and the truck pass the right curve, the position of the truck in relation to the ego vehicle changes and blind spots are generated at vehicle positions 6, 9, 13, 20 and 21. Similarly, for the left curve, the vehicles at positions 3, 9, 11, 15 and 16 could be hidden by the truck. Therefore, nine total blind spots positions (3, 6, 9, 11, 13, 15, 16, 20 and 21) are added, and they can potentially lead to risky operations. There are positions that are in inclusion relation among the nine blind spot positions. For instance, at the right curve, a lane change at blind spot position 20 is a movement toward blind spot position 13. Blind spot position 13 is closer to the ego vehicle than blind spot position 20; it is a more difficult condition that has a shorter amount of time for reaction. Thus, by performing a safety evalution on blind spot position 13, the dangerous motions of blind spot position 20 can be included. Following the same theory, the blind spot positions 15, 16 and 21 can be removed from the final list of blind spot positions. Therefore, the blind spot positions induced by the vehicle on the position 1 that are considered in the safety analysis in the end are reduced to five (3, 6, 9, 11 and 13). These five positions are summarized in the simplified rectangular diagram in Figure 69.

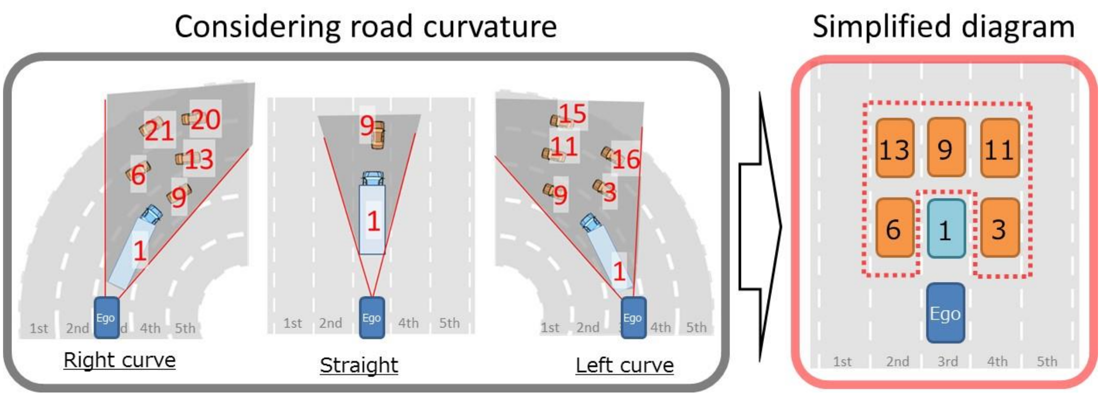


Figure 69. Blind spot positions generated by the peripheral vehicle at front position 1

Figure 70 shows every blind spot position generated by the truck on peripheral vehicle position 4. On straight roads, five blind spot positions (3, 5, 16, 17 and 18) can be extracted from the truck. When both the ego vehicle and the truck pass a right curve, the number of blind spots increases to 11 peripheral vehicle positions (1, 2, 3, 5, 6, 8, 16, 17, 18, 21 and 23). At a left curve, the vehicles at these three positions (16, 17 and 18) can become hidden. In this case, a reduction in the blind spot positions to be considered in the safety analysis is performed, e.g. if the vehicle at position 6 changes lanes to the next one on its right, it moves to the same position as position 1. Thus, when performing a safety analysis, the vehicle at position 1 covers the operations of the vehicle at position 6 following the principle of the most diffiuclt scenario. The same theory can be applied to the vehicles changing lanes to the next one on the right from positions 21, 8 and 23. Deceleration by the vehicle at position 6 has a requirement such that the simultaneous lane change to the next one on the left by the ego vehicle and the vehicle at the position 1. Thus, the vehicle at position 6 can be replaced by the vehicle at position 1. Similarly, acceleration by the vehicle at location 8 is less important than the simultaneous lane change by the ego vehicle and vehcle 2. Furthermore, the cut-in scenarios by vehicles 16, 17 and 18 are excluded from the analysis because vehicle e4 is next to the ego vehicle, which prevents the ego vehicle from changing lanes. Therefore, the number of blind spot positions generated by the vehicle on postion 4 considered in the safety analysis in the end is reduced to four (1, 2, 3 and 5), and these are summarized in the simplified diagram on the right of Figure 70.

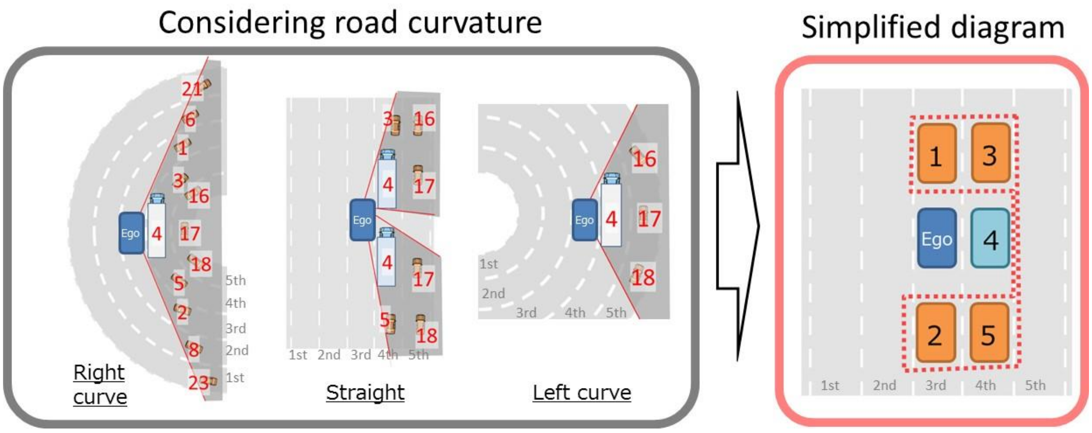


Figure 70. Blind spot positions generated by the peripheral vehicle at lateral position 4

Figure 71 shows every blind spot position generated by the truck on the peripheral vehicle position 3 that are diagonal to the ego vehicle. On a straight road, the truck can generate three blind spot positions (11, 15 and 16). When both the ego vehicle and the truck pass a right curve, the blind spots increase to nine peripheral vehicle positions (1, 6, 9, 11, 13, 15, 16, 20 and 21). On a left curve, positions 15 and 16 become blind spots. As was with the preveious case shown in Figure 70, the cut-in scenarios by the vehicles at positions 6, 13, 20 and 21 can be replaced by more difficult scenarios of the vehicles on positions 9 and 11. Moreover, the deceleration scenarios of vehicles 6 and 13 can be replaced by the motions of simultaneous lane change to the left by the ego vehicle and vehicle 9. Lastly, the number of blind spot positions generated by the vehicle at diagonal position 3 considered in the safety analysis is reduced to five positions (1, 9, 11, 15 and 16). These are shown in the simplified rectanglar diagram on the right of Figure 72.

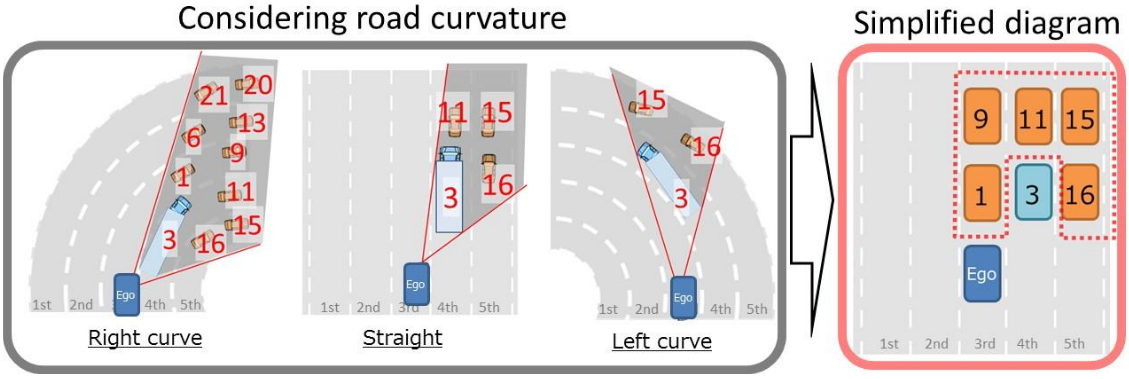


Figure 71. Blind spot positions generated by the peripheral vehicle at position 4

By applying the principles of analogy and symmetry to the three cases shown in Figures 67–69, all the positions considered in the safety analysis can be summarized in a single diagram (Figure 72).

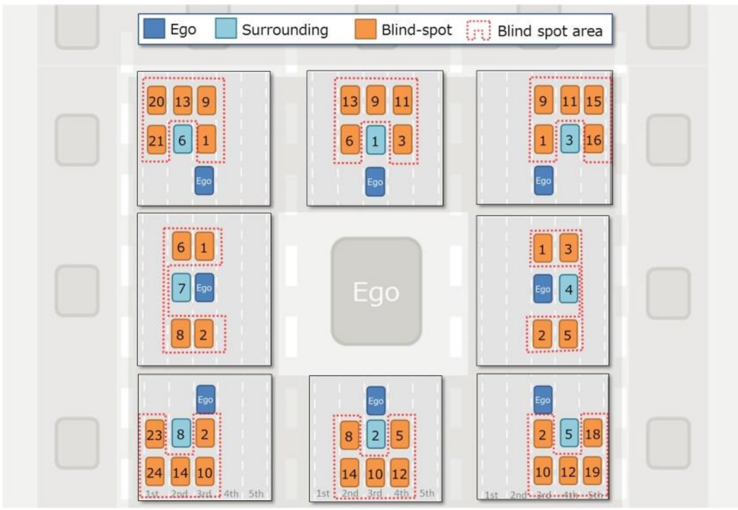
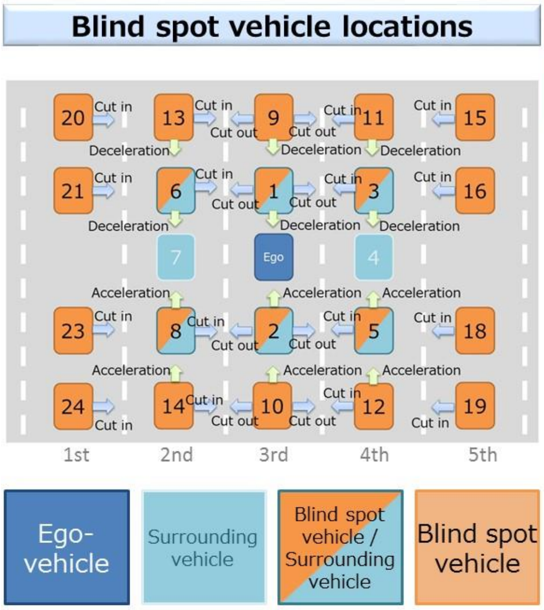


Figure 72. Diagram of all the blind spot positions generated by the peripheral vehicles considered in the safety analysis

The possible blind spot-generating vehicle motions are classified into cut-in, cut-out, acceleration, deceleration and synchronization. The reduction in the number of combinations to be considered in the safety analysis is performed by focusing on the motions of blind spot vehicles that can potentially hinder the behaviour of the ego vehicle (Figure 73). For instance, all the deceleration operations of the vehicles that are in the blind spots behind the ego vehicle (2, 5, 8, 10, 12, 14, 18, 19, 23 and 24) are excluded because they do not pose a danger to the ego vehicle. Moreover, the synchronization between the ego vehicle and the blind spot vehicles does not pose a danger to the ego vehicle. The circles in the figure indicate the corresponding combinations of the positions of blind spot vehicles and their motions that can potentially hinder the ego vehicle; thus, it is necessary to consider these in the safety analysis.



Blind spot vehicle locations and motions

Blind spot vehicle location	Blind spot vehicle's motion				
	Cut-in	Cut-out	Accel.	Decel.	Sync
1		○		○	
2		○	○		
3 (6)	○			○	
5 (8)	○		○		
9		○		○	
10		○	○		
11 (13)	○			○	
12 (14)	○		○		
15 (20)	○				
16 (21)	○				
18 (23)	○				
19 (24)	○				

Figure 73. Positions of blind spot vehicles (left) and the combinations of the positions of blind spot vehicles and the motions that can potentially hinder the ego vehicle (right)

Because of the systemization process discussed to date, a structure that contains all the blind spot scenarios that involve surrounding vehicles (road geometry, ego vehicle behaviour, blind spot vehicle motions and combinations of peripheral vehicle motions) has been defined. This structure comprises a matrix that contains 64 total possible combinations, of which 42 correspond with realizable scenarios in an actual traffic flow (Figure 74).

Ego vehicle / Surrounding vehicle / Blind spot vehicle		Blind spot vehicle motion									
		Cut-in		Cut-out		Acceleration		Deceleration		Sync	
		Surrounding vehicle motion									
Road geometry	Ego-vehicle behaviour	Lane Keep	Lane Change	Lane Keep	Lane Change	Lane Keep	Lane Change	Lane Keep	Lane Change	L/K	L/C
Main road	Lane Keep	No. 1	No. 2	—	—	No. 3	No. 4	No. 5	No. 6	—	—
	Lane Change	—	No.7	No.8	No. 9	No. 10	No. 11	No. 12	No. 13	—	—
Merge zone	Lane Keep	No. 14	No. 15	—	—	—	—	—	—	—	—
	Lane Change	—	No. 16	No. 17	No. 18	No. 19	No. 20	No. 21	No. 22	—	—
Departure zone	Lane Keep	No. 23	No. 24	—	—	—	—	—	—	—	—
	Lane Change	—	No. 25	No. 26	No. 27	No. 28	No. 29	No. 30	No. 31	—	—
Ramp	Lane Keep	No.32	No. 33	—	—	—	No. 34	—	No. 35	—	—
	Lane Change	—	No. 36	No. 37	No. 38	No. 39	No. 40	No. 41	No. 42	—	—

Figure 74. Perception disturbance scenarios related to blind spots generated by surrounding vehicles

4.2.2.2. Blind spot scenarios generated by road structures

The blind spot scenarios related to road structures are defined by considering the road structure positions and the relative motion patterns between the ego vehicle and blind spot vehicles. Generally, these blocking elements exist inside the road structures, and are classified into inner barriers and outer walls according to the types and positions of road structures (Figure 75).

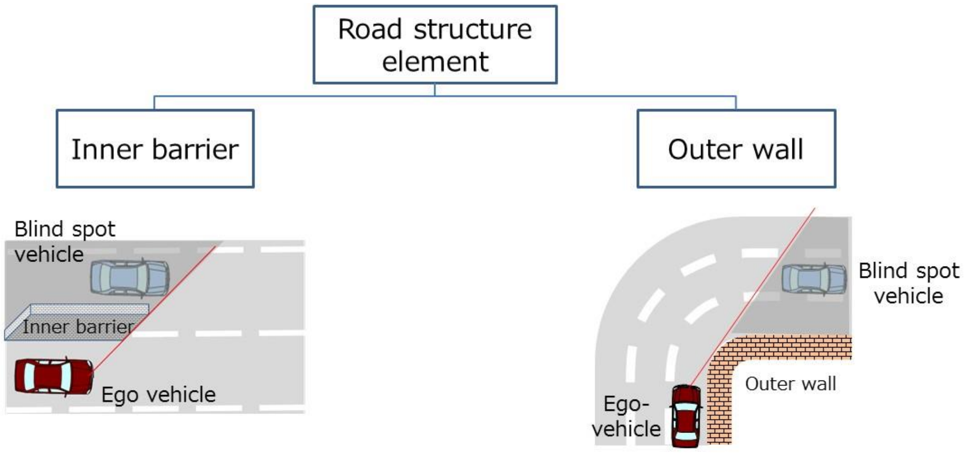


Figure 75. Categories of blind spot scenarios generated by road structures

4.2.2.2.1. Blind spot scenarios generated by inner barriers

As shown in Figure 76, the vehicle behind the structure (vehicle 1) cannot be perceived when the ego vehicle is reaching toward of the structure; it can be regarded as a blind spot vehicle. The situation is the same when the ego vehicle is in front of the structure, and the blind spot vehicles are at the back (vehicle 3) and at the front (vehicle 4). The vehicle at the centre of the structure is not considered to affect the safety. This is because the vehicle next to the blind spot cannot reach the lane of the ego vehicle because of the structure. However, if the blind spot vehicle is diagonally positioned behind the ego vehicle (vehicle 2), there is a safety concern in case it appears immediately after the end of the structure.

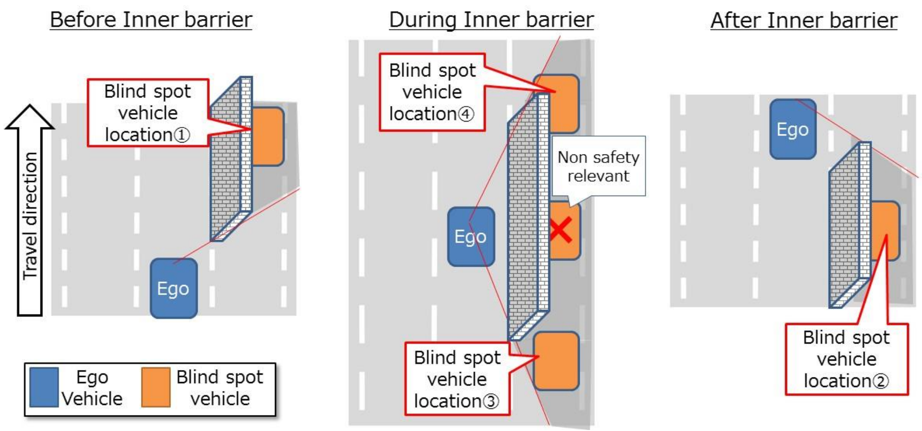


Figure 76. Definitions of blind spots related to inner barrier

Figure 77 summarizes, using a matrix, the blind spot recognition limit scenarios that are associated with inner barriers. The four blind spots mentioned above in the matrix (the ego vehicle is represented by the blue square and the blind spot vehicle is positioned in the dark grey area) are combined with the five possible operations that the vehicle in these blind spot areas can perform (cut-in, cut-out, acceleration, deceleration, and synchronization). The resulting matrix has 20 possible combinations, not all of which are safely related. In an inner barrier scenario, e.g., as the ego vehicle and the blind spot vehicle are in different lanes, this does not pose any danger. Furthermore, when the vehicles travel in parallel at the same speed with the inner barrier in between them, the ego vehicle and the blind spot vehicle cannot make contact with each other. Therefore, we can exclude all cut-out and synchronization scenarios. The safety analysis, therefore, incorporates a total of five inner barrier blind spot scenarios (marked with a circle in Figure 77).

Inner barrier related blind spot pattern	Blind spot vehicle's movement				
	Cut-in	Cut-out	Accel.	Decel.	Sync.
①				○	
②	○		○		
③	○				
④	○				

Figure 77. Blind spot-related recognition limitation scenarios due to inner barriers

4.2.2.2.2. Blind spot scenario due to outer barriers

Road structures, such as outer barriers, can create blind spots on curves. Figure 78 demonstrates that the outer barrier may become a blind spot for the front and rear vehicles depending on the curve angle. A vehicle, therefore, located in either the front lane or the rear lane (1, 2, 3, 5, 6, 8) of the ego vehicle may become a blind spot vehicle.

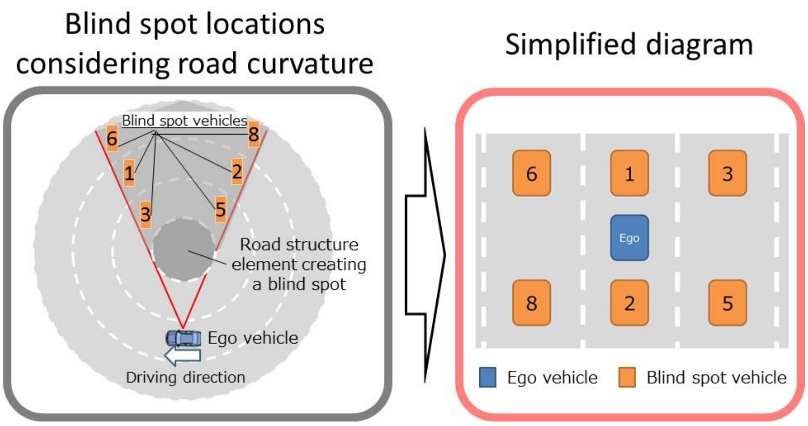


Figure 78. Definition of blind spots related to position and outer barrier

Figure 79 shows the movement of a blind spot vehicle in a situation in which it might interfere with the ego vehicle. Blind spot vehicle movements comprise cut-in, cut-out, acceleration, deceleration, and synchronization movements. The target pattern is one in which a blind spot vehicle enters the lane of the ego vehicle. However, scenarios where vehicles do not approach each other or when safety concerns are not raised such as when both the ego vehicle and the blind spot vehicle are running parallel (Sync) to each other on either side of the barrier are not covered in this scenario.

Outer wall related blind spot pattern	Blind-spot vehicle motion				
	Cut-in	Cut-out	Accel.	Decel.	Sync
1		○		○	
2		○	○		
3 (6)	○			○	
5 (8)	○		○		

Figure 79. Scenario in which blind spot-related recognition is limited due to partial barrier

4.2.2.3 Blind spot scenarios by road shape

Blind spot scenarios based on the road shape are defined as per the features of the road shape and the traffic patterns of the ego vehicle and the blind spot vehicle. Blind spots based on the shape of the road are created by height differences along the same road. We can characterize these particular road shapes as vertical curve and parallel slope shapes (Figure 80).

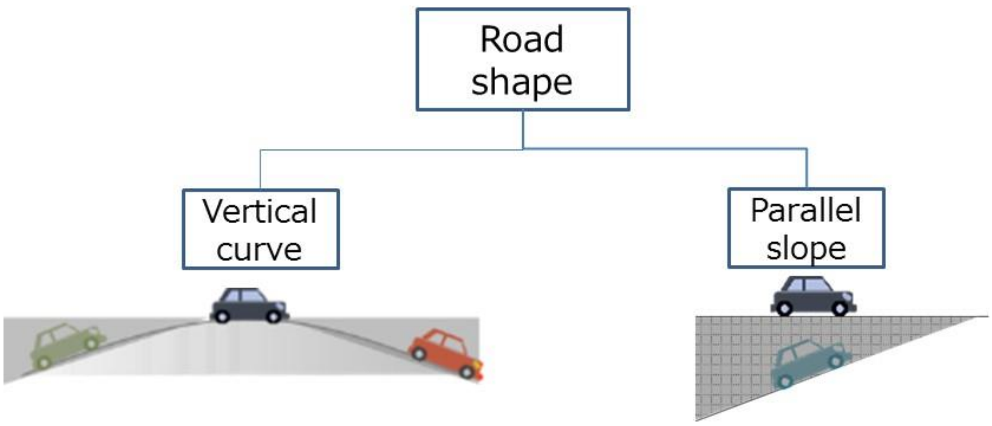


Figure 80. Blind spot scenario classifications based on road shape

4.2.2.3.1 Vertical curve scenario

The blind spot areas may occur in the front or rear when the road shape is that of a vertical curve (Fig.81). The vertical road gradient shortens the viewing distance of the vehicle. A potentially dangerous traffic pattern is created by the combination of the position and movement of surrounding vehicles (1, 2, 3, 5, 6 and 8) and the movement of the ego vehicle itself.

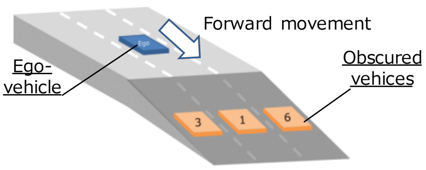
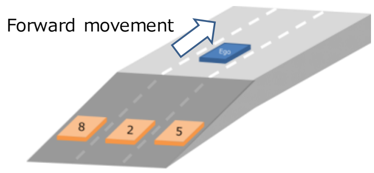
Blind spot area	Ego-vehicle and obscured vehicle postions
Front	
Rear	

Figure 81. Cognitive dysfunction related to blind spots caused by vertical curve

4.2.2.3.2 Gradient scenario for adjacent lane

A blind spot is created by the height difference because of the slope of the adjacent lane. These can be reported in junctions and branch roads. The blind spot caused by the combination of the particular road shape and the movement of the vehicle. A potentially dangerous traffic pattern is created by the position and movement of the vehicle hidden in the blind spot. These patterns can be classified into four groups: obscured vehicle cut-in (1), cut-out (2), acceleration (3), and synchronization with ego vehicle (4). This creates a matrix of 20 scenarios. We shall incorporate five of these scenarios into the safety analysis (Figure 82).

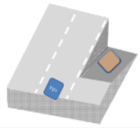
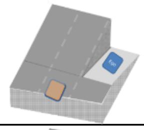
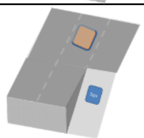
Ego-vehicle and obscured vehicle postions	Obscured vehicle motions				
	Cut-in	Cut-out	Accel	Decel	Sync
① 				○	
② 	○		○		
③ 	○				
④ 	○				

Figure 82. Parallel slope blind spot related cognitive disturbance scenarios

4.2.3. Communication disturbance scenario

Communication disturbance scenarios are defined based on the connectivity-related characteristics in the three categories of sensors, environment, and transmitter (Fig. 83).

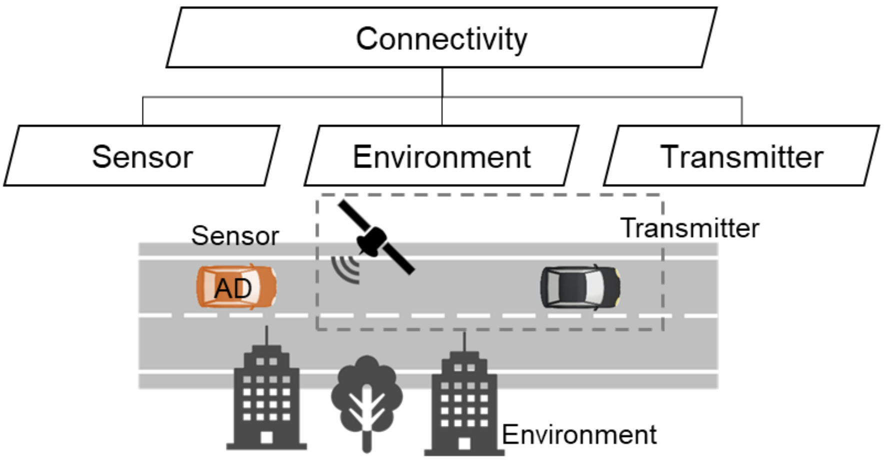


Figure 83. Classification of cognitive limits related to communication disturbances

4.2.3.1. Sensor type

Sensor-related communication disturbances are classified into the effects of digital map factors and the effects of V2X (Vehicle-to-everything) factors, as shown by Fig. 84.

Digital maps are used to support or implement positioning and navigation assistance, in addition to other capabilities required for ADAS / AD. Moreover, we can combine digital maps with perceptual sensors to increase the reliability of cognitive systems.

V2X allows vehicles to communicate with other vehicles, road infrastructure, pedestrians, and servers. The situation surrounding the vehicle is communicated to V2X in advance, which gives it an advantage, particularly in bad weather and complex traffic environments.

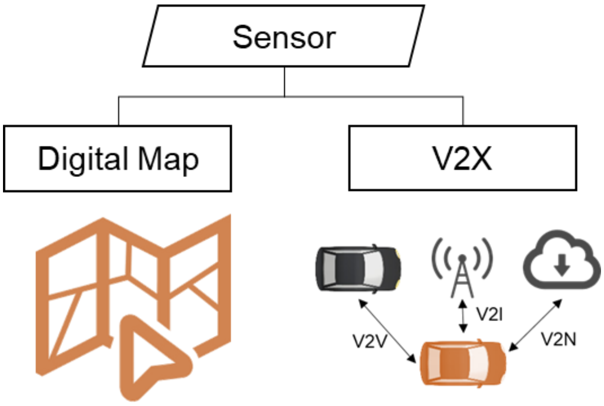


Figure 84. Classification of cognitive limits associated with sensor communication disturbances

If the map data is not correctly collected because of a flaw in the algorithm or incorrect data collection timing (such as temporary lane closure and road curvature change), a digital map-related communication disturbance may occur. The result of this is that obsolete data are collected. Poor fusion behaviour of the sensor affects, however, affects both the digital map and V2X. This may happen, for example, if the digital map, V2X and other sensors generate different information.

4.2.3.2 Environment type

Environment-related communication disturbances are shown in Figure 85. As seen from the figure, such disturbances comprise static entities, spatial entities, and dynamic entities. These interfere with communication and positioning signals. These can create blind spots and negatively affect the transmission of digital map and V2X signals.

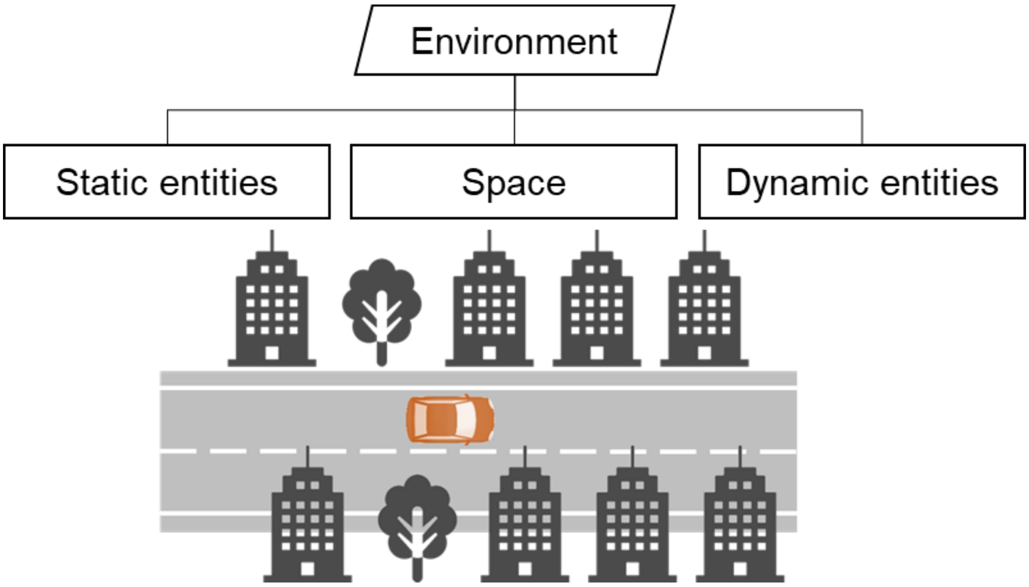


Figure 85. Classification of cognitive limits associated with environmental disturbances

Static entity factors include those related to roadside objects (such as buildings, trees, and tunnels), bridging structures (such as overpasses), and underground objects (such as parking lots). Connectivity failures may be caused by aspects of the surrounding environment of the vehicle (such as signal interference, rain and fog attenuation). Dynamic entities include such factors as surrounding vehicles, motorcycles, and pedestrians.

4.2.3.3. Transmitter classification

Transmitter-related communication disturbances shown in Figure 86. These can be classified into those caused by other vehicles, infrastructure, pedestrians, servers, and satellites. V2X messages may become unavailable or unreliable because of transmitter errors, while satellite errors can cause GNSS signals to be lost or overlooked.

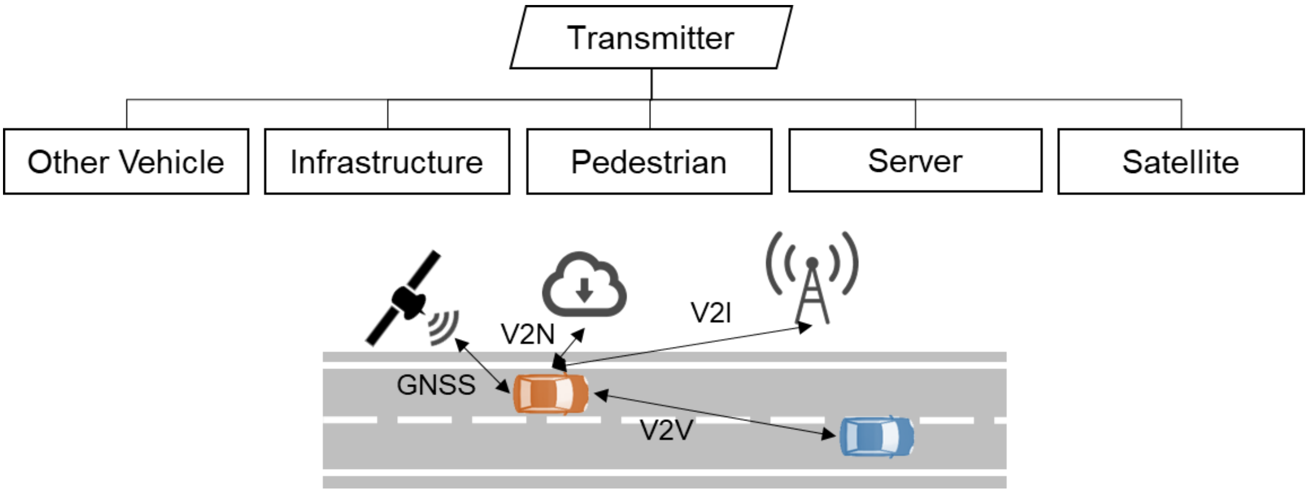


Figure 86. Classification of cognitive limits related to transmitter communication disturbances

4.3. Vehicle motion disturbance scenarios

In this section, we will explain our thinking regarding the setting of the system and standards for vehicle motion disturbance scenarios with the aim of ensuring the safety of AD. In vehicle motion disturbance, a safe state is one in which "an accident does not occur even if the vehicle motion changes due to a sudden disturbance." The two types of effects on vehicle movement are factors that exert an external force on the vehicle body and affect lateral/front-back and unidirectional movement, in addition to factors that cause the tyre generation force to fluctuate and affect the lateral/front/rear/up/down and yaw direction of the vehicle (Fig. 87). Therefore, vehicle motion disturbance scenarios can be classified into vehicle body inputs and tyre inputs (Fig. 88).

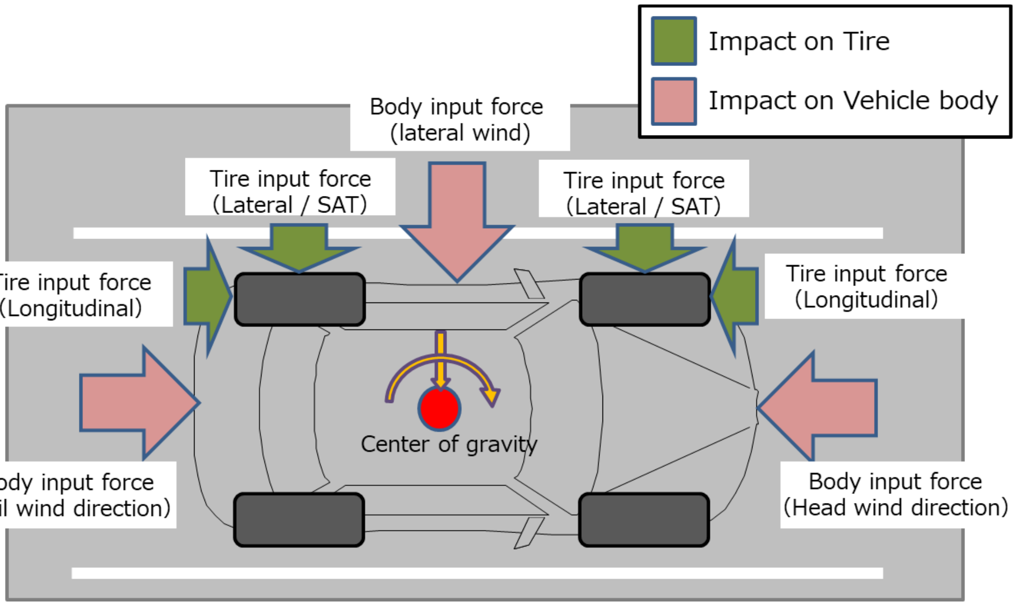


Figure 87. External physical forces considered in the definition of vehicle motion disturbance scenarios

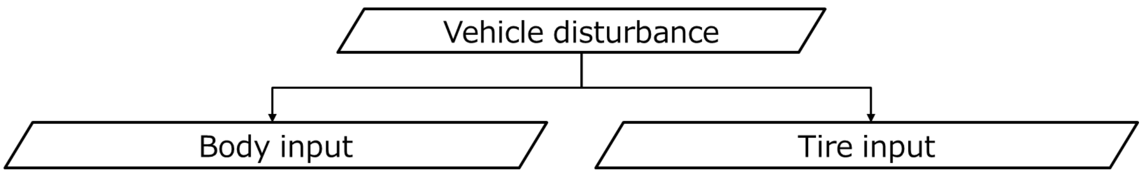


Figure 88. Vehicle motion disturbance scenario system

4.3.1. Classification of vehicle body input

There are two classes of factors that affect the vehicle body, namely, road shapes and natural phenomena (Fig. 89).

The road shape comprises a one-sided slope, a longitudinal slope, or a curvature of a curved portion. Natural phenomena, however, comprised naturally occurring crosswinds, tailwinds, and headwinds.

These are elements that act directly on the vehicle body and affect the lateral, front-back, or yaw directions.

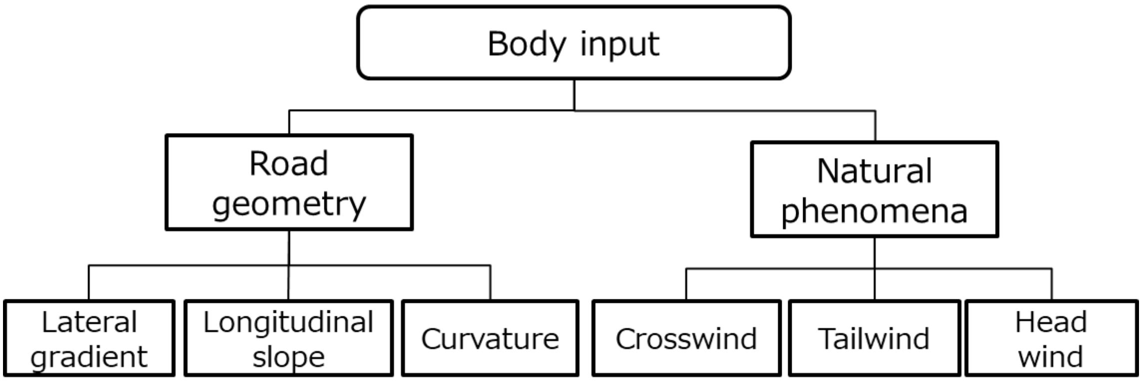


Figure 89. Scenario system for vehicle body input

4.3.1.1 Road shape

The road shape (curvature and slope of the road surface) causes the direction of gravity acting on the vehicle to change e.g., a lateral force is generated by the component of gravity on a curve as it is a one-sided slope of the road; this may increase the risk of the vehicle deviating from the lane. Similarly, in an uphill scenario, a backward force (forward on a downhill) may be generated. This in turn may increase the risk of collision with other vehicles because speed fluctuations are induced (Fig. 90).

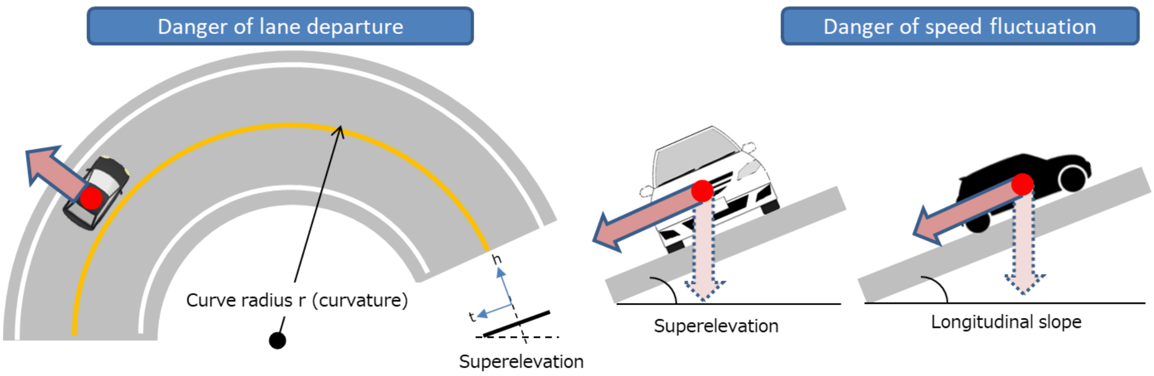


Figure 90. Road shape classification

4.3.1.2 Natural phenomena

Lateral and front-rear forces can be generated by naturally generated gusts and strong winds. These act to push the vehicle body, and, may, in some cases, cause deviation from the lane and vehicle speed fluctuations, which in turn can increase the risk of colliding with other vehicles (Fig. 91).

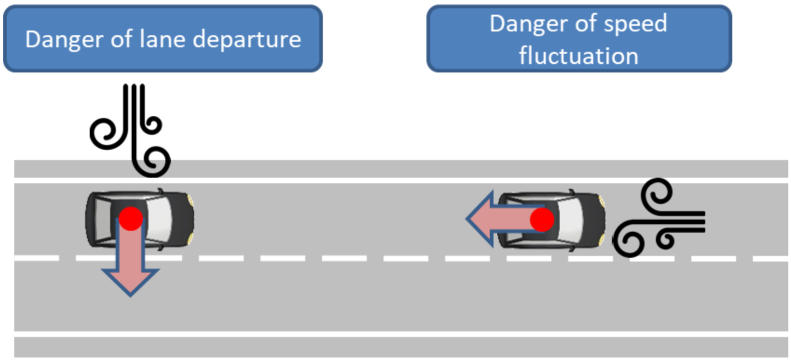


Figure 91. Classification of natural phenomena

4.3.2. Classification of tyre inputs

Tyres are affected by such factors as road surface conditions and tyre conditions. A road surface that directly affects the tyres can be classified as a road surface condition, e.g., uneven surfaces or wet surfaces can cause the coefficient of friction between the road surface and the tyres to change. This reduces the grip of the tyres and in some cases this will affect vehicle stability. Tyre condition refers to sudden changes because of punctures, bursts, and tyre wear that significantly change the tyre's characteristics (Fig. 92). The instability this causes may lead you to lose control of the vehicle, resulting in a potentially dangerous situation.

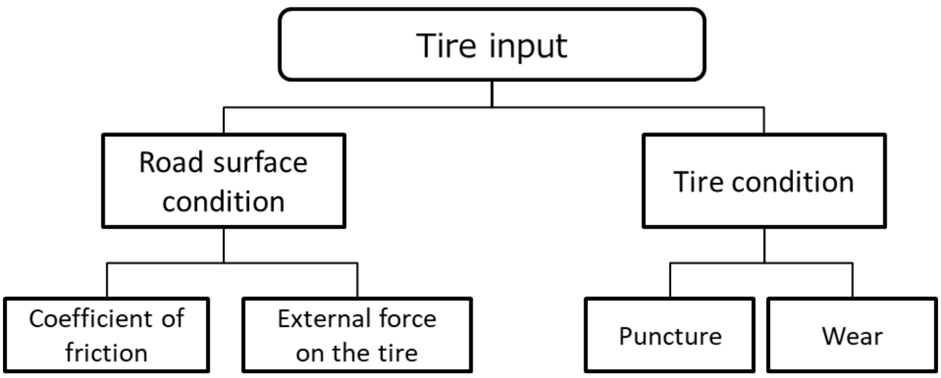


Figure 92. Scenario system for tyre input

4.3.2.1 Road surface condition

The tyre stress changes depending on the road surface shape input to the tyre, in addition to changes in the road surface. For example, when an external force causes the road surface friction to change as a result of unevenness, such as road surface shape or rain, the tyre stress changes, in addition to the direction of the vehicle. Furthermore, in some cases, there is a risk of collision with another vehicle because of deviation from the lane or vehicle speed fluctuation. The road surface condition, therefore, can be classified into the coefficient of friction and external force (Fig. 93).

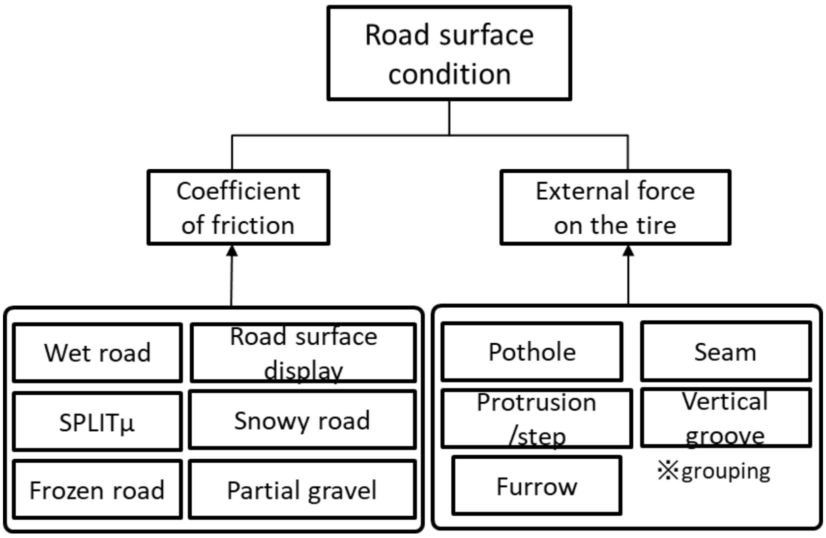


Figure 93. Classification of road surface conditions

The coefficient of friction between the tyres and the road are affected by such road surface factors as wet roads, icy roads, snowy roads, and partial gravel, e.g., a reduction in the coefficient of friction may be triggered by a sudden move from a dry road to a wet road (Figure 94, left).

This reduction can cause the vehicle to become unstable. External forces that may affect the road surface include potholes, protrusions, and striations. For example, when a vehicle crosses a step or protrusion on the road, a sudden diagonal-upward force is applied to the tyre (upper right) (upper right in Fig. 94). This in turn causes the direction of the vehicle to change. This change in movement can cause the vehicle to deviate from the planned trajectory and lead to a collision.

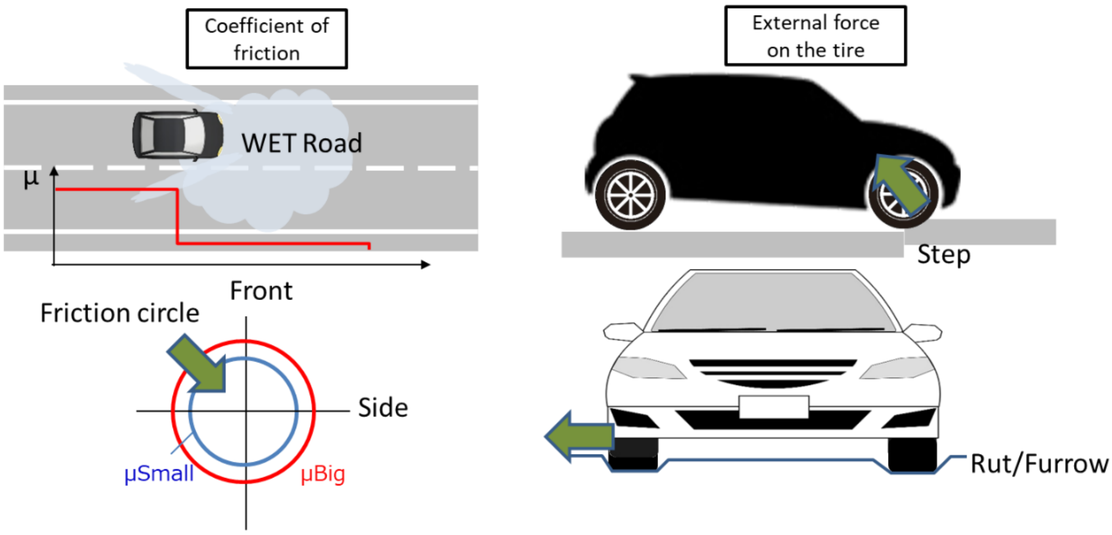


Figure 94. Vehicle motion disturbances related to road surface conditions due to changes in friction coefficient (left) and external force of tyres (right)

4.3.2.2 Tyre condition

The tyre condition fluctuates and this fluctuation affects the tyre characteristics. This may be attributed to tyre wear, punctures, and bursts (Fig. 95). These reduce tyre strength and, in some cases, may lead to collisions with other vehicles because of the vehicle deviating from the lane or vehicle speed fluctuations.

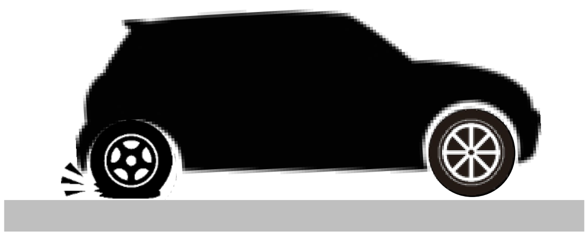


Figure 95. Vehicle motion disturbance related to tyre conditions due to bursting

4.3.3. Predictable vehicle motion disturbance safety approach

This chapter describes two general assumptions. Following this, we elaborate a technical safety approach to predictable vehicle motion disturbances.

4.3.3.1 Assumptions

The first assumption is a common sense one regarding road design, road maintenance and management, as well as road environmental conditions used by vehicles. This assumption states that roads are constructed, constantly maintained, and managed by responsible public or private institutions and that this is done in line with basic principles such as legality, ethics and engineering. Most countries have road structure ordinances. These design the shape of roads in a way that enable all persons (regardless of age such as driving skills and reflexes) with a license to drive safely. For example, in Japan, given a pre-designed speed limit of 100 km/h, a curved radius is specified on which the lateral acceleration of the vehicle below 0.11 G can be maintained even on wet roads. The design road speed limit is lowered when constructing roads for which acceleration cannot be maintained under these conditions (such as due to space availability). Similarly, mechanisms for quickly detecting surface deterioration such as those caused by a reduction in slip friction because of frozen roads or the presence of cracks, ridges, or potholes on the road surface. Another example of this is when the natural environment such as rain and wind must be within the driving range determined to be safe on the road management side. For example, in case of a disaster-level storm, road managers need to take measures such as imposing speed limits or making road closures, and drivers must follow their instructions. This is also the case for self-driving vehicles.

This means safety may be compromised by a failure to comply with road design, road maintenance and management, or road environmental, regardless of whether the vehicle is automated or not. Therefore, it is unacceptable for the road surface to be deteriorated or to have inadequate maintenance. Such scenarios are classified as unpreventable for the purpose of the AD Safety Assurance Engineering Framework methodology.

The second assumption relates to common sense on the responsibilities of AD system operators. The AD system is responsible while driving is in progress; however, the driver may not have conducted proper maintenance (e.g., excessive tyre wear may be below legal technical inspection standards, air pressure drop below the tyre manufacturer's recommended air pressure, flat tyres) or may have a puncture before operating the vehicle. If the operator is aware that the vehicle is in a state where the default vehicle performance cannot be achieved (e.g., temper tyres installed, studless tyre / chain installed), it is considered to be their responsibility. If the system is operated in this state, it may not be possible to avoid collisions.

4.3.3.2 Engineering safety approach to vehicle motion disturbance

We shall introduce a technical safety approach to predictable vehicle motion disturbances based on the assumptions in the previous chapter. Current standards, as mentioned earlier in Figure 2, specifically consider collision avoidance strategies in predictable and avoidable scenarios and collision mitigation strategies in visible and unavoidable scenarios. Therefore, if the vehicle motion disturbance causes the behaviour of the vehicle to change within a range of conditions that can be temporarily avoided, the AD vehicle is required to have to the ability to control and stabilize the vehicle without interrupting the running of the vehicle. However, if unavoidable instability is caused by these disturbances, AD vehicles need to apply a "best effort" strategy to mitigate possible collisions. This must be done without interrupting the running of the vehicle.

Figure 96 shows specific examples of this safety approach to predictable vehicle motion disturbances. The top half of the figure shows an example in which, to meet avoidable conditions on a wet road, an AD vehicle faces a sharp decrease in slip friction. In this state, it must be possible to control the vehicle safely without interrupting travel. However, in the bottom half of the figure, an extreme reduction in slip friction, resulting in unavoidable pre-defined vehicle conditions (e.g., maximum deceleration) is caused when an AD vehicle with summer tyres encounters a frozen road. Therefore, the safety approach to vehicle motion disturbance is based on a clear definition of the principles of vehicle motion engineering as related to the definition of vehicle controllable and uncontrollable conditions. These can be defined as follows:

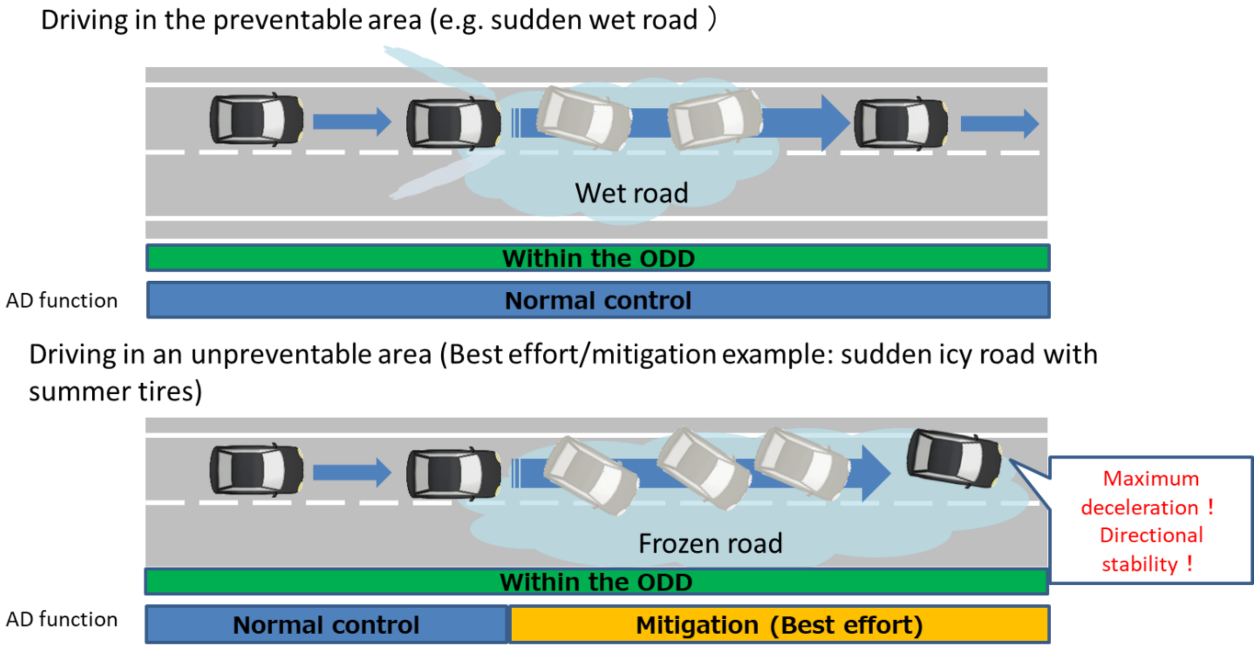
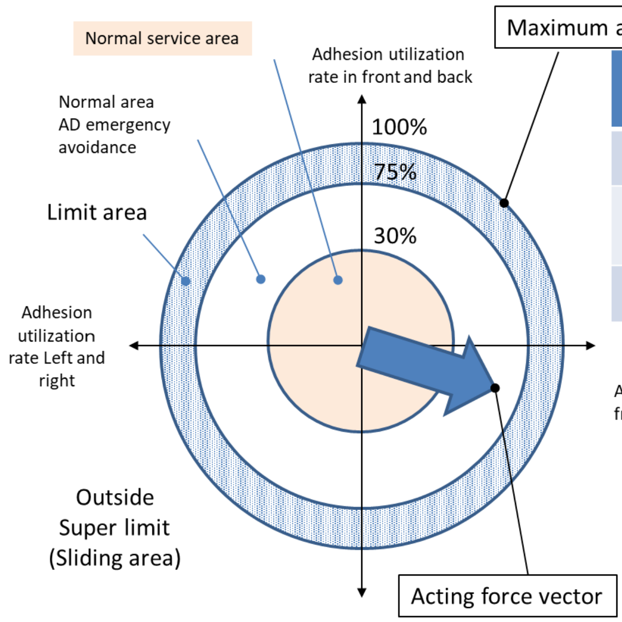


Figure 96. Safe approach to avoidable (upper) and unavoidable (lower) vehicle motion disturbances

Two mechanical indicators determine the relationship between the principles of vehicle motion and avoidance conditions. The first of these indicators is the acting force of the vehicle. This is determined by the force exerted by the vehicle as it travels. There are also one or more vehicle motion disturbance factors (e.g., road shape, wind, road surface, tyre-related conditions); this is defined as the sum of the triggered forces. The second indicator is the adhesive utilization rate ε between the road surface and the tyre. Figure 97 shows the four areas where the vehicle may operate based on adhesive utilization rate ε. These areas are classified as the area used during normal operation (ε30% or less), the area normally used by AD vehicles for emergency avoidance (ε30%–75%), the area of limit of ABS operation (ε75%–100%), and the area beyond limit, where tyre grip does not work (ε100% or more). Only when the force of action (indicated by the blue arrow) resulting from driving, including various vehicle motion disturbances, is <75% adhesive utilization, does motion control become physically possible. The collision avoidance strategy can be secured in this scenario. There are scenarios where motion control cannot be performed if the force of action is >75%. In such cases, it is necessary to adopt a collision mitigation strategy.



	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)

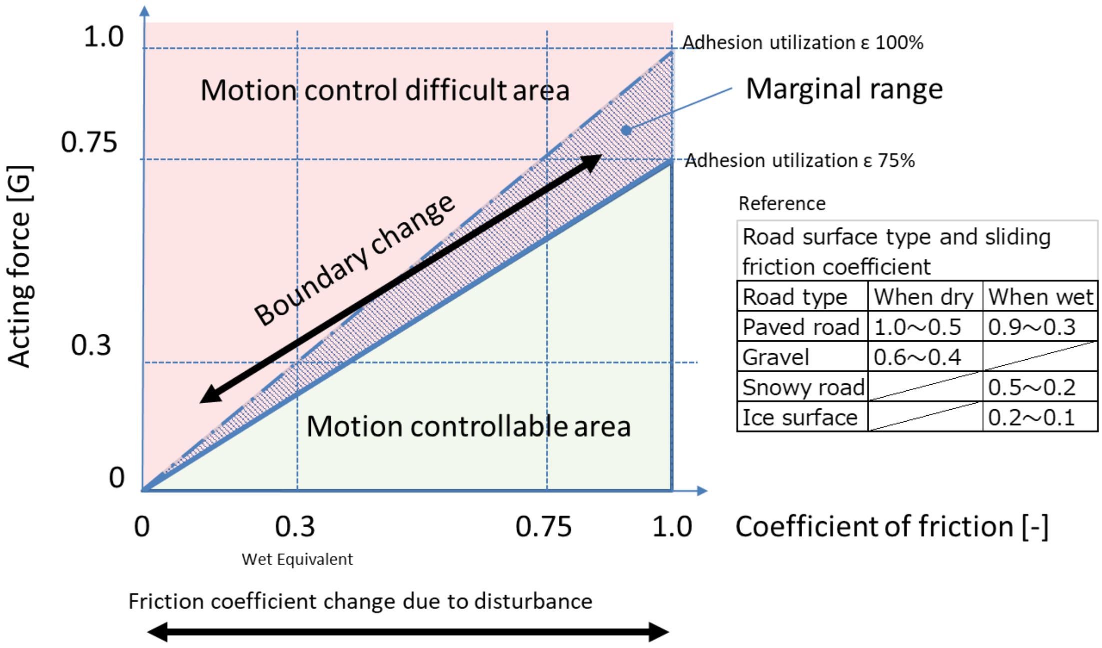
Adhesion utilization rate: Ratio of acting force to maximum friction force

Figure 97. Concept diagram showing the vehicle action force and cohesive usage rate defining the vehicle movement disturbance safety approach

4.3.3.3 Scope of controllable vehicle movement

Vehicle movement disturbances may dynamically change the force in relation to the vehicle and then turn it into areas in which it is difficult to control vehicle movement. Figure 98, with the action force and friction coefficients as axes, shows areas in which vehicle movement can be controlled in all environments and areas where control of vehicle movement is difficult. Here, the slip friction coefficient for a paved road is 0.5–1.0 when dry, 0.3–0.9 when wet, and 0.1–0.2 when frozen. Therefore, it is necessary to develop and test an AD vehicle movement strategy, in which the force caused by the vehicle disturbance always falls within the movement controllable area (triangular green area in the bottom right of the figure).

> NOTE: The slip coefficient of friction value is the value when locked normally. According to Development of a real time friction estimation procedure, Gerd MüllerS. Müller, 2017, the slip friction coefficient when driving in the rain is approximately 0.6.



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 98. Controllable range of vehicle movement

4.3.3.4 Controllable vehicle movement in relation to vehicle body input road shape disturbance

The road shape with difficult conditions in terms of vehicle movement is the curve radius. According to the Japan Road Ordinance, a minimum diameter is determined for the curved sections of roads such that driving can be performed in a stable manner. Furthermore, in terms of the minimum curve radius, the power laterally working, such as the centrifugal force applied to the automobile, must not exceed the force applied by the friction of the tyres and road, and is determined in consideration of a balance between the centrifugal force working on the vehicle occupants as well as the comfort in riding the vehicle. To quote this road ordinance, the minimum value for the curve radius at a design velocity of 100 km/h is 460 m (in case of temporary measures, 380 m). Here, the relational formula for the velocity, curve radius, banking, and lateral slip friction coefficient for stability in relation to lateral slip is as follows. The curve radius can be obtained from the relationship between the design velocity, lateral slip friction coefficient, and banking.

Z=$Ggv2$ ・・・formula (1)

Here,

Z：Centrifugal force(N)

v：Automobile velocity (m/s)

g：Gravitational acceleration(=9.81m/s^2)

G：Total weight of vehicle(N)

f：Road and tyre friction coefficient in relation to lateral slip\

i：Road banking (=tan α)

R：Curve radius (m)

Here, the conditions for lateral slip to not occur are

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

With formula development, replacing formula (2) with formula (1)

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

The road and tyre friction coefficient f(= lateral acceleration) in relation to lateral slip based on formula (3) is

$$f = V2R*127 - i \quad \cdot\cdot\cdot \text{formula (4)}$$

were if design velocity V = 100(km/h), road banking i = 6(%) and curve radius R = 463(m), f = 0.11. In other words, on Japanese motorways, this indicates that it is a structure in which you can drive with a lateral acceleration of 0.11 G（velocity: 100 km/h). Moreover, the speed limit may be lowered and set in case the road shape does not meet the conditions at 100 km/h. Therefore, when travelling on a motorway within Japan, it is necessary to have a cohesive force equivalent to a maximum lateral acceleration of 0.11 G. Figure 99 shows a line at 0.11 G as the maximum value for road shape disturbance required for normal driving, and shows that the action force used for disturbance other than road shape is, for example, 0.45 G (=0.56 G − 0.11 G) for dry roads and 0.12 G for wet roads. For vehicle movement disturbances, it is constantly necessary to consider the road shape for normal driving, and the total of the action force when combined with other disturbance elements must be kept within the controllable area of driving.

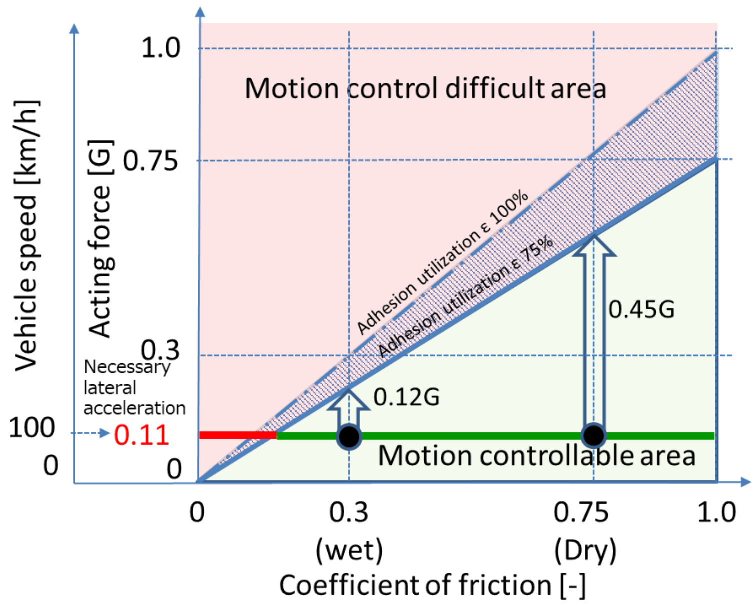


Figure 99. Relationship between friction coefficient and action force in relation to road shape

Moreover, as the elements of vehicle disturbance do not necessarily occur singly, it is necessary to consider combinations with other elements. In an actual environment, for example, there may be situations where there is a crosswind blowing while driving on a curve in the rain. Whether the road is dry, wet, or snowy can be expressed by the friction coefficient, and the road surface and natural phenomena (e.g. crosswind) and external force (unevenness) of tyres can be expressed as an action force. Moreover, in case of punctures, this can be expressed as a state in which the cohesive usage rate of 100% cannot be realized (Figure 100). In other words, as in the diagram, it is necessary to combine the elements for vehicle movement disturbances.

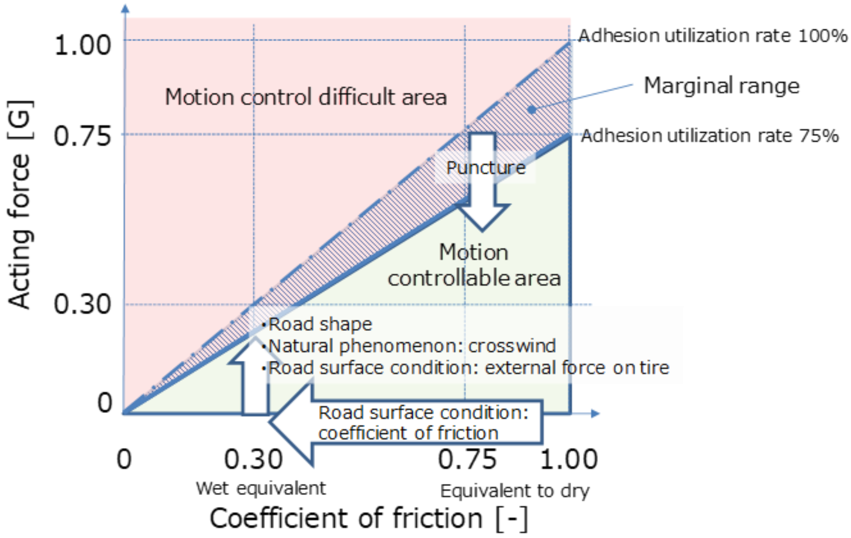
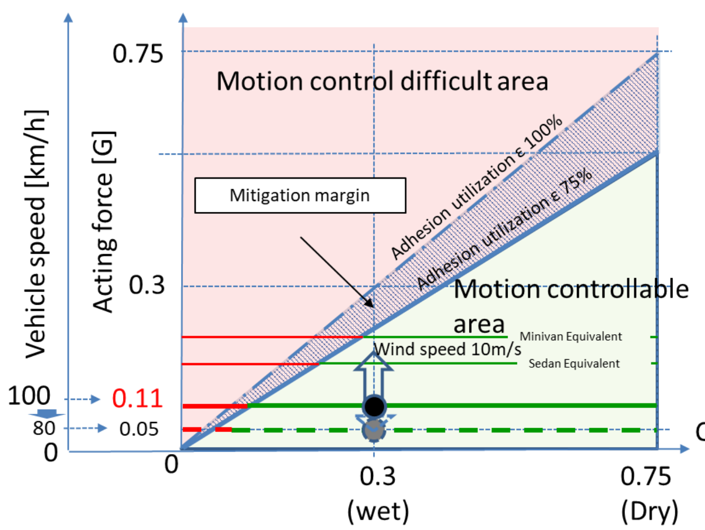


Figure 100. Relationship between combinations of elements in vehicle movement disturbance

4.3.3.5 Controllability of vehicle movement in relation to vehicle body input natural phenomena disturbance

The natural phenomenon of wind disturbance is calculated as an action force. In other words, it is added to the required action force (11 G) in the road shape. Here, the action force because of crosswind force changes depending on the shape and size of the vehicle. For example, as shown in the figure, with a wind speed of 10 m/s, there is this amount of difference between a sedan and a minivan.

Furthermore, with a wind speed of 20 m/s, even with a vehicle equivalent to a sedan, the area will have a cohesion rate of 75% or above; in other words, it will be an area where it is difficult to control movement. In such a case, it is necessary to respond on a best effort basis. However, on Japanese motorways, if there is a wind speed of 10 m/s or greater, speed restrictions come into play, and the necessary action force required for the road shape will decrease. Therefore, it is safe to drive even with wind speeds of >10 m/s. Therefore, on Japanese motorways, as speed restrictions are set in relation to the wind speed, the boundaries concerning wind speed with which it is possible to travel at 100 km/h are below 10 m/s (Figure 101).

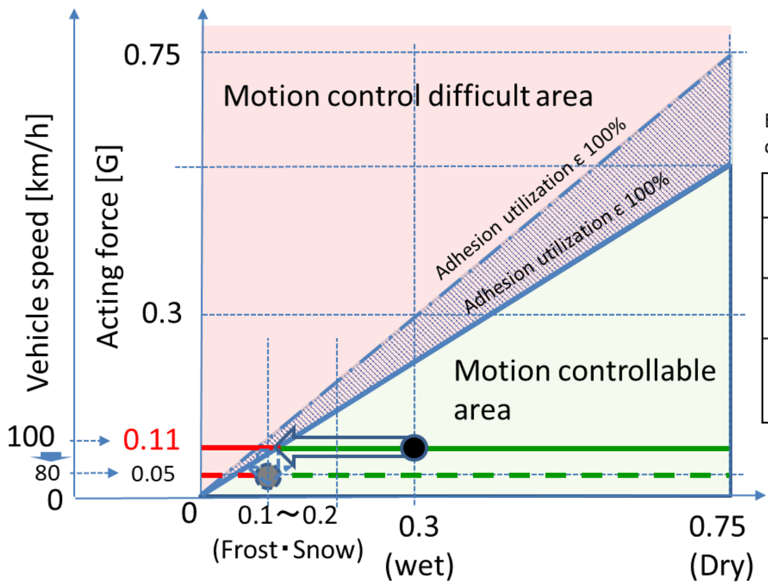


Wind speed	Speed limit
More than 10m/s Less than 15m/s	80km/h
More than15m/s Less than20m/s	50km/h
More than 20m/s	Road closed

Figure 101. Relationship between friction coefficient and action force in response to natural phenomena (crosswind)

4.3.3.6 Controllability of vehicle movement in response to tyre input road state disturbance

On Japanese motorways, speed restrictions are enforced based on weather conditions, as shown in the table (example of speed restrictions in relation to weather conditions on Japanese motorways). In other words, the weather conditions where no speed restrictions are in place are the boundary values. Here, in cases involving precipitation of 20 mm/h when traveling at 100 km/h, hydroplaning does not occur; therefore, the friction coefficient of 0.3 (lockμ) or above is the boundary value. However, with precipitation of 20 mm/h or above, hydroplaning occurs; therefore, the friction coefficient is greatly decreased. Furthermore, as freezing or snowy conditions cause the friction coefficient to decrease to 0.2 or below when considering the crosswind just mentioned, this cannot be kept within the controllable area of movement. Therefore, even in environments where it is common sense to always use normal tyres, the friction coefficient boundary conditions are equivalent to wet surfaces at 0.3 (Figure 102). Moreover, external force on tyres, such as deep gaps and pot holes, cause action forces, and may disturb vehicle behaviour. However, road administrators have a responsibility to maintain and manage safety on roads. Therefore, objective values are set to determine whether repair is necessary（Table 3）. In other words, if it is below this objective value, it is expected that a normal driver will be able to drive safely. Therefore, the boundary values related to external force on tyres are set to these objective values, and these are added to action forces in the same way as lateral wind.



Example of speed regulation for weather conditions in Japan's own road

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 102. Relationship between friction coefficient and action force in relation to road state

Table 3. Objective values for judging necessity of repair

Road type \ Item	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)

4.3.3.7 Controllability of vehicle movement in relation to tyre input tyre state disturbance

With regard to punctures while driving, this does not increase action force but cohesive usage rate decreases to 100% or below. According to SAE2013, even if one tyre punctures, provided that the rim does not make contact with the ground, the vehicle can be controlled up to 0.6 G (Tandy, Ault, Colborn, & Pascarella, 2013). This indicates that the cohesive usage rate drops to 60%. Moreover, at this extent, as it does not cause a dangerous state immediately, TD and stopping safely is required before the rim touches the ground, thus causing a burst.

4.3.3.8 Preventability/Unpreventability boundary conditions in vehicle movement disturbance

Preventability/Unpreventability boundary conditions in vehicle movement disturbances are conditions concerning whether driving can continue at the designed velocity (100 km/h in Japan) on a motorway as follows.

- Road state：Friction coefficient of 0.3（lock μ）or above, and external force on tyres of the objective value for road maintenance and repair or below（e.g.：ruts : 25 mm, gap :30 mm, pot holes: 20 cm）

- Road shape：Curves within the Japan Road Ordinance specifications（R = 460 m)

- Natural phenomena：Where lateral wind is wind speed without speed restrictions (<10 m/s)

With regard to the above three factors, all the added conditions are preventable.

If it is not possible to drive under these conditions (such as not possible at lateral wind of 5 m/s or above), it is necessary to for the manufacturer to define this as ODD in advance.

Tyre state：Slow puncture caused during driving; however, this is detected before the rim makes contact with the road surface.

Figure 103 shows the respective unpreventable conditions and conditions of operator responsibility.

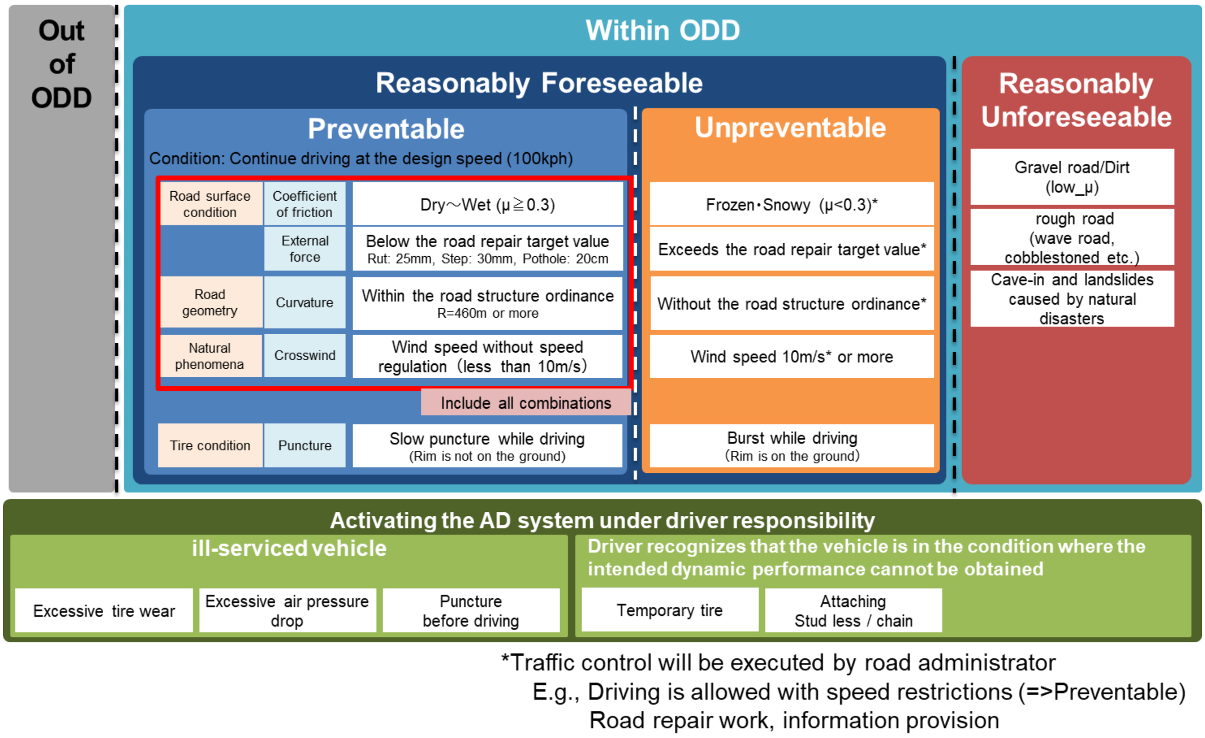


Figure 103. Motorways in Japan: preventability/unpreventability boundary conditions in vehicle movement disturbance

On general roads, unlike motorways, traffic rules cannot be strictly controlled (low necessity due to low to medium speeds). Thus, the preventability/unpreventability boundary conditions for vehicle movement disturbances on general roads are as follows:

- Road conditions: the coefficient of friction (μ) is 0.3 or higher; the external force on the tires is below the target value of road maintenance and repair (e.g., rut: 30–40 mm, step: 40 mm, and pothole: 20 cm).
- Road geometry: curves within what is stipulated by the road construction ordinance (e.g., for a designed speed of 60 km/h, R = 120 m).
- Natural phenomenon: the highest wind speed at which vehicles can be controlled against crosswinds (<20 m/s).

Deep water conditions on general roads can cause roads to be submerged; however, being submerged in water is not a function guaranteed by vehicle movement performance and is therefore excluded.

5 Scenario Database

5.1 Three layers of extraction

Functional scenarios that define qualitative scenario structures at the upper level, based on the three elements of driving actions, namely, “perception,” “judgement,” and “operation” can be systematically structured under the three scenarios of “perception disharmony,” “traffic disturbance,” and “vehicle movement disturbance,” thus enabling comprehensive scenario evaluations (Chapter 3).

Logical scenarios apply a quantitative parameter range to structuralized functional scenarios. Therefore, for example, in the case of a traffic disturbance, this is defined by extracting the vehicle path from the traffic flow data, and taking a data-driven approach where traffic flow parameters such as relative velocity and cut-in speed are defined based on statistical distributions. The traffic flow data refers to traffic monitoring and operation data, accident databases, insurance data, maps, and road data.

Concrete scenarios can be considered as individual evaluation conditions for concrete evaluations, that extract safety judgement boundaries for distinguishing safety state and unsafe states (Section 1.3).

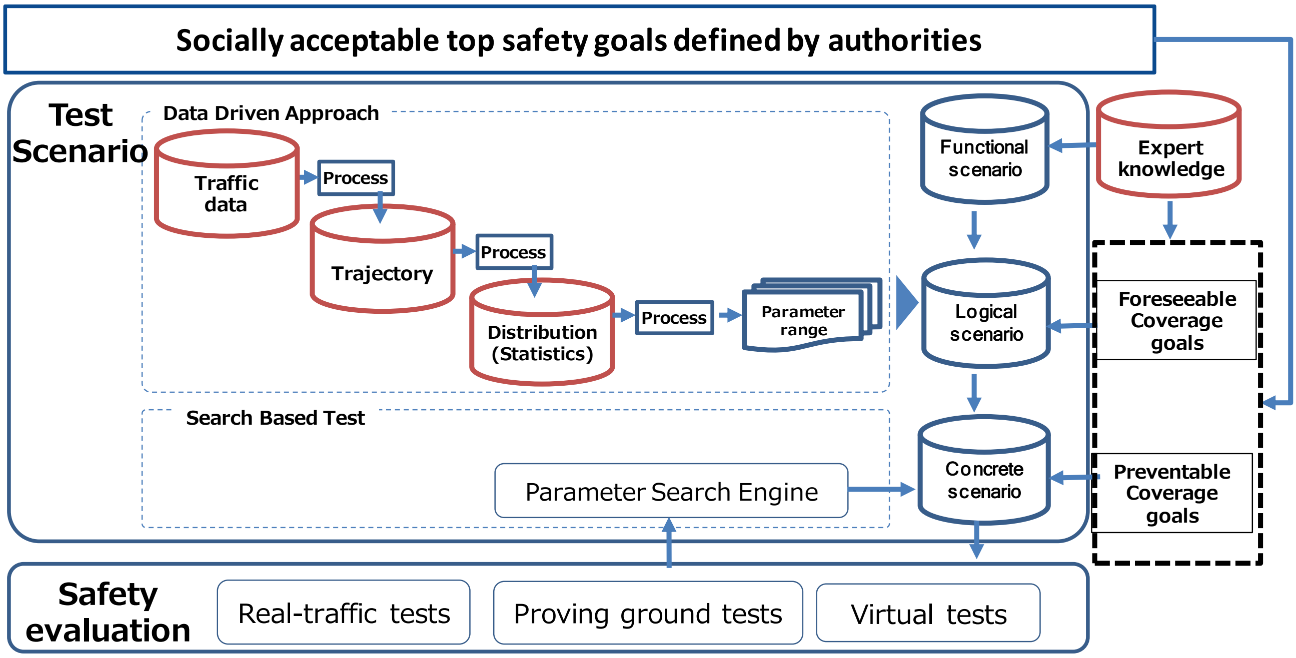


Figure 104. Process of developing and applying data-driven AD safe scenarios

5.2 Database parameters, format, and architecture

Figure 105 shows the information flow scheme required for creating actual test scenarios from a scenario catalogue and outputting them in a form in which these scenarios are standardized. These versatile standardized formats that can adapt to a wide range of simulation environments may be beneficial for AD safety evaluations. Files including information related to vehicle behaviour and road shape are generated via a test data generator from the scenario catalogue. These files can be applied to various simulation environments via a converter, and can be made independent using specific, commercially available software.

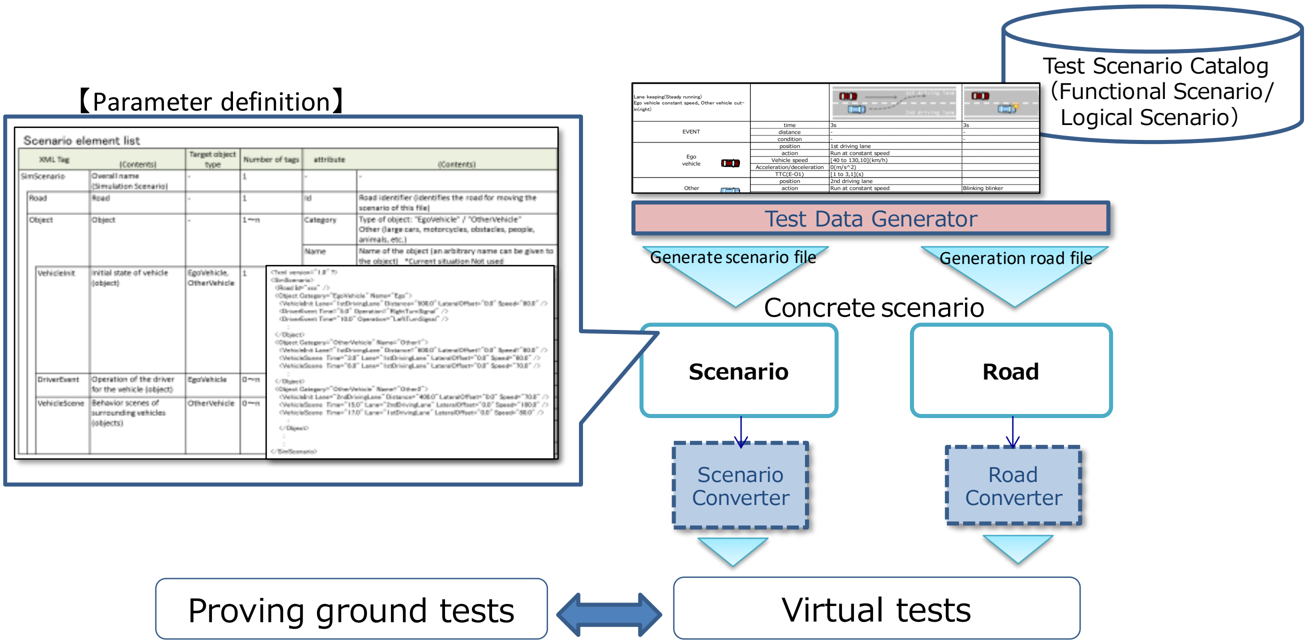


Figure 105. Information flow scheme for AD safety evaluation based on standardization scenarios

5.3 Test scenario database interface specification

Figure 106 shows the scenario database system. The scenario database uses actual traffic observation data as input and outputs scenarios required for safety evaluation. To realize this, an input/output interface is required. Moreover, a safety evaluation is performed using the output scenario data, and the result is fed back to the scenario database.

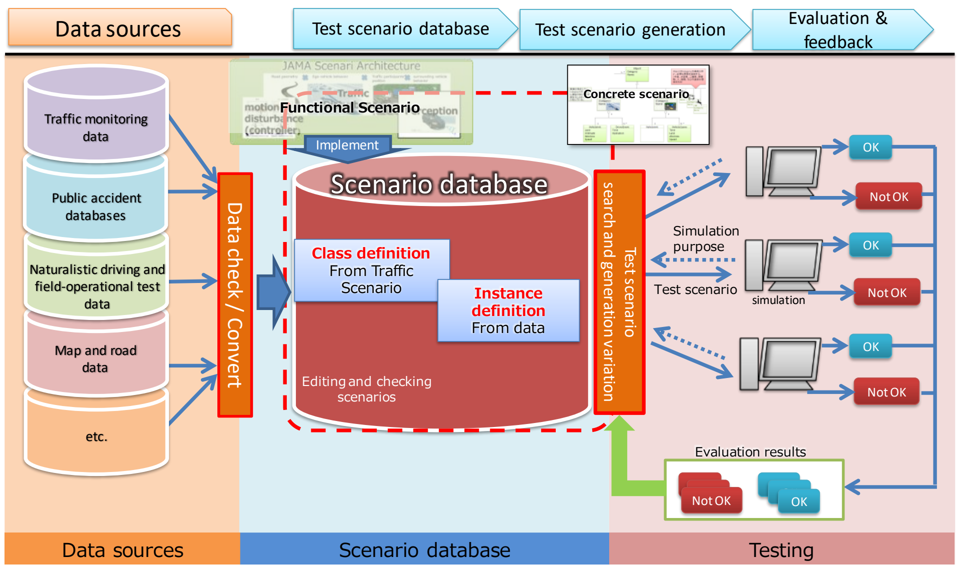


Figure 106. Scenario database scheme and interface

There is a wide array of actual traffic data, including traffic monitoring data, accident data, field test collection data, maps, and road data. To incorporate all of these unspecified large number of actual data items in a scenario database, it is necessary to convert them into an appropriate format (Figure 106 Data check/Convert). Data that are appropriately incorporated into a shared database can be used to generate scenarios in accordance with a standardized methodology.

To use the scenarios generated within a scenario database, an interface that enables searching, generation, and exporting of scenarios is required (Figure   Test scenario search and generation variation).

Annex A
Road Geometry

The tree diagram for the road component elements identified from the road structure shows corresponding parameters related to road component elements. Definitions of these parameters are shown in Table A-1.

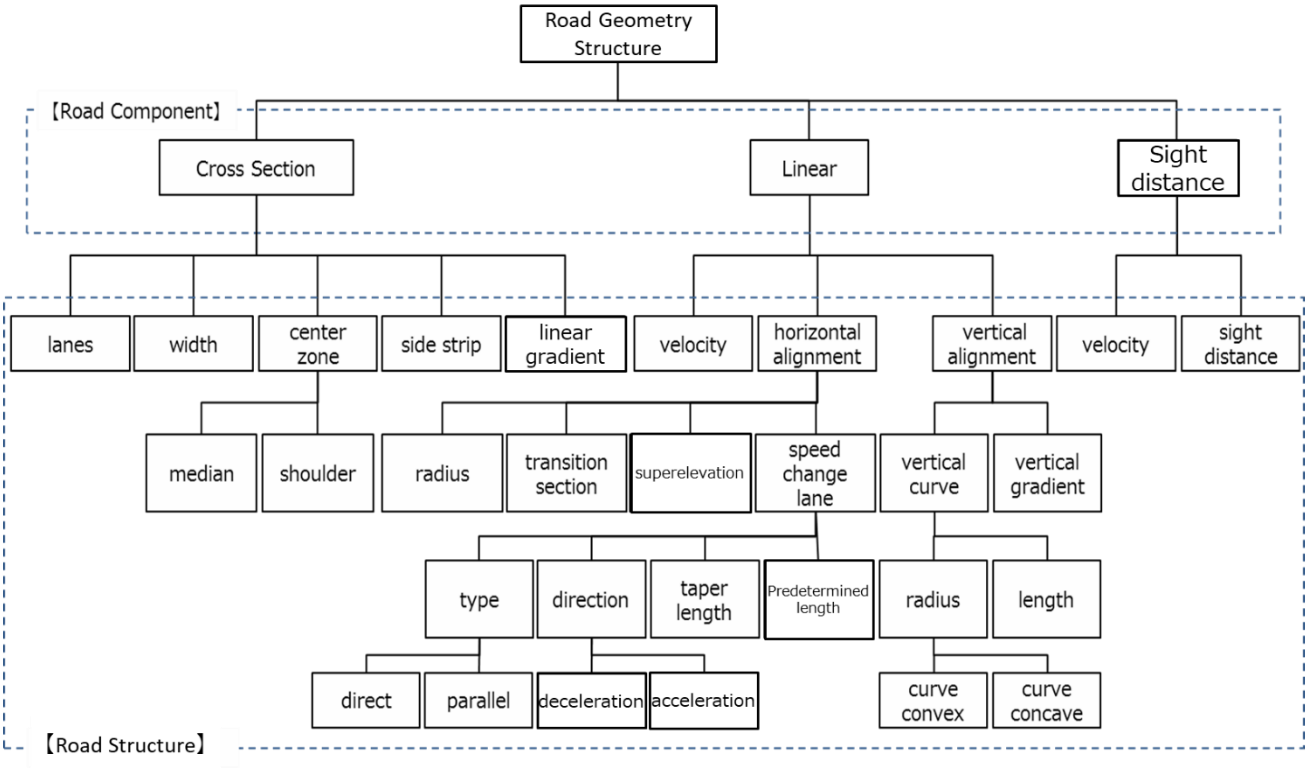


Figure A-1. Parameters related to road component elements (cross-sections, lines, and viewing distance) based on the Cabinet Order on Road Structure.

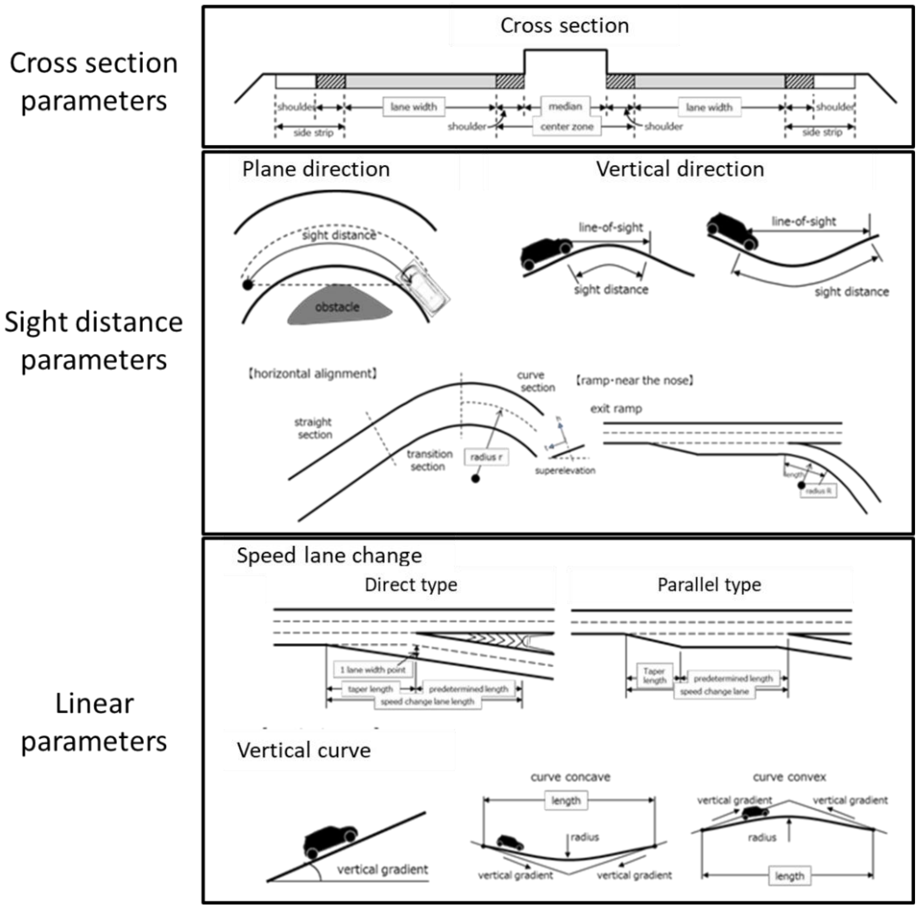


Figure A-2. An example of cross-sections, viewing distance, and linear road parameters based on the Japanese Cabinet Order on Road Structure.

Road geometry parameters were examined for each scenario category (cognition disturbance perceptual limitations, traffic disturbance, and disturbance in vehicle motion). For example, with traffic disturbances, as the number of surrounding vehicles increases, the number of lanes is increased in some cases. However, this is not directly related to cognition disturbance or disturbance in vehicle motion. Table A-1 shows the road geometry parameters to develop scenarios for each scenario category.

Table A-1. Road geometry parameters to develop scenarios for vehicle control categories.

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	-	-

Similarly, when each parameter is considered, important parameters for each scenario would be as follows:

— Parameters associated with cognition disturbance scenario include, for example, the median, the radius of curvature, vertical alignment, and viewing distance.

— Parameters associated with traffic disturbance scenario include the number of lanes, width, speed change lane, and vertical gradient.

— Parameters associated with disturbance in vehicle motion scenario include width, the radius of curvature, non-controlled interval, superelevation, and vertical alignment.

In terms of road geometry parameters for test scenarios, parameters that have no impact on safety were set to fixed values, and only the range of safety-related parameters are defined. In this manner, number of test cases can be reduced.

A.1 Road geometry component elements

Based on driving environment definitions, road geometry was classified into main roads, merge zones, departure zones, and ramps. Moreover, road geometry classification comprises four elements: main road, speed change lane, ramp, and nose vicinity (Figure A-3). Road structure parameters from the Cabinet Order on Road Structure are defined for each component of this book [4]. According to this basic classification, the relationship between four categories used to prepare scenarios and road geometry components standardized from the Cabinet Order on Road Structure used to build roads in Japan can be established. The examples of these standardized road geometry components are the main road, speed change lane, ramp, and nose vicinity. Moreover, the cabinet order incorporates the relationship between road geometry components and road geometry parameters important for safety such as cross-sections, lines, and viewing distance that are related to different road component parameters.

Note: The road geometry components and related parameters described herein are defined according to road technique standards related to Japanese road construction. The majority of standards in other countries employ similar rules, which facilitates the easy application of the methodologies proposed for different countries and areas.

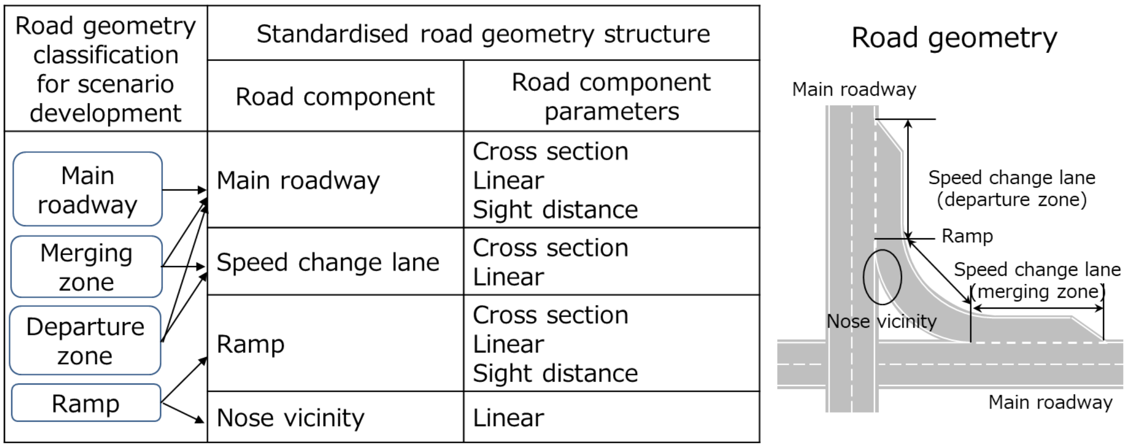


Figure A-3. Relationship between road geometry classification to develop scenario, standardized road components, and corresponding safety-related parameters.

A.2 Basic parameters of road geometry

To determine the basic road geometry parameters in a road structure model (for Japan, Table A-2), important parameters are set for strict values for each scenario (first column from the right in Table A-2). These parameters are presented with the upper and lower limits, and depend on the scenario.

Table A-2. A list of road parameters from the Cabinet Order on Road Structure (RSO) and baseline road geometry parameters from the Cabinet Order on Road Structure in Japan.

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 with actual environmental data

Actual road geometry may not strictly adhere to the law for a variety of reasons (e.g., limited by the landform). This is handled as a tentative scale, and may be extended over a long period of time. As such, since road conditions change, actual harsh conditions must be reflected in scenarios.

Table A-3. Examples of harsh conditions in real environment.

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 based on actual world map data

In this section, we explain the definition of important parameters for road geometry. Based on the road structure ordinances of each country, road geometry parameters were identified. However, parameters are not important elements. For example, when there are a large number of lanes, the number of surrounding vehicles increases, and there may be an impact as traffic disturbance; however, there may not be an impact on cognition disturbance and disturbance in vehicle motion. Therefore, the selection of road geometry parameters depends on scenario categories.

— Important parameters covered by the cognition disturbance scenario include the departure zone, the radius of curvature, length of the curve, longitudinal open circuit, and viewing distance.

— Important parameters covered by the traffic disturbance scenario include the number of lanes, width of lanes, acceleration and deceleration lanes, and longitudinal gradient.

— Important parameters for disturbance in the vehicle motion scenario include the lane width, the radius of curvature, transition zone, superelevation, and vertical alignment.

Note 1-Entry: By setting critical parameters, where unimpacted parameters are fixed, as road geometry parameters of test scenarios, the number of test cases can be reduced.

To determine road geometry parameters, according to Table B2, we assigned the harshest values for important parameters of road geometry based on the Cabinet Order on Road Structure in Japan. However, the actual shape of roads may not strictly follow the Cabinet Order on Road Structure (e.g., the length of merge zone may be shorter than what is stipulated by the ordinance since construction space in a crowded city is limited). Therefore, baseline values of road geometry parameters defined by the Cabinet Order on Road Structure must be updated with actual harsh conditions of road geometry. To this end, we incorporated dynamic map data into the process, e.g., in a survey of motorway characteristics in Tokyo region where the “legal speed is 100 km/h” and “the minimum radius of the curved section is less than 100 m” (left in Figure A-4), multiple locations fit the description (blue spots to the right of Figure A-4). Such searches reflect actual road requirement parameters for the radius of curvature in the Tokyo region; thus, road geometry baseline parameters (Table Table A-2) must be updated from 380 m to 100 m or less.

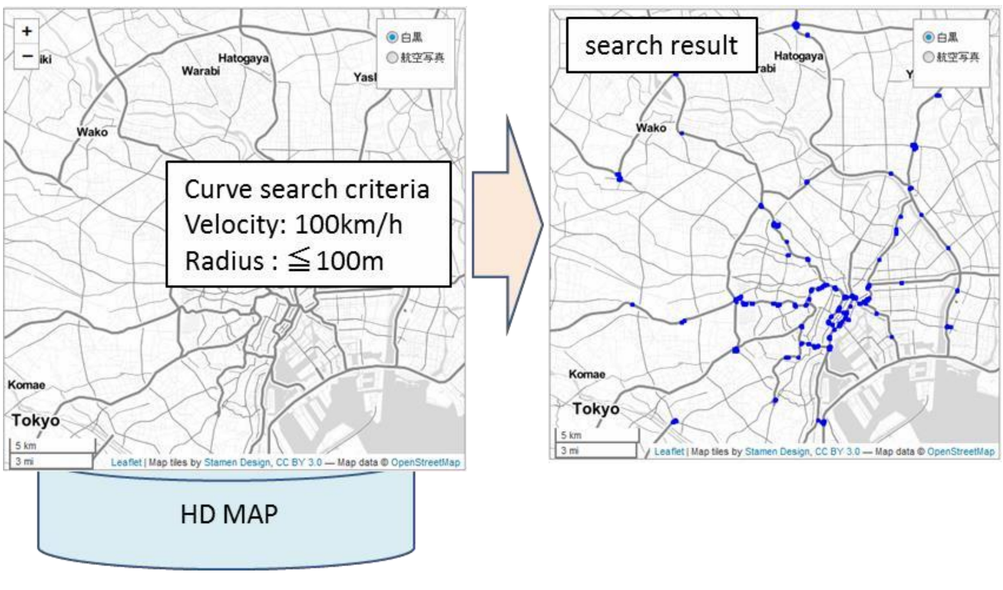


Figure A-4. Data extraction from a dynamic map.

Annex B

Scenarios for Motorcycles

Similar to the systemizing process explained in regard to traffic disturbance scenarios, road geometry, ego vehicle behaviour, and surrounding motorcycle location and motion, we propose a methodology to structure traffic disturbance scenario for motorcycles (Figure B-1).

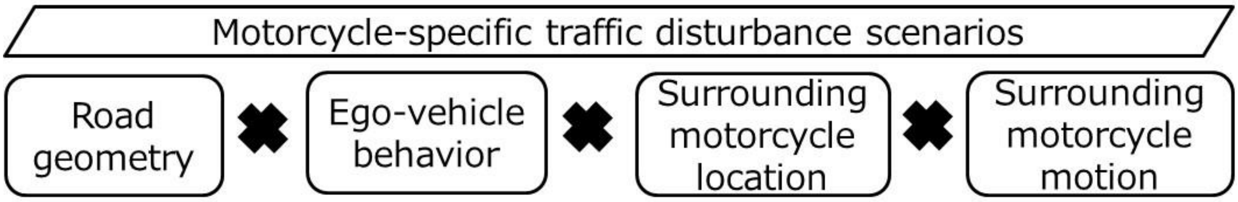


Figure B-1. Structural concept of traffic disturbance scenario for motorcycles.

B.1 Classification of surrounding motorcycle location and motion

When defining scenarios for general vehicles, we defined the location of surrounding vehicles in eight directions around the vehicle. In motorcycle scenarios, in addition to this, we defined right and left of the vehicle as unique locations for motorcycles to build scenarios.

As shown on the left side of Figure B-2, locations unique to motorcycles [L] and [R] are on both sides of the vehicle within the same lane. Motorcycles can move to [L] or [R] by decelerating from 1 in front (a), accelerating from 2 behind (b), or by changing the lane from surrounding locations, 3,4, 5, 6, 7, ot 8 (c) (centre in Figure B-2). As shown on the right side of Figure B-2, a motorcycle can move from [L] and [R], where it may approach the vehicle laterally (d), move forward (e), move backward (f), or be parallel to the vehicle (g).

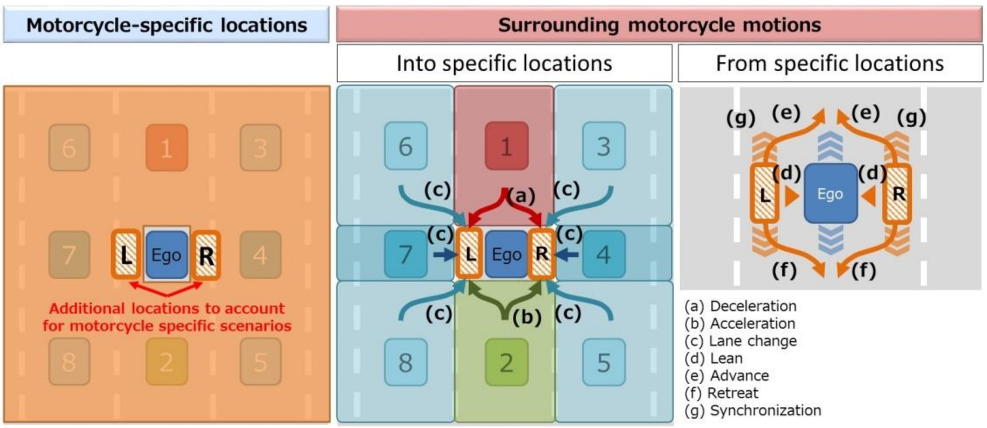


Figure B-2. Locations and motion of motorcycles that could prevent motion of a vehicle (left)

Motorcycles can be evaluated in the same manner as the traffic disturbance scenarios for general vehicles (Figure 48), but the motorcycle-specific locations discussed above must be considered.

B.2 Traffic disturbance scenario unique to motorcycles

The structure of motorcycle scenarios is expressed by a matrix that includes 56 possible combinations. In a lane change scenario for vehicle, only synchronized motions are targeted. This is because lane change for the vehicle is physically impossible if there are vehicles in locations unique to motorcycles: [L] and [R]. This leaves 18 scenarios that are actually achievable in the real traffic, which are incorporated in the safety assessment (Figure B- 3).

: EGO : Motorcycle

Road geometry	Ego-vehicle behavior	Surrounding motorcycle position and motion						
		Into specific locations			From specific locations			
		Deceleration to side	Acceleration to side	Lane change to side	Lateral approach	Advance	Retreat	Synchronization
Main road	Lane keep	No.1	No.2	No.3	No.4	No.5	No.6	–
	Lane change	–	–	–	–	–	–	No.7
Merging zone	Lane keep	–	–	No.8	–	–	–	–
	Lane change	–	–	–	–	–	–	No.9
Departure zone	Lane keep	–	–	No.10	–	–	–	–
	Lane change	–	–	–	–	–	–	No.11
Ramp	Lane keep	No.12	No.13	No.14	No.15	No.16	No.17	–
	Lane change	–	–	–	–	–	–	No.18

Figure B- 3. Traffic disturbance scenario for motorcycles.

Annex C

Approach for complex scenarios of traffic disturbance

In an actual traffic environment, multiple traffic participants can take multiple actions at various times. In this Section, we examine scenarios including multiple traffic participants based on the developed concept for the traffic flow scenario.

C.1 Concept of avoidance motion scenario

When surrounding vehicles make sudden dangerous moves, the ego vehicle must react to avoid such action. Such danger can take place during lane keep and lane change. The latter refers to situations when surrounding vehicles are trying to move into the same space as the ego vehicle as they try to change lanes. Action to avoid these vehicles is called avoidance motion, which is a secondary motion by the ego vehicle. Thus, avoidance motion scenarios aim to assess the safety of such secondary behaviour by the ego vehicle.

C.2 Traffic flow scenarios

To understand scenarios created by avoiding dangerous movements of surrounding vehicles, we present a stepwise sequence. This sequence begins with a sudden approach by surrounding vehicles, such as a dangerous approach by surrounding vehicles to the ego vehicle driving while keeping the lane, or when the ego vehicle tries to change the lane (Figure C-1). This is the starting point of avoidance motion by the ego vehicle. Before executing this avoidance motion, the ego vehicle must determine the range wherein it is able to execute the avoidance motion. This range is called the “avoidance area”. For example, when a preceding vehicle suddenly decelerates, creating a potentially dangerous scenario (avoidance trigger), the ego vehicle must judge if there is a space immediately behind (avoidance area), and then must decelerate as the avoidance motion. However, when determining avoidance area, the ego vehicle must consider cut-in vehicles that might enter the same area. When considering these aspects and the environment of the road the vehicle is driving on (e.g., main road, merge lane, etc.), different traffic flow scenarios can be created.

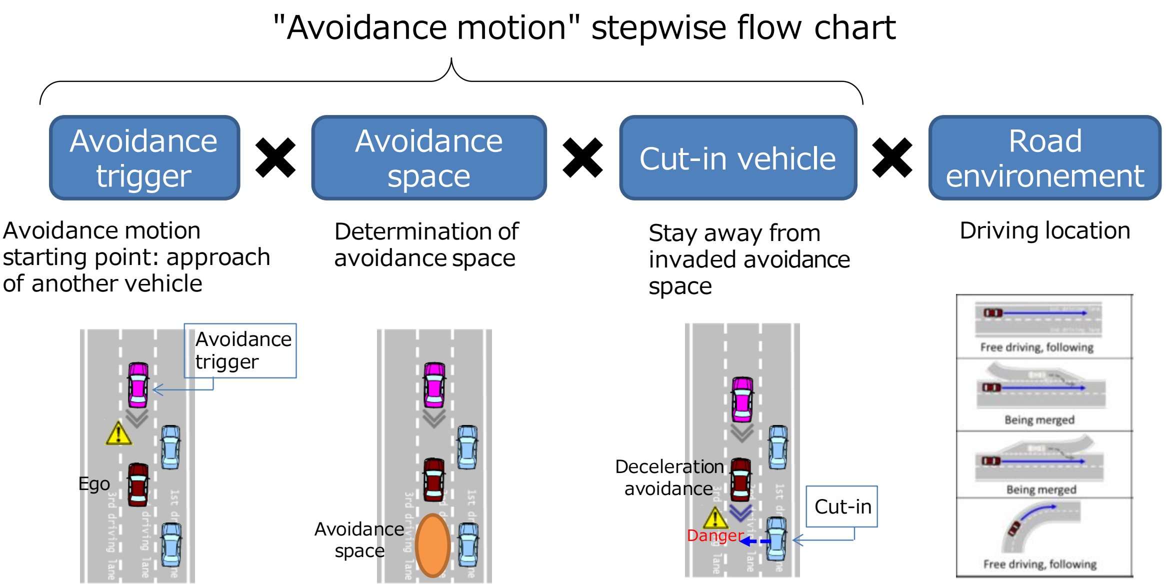


Figure C-1. Steps from the start and finish of an avoidance motion.

C.2.1 Avoidance trigger

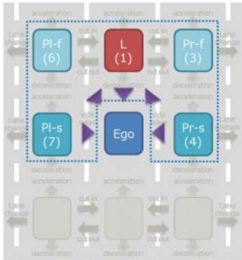
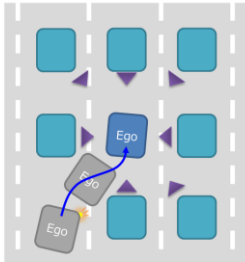
<table>
<tr><th>Ego-vehicle motion</th><th>Avoidance trigger types</th><th>Pattern diagram</th></tr>
<tr><td>Lane keep</td><td>a)Approach from the front and sides
Deceleration of the lead vehicle, cut-in by the lead side vehicles.
※Approach from the back (rear-end collision) is not considered.</td><td>a)Approach from the front and sides

</td></tr>
<tr><td>Lane change</td><td>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</td><td>b) Approach to the lane change destination

</td></tr>
</table>

Figure C-2. Driving situation of the ego vehicle in avoidance motion scenarios.

C.2.2 Avoidance space

Avoidance space is defined as a range wherein the ego vehicle can take an avoidance motion. When approached by surrounding vehicles, the avoidance trigger begins, and the ego vehicle must determine the avoidance space. For safety, the avoidance space is not in the direction where the trigger vehicle is approaching from. Figure C-3 emphasizes the avoidance space for both lane keep scenarios and lane change scenarios.

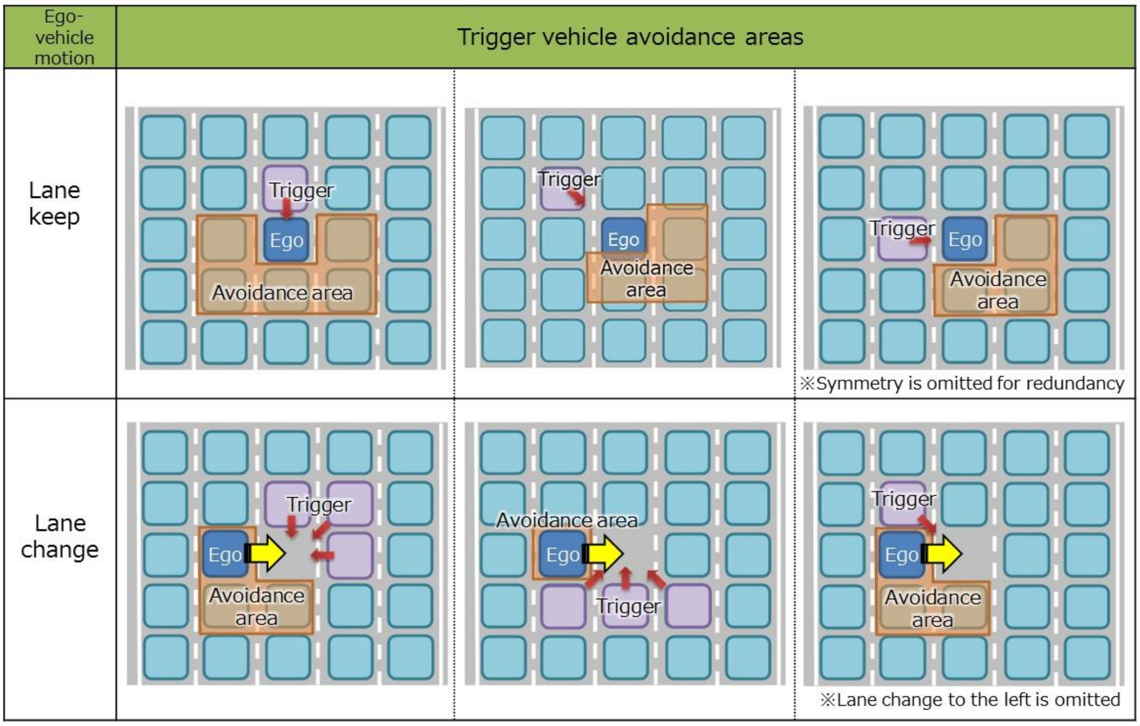


Figure C-3. Avoidance areas for each trigger vehicle for lane keep (top) and lane change (bottom).

In a case of lane keep (top half of Figure C-3), the trigger vehicle approaches from in front of the ego vehicle [L(1)], from front and the side of the ego vehicle [Pl-f (6)、Pl-f (3)], or from the side of the ego vehicle [Pl-s (7)、Pl-s (4)]. The areas highlighted in red are the avoidance areas (lateral symmetry is omitted). The lower half of Figure C-3 shows a scenario in which the ego vehicle changes lanes (lateral symmetry is omitted). In this case, vehicles in the lane change destination for the ego vehicle become trigger vehicles. Areas highlighted in red are the avoidance areas.

After determining the avoidance area, the pattern of vehicles in the avoidance area must be determined. For example, if deceleration by the preceding vehicle is the trigger, combinations of patterns of vehicles in each cell of the avoidance area becomes $2^5 = 32$ (Figure C-4).

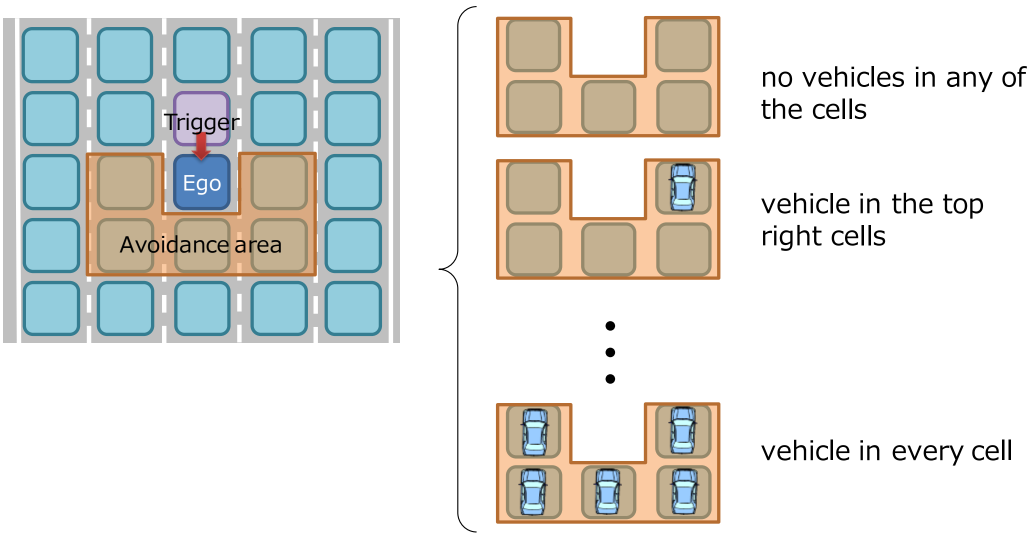


Figure C-4. Patterns of vehicles in each cell in the avoidance area.

C.2.3 Cut-in vehicles into the avoidance area

After confirming whether there are vehicles in the avoidance area (how many and which cell), vehicles that could cut into the avoidance area from adjacent spaces must be identified. Ranges from where cut-in into the avoidance area is possible are shown in Figure C-5.

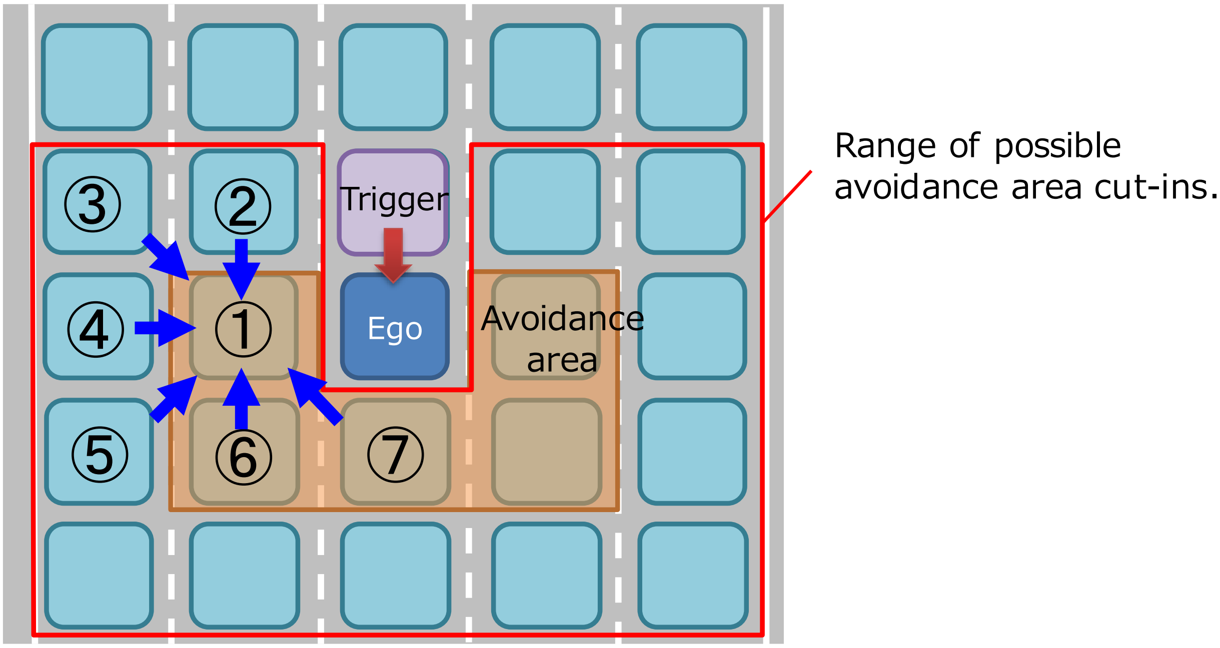


Figure C-5. Range where cut-in into the avoidance area is possible.

The avoidance area is highlighted in red. Considering a case where the ego vehicle moves into cell ① to avoid the trigger vehicle, possible cut-in by vehicles in locations⑥ and ⑦ in the avoidance area and in adjacent locations②, ③, ④, and ⑤, must be considered.

C.2.4 Road environment

The road environment is a combination of road geometry and the ego vehicle location, which are two factors that impact the avoidance motion. “Road geometry” is classified into the main road, merge lane, departure lane, and ramp. Ego vehicle locations are defined by the shape of the avoidance area and number of lanes in each road geometry.

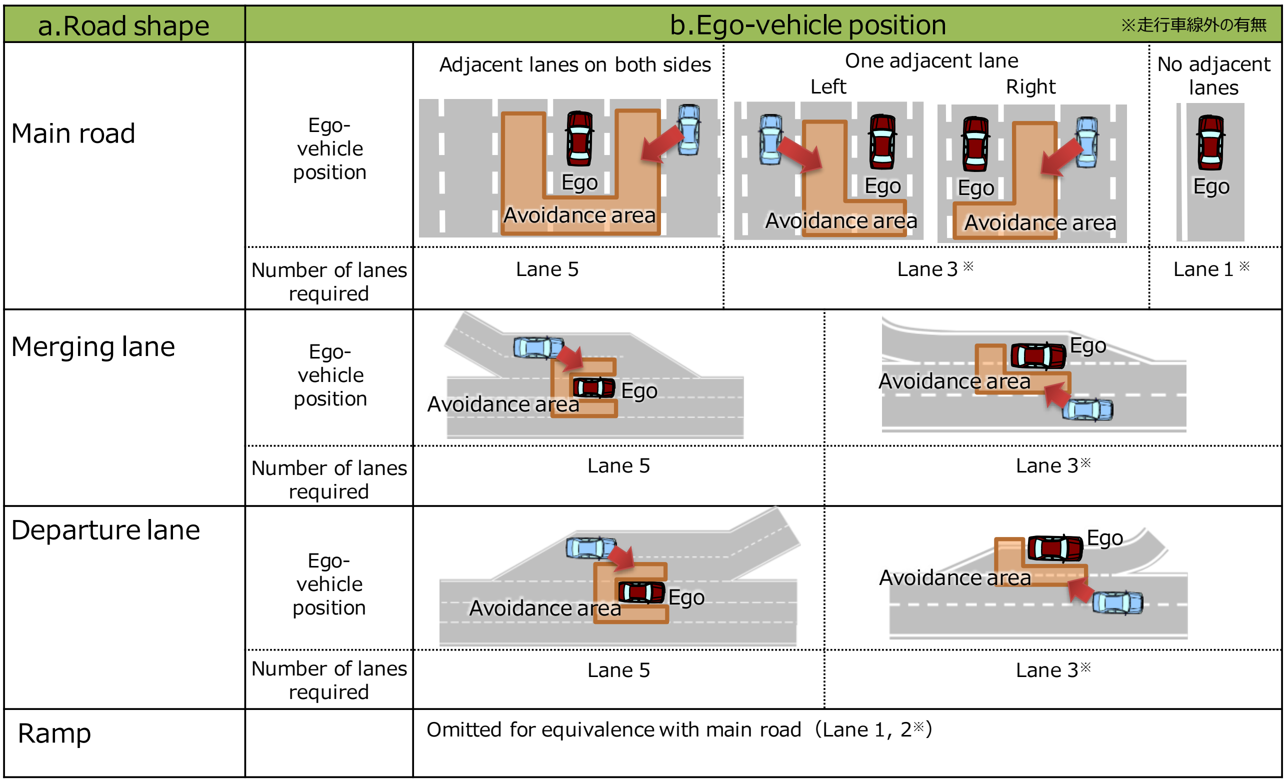


Figure C-6. Classification of road environment in avoidance motion scenarios.

Annex D

Verifying the completeness of scenario database based on accident data

There are three cases to explain how completeness of scenario database is verified based on accident data.

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

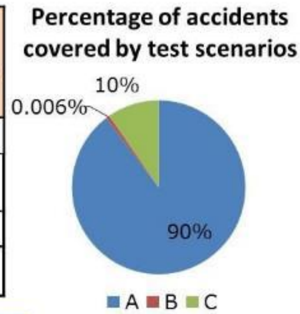
Verification of the completeness of the traffic flow scenario system is possible. For example, one can assess if accidents reported in the German In-Depth Accident Study (GIDAS) database (Otte, Krettek, Brunner, & Zwipp, 2003) are covered. As an assumption, all possible scenarios in the German traffic environment must be presented in the accident classification system of GIDAS.

GIDAS classifies traffic accidents according to the pre-defined rules related to accident characteristics. We related and compared the accident classification system defined by GIDAS (GIDAS code) and traffic flow scenario system.

The table to the upper left of Figure D-1 shows the number of GIDAS accident codes classified after correlation. Categories A, B, and C represent 78 codes and 7,567 accidents for motorways included in the analysed database. The verification result of these accident data showed that 33 codes and 6,787 accidents can be analysed under the traffic flow scenario system. The traffic flow scenario system possibly covers 90% of all motorway accidents reported in Germany.

Category B comprises eight codes and 49 accidents (0.006% of all motorway accidents) related to road characteristics that are not covered by the scenario matrix. Road geometry data used to prepare the list of scenarios is based on Japanese Road Structure Regulations (Japan Road Association, 2004), but it may not cover some characteristics of German motorways. To cover the remaining eight signs, adaptation to German road characteristics may be necessary.

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
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

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

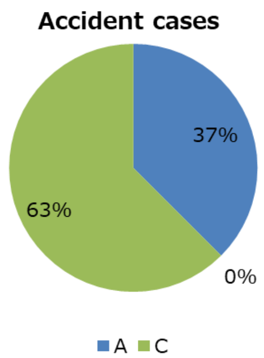
Figure D-1. Scenario database and number of cases (per road and ego-driving).

Category C includes 37 codes and 731 accidents (10% of total) that are not covered by the proposed safety method. Further analysis of codes indicates that three code subcategories (total of 28 codes) were unlawful operations such as driving in the wrong direction on a motorway or unlawful parking on the motorway shoulder (C1−C3). Seven remaining codes include obstacles on the road, animals, and other unknowns (C4−C6). Prevention of collision in this category (C) is difficult for AD engineers. For example, an auxiliary approach such as tighter regulations is necessary.

D.2 Pre-crash scenario typology for crash avoidance research (NHTSA)

The NHTSA Pre-Crash Scenario Typology for Crash Avoidance Research defines pre-crash scenario typology for crash avoidance research based on the NHTSA general estimate system crush database. This typology comprises pre-crash scenarios that present vehicle motion, dynamics, and important phenomena immediately before a crash (Najm, Smith, & Yanagisawa, 2007). By applying the same methodology to the GIDAS data, a comparison can be made between typology and the list of scenarios developed in the present report. This typology includes 27 pre-crash scenario categories, 16 of which are about motorway accidents. By comparing the scenario database developed from these categories, the completeness of the scenario database can be verified (Figure D- 2). This comparison shows that 6 out of 16 categories are subject to the traffic scenario database. The remaining 10 codes belong to categories that include unlawful or unpreventable actions. For complete coverage, an auxiliary approach for vehicle engineering may be necessary.

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 of traffic 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 (https://www.itarda.or.jp/) compiles data on traffic accidents in Japan. Therefore, by obtaining the data from 633,639 accidents that occurred between 2018 and 2019 (totalling conditions: Table D-1) and comparing the same data with the traffic disturbance scenario (Figure 47), the completeness of the scenario can be verified.

Table D-1. Totalling conditions for accident data

Items	ITARDA data categories	Approach to totalling
Accident type	"Person vs. vehicle," "vehicle interaction," "single vehicle," and "train"	Because the scenario structure targets complicated scenarios with other vehicles, it is limited to vehicle-to-vehicle accidents.
Accident details	"Death," "serious injury," and "minor injury"	Because the goal is to verify completeness, all accidents involving people are targeted.
Road geometry	"Intersection," "near an intersection," "single road," "railroad crossing," and "general traffic location"	Because the ITARDA accident data cannot distinguish between merging and branching zones, these are included in single roads. "Location of general traffic" among the accident types is not included in the analysis. "Near intersection," "single road," and "railroad crossing" are defined as the single road (including merging / branching zones) of the functional scenario, and the "intersection" is defined as the intersection section of functional scenario. However, accidents classified as single-road is classified as intersections if either vehicle's action includes "right turn" or "left turn" or if the vehicles approach from the crossing direction.
Involved parties	"Passenger car," "freight vehicle," "special vehicle," "motorcycle," "tram," "train," "light vehicle," "pedestrian," "property," "no other party," and "excluded parties"	Ego vehicle and other vehicles in the scenario structure are replaced with the first and second parties of the ITARDA accident data for analysis. Ego vehicle is a "passenger vehicle" (excluding minicars) and "cargo vehicle," while the other vehicle is a "passenger vehicle," "cargo vehicle," "motorcycle," "tram," "train," or "light vehicle."
Behavior types	"Starting," "going straight," "passing," "route change," "left turn," "right turn," "rotation," "backing up," "crossing," "meandering," "sudden stop," "parking," "other," and "excluded parties"	The behavior of the scenario structure – "going straight," "lane change/swerving," and "turning" are matched with a behavior type for analysis (Table D-2).
Involved parties' traveling direction	"Road Standards for Vehicles" and "Off-road standards for Vehicles"	Based on the involved party's direction of travel, determine from which direction other vehicles approach the ego vehicle (same/crossed (from R/L)/oncoming).

NOTE: Among the accidents that occur between vehicles, AD vehicles are analyzed as passenger vehicles and cargo vehicles; thus, in an accident where both the first party turning right at an intersection and the second party that is going straight can be substituted with AD vehicles, the analytical target will have AD vehicles substituting for both the first and second parties. Therefore, the number of cases the scenario covers will be larger than the number of actual accidents.

Table D- 2. Relationship between behavior categories in accident statistics and behavior of the scenario structure

Behaviors in FS	Accident statistics categories*1
Going straight	**"Starting," "going straight," "crossing*2,"** "sudden stop," "stop," and "parking"
Lane change/Swerving	"Passing," **"lane change*3,"** and "meandering"
Turning	**"Left turn," "right turn," and "crossing*2"**
Other	"Other" and "excluded parties"

*1. Only the behaviors of AD vehicles in bold letters are considered.
*2. In "crossing," where vehicles come from roadside facilities, if the vehicle is going straight, it is classified as "going straight," and if it is turning right or left, it is classified as "turning."
*3. It is assumed that AD vehicles do not change course in an intersection.

Analytical results

The analytical result of the number of accidents for each scenario structure is shown in Table D-3. The vertical column shows the road geometry and the behavior of the ego vehicle. The horizontal axis shows the behavior of other vehicles and the direction of approach. There are four road geometry categories in a scenario structure: "non-intersection," "merge," "branch," and "intersection;" however, because merge and branch zones cannot be separated in the ITARDA data, these are all included in "intersection." The direction of approach for other vehicles on the horizontal axis considers the same direction as the ego vehicle as "same," the cross direction as "crossed (from R/L)," and an approach from the opposite direction as "oncoming." The green cells in the table indicate the number of accidents included in the scenario structure, while the red cells indicate the number of accidents for which the details are unknown.

The number of scenarios included totaled 1,004,752 (green cells) and 1,136 (red cells). If the coverage rate is defined as the accident scenes covered by the scenario (green cells) within possible accident scenes for AD vehicles (green and red cells), 99.89% of accident scenarios are covered (Table D-4).

Table D-3. Comparison with the ITARDA data accidents for the scenario structure

			Surrounding vehicle behavior and coming direction											
			Going straight			Lane Change/Swerbing			Turning			Other		
			Same	Crossed	On coming	Same	Crossed	On coming	Same	Crossed	On coming	Same	Crossed	On coming
Road structure and Subject vehicle vehavior	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
		TN	41K	49K	47K	1K	192	89	2K	3K	1K	29	43	36

Table D-4. Estimate of the coverage rate

Items	Numbers
Number of accident scenes covered by FS (green cells)	1,004,752 [cases]
Unknown details (red cells)	1,136 [cases]
Coverage rate (green/(green + red))	99.89%

Annex E

Principle models and evaluation scenarios of perception disturbances

As described in 4.2.1, the principle models of each sensor should be understood and the parameters with their ranges which characterize the models should be defined, in order to derive the perception disturbance scenarios based on sensors' principles. The principle models, parameters with their ranges and the representative of evaluation scenarios for perception disturbances generated in sensors of mmWave Radar, LiDAR and Camera are written up below. The principles related to the phenomenon with high frequency and proving tests in exclusive roads (pedestrian approaching, rain drops, puddles etc.) are written as representative examples.

E.1 Processes of principle models description and evaluation scenario derivation

Principle models and evaluation scenarios of perception disturbances are derived according to the following procedure.

- Describe a phenomenon which occurs as a perception disturbance and identify phenomenon parameters
- Make out the model (= principle model) which describes the phenomenon above and identify principle parameters
- List up causal factors and their parameters which contribute to changes of the principle parameters
- Identify a range of each causal factor parameter
- Describe the perception disturbance as change of the causal factor parameters, and define an evaluation scenario with the combination of parameter changing and a traffic flow scenario

Here, any causal factors can be selected for an evaluation scenario in the case that these are described in the same principle model, while the range of causal factor parameters should cover the range of ODD of a system.

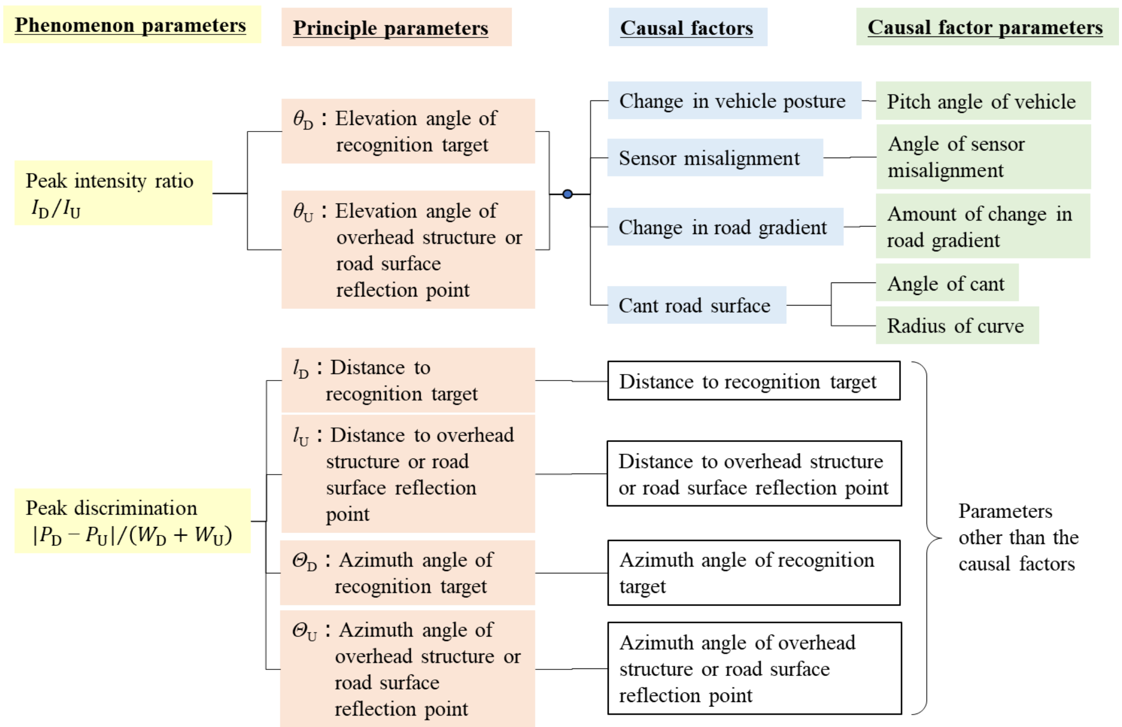


Figure E- 1. Example of a relationship between phenomenon parameters, principle parameters, causal factors and causal factor parameters of a perception disturbance

Henceforth the examples of principle models and evaluation scenarios of the perception disturbance for each sensor are showed. For evaluation scenarios in which the ego vehicle speed is defined as ‘maximum speed within ODD’, the conditions with shortest TTC to recognition targets are selected and written from the aspect of safety evaluation.

E.2 Principle models and evaluation scenarios of mmWave Radar

As examples for mmWave Radar, following 5 of principle models and evaluation scenarios of perception disturbances are described.

- Large difference of signal (S) (recognition target)
- Low D/U (road surface multipath)
- Low D/U (change of angle)
- Low S/N (direction of a vehicle)
- Low D/U (surrounding structures)

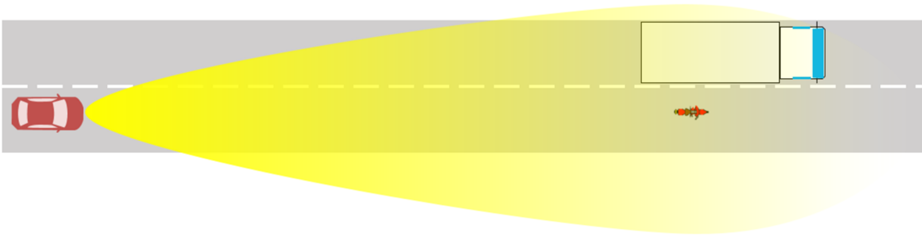
E.2.1 [mmWave Radar] Large difference of signal (S) (recognition target)

E.2.1.1 Phenomenon and Principle

Large difference of signals (recognition target)

E.2.1.1.1 Phenomenon

When pedestrians or motorcycles, etc., that have relatively weak reflection pass by the side of a recognition target with an intense reflection (such as a truck), the reflection signals from the motorcycles, etc., then become buried in the intense reflection signals from the truck, resulting in a false negative.



Phenomenon Parameters

Reflection point cloud

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

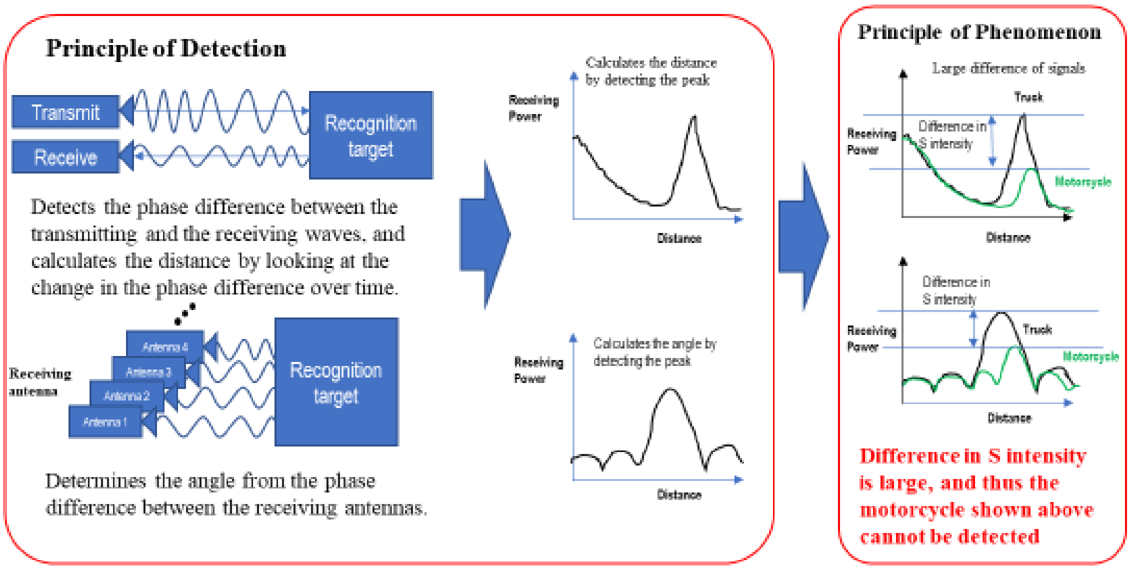
Phenomenon Mode

False negative; a target exists but is not detected.

Large difference of signals (recognition target)

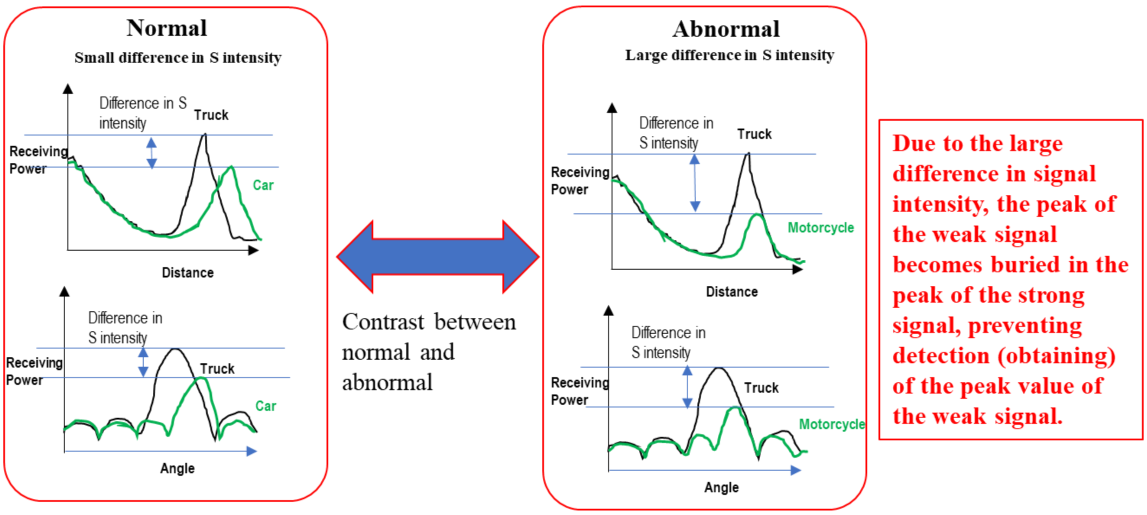
E.2.1.1.2 Outline of the Principle

Due to the large difference in the reflection intensity of the targets, the small signal becomes buried in the large signal, resulting in the recognition target with the weaker reflection going undetected.



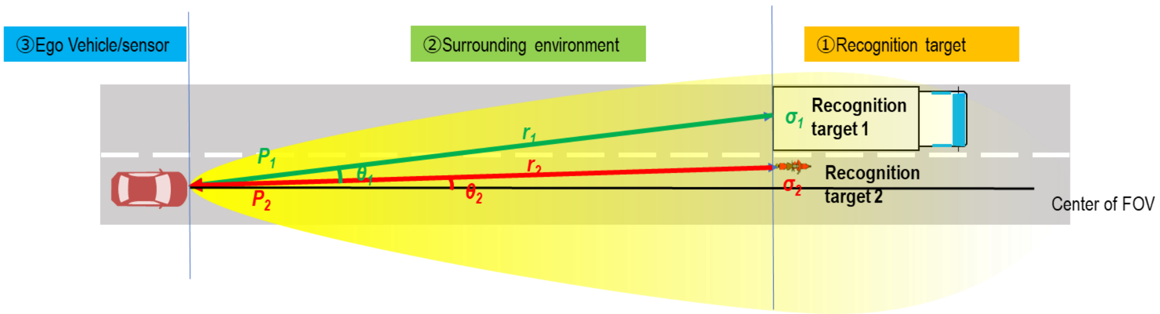
Large difference of signals (recognition target)

Contrast Between Normal and Abnormal



E.2.1.1.3 Principle Model

Large difference of signals (recognition target)



Model Description

S intensity is the power value of the reflection signal.

Focus on a model describing power

P_t: Power of transmitted waves

P_n: Power of reflected waves from the recognition target (n)

λ: Wavelength of radio waves

$G(\theta)$: Antenna gain

σ_n: RCS (radar cross section) of the recognition target (n)

Power by the reflection from the recognition target (n)

$$P_n = \frac{\lambda^2 \{G(\theta_n)\}^2 P_t}{(4\pi)^3 {r_n}^4}\sigma_n \quad \rightarrow \quad \sigma = \lim_{r \to \infty} 4\pi r^2 \left|\frac{E_s(\vartheta,\varphi)}{E_i}\right|^2$$

E_s: Scattered electric field from the recognition target

E_i: Incidence electric field into the recognition target

In the case of 2 recognition targets, the power from reflection is:

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

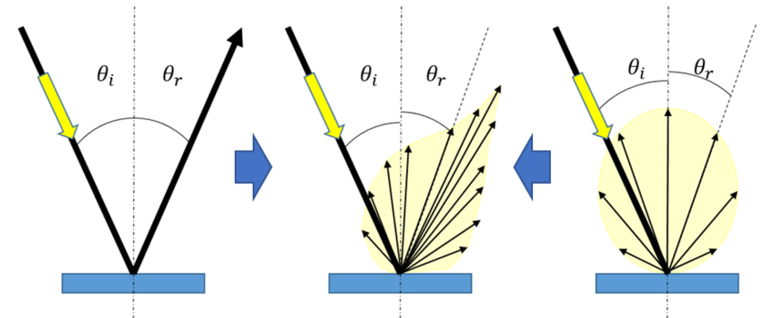
※If there are n numbers of recognition target, insert the reference number of each recognition target as a subscript to *P, r, and σ. E.g.* (n=1,2,3,…)

Large difference of signals
(recognition target)

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

E_s: Scattered electric field from the recognition target
E_i: Incidence electric field into the recognition target

The radar cross-section (RCS) of the recognition target is expressed as the product of the **projected area, reflectance and the directivity of the scattered waves.**
The **directivity of the scattered waves** referred to here, is normally a combination of a specular surface reflection and a perfect diffuse reflection.



Specular surface reflection Normal reflection Perfect diffuse reflection

Large difference of signals
(recognition target)

Reflectance is…

In the case of vertical polarization:

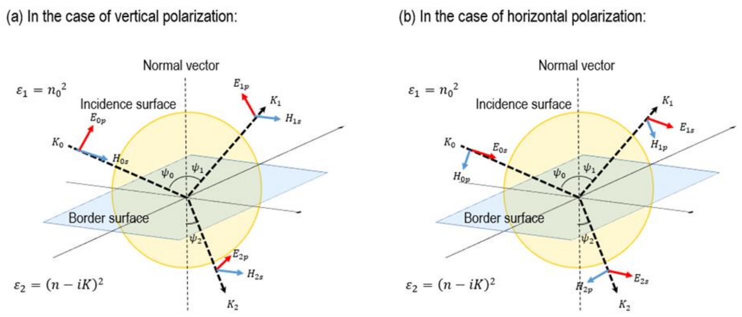
$$R_p = \frac{\left|\varepsilon_2 \cos\psi_0 - \sqrt{\varepsilon_1(\varepsilon_2 - \varepsilon_1 \sin^2\psi_0)}\right|^2}{\left|\varepsilon_2 \cos\psi_0 + \sqrt{\varepsilon_1(\varepsilon_2 - \varepsilon_1 \sin^2\psi_0)}\right|^2}$$

In the case of horizontal polarization:

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

In the case the reflector is a metal, permittivity (ε_r) is:

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



※The relationship between permittivity and relative permittivity ⇒
Relative permittivity = permittivity of the medium / permittivity in the vacuum

R_p: Reflectance with horizontal polarization	
R_s: Reflectance with vertical polarization	
ε_1:Permittivity of air	ε_2:Permittivity of reflector
ψ_0:Incidence angle of the wave	ε_r:Permittivity of metal
ω:Radio wave frequency	ω_p:Plasma frequency

In terms of 'Reflectance,' the parameters are **permittivity and incidence angle, and permittivity is a parameter related to the material.**

Further, **projected area** refers to the reflective surface area of the recognition target, and this will vary depending on the shape, orientation, size and relative position of the recognition target.

Large difference of signals
(recognition target)

Let's summarize what we have learnt so far…
The intensity of the reflected signal (S) from the recognition target depends on the power value (P).

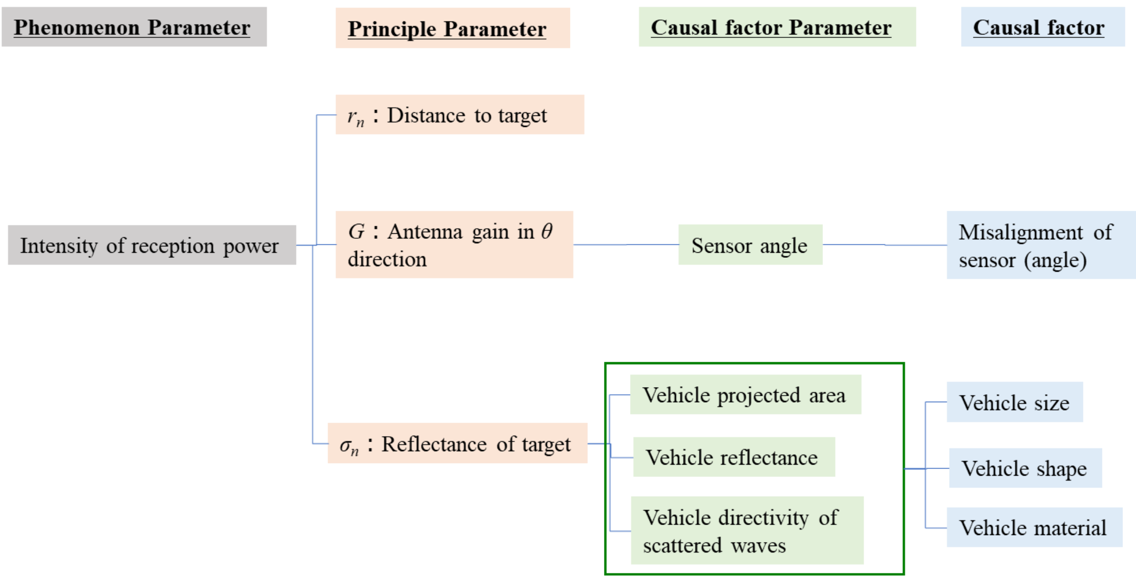
The power value will depend on the positional relationship of the radar to the recognition target, and the RCS of the recognition target.
Therefore, all we need to do is understand the distance and angle between the radar and the recognition target, as well as the RCS.

E.2.1.2 Relationship between Principle & Causal Factors of Perception Disturbance

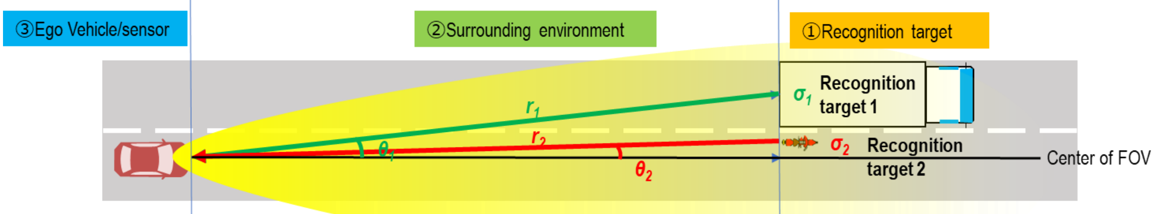
Large difference of signals
(recognition target)

E.2.1.2.1 Causal factor based on Principle

The below is a summary of the relationship so far, between the phenomenon parameter, the principle parameter, the causal factor parameter and the causal factor.



Large difference of signals
(recognition target)



※If there are n numbers of recognition targets, insert the reference number of each recognition target as a subscript to *P, r, and σ. E.g.* (n=1,2,3,…)

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	←	-	-	-

Large difference of signals
(recognition target)

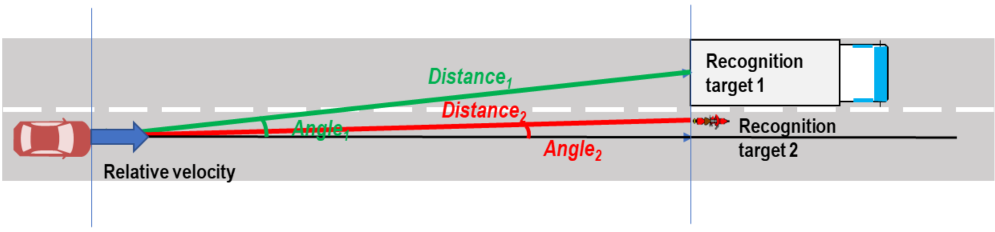
E.2.1.2.2 Parameter Range

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

Large difference of signals (recognition target)

E.2.1.2.3 Evaluation Scenario

- 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)



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

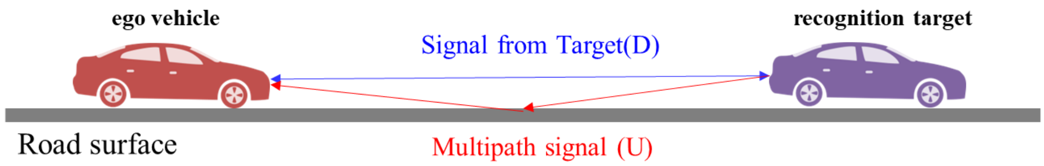
E.2.2 [mmWave Radar] Low D/U (road surface multipath)

E.2.2.1 Phenomenon and Principle of Perception Disturbance

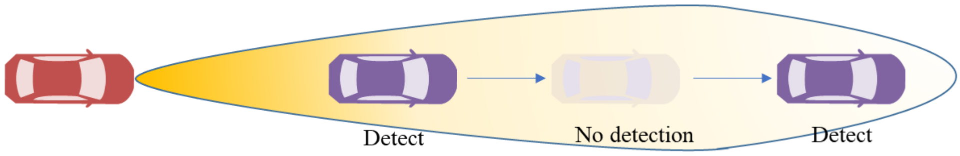
Low D/U
(Road surface multipath)

E.2.2.1.1 Phenomenon

When there is interference between the signal from the recognition target (D: Desired-Signal) and the signal from the indirect path via the road surface (U: Undesired-Signal), the **"signal intensity"** of the received signal by the sensor from the recognition target becomes smaller, resulting in a false negative.



At certain distances within the detection area, the **"signal intensity"** decrease, resulting in the recognition target becoming 'lost'.



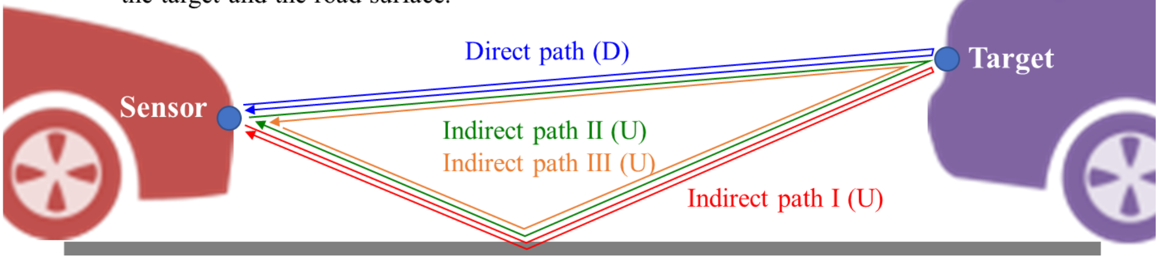
Low D/U
(Road surface multipath)

E.2.2.1.2 Outline of the Principle

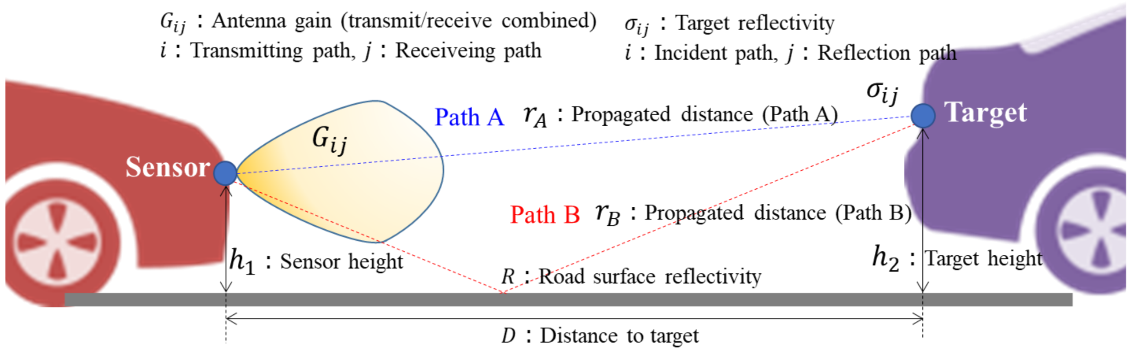
The propagation path, when the signal transmitted from the sensor are reflected by the target and received by the sensor, are categorized into the following four paths:

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 signal received by the sensor are combined of the above signals. The amplitude/phase of each signal will depend on the reflectivity and propagated distance of each path, and therefore the **"signal intensity"** of combined signal will increase/decrease depending on the relative position between the sensor, the target and the road surface.



Low D/U
(Road surface multipath)



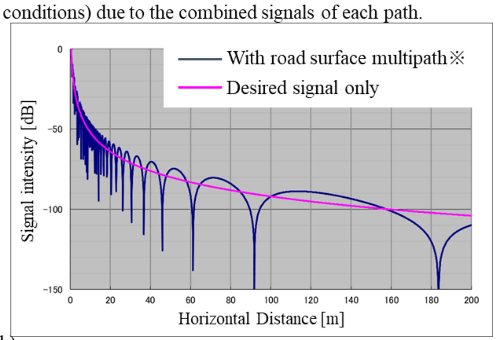
The signal received through each path is calculated as below:

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	$\frac{P_{tx}\lambda^2}{(4\pi)^3} \cdot \frac{G_{BA}\sigma_{BA}R}{r_B^2 r_A^2}$	$\phi_0 + \frac{2\pi}{\lambda} \cdot (r_A + r_B) + \pi$

The propagated distance (r_A, r_B), transmitting path (i) and receiving path (j) are determined by the sensor height (h_1), target height (h_2) and distance to the target (D).

(λ : wavelength)

The "**signal intensity**" decrease at certain distances (determined by conditions) due to the combined signals of each path.



※Example of the direct path and an indirect pathI

E.2.2.2 Relationship between Principle & Causal Factors of Perception Disturbance

Low D/U
(Road surface multipath)

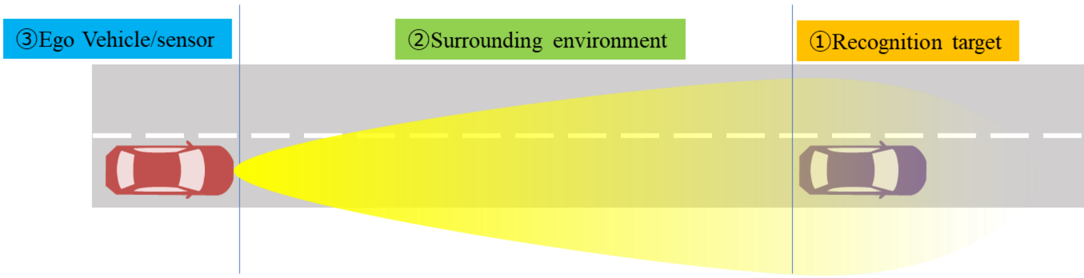
E.2.2.2.1 Causal factors of Perception Disturbance based on Principle

The below is a summary of the relationship between the principle parameter, causal factor parameter and causal factor which contribute to the "signal intensity" (phenomenon parameter).

Phenomenon Parameter	**Principle Parameter**	**Causal factor Parameter**	**Causal Factor**
Signal intensity	G_{ij} : Antenna gain (transmit & receive)	Sensor angle	Sensor misalignment Vehicle posture Change in road shape
	D : Distance to target	Distance to target	Distance to target
	h_1 : Sensor height	Sensor mount height	Sensor mount height
	h_2 : Target height	Vehicle reflection position	Size of vehicle Shape of vehicle Material of vehicle
	σ_{ij} : Target reflectivity	Vehicle projected area Vehicle reflectivity Vehicle directivity of scattered waves	
	R : Road surface reflectivity	Road surface reflectivity	Shape/material of road surface Condition of road surface

Low D/U
(Road surface multipath)

The below table shows the relationship between the phenomenon parameter, principle parameter, causal factor parameter and the causal factor.



Phenomenon Parameter	Principle Parameter	Causal factor Parameter	Causal factor		
			①Recognition target	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	—

Low D/U
(Road surface multipath)

E.2.2.2.2 Parameter Range

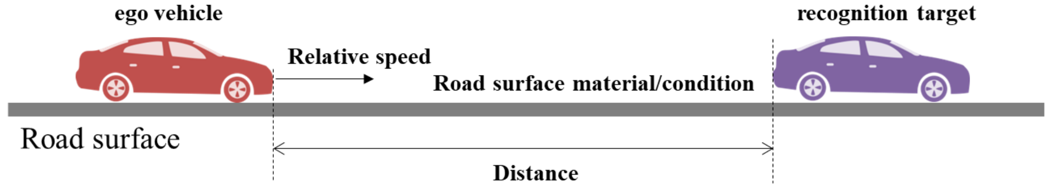
Listing the range of causal factor parameter.

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…	

Low D/U
(Road surface multipath)

E.2.2.2.3 Evaluation Scenario

- The ego vehicle approaches the target (stationary vehicle) up ahead in its path.



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

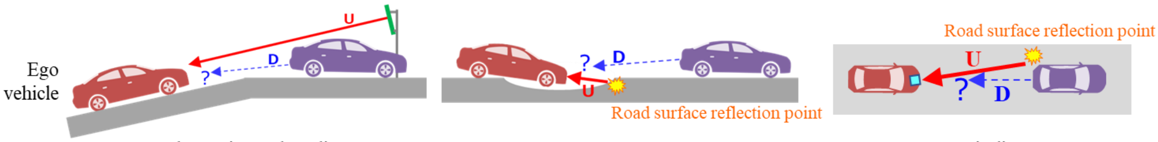
E.2.3 [mmWave Radar] Low D/U (change of angle)

Low D/U
(Change of the angle)

E.2.3.1. Phenomenon and Principle of Perception Disturbance

E.2.3.1.1. Phenomenon

When the radar's central axis of FOV and the road's surface/traveling direction are not parallel due to the road's gradient/cant, the vehicles posture or due to sensor misalignment, etc., then the reflected signal from the recognition target becomes relatively smaller than the undesired signals from surrounding structures, thus causing it to become buried and resulting in a false negative.

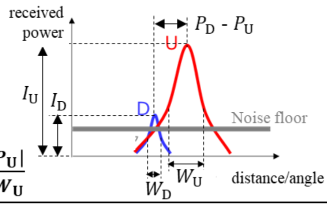


Change in road gradient   Change in vehicle posture   Sensor misalignment

Phenomenon Parameters

Peak intensity ratio $\frac{I_D}{I_U}$

Peak discrimination $\frac{|P_D - P_U|}{W_D + W_U}$



I_D , I_U : Peak intensity
P_D , P_U : Peak position
W_D , W_U : HMFW

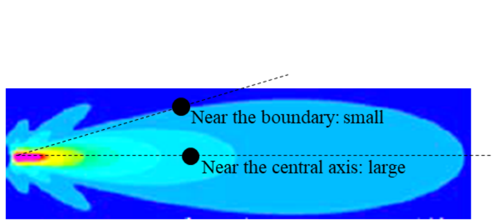
Phenomenon Mode :
False negative (situation where although a recognition target exists, it is not detected)

Low D/U
(Change of the angle)

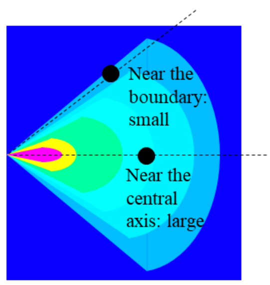
E.2.3.1.2. Principle of Perception Disturbance

- When taking a cross-section of the intensity distribution of the radar's transmission waves in the vertical and horizontal directions, the intensity becomes relatively smaller as the angle moves further away from the central axis of the FOV. (see below)
- The intensity of the receiving wave will also vary depending on whether the reflective object is placed near the central axis or the boundary.

<Distribution of the Radio Field Intensity from a mmWave Radar>



Vertical section

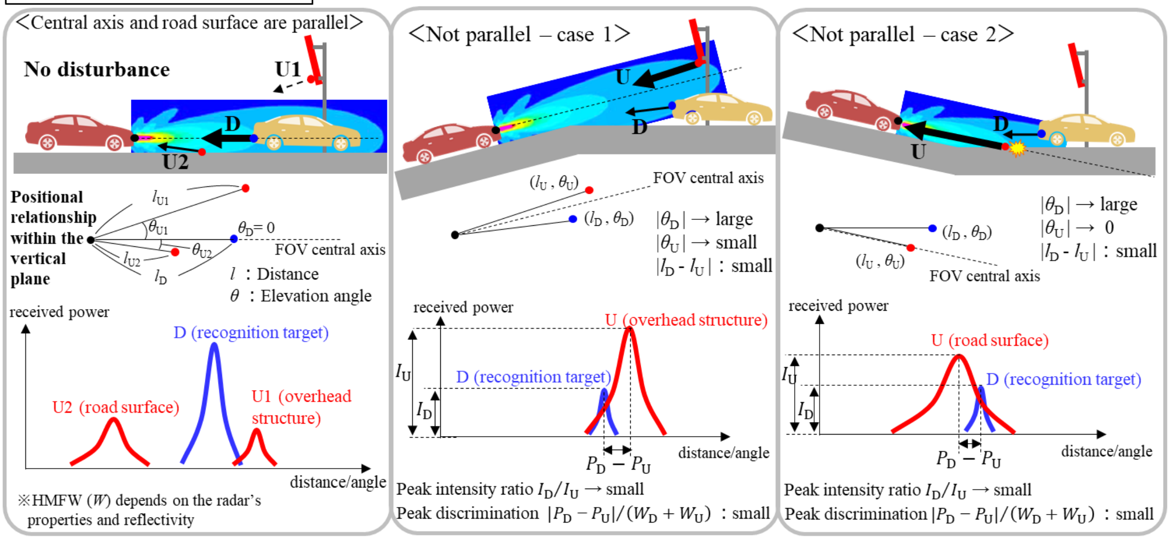


Horizontal section

Low D/U
(Change of the angle)

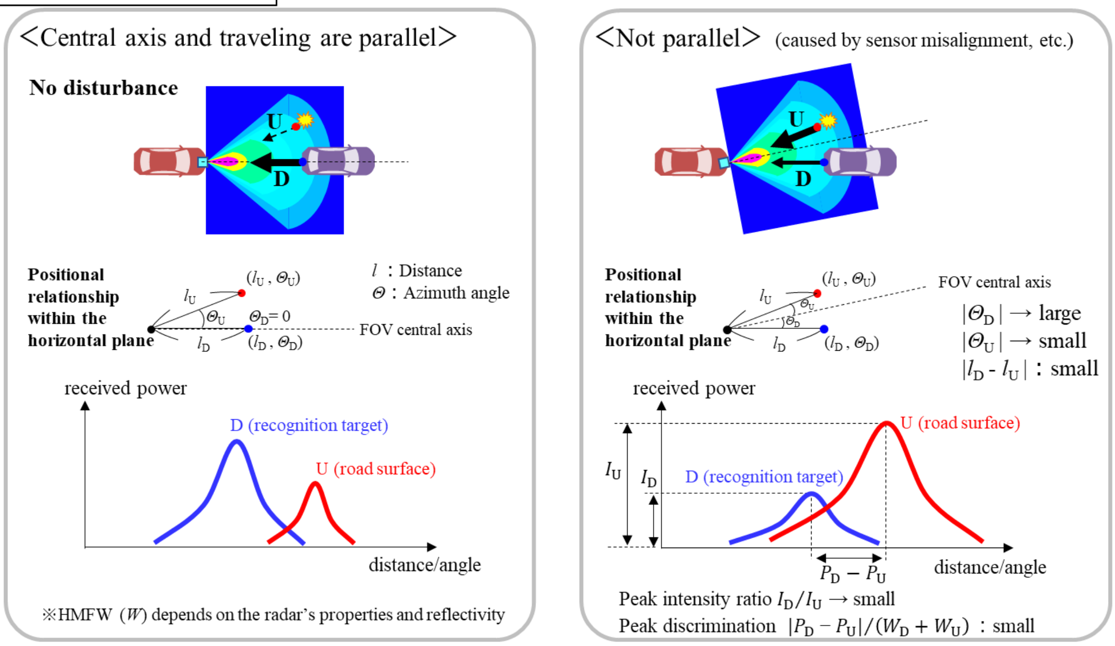
- When the central axis of the radar's FOV is not parallel to the road surface/traveling direction, surrounding structures will move closer to the central axis, and the recognition target will move closer to the boundary. ($|\theta_U|$ → small, $|\theta_D|$ → large)
- As a result, the intensity of the undesired signal from surrounding structures (I_U) becomes relatively larger than the intensity of the recognition target's signal (I_D).
- When another condition is added which makes the peak discrimination low ($|P_D - P_U|$: small or $|W_D + W_U|$: large), signal D becomes buried in U, and is therefore not detected.

Change in Elevation Angle



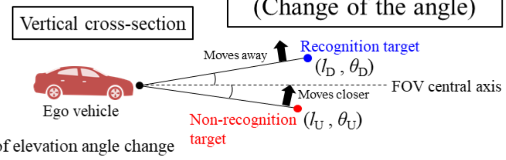
Low D/U
(Change of the angle)

Change in Azimuth Angle



Only the parameters which represent Low D/U phenomenon caused by change of elevation angle are described below because the phenomena in cases of elevation angle change and azimuth angle change are the same essentially.

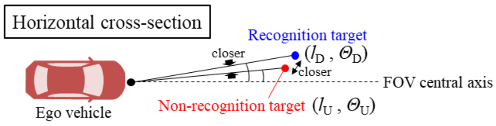
Low D/U
(Change of the angle)



<Parameter conditions for where D becomes buried in U> ※in case of elevation angle change

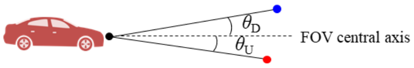
- Elevation angle $|\theta_D| \rightarrow$ large (recognition target moves away from the FOV central axis)
- Elevation angle $|\theta_U| \rightarrow$ small (non-recognition target moves closer to the FOV central axis)

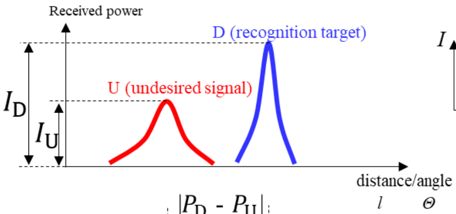
- Distance to recognition target $l_D \approx l_U$
- Azimuth angle of recognition target $\Theta_D \approx \Theta_U$
- The sum of HMFW $W_D + W_U \rightarrow$ large
  (※Dependent on the radar's properties and reflectivity)

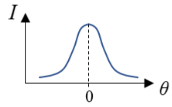


Principle Parameters:

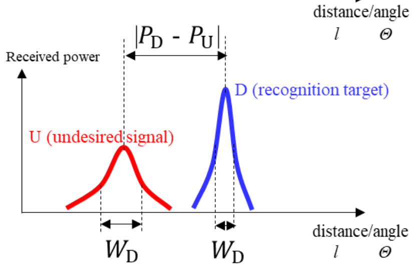
Elevation angle θ_D, θ_U (variable)
⇒ affects I_D / I_U value







Distance l_D, l_U
Azimuth angle Θ_D, Θ_U
⇒ affects $|P_D - P_U| / (W_D + W_U)$ value



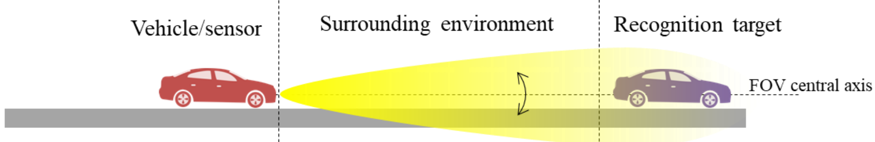
※ θ_D, θ_U, Θ_D, Θ_U are the angles in relation to the FOV central axis

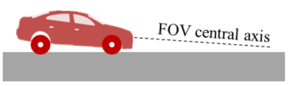
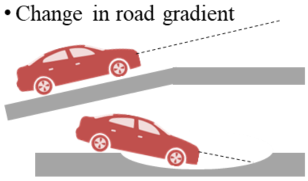
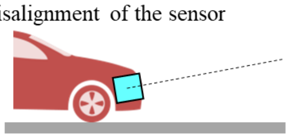
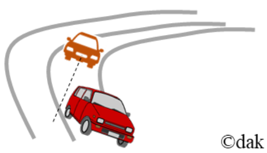
E.2.3.2. Relationship between Principle & Causal Factors of Perception Disturbance

Low D/U
(Change of the angle)

E.2.3.2.1. Causal factors of Perception Disturbance based on Principle

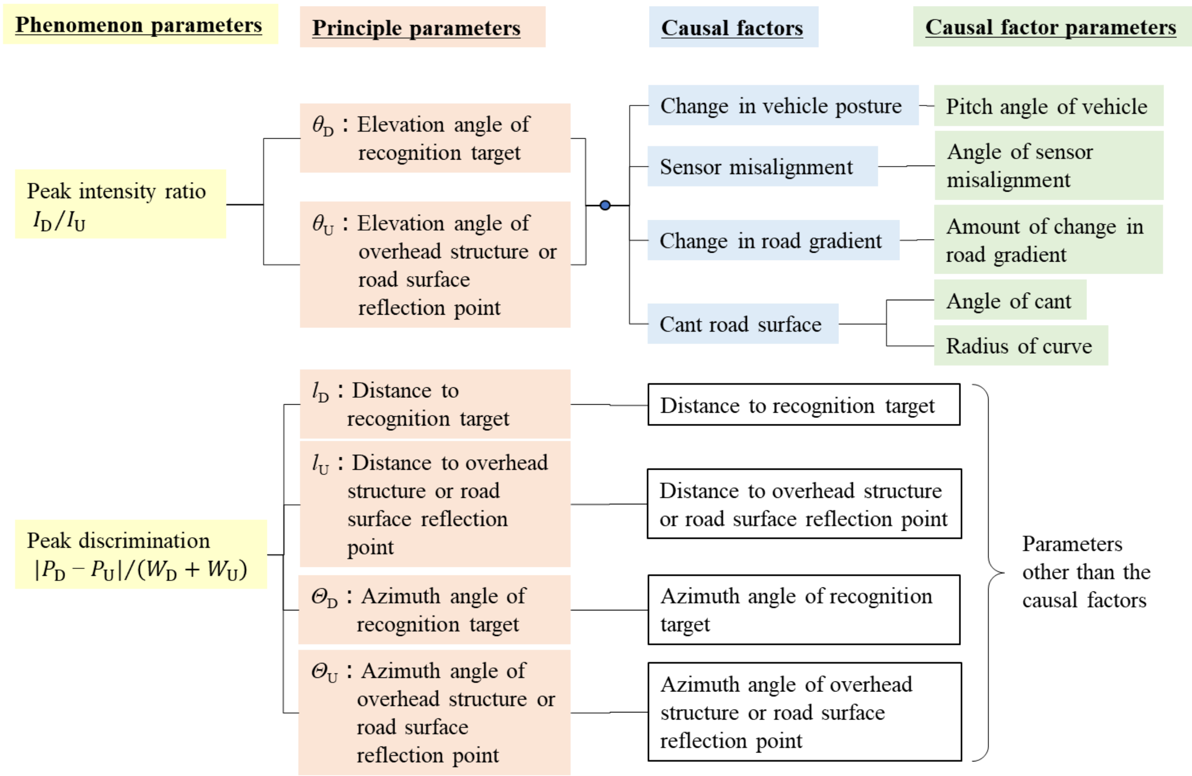
Of the principle parameters, the below are the causal factors of the perception disturbance which give rise to a change in elevation angle $|\theta_D| \rightarrow$ large and $|\theta_U| \rightarrow$ small, being the cause for this phenomenon.



Variable Principle Parameters	Causal factors of the disturbance		
	Vehicle/sensor	Surrounding environment	Recognition target
Elevation angle θ_D, θ_U	• Change of the vehicle posture 	• Change in road gradient 	N/A
	• Misalignment of the sensor 	• Cant road surface 	

Below shows the relationship between the phenomenon parameters, principle parameters and causal factor parameters.

Low D/U
(Change of the angle)



Low D/U
(Change of the angle)

E.2.3.2.2. Parameter Range

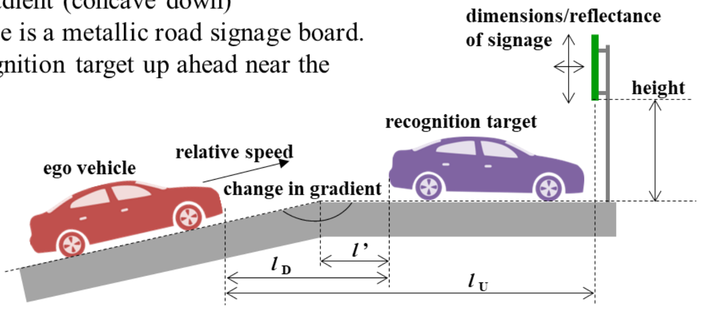
Phenomenon Parameters	Principle Parameters	Contributing Causal Factors	Causal Factor Parameters	Range of Causal Factor Parameters	Explanation
Peak intensity ratio l_D/l_U	Elevation angles θ_D, θ_U (variable parameters)	Change in road gradient	Amount of change in road gradient	0 to 18 % (according to 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 $\frac{|P_D - P_U|}{(W_D + W_U)}$	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 Θ_D, Θ_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 Scenario

Low D/U
(Change of the angle)

- Traveling a road with a change in gradient (concave down)
- Ahead of the change in gradient, there is a metallic road signage board.
- The ego vehicle approaches the recognition target up ahead near the signage board in its path.

※The situation with a gradient change (concave down) is selected as the representative scenario because of the higher probability of large reflective intensity from a metallic overhead structure than the road surface.



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

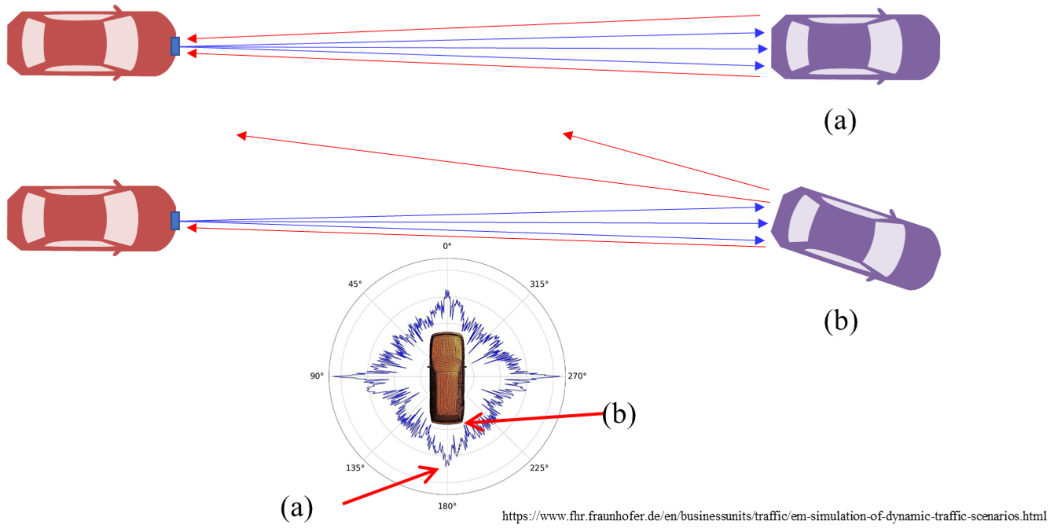
E.2.4 [mmWave Radar] Low S/N (direction of a vehicle)

Low S/N
(Orientation of the vehicle)

E.2.4.1. The Phenomenon and Principle of Perception Disturbance

E.2.4.1.1 The Phenomenon

Electromagnetic waves are transmitted from the radar, and the intensity of the reflected electromagnetic waves which return in the direction of the radar, will depend on the projected area, reflectance and orientation of the target's surface. If the same vehicle is on a different angle, this can cause the reflection to become extremely weak, thus the vehicle, although it may be within the FOV, may go undetected.



Low S/N
(Orientation of the vehicle)

E.2.4.1.2 Outline of the Principle

When reflected waves from the target are received by the radar, the intensity of the signal (S) received by the radar will depend on the receiving power (P_r) as determined by the below radar equation.

$$P_r = \frac{\lambda^2 \cdot P_t \cdot G_t(\theta) \cdot G_r(\theta) \cdot \sigma}{(4\pi)^3 \cdot R^4}$$

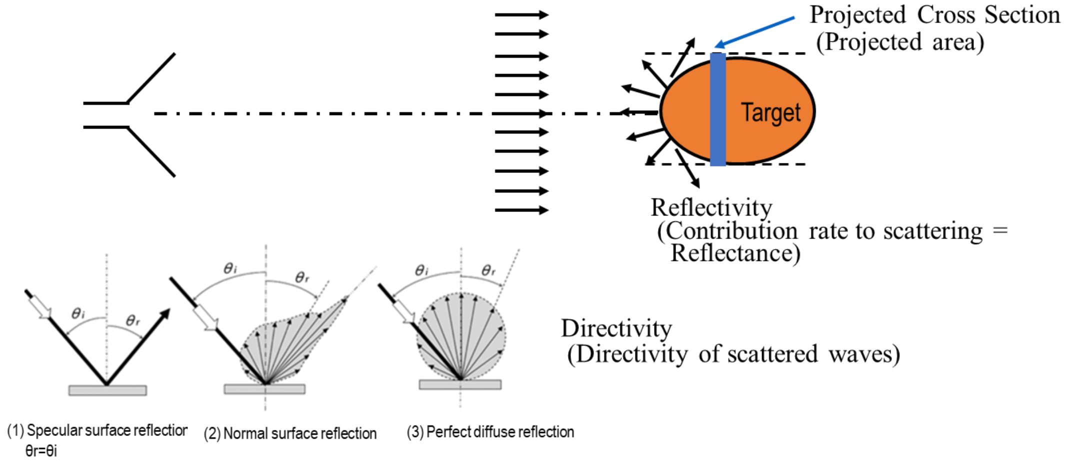
In this equation, P_t is the transmitting power, $G_t(\theta)$ is the transmitting antenna gain, $G_r(\theta)$ is the receiving antenna gain, σ is the target's radar cross-section, λ is the wavelength, and R is the range between the radar and the target.

As evident by this radar equation, the orientation of the vehicle contributes to low S/N (the radar cross-section (σ) of the target, or in other words the vehicle, will depend and vary according to the orientation).

Low S/N
(Orientation of the vehicle)

The radar cross-section (σ) is expressed as a product of (a) the target's projected area, (b) the contribution rate to scattering, and (c) the directivity of scattered waves. If an object uses the same material, then the area with high directivity (in other words the points facing the radar) will have stronger reflection.
Further, the contribution rate to scattering (＝Reflectance) is, "metal ≒ 1" and "0 ≦ non-metal < 1".

Radar cross-section (σ) ＝ Projected Cross Section × Reflectivity × Directivity (m^2)



E.2.4.2. Relationship between Principle & Causal Factors of Perception Disturbance

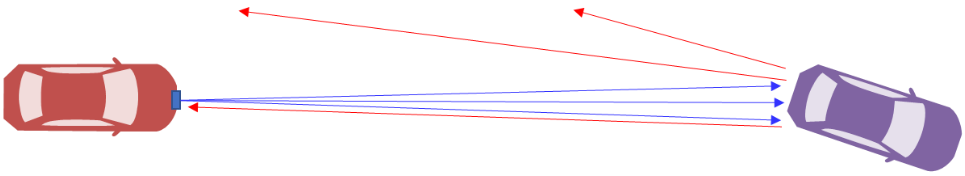
Low S/N
(Orientation of the vehicle)

E.2.4.2.1 Causal factors of Perception Disturbance based on Principle

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

Low S/N (Orientation of the vehicle)

As explained in E.2.4.1, the radar cross-section will vary depending on the orientation of the vehicle. Even if the size, shape and material of the vehicle remain the same, depending on the angle at which it is viewed, the projected area, contribution rate to scattering, and the directivity of the scattered waves will differ, thus making them causal factor parameters.



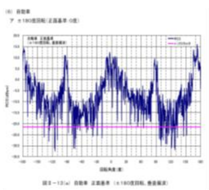
Phenomenon Parameter	Principle Parameter	Causal Factor Parameter	Causal Factors contributing to the change in principle parameter		
			①Recognition target	②Surrounding environment	③Vehicle/sensor
Signal intensity	Radar cross-section	Projected area	Size of vehicle	–	–
		Contribution rate to scattering (Reflectance)	Material of vehicle	–	–
		Directivity of scattered waves	Shape of vehicle	–	–

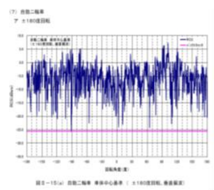
Low S/N (Orientation of the vehicle)

E.2.4.2.2 Parameter Range

If the target is something of a complex shape, such as a vehicle, the relationship between the projected area, reflectance, and directivity will be complex. Thus, the radar cross-section (σ) (large, medium and small) has been selected based on previous research, etc.

<u>Examples of Past Research (Measurement Results)</u>





Source) JARI report (J-GLOBAL ID：200909086392246974), 2004

Phenomenon 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)

Low S/N
(Orientation of the vehicle)

E.2.4.2.3 Evaluation Scenario

A scenario whereby the ego vehicle approaches the recognition target (stationary vehicle) up ahead in the ego vehicle's lane, at a constant speed.

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

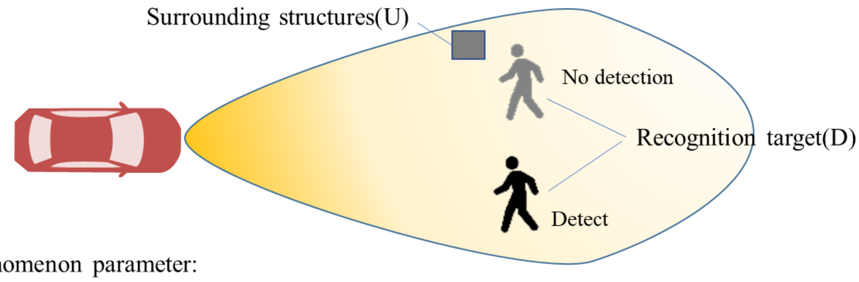
E.2.5 [mmWave Radar] Low D/U (surrounding structures)

Low D/U
(Surrounding structures)

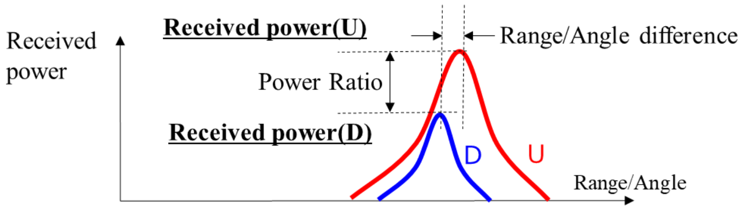
E.2.5.1. Phenomenon and Principle of Perception Disturbance

E.2.5.1.1. Phenomenon

When Surrounding structure and Pedestrian are close to each other, Undesired-Signal(U) from Surrounding structures obscures Desired-Signal(D) with low reflection intensity from the Pedestrian, resulting in a false negative.



Phenomenon parameter:

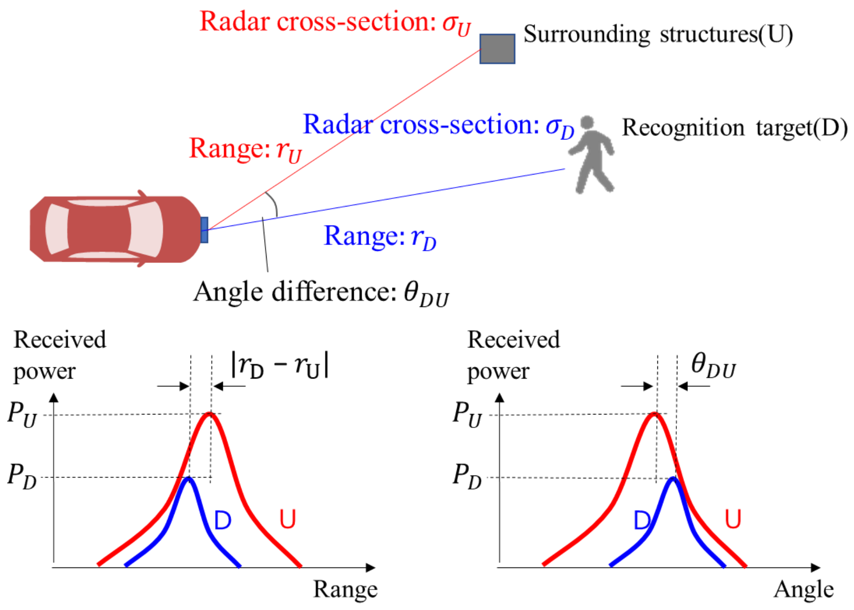


Phenomenon mode: False negative(A target exists but is not detected)

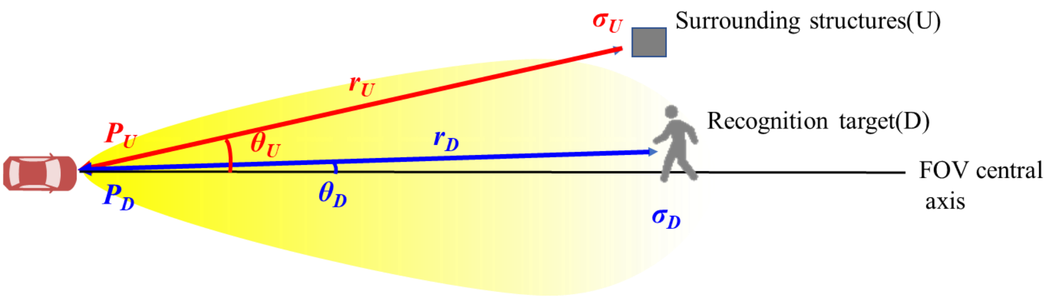
Low D/U
(Surrounding structures)

E.2.5.1.2. Outline of the Principle

If the Received power from Surrounding structures(U) is higher than the Received power from the Recognition target(D), and the D is buried in the U in both Range and Angle, D cannot be detected.



Low D/U
(Surrounding structures)



Model Description

P_t : Transmitting power
λ : Wavelength
$G(\theta)$: Antenna gain

Received power(D)

$$P_D = \frac{\lambda^2\{G(\theta_D)\}^2 P_t}{(4\pi)^3 {r_D}^4}\sigma_D$$

Received power(U)

$$P_U = \frac{\lambda^2\{G(\theta_U)\}^2 P_t}{(4\pi)^3 {r_U}^4}\sigma_U$$

E.2.5.2 Relationship between Principle & Causal Factors of Perception Disturbance

Low D/U
(Surrounding structures)

E.2.5.2.1 Causal factors of Perception Disturbance based on principle

The below is a summary of the relationship so far, between the phenomenon parameter, the principle parameter, the causal factor parameter and the causal factor.

Phenomenon parameters	**Principle parameters**	**Causal factor parameters**	**Causal factors**
Received power(D)	r_n: Distance to subject of recognition	Distance to subject of recognition target	Distance to subject of recognition target
	G: Antenna gain	Azimuth angle of recognition target	Azimuth angle of recognition target
	σ_n: Radar cross-section	Projected Cross Section of pedestrian Reflectivity of pedestrian Directivity of pedestrian	Size of pedestrian Material of pedestrian Shape of pedestrian Posture of pedestrian
Received power(U)	r_n: Distance to subject of recognition	Distance to subject of recognition target	Distance to subject of recognition target
	G: Antenna gain	Azimuth angle of recognition target	Azimuth angle of recognition target
	σ_n: Radar cross-section	Projected Cross Section of structures Reflectivity of structures Directivity of structures	Size of structures Material of structures Shape of structures Posture of structures

Low D/U
(Surrounding structures)

Pedestrian

Phenomenon parameter	Principle parameter	Causal factor parameter	Causal factor ①Target	Causal factor ②Surrounding environment	Causal factor 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	—	—

Surrounding structures

Phenomenon parameter	Principle parameter	Causal factor parameter	Causal factor ①Target	Causal factor ②Surrounding environment	Causal factor 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	—

Low D/U
(Surrounding structures)

E.2.5.2.2 Parameter Range

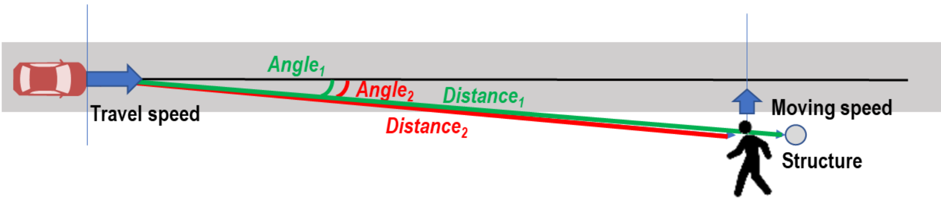
Pedestrian, Surrounding structures

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

Low D/U
(Surrounding structures)

E.2.5.2.3. Evaluation Scenario

- Evaluated by driving on a road where utility poles exist on the side of the traveled way as roadside objects.
- Ego vehicle evaluate by driving in the center position of the lane.
- Evaluated in a scene where a pedestrian crosses the path of own vehicle.
- The evaluation will place roadside structures (poles, posts, etc.) behind pedestrians.



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 of LiDAR

As examples for LiDAR, following 3 of principle models and evaluation scenarios of perception disturbances are described.

・Attenuation of signal (recognition target)

・Noise

・ Signal not from recognition target（reflection from raindrops）

E.3.1 [LiDAR] Attenuation of signal (recognition target)

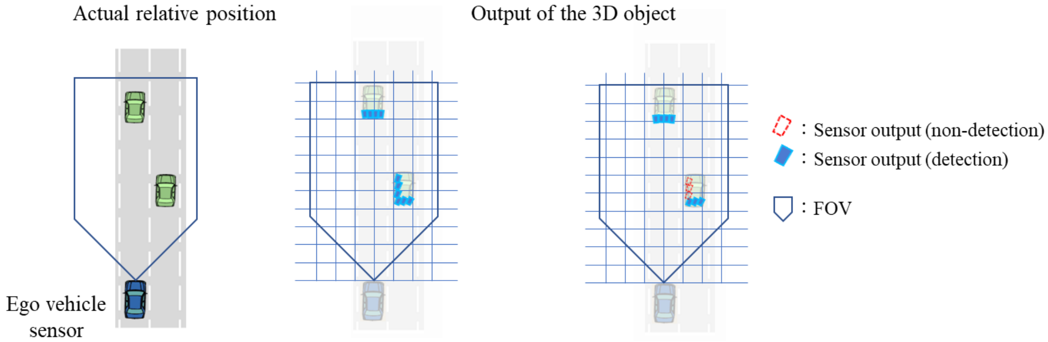
E.3.1.1 Phenomenon and Principle

S attenuation
(Recognition target)

E.3.1.1.1 Phenomenon

Explanation of the Phenomenon (1/2)

The situation whereby the target cannot be detected as a three-dimensional object unless it is closer in range than what is the assumed detectable range (false negative).



Correct detection

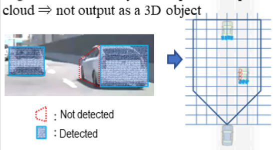
Although a recognition target exits, there is no output of a 3D object due to malfunction.

S attenuation
(Recognition target)

Explanation of the Phenomenon (2/2)

The phenomenon of a non-detection occurs when the reflection points attached to a recognition target are continuously not output as the point cloud.

			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	← 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.	



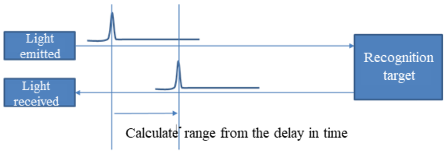
E.3.1.1.2 Outline of the Principle

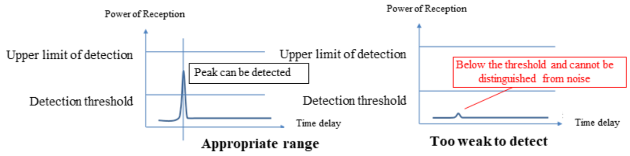
S attenuation
(Recognition target)

The reflection from the target is too weak and thus the peak cannot be detected at the assumed detectable range, leading to the target not being detected.

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.



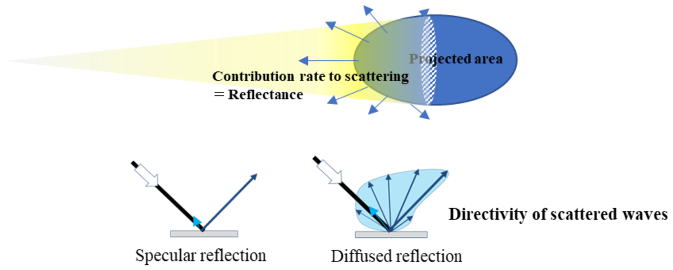


E.3.1.1.3 Principle Model

S attenuation
(Recognition target)

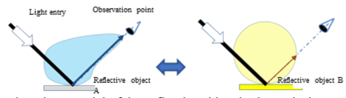
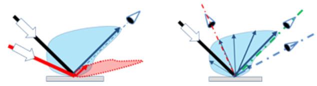
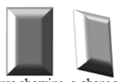
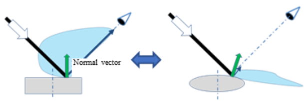
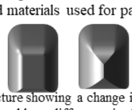
The reflection intensity of the target, the same as for the Millimeter wave, is believed to be expressed as the product of the projected area of the target, the contribution rate to scattering and the directivity of scattered waves, and a large reflection is acquired with higher directivity (in other words the points facing the LiDAR) as compared to another object with the same surface material.

Reflection intensity = Projected area of the target * Contribution rate to scattering * Directivity of scattered waves



S attenuation
(Recognition target)

Derive the causal factors of disturbance from the principle of the targets' reflection.

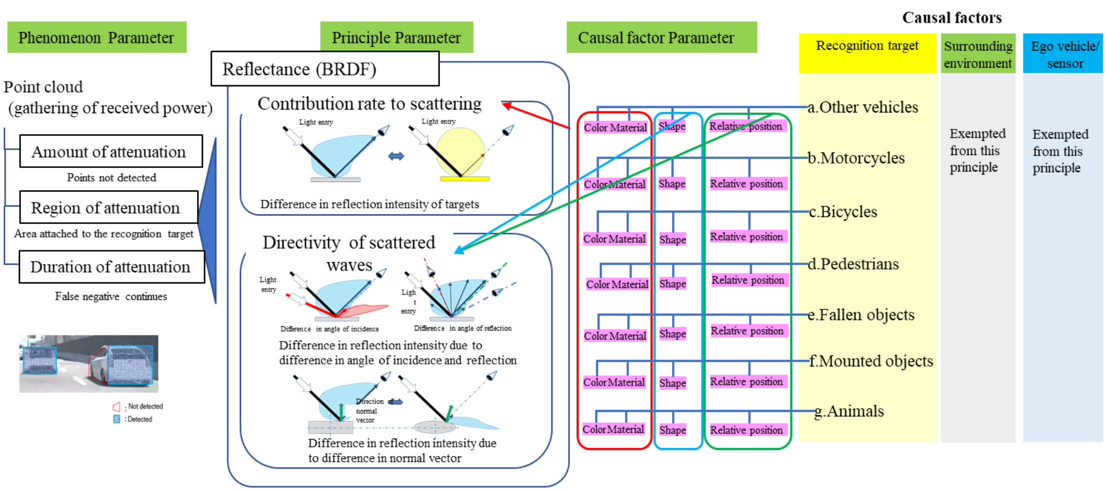
	Principle	Causal factors of disturbance
Contribution rate to scattering Difference in the reflection intensity of targets	 When the material of the reflective object is changed, the reflection intensity will change even if the angle of incidence and the observation point remain the same	The factors that 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.
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.	 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 Principle and Causal Factors of Perception Disturbance

S attenuation
(Recognition target)

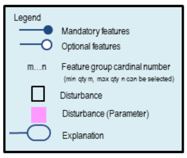
E.3.1.2.1 Causal factors based on Principle

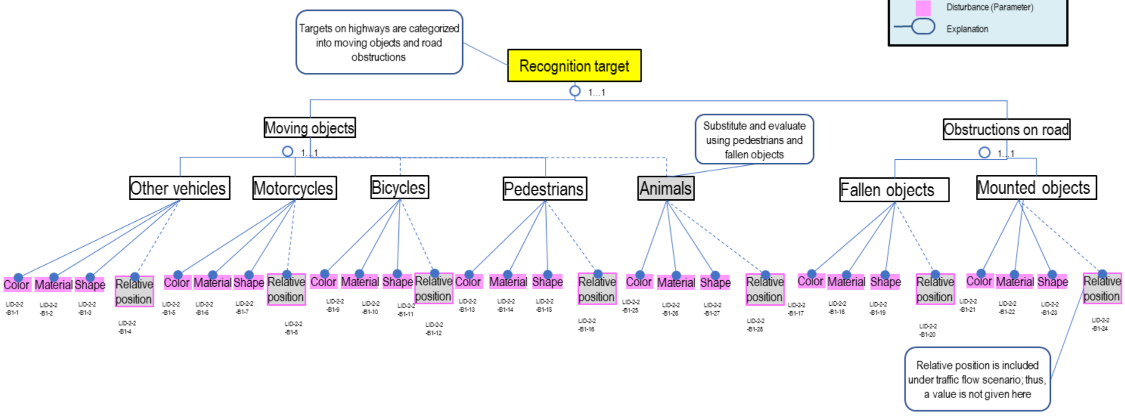
The causal factor parameters are derived from the causal factors of perception disturbance related to reflection from the recognition target based on the principle parameters.



S attenuation
(Recognition target)

When looking at combinations of causal factors, the recognition targets are not combined and are evaluated independently.

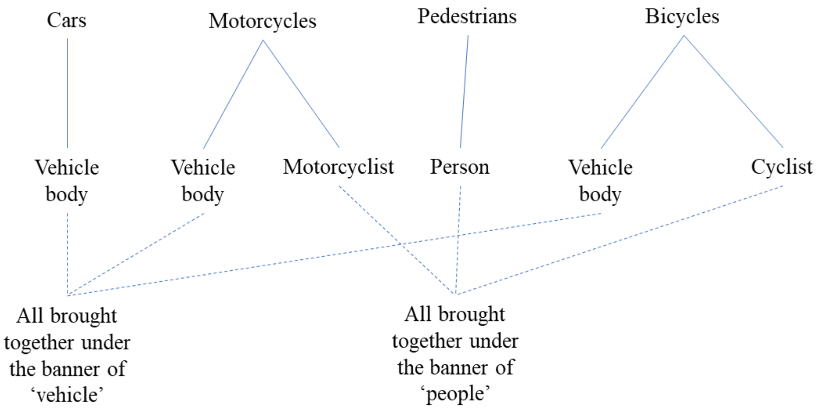




E.3.1.2.2 Parameter Range

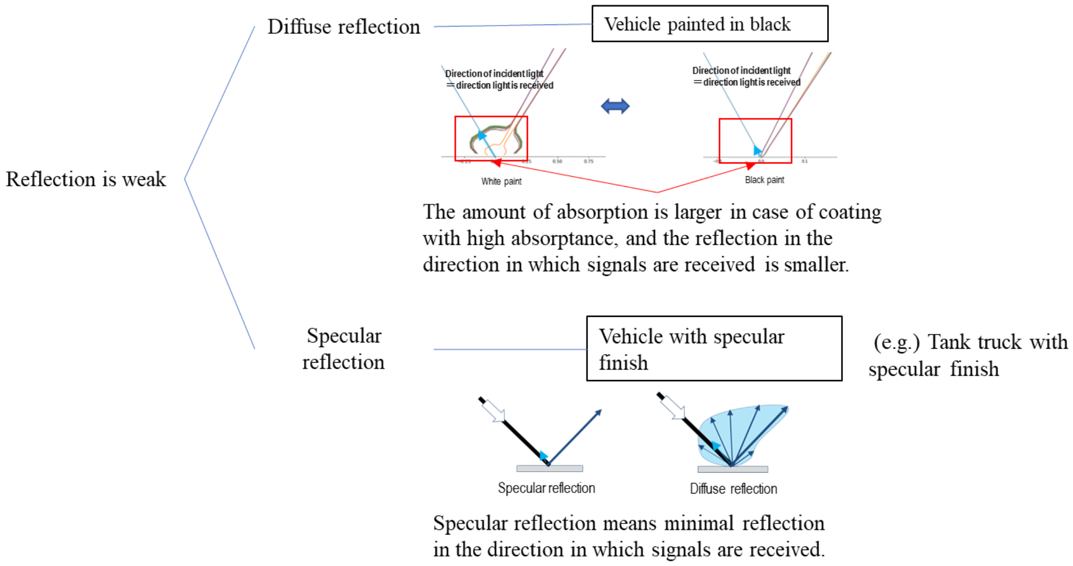
S attenuation
(Recognition target)

Moving objects are considered in terms of 'vehicles' and 'people'.



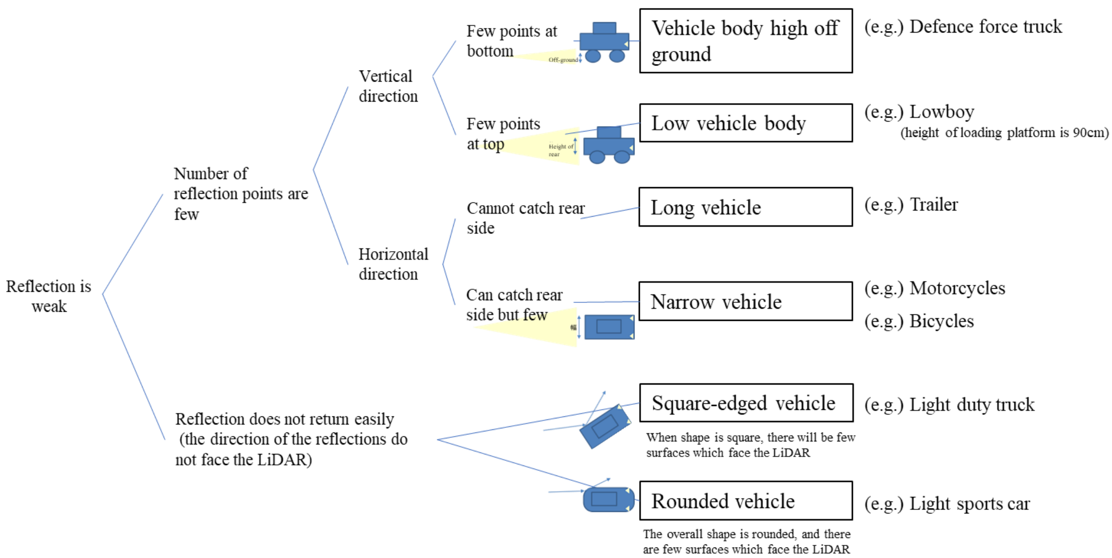
S attenuation
(Recognition target)

The color and the material of a vehicle are looked at in terms of the reflective properties of the surface coating. A black vehicle has been selected for its low diffuse reflection, alongside a vehicle with specular reflection.



S attenuation
(Recognition target)

The shape of a vehicle is considered in terms of how it hits the LiDAR.
A shape for which the number of reflection points the LiDAR hits is few and a shape for which reflection does not return easily, have been selected.



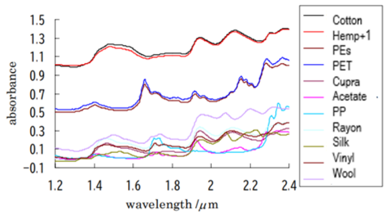
S attenuation
(Recognition target)

The difference in reflection intensity of pedestrians, motorcyclists (motorcycles) and cyclists (bicycles):

The reflection intensity will differ depending on the person’s clothing, luggage, color of skin and hair, helmet, etc. The parameter range to be considered here is reflection from the clothing only, as this occupies the biggest area.

Select from plant-based (cotton), animal-based (leather) and artificial (chemical fibers, reflective material).

Example of the Different Near Infrared Reflections by Material



http://molsci.center.ims.ac.jp/discussion_past/2003/BK2003/Abs/4pp/4Pp063.pdf

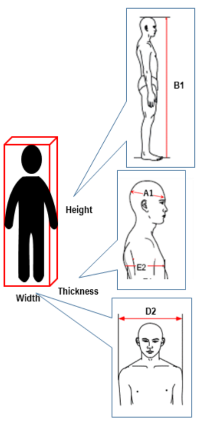
S attenuation
(Recognition target)

Pedestrians

When considering the difference in the shape of pedestrians we look at their size and posture. Smaller people are more difficult to detect; therefore, we will consider the build of a Japanese person (who is relatively small) as the worst case scenario.

① Difference in Size (Standing)

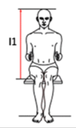
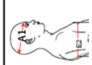
The size of pedestrians is expressed by the frame that surrounds the body. Height, width and thickness correspond to height (B1), shoulder width (D2) and thickness at chest diameter (E2).



 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

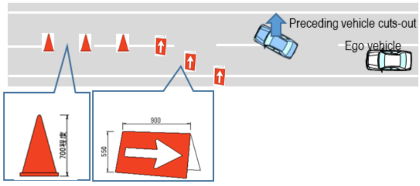
The height from the road will differ depending on posture.
‘Posture’ is to be considered as a parameter.

 Sitting	 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	 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

S attenuation
(Recognition target)

Mounted objects

For now this includes arrow boards and safety cones which appear at the boarder of driving lanes.



Fallen objects

For now, this will include tires, included under car parts, which ranked one of the highest for fallen objects based on occurrences.

2nd

Tires
(outer circumference 503 mm
165/60R12 for light vehicles)

3rd

Wood

Object was selected in reference to the ranking in NEXCO's (Central Nippon Expressway Company Limited) study.
1st Plastics (hard/soft), fabrics (blankets, bedsheets, etc.): 25,400 occurrences
⇒× not tall, little impact when driven over
2nd Car parts (tires, automobile accessories, etc.): 8,900 occurrences
⇒○ some are more than 15cm, can be hard (made of metals, etc.)
3rd Wood (square lumber, veneer boards, etc.): 6,900 occurrences
⇒△ square lumber can be more than 15 cm and hard. To be considered at next stage.
4th Road kill (animal corpses): 6,900 occurrences
⇒× in Japan this is considered to be mainly small animals such as raccoons.
Other: 17,400 occurrences

S attenuation
(Recognition target)

The below list summarizes the parameter ranges

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 Scenario

S attenuation
(Recognition target)

Scenario F-1

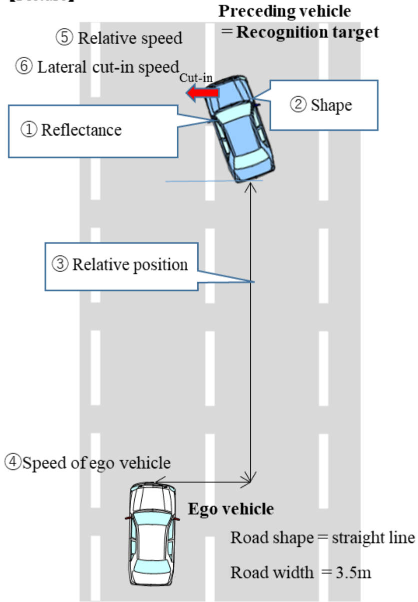
Evaluate based on "a vehicle cut-in on a straight road" scenario.

【Outline】
- Recognition target: Cut-in vehicle
- Change the reflectance and shape of the target

【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	This is defined under the traffic flow scenario, thus is not determined here.
	⑥ Lateral cut-in speed	

【Picture】



S attenuation
(Recognition target)

Scenario F-2

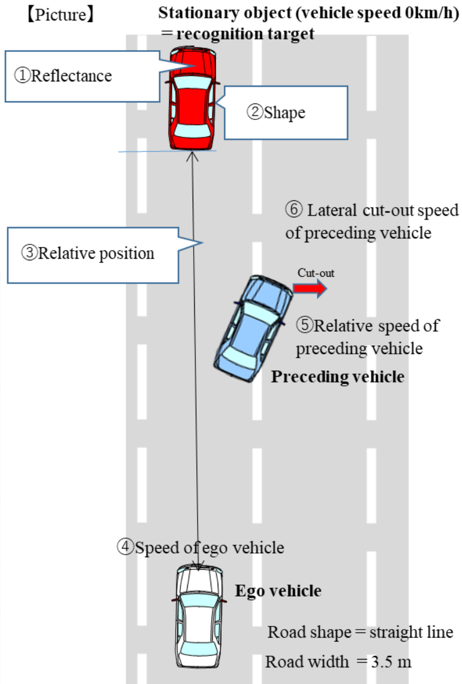
Evaluate based on "a vehicle cut-out on a straight road" scenario.

【Outline】
- Recognition target: a stationary object in front of the preceding vehicle which cuts-out
- Change the reflectance and shape of the target

【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	

【Picture】



S attenuation
(Recognition target)

Scenario F-3

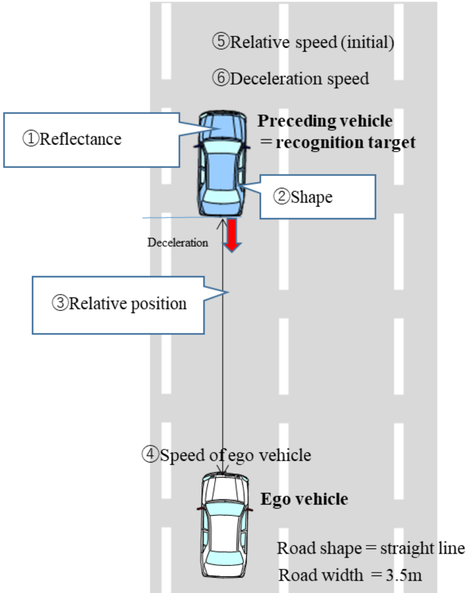
Evaluate based on “a vehicle decelerates on a straight road” scenario

【Outline】
• Recognition target: a decelerating vehicle
• Changing the reflectance and shape of the target

【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	

【Picture】



E.3.2 [LiDAR] Noise

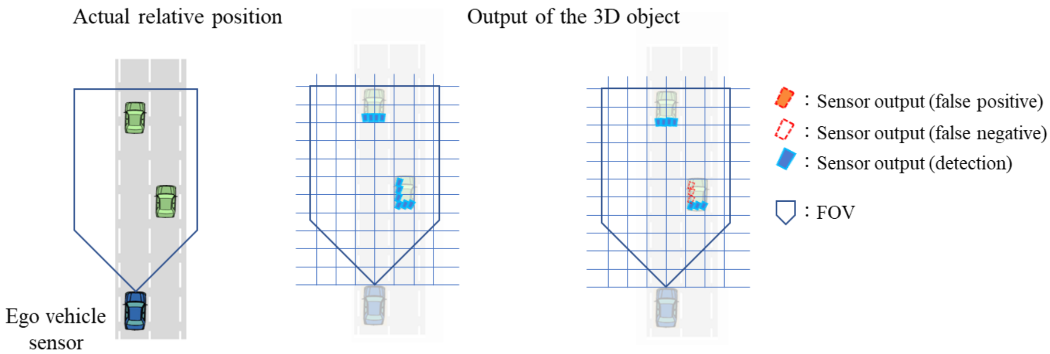
E.3.2.1 Phenomenon and Principle

Noise

E.3.2.1.1 Phenomenon

Explanation of the Phenomenon (1/2)

The situation whereby the target cannot be detected as a three-dimensional object unless it is closer in range than what is the assumed detectable range (false negative).



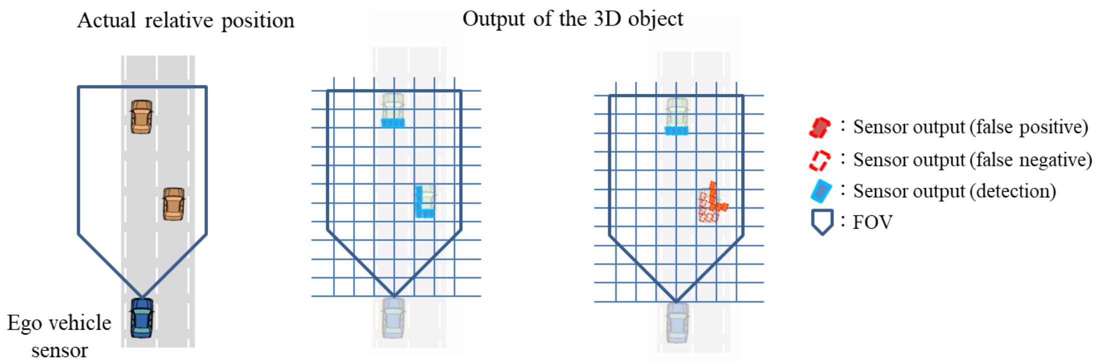
Correct detection

Although a recognition target exits, there is no output of a 3D object due to disturbance.

Noise

Explanation of the Phenomenon

The target is detected in a position which is not the true position (false positive).

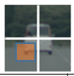
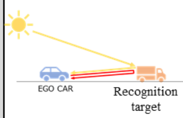
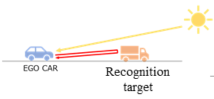
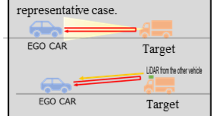


Correct detection

The distance of the 3D object, output by the sensor, is offset due to disturbance.

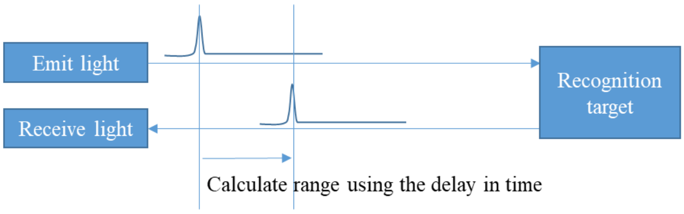
Explanation of the Phenomenon

The phenomenon occurs when the reflection points attached to a recognition target are continuously not output as the point cloud.

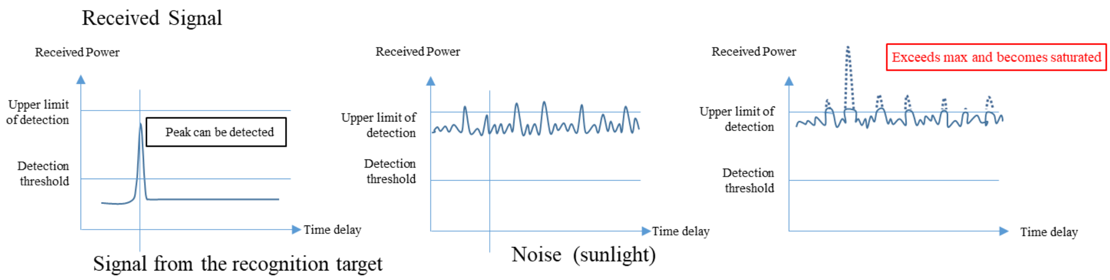
			A		B		C	
			1	2	1	2	1	2
Phenomenon Parameter	Degree	Amount of noise	Reflection points which should exist are not output as the point cloud due to noise					
		Region of noise	Full area within frame 		Attached to the recognition target 		Attached to the frame 	
	Time	Duration of attenuation	Continuous	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. 

E.3.2.1.2 Outline of the Principle

The peak of the received signal is detected, and the range is calculated to determine the delay in time.



【Case of saturation】



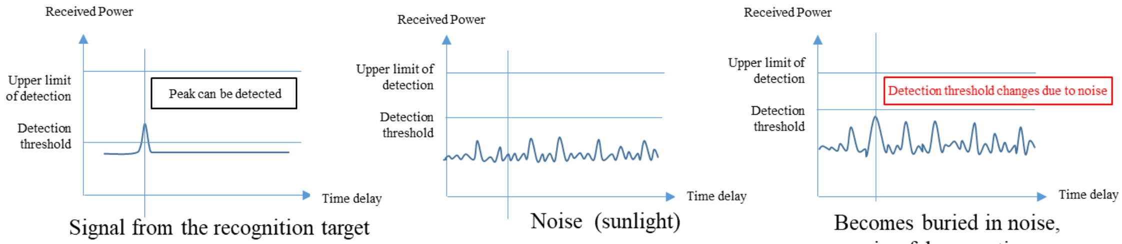
If an infrared light such as sunlight, which occurs routinely, enters the light receiver as 'noise', this noise and the reflection from the recognition target as a total becomes saturated, preventing proper detection.

If a powerful light that occurs routinely, such as sunlight, enters the signal receiver, this causes saturation and ultimately malfunction.

Noise

【Case of buried signals in noise】

Received Signal



Signal from the recognition target

Noise (sunlight)

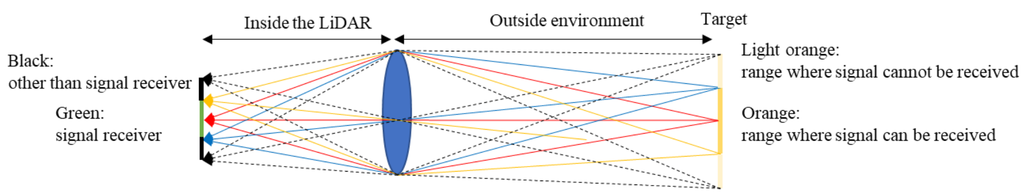
Becomes buried in noise, causing false negative

If an infrared light such as sunlight, which occurs routinely, enters the light receiver as ‘noise’, and the reflection from the recognition target (which has weak reflection) becomes mixed with the noise, this can prevent detection.

If a powerful light that occurs routinely, such as sunlight, enters the signal receiver, this can cause malfunction.

Noise

<Noise Due to Disturbance Light>

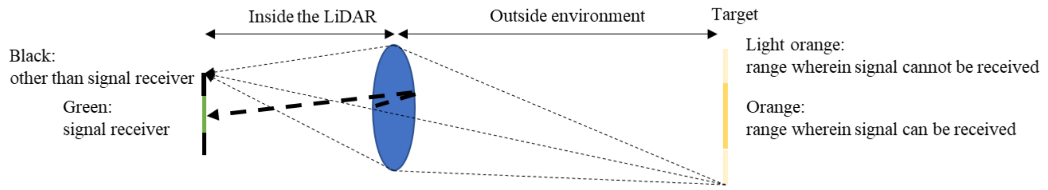


The lights that pass through the lens from the range where signals can be received include ① scattered light from the one that the LiDAR sent, ② scattered lights from other lights and ③ self-emitting lights within the range. These cannot be distinguished from each other, and thus they will all pass through the same optical path, and all be received as signals.*

All lights other than ① become noise components.

*As the wavelength sent by the LiDAR itself is recognized, it will normally have a filter that cuts out light from any other wavelength. Lights that become noise components are what fall within the wavelength range used for LiDAR transmission.

<Noise Due to Ghost>



Lights that fall outside of the range wherein signals can be received will travel along a normal light path to somewhere other than the signal receiver; thus, they will not be received. However, there are times when lights from outside of the signal receiving range may be received due to internal reflection, etc. (thick line).

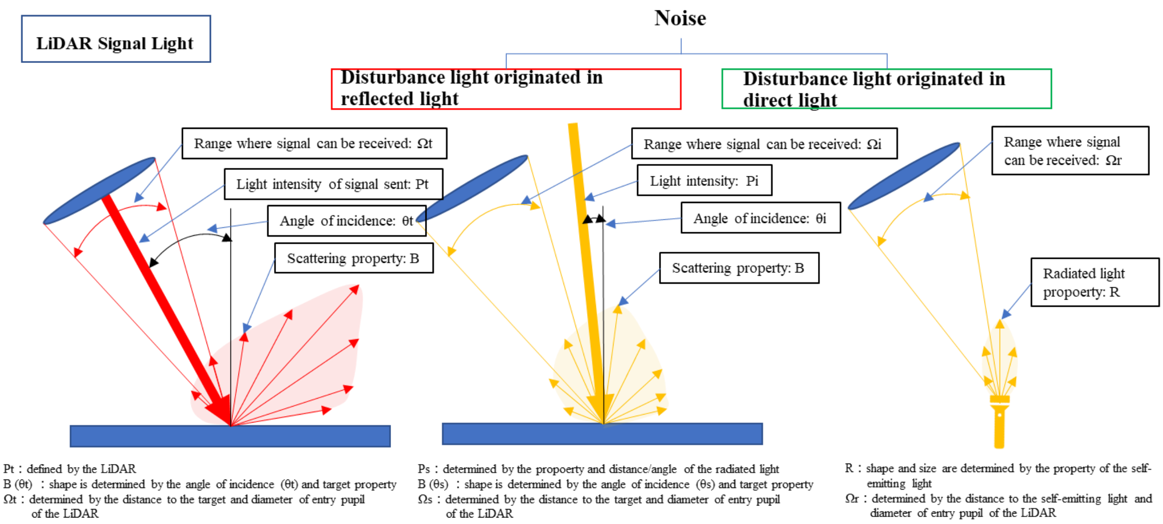
Normally, antireflection film, etc., would be used to suppress internal reflection; therefore, this might occur when there is a strong incident light (such as sunlight, headlamps, signals from other manufacturers' LiDAR, etc.)

Noise caused by internal reflection has been deemed low priority; thus, it will not be dealt with as a perception disturbance scenario in the safety evaluation

E.3.2.1.3 Principle Model

Noise

※ Intended noise: disturbance light originated in reflected light or direct light



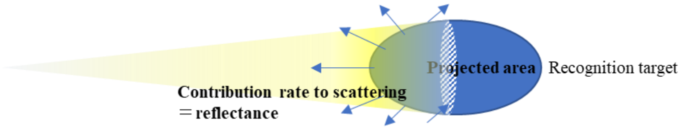
$$Pa = \boxed{Pt\int_{\Omega t} B(\theta t)d\Omega} + \underbrace{\boxed{Pi\int_{\Omega i} B(\theta i)d\Omega} + \boxed{\int_{\Omega r} R d\Omega}}_{\textbf{Parameters considered as noise}} + N$$

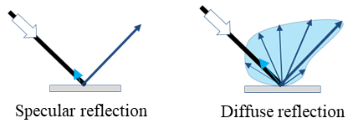
N : amount of received signal light from ghost
Pa : amount of total received signal light

Scattering property

The reflection intensity of the target, the same as for the Millimeter wave, is believed to be expressed as the product of the projected area of the target, the contribution rate to scattering and the directivity of scattered waves, and a large reflection is acquired with higher directivity (in other words the points facing the LiDAR) as compared to another object with the same surface material.

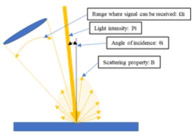
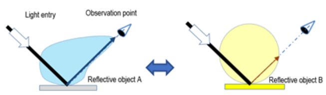
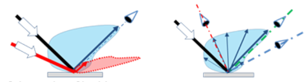
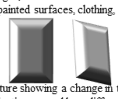
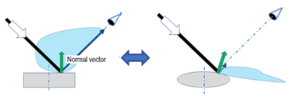
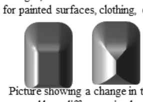
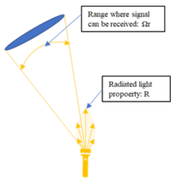
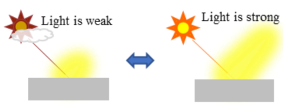
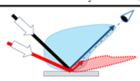
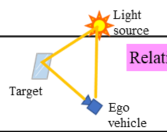
Reflection intensity = Projected area of the target * Contribution rate to scattering * Directivity of scattered waves





Directivity of scattered waves

Derive each causal factor of disturbance, from the principle of the target's reflection.

Disturbance	Factor	Principle	Causal factors
Disturbance light originated in reflected light 	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
Disturbance light originated in direct light 	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 Principle and Causal Factors of Perception Disturbances

Noise

E.3.2.2.1 Causal Factors based on Principle

Derive causal factors from the causal factor parameters.

Phenomenon Parameter	**Principle Parameter**	**Causal Factor Parameter**			
		Vehicle/sensor	Surrounding environment	Recognition target	
Amount of noise Noise region	Scattering property B(θ)			Color / material, shape	**Disturbance light originated in reflected light**
	Angle of incidence θi		Position (light source)	Position, shape	
	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 Range

Noise

The below is a list summarizing the parameter ranges.

- In case of disturbance light originated in reflected light

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)

- In case of disturbance light originated in direct light

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.

E.3.2.2.3 Evaluation Scenario

Noise

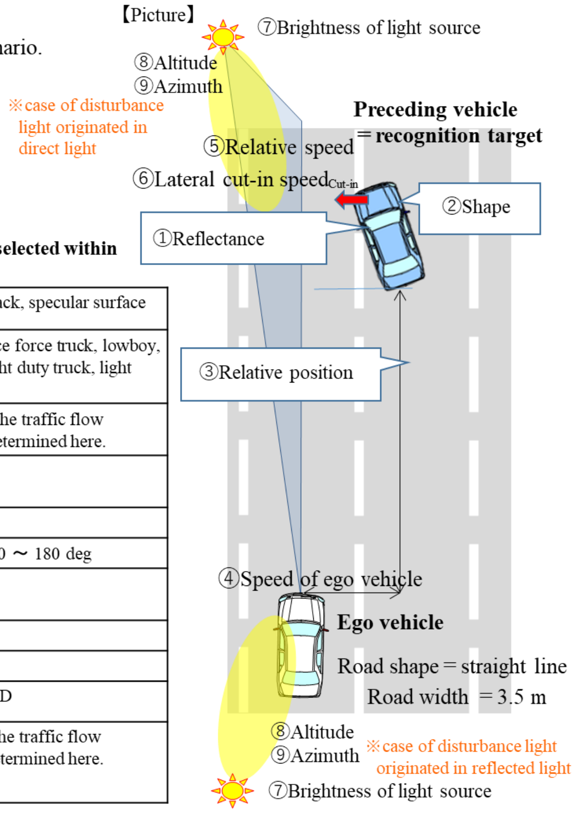
Scenario F-1

Evaluate based on “a vehicle cut-in on a straight road” scenario.

【Outline】

- Recognition target: a cutting-in vehicle
- Changing the reflectance and shape of the target
- Allocating the light source (the sun) and the target within the parameters below

【Picture】



【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			

Noise

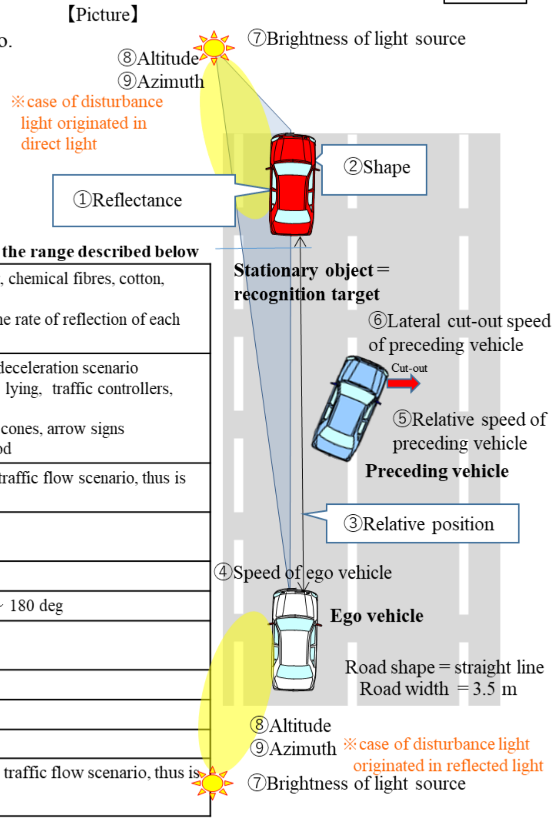
Scenario F-2

Evaluate based on “a vehicle cut-out on a straight road” scenario.

【Outline】

- Recognition target: a stationary object in front of the preceding vehicle which cut-out
- Changing the reflectance and shape of the target
- Allocating the light source (the sun) and the target within the parameters below

【Picture】



【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			

Noise

Scenario F-3

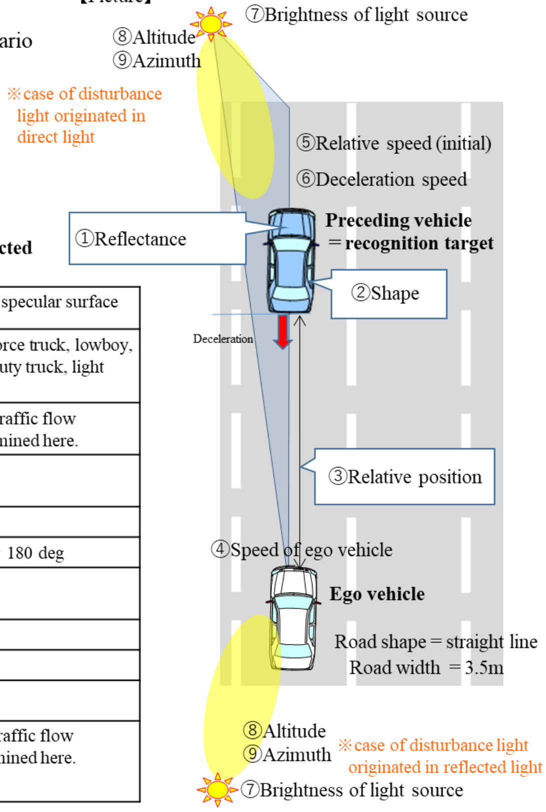
Evaluate based on “a vehicle decelerates on a straight road” scenario

【Outline】
- Recognition target: a decelerating vehicle
- Changing the reflectance and shape of the target
- Allocating the light source (the sun) and the target within the parameters below

【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			

【Picture】



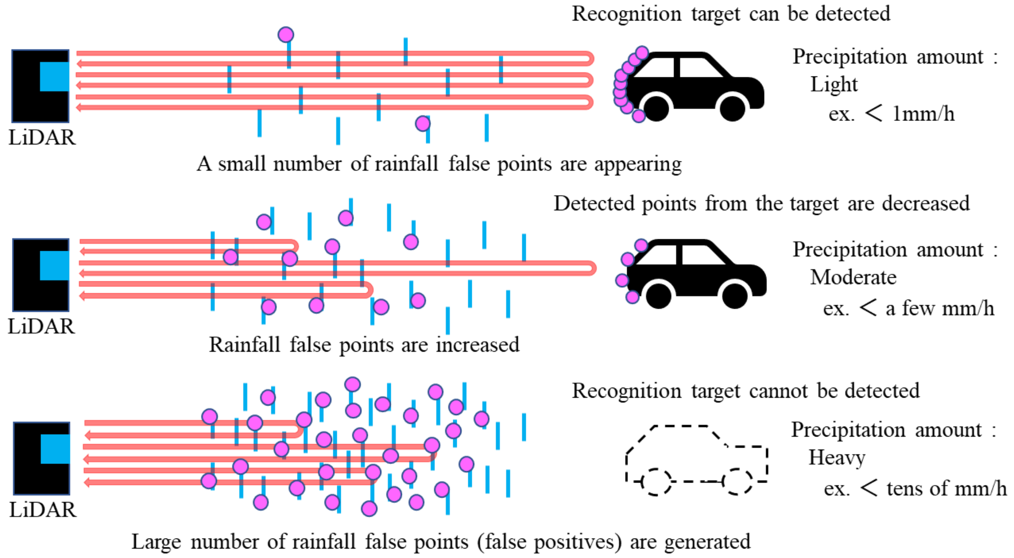
E.3.3 [LiDAR] Signal not from recognition target (reflection from raindrops)

E.3.3.1 Phenomenon and Principle

Signal not from recognition target
(Reflection from raindrops)

E.3.3.1.1 Phenomenon

Generation of False Points due to Reflection (Scattering) by Raindrops



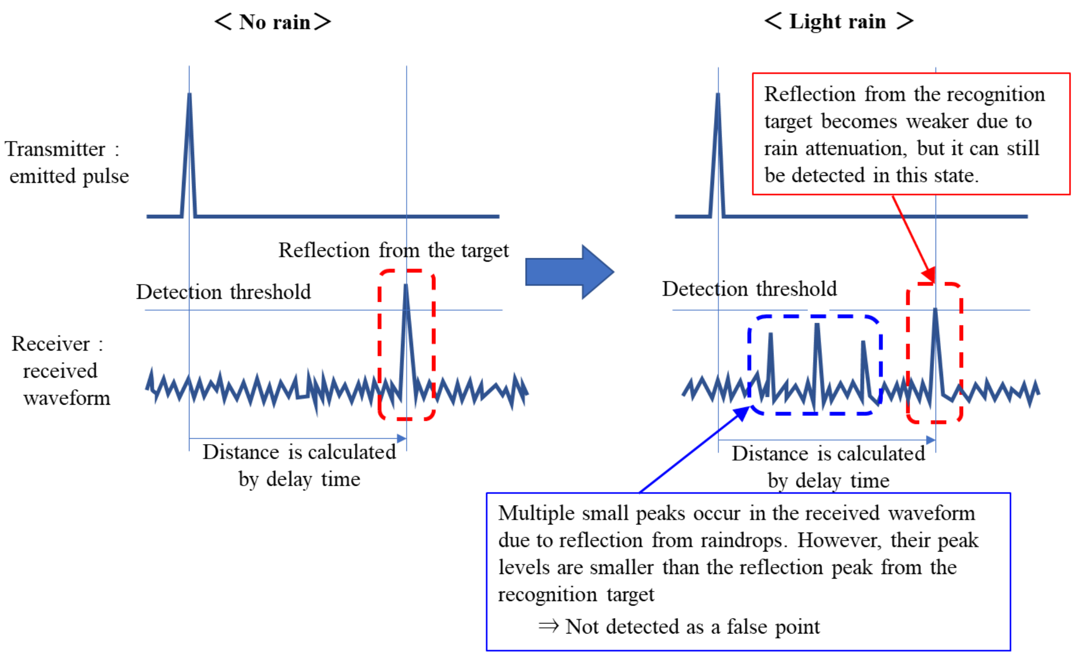
The beam emitted from the LiDAR is reflected and scattered by raindrops in space, which weakens the reflection from the recognition target. Rainfall false points are generated due to reflections from raindrops, reducing the number of target detection points. As the amount of rainfall increases, the number of false points increases, and eventually the target cannot be detected.

Signal not from recognition target
(Reflection from raindrops)

E.3.3.1.2 Outline of the Principle

Principle of False Point Generation by Raindrops

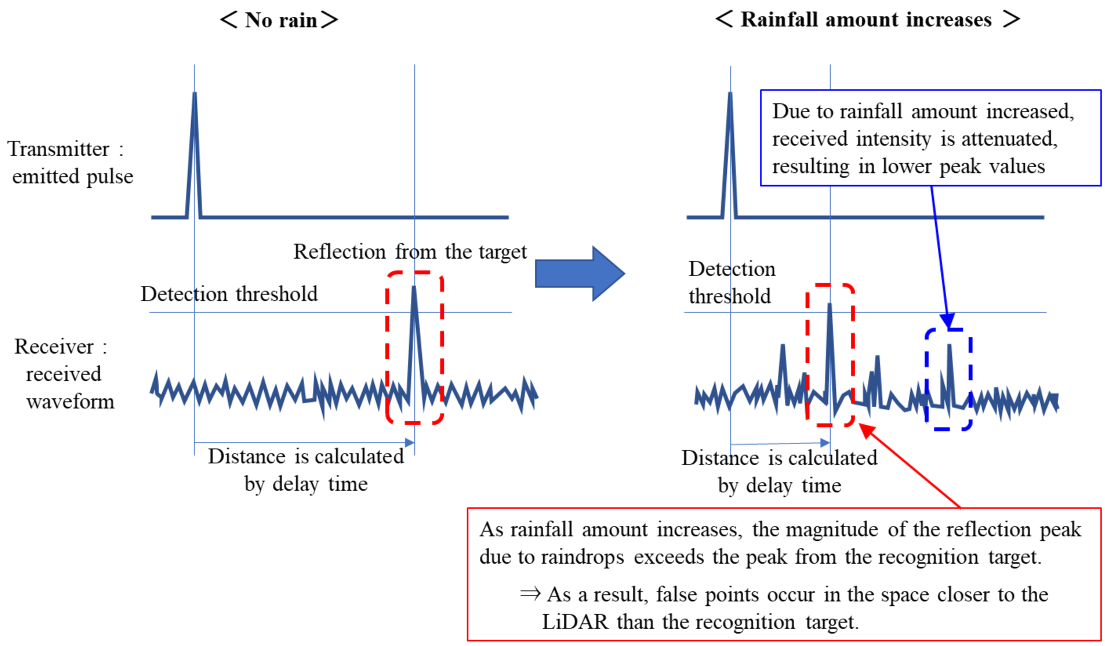
【 Case : Light rain (that does not cause false points) 】



Signal not from recognition target
(Reflection from raindrops)

Principle of False Point Generation by Raindrops

【 Case : Rainfall amount increases (false points occur) 】

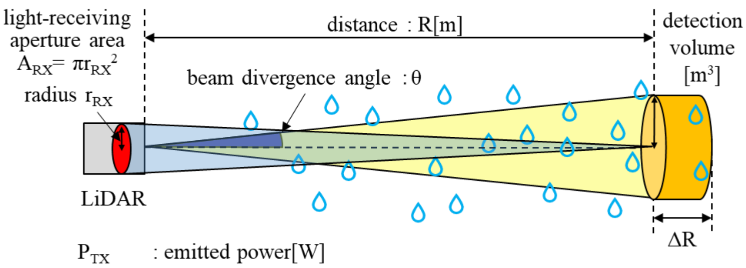


Signal not from recognition target
(Reflection from raindrops)

E.3.3.1.3 Principle Model

LiDAR Equation due to Scattering of Raindrops in Space *** Assuming coaxial type LiDAR**

The received power due to the scattering of raindrops in space at a distance R from the LiDAR is expressed by the LiDAR equation below. It considers the reflection (scattering) from raindrops to be from a detection volume existing in space. And it considers the term (transmittance) T that represents the attenuation by rain and the term (reflectance equivalent value) ρ that represents the reflection due to the scattering of raindrops.



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]

$$P_{RX(rain)}(R) = P_{TX} * \frac{A_{RX}}{R^2} * \rho * T$$

T : Spatial transmittance of raindrops
ρ : Reflectance equivalent value of raindrops [sr^{-1}]

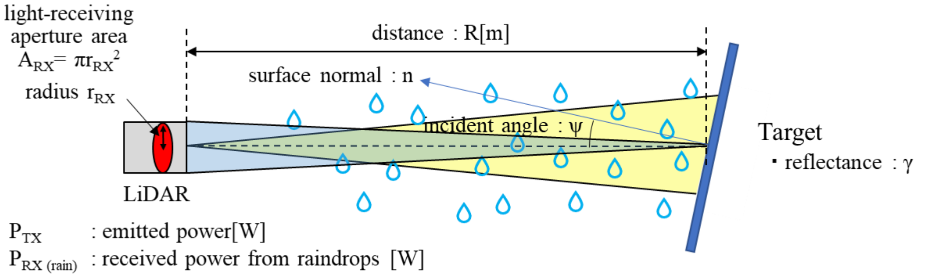
Factors Affecting Spatial Transmittance T due to Raindrops	Factors Affecting Reflectance Equivalent Value due to Raindrops
・Precipitation, raindrop distribution (raindrop size, raindrop velocity) ・Distance at which scattering occurs ・Wavelength of the LiDAR	・Precipitation, raindrop distribution (raindrop size, raindrop velocity) ・Distance at which scattering occurs ・Beam divergence angle, pulse width, wavelength

Signal not from recognition target
(Reflection from raindrops)

LiDAR equations when the reflection from the target is attenuated by raindrops

*** Assuming coaxial type LiDAR**

The received power when the reflection from an object (target) at a distance R from the LiDAR is attenuated by raindrops in space is expressed by the LiDAR equation below. It is the one representing the reflection from the target (reflectance (BRDF)γ) multiplied by a term (transmittance)T representing the attenuation due to raindrops.



P_{TX} : emitted power[W]
$P_{RX\,(rain)}$: received power from raindrops [W]

$$P_{RX(Target)}(R) = P_{TX} * \frac{A_{RX}}{R^2} * \gamma * \cos(\psi) * T$$

T : Spatial transmittance of raindrops
γ: Reflectance of target (BRDF) [sr^{-1}]

Factors Affecting Spatial Transmittance T due to Raindrops
- Precipitation, raindrop distribution
  (raindrop size, raindrop velocity)
- Distance to the target
- Wavelength of the LiDAR

In case of $P_{RX\,(rain)}(R) > P_{RX\,(Target)}(R)$, false point due to raindrops occurs at that beam.

E.3.3.2 Relationship Between Principle and Causal Factors of Perception Disturbances

Signal not from recognition target
(Reflection from raindrops)

E.3.3.2.1 Causal Factors based on Principle

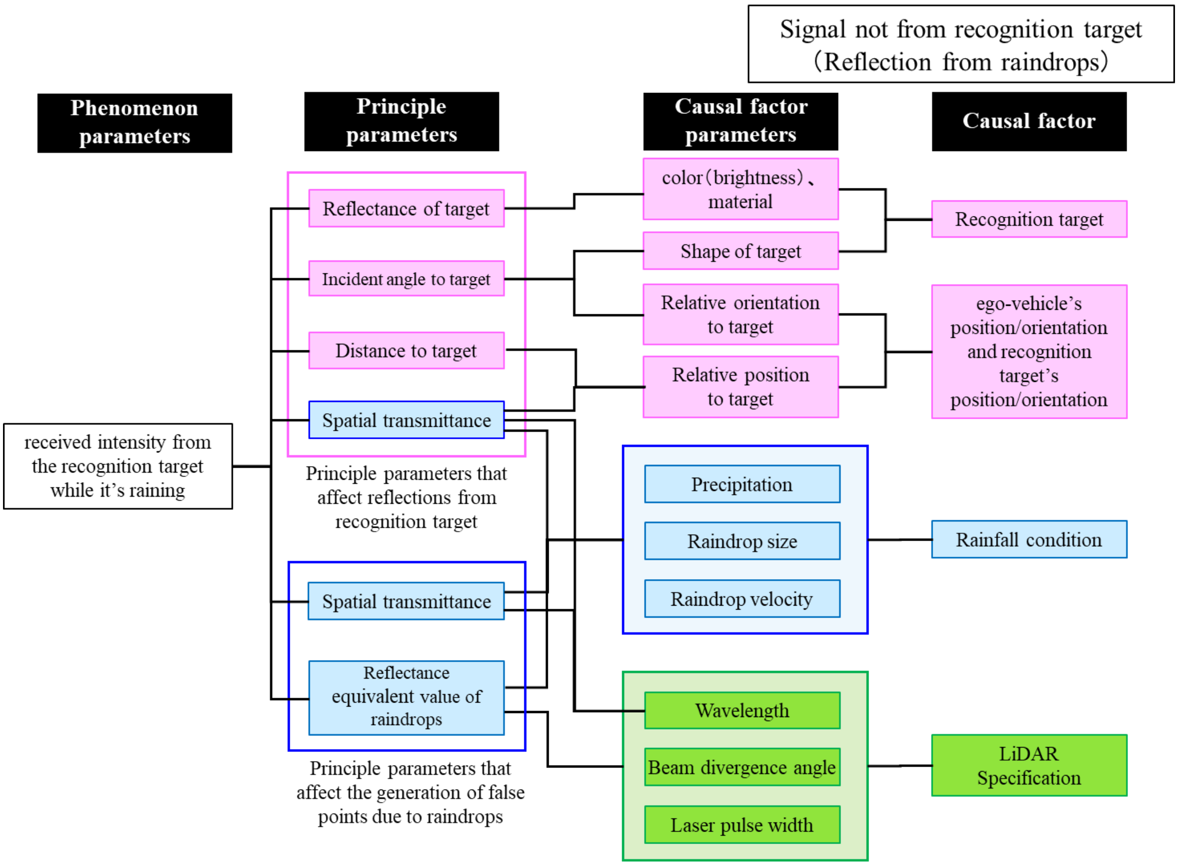
Causal Factors of Perception Disturbance due to Rainfall and their Parameters (Phenomenon, Principle, Causal Factors)

Phenomena that occur as perception disturbances due to rainfall are the attenuation of reflected light from the recognition target and non-detection (shielding) of it due to the occurrence of rainfall false points in space. The phenomenon parameter is the received intensity from the recognition target while it's raining.

In this case, the causal factors are organized into four categories: "recognition target", "ego-vehicle's position/orientation and recognition target's position/orientation", "rainfall condition", and "LiDAR specification".

The following page summarizes the relationship between phenomenon parameters, principle parameters related to them, and causal factors and causal factor parameters.

The received intensity from the recognition target while it's raining is related to two phenomena: the reflection from the recognition target, which is attenuated by rainfall, and the effect of the false points due to the scattering of raindrops in space.



Signal not from recognition target (Reflection from raindrops)

E.3.3.2.2 Parameter Range

Parameter Range of Causal Factor : Rainfall Condition

The parameter range related to the causal factor "rainfall condition" is shown below.

Note 1) Causal factors : Recognition target, ego-vehicle and target position/orientation are subject to description in other recognition disturbance principles, so they are omitted here.

Note 2) Causal factor: LiDAR specification is out of the scope for description of this page because the parameter values intrinsic to the LiDAR hardware used should be set for validation.

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 3) This range was set based on the raindrop size and velocity distribution data measured using a distrometer at the Large-scale Rainfall Simulator of National Research Institute for Earth Science and Disaster Resilience (NIED).

- Precipitation setting 50mm/h
- Using the 2nd system nozzle

E.3.3.2.3 Evaluation Scenario

Signal not from recognition target
(Reflection from raindrops)

Scenario F-1

Evaluate based on "a vehicle cut-in on a straight road" scenario

【Outline】

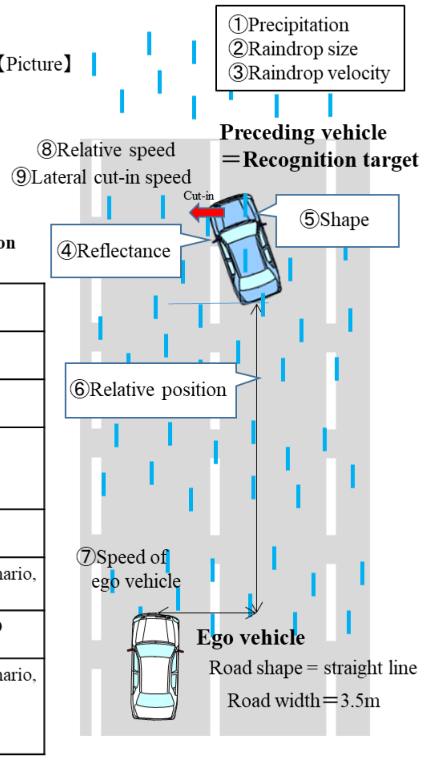
- Recognition target: Cut-in vehicle
- Set the rainfall condition within the following parameter range
- Change the reflectance and shape of the target

【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		

【Picture】



Signal not from recognition target
(Reflection from raindrops)

Scenario F-2

Evaluate based on "a vehicle cut-out on a straight road" scenario

【Outline】

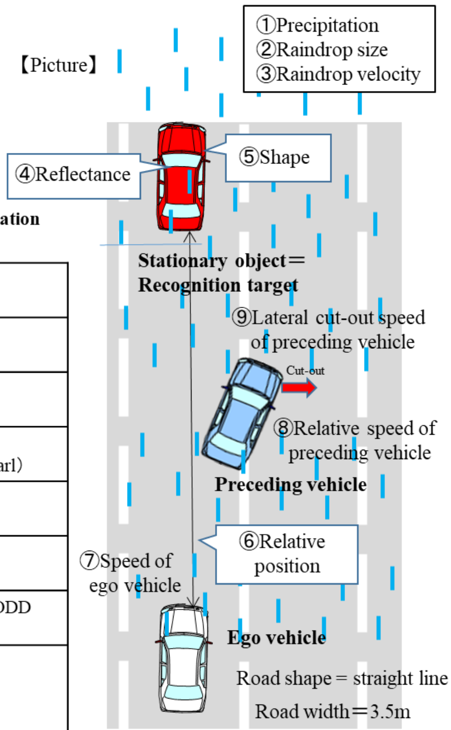
- Recognition target: Stops after the preceding vehicle cut-out
- Set the rainfall condition within the following parameter range
- Change the reflectance and shape of the target

【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		

【Picture】

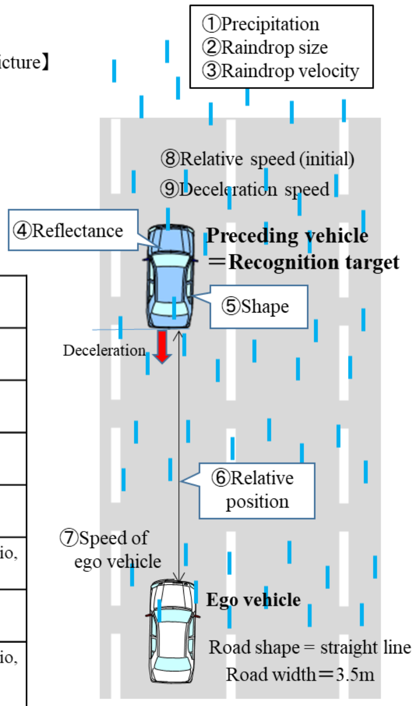


Scenario F-3

Signal not from recognition target
(Reflection from raindrops)

Evaluate based on “a vehicle decelerates on a straight road” scenario

【Picture】



【Outline】
- Recognition target: Decelerating vehicle
- Set the rainfall condition within the following parameter range
- Change the reflectance and shape of the target

【Parameters】

For the items marked with (*), select the evaluation conditions from the description range.

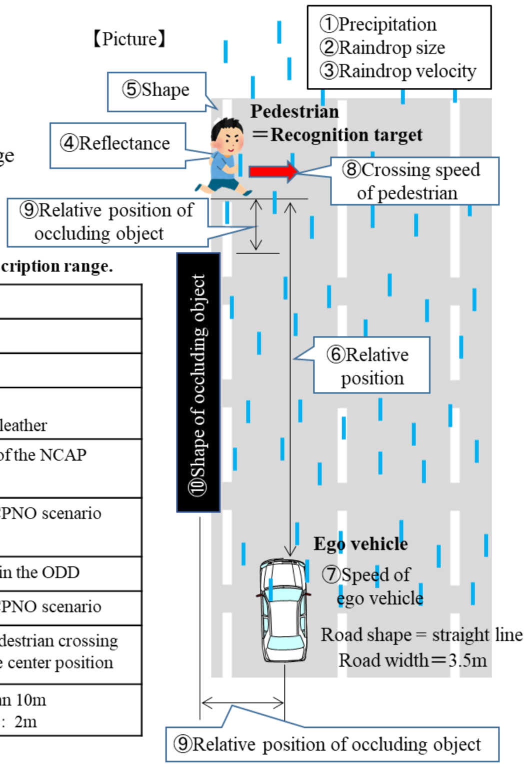
Causal factor Parameters	Rainfall condition	①Precipitation (*)	0 ～ 50 mm/h
		②Raindrop size (*)	0.1 ～ 5mm
		③Raindrop velocity (*)	0.1 ～ 10m/s
Parameters required for evaluation	Recognition target	④Reflectance	Coating material＝black, white effect pigment (metallic/pearl)
		⑤Shape	Vehicle＝passenger car, 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 (initial)		Range defined under the traffic flow scenario, not determined here
	⑨Deceleration speed		

Pedestrian Scenario

Signal not from recognition target
(Reflection from raindrops)

Evaluate based on “Pedestrian crossing” scenario

【Picture】



【Outline】
- Recognition target: Pedestrian
- Set the rainfall condition within the following parameter range
- Change the reflectance and shape 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 of Camera

As examples for Camera, following 3 of principle models and evaluation scenarios of perception disturbances are described.

- Hidden (image cut out)
- Low spatial frequency / Low contrast (caused by spatial obstruction)
- Overexposure

E.4.1 [Camera] Hidden (image cut out)

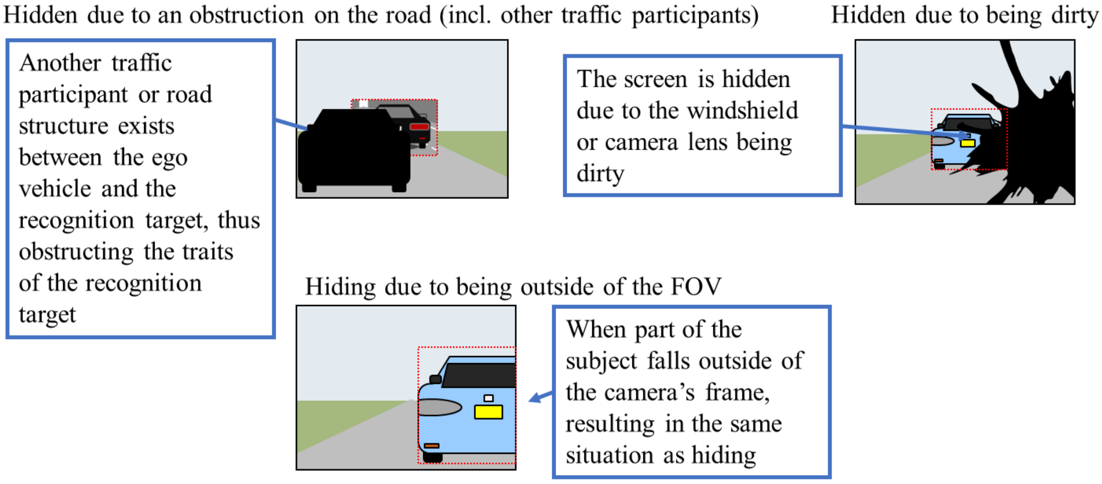
E.4.1.1 Phenomenon and Principle

Hidden
(image cut out)

E.4.1.1.1 Phenomenon

The recognition target is partially or fully cut off due to hiding by an object or due to moving out of the FOV, leading to a loss of information required for extracting features. It leads False Negative or position error.

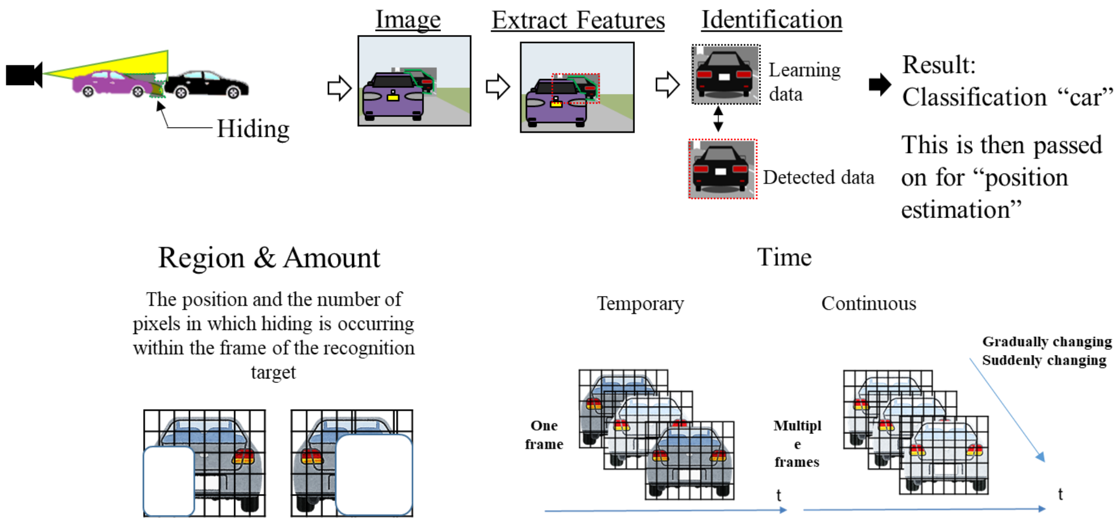
Example



E.4.1.1.2 Outline of the Principle

Hidden
(image cut out)

When the recognition target is partially hidden, the camera's recognition function may not be able to properly extract features. Even if features can be extracted, the identification function will not be able to match the learning data, resulting in an error in recognition (non-detection or incorrect classification).



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Causal factors based on the principle

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.

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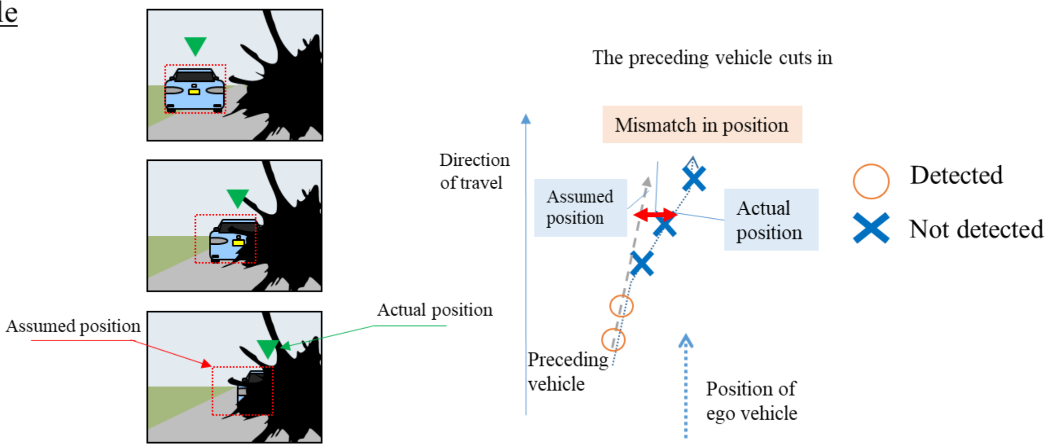
If correct feature extraction is not achieved, the size, orientation, and position of the object cannot be detected correctly. In addition, if the orientation and position are not detected correctly, errors will occur in tracking, causing recognition errors in estimated position and velocity.

Example



E.4.1.1.3 Principle Model

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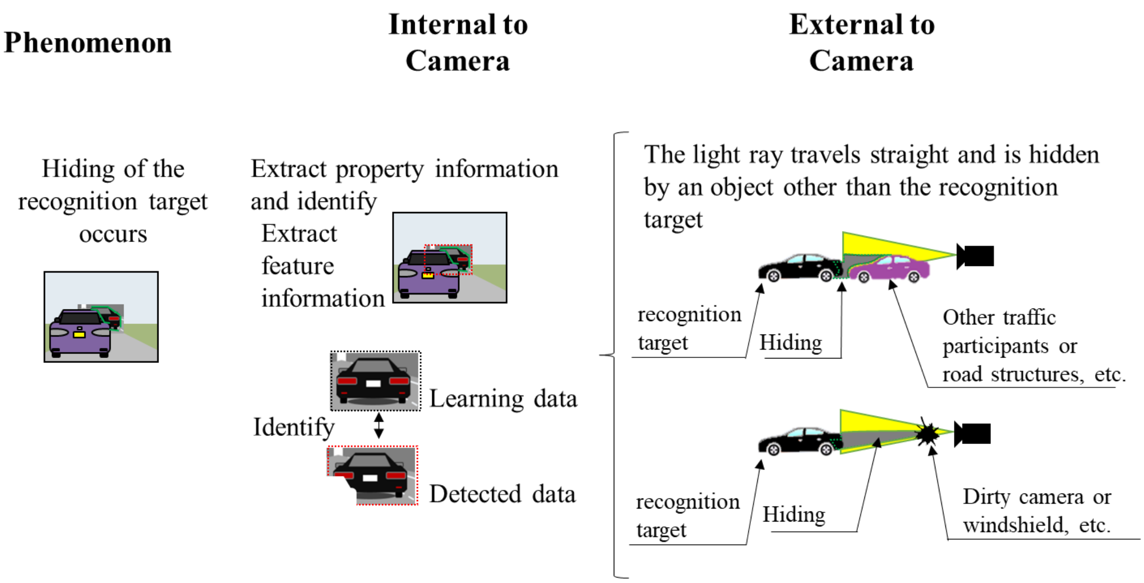
Relationship between internal and external models



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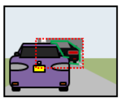
Internal to Camera

Several techniques exist for extracting trait information and for identification, and therefore cannot be specified. However, here we provide examples of some classic techniques

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

Learning data

Detected data

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.

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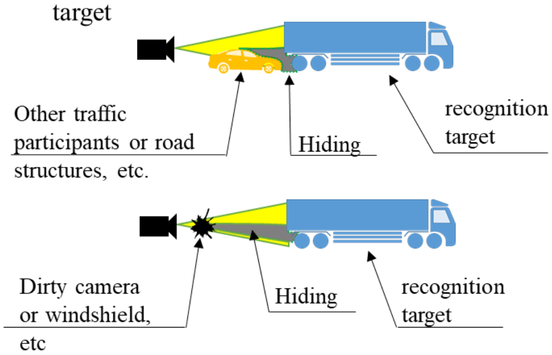
(image cut out)

External to Camera

The light ray travels straight and is hidden by an object other than the recognition target



<Model directly related to recognition error >

- Use a model where light emitted from the object (including reflected light) travels straight through a constant medium.

<Model related to recognition error, however impact is minimal (for reference) >

- Refraction occurs on the border of a medium, such as a glass surface or rainwater, etc.
- A phenomenon known for electromagnetic waves (incl. visible light). Strictly speaking there is diffraction, however, based on the degree of impact it is not considered as a problem causing hiding error

E.4.1.2 Causal Factors based on the Principle

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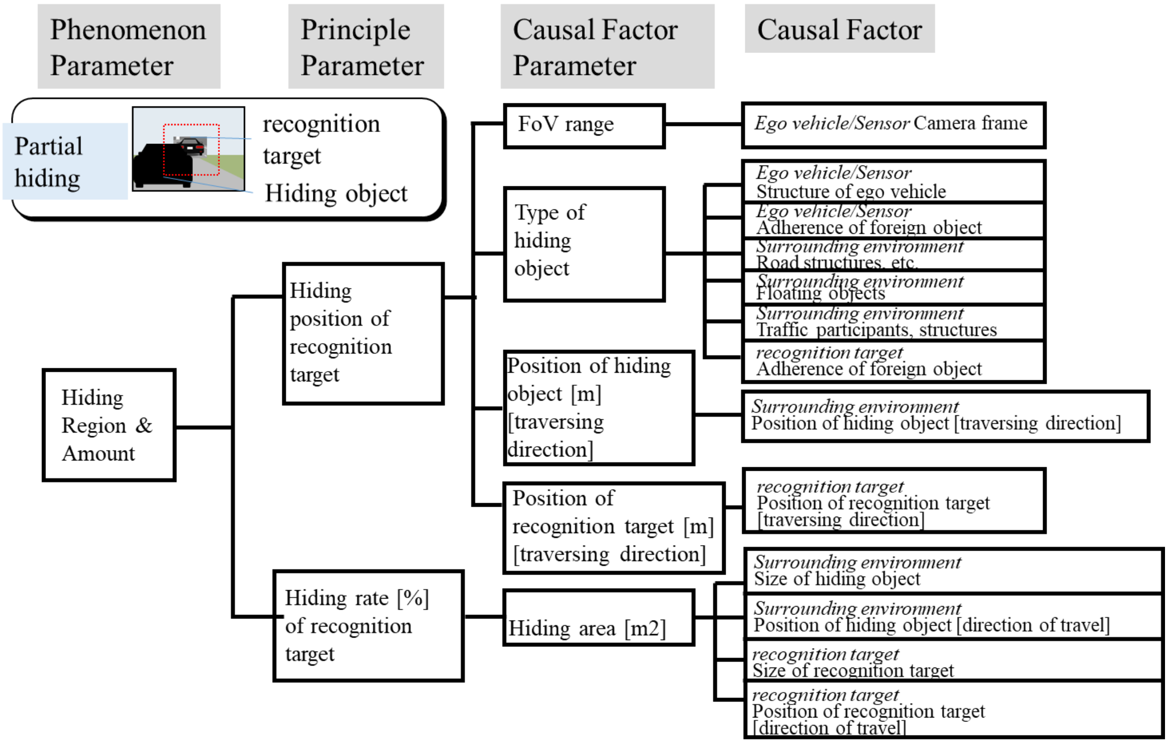
E.4.1.2.1 Relationship Between Principle and Causal Factors



E.4.1.2.2 Causal Factors

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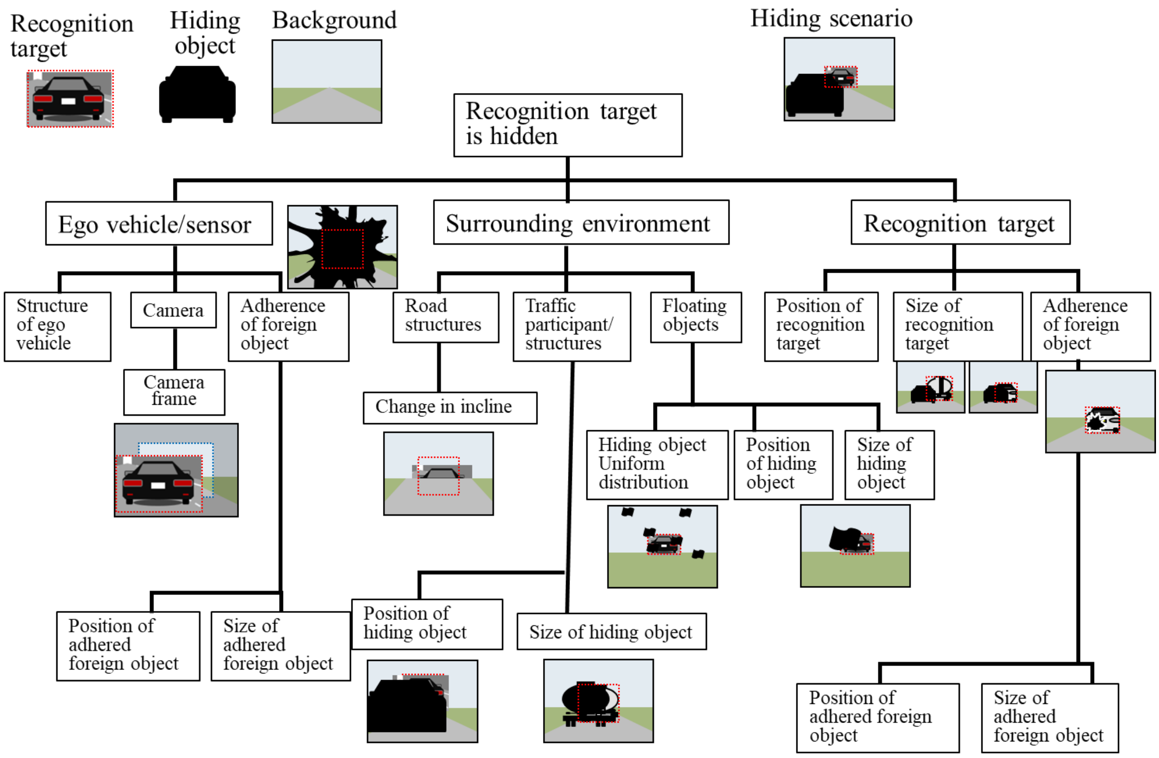

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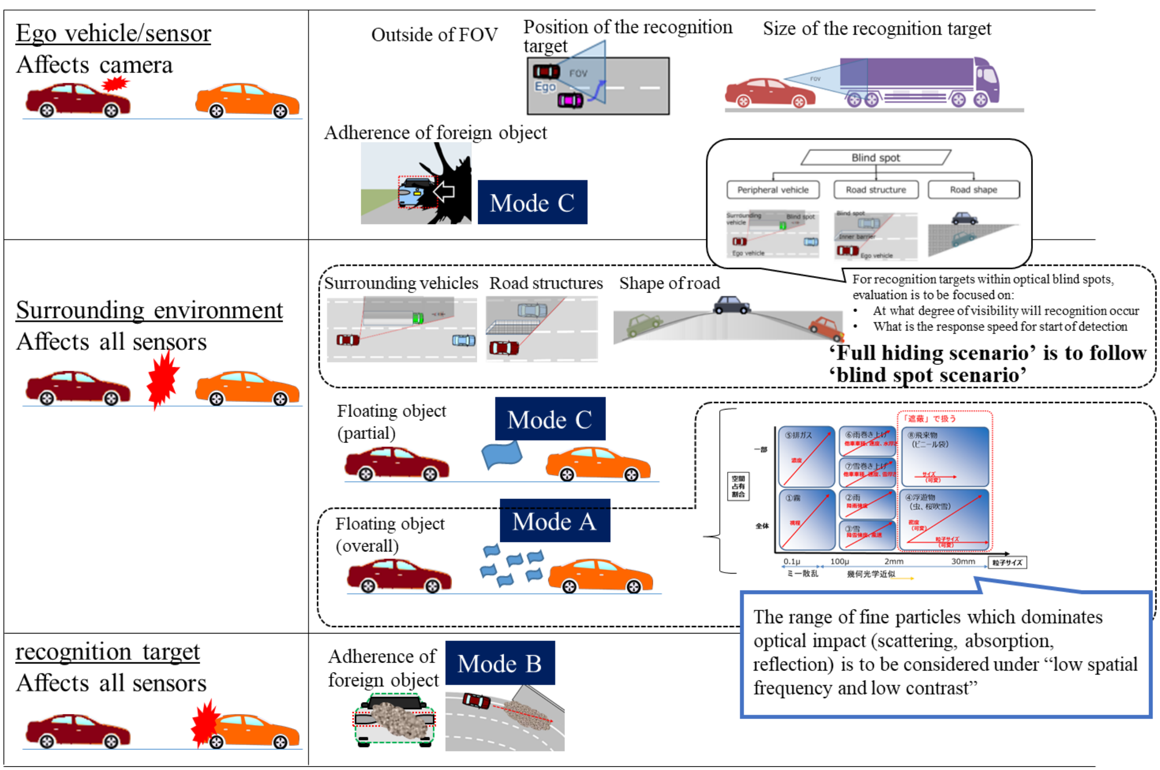

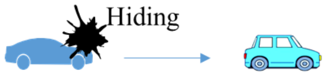

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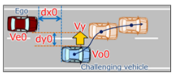
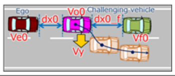
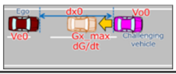
Functional Scenario	ALKS Scenario	Lane			Traffic Information			Moving Object				Obstruction on Road			Environment		
		Lane markings	Structures	Edge of road	Traffic lights	Road signs	Road surface signs	Other vehicles	Motorcycles	Bicycles	Pedestrians	Fallen objects	Mounted objects	Animals	Sunlight	Road 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) 	○						○	○			○	○				

E.4.1.2.3 Parameter Range

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(image cut out)

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		

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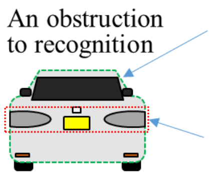
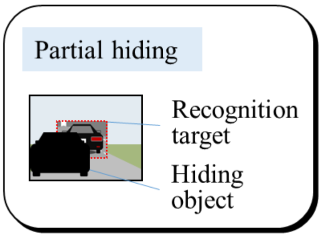
(image cut out)

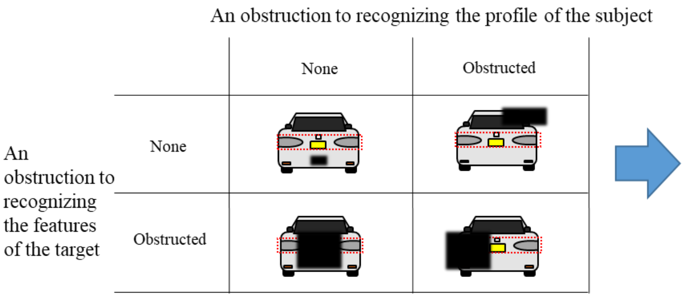
The Hiding Position



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)



Impact according to the type of hiding object

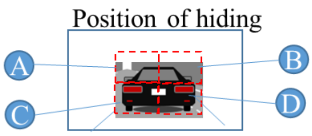


Mandatory evaluation scenario

Evaluation of C D

which hides features is a must

Note) Including hiding of C&D at the same time



E.4.1.2.4 Evaluation Scenario

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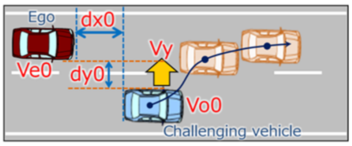
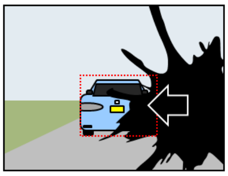
E.4.1.2.4.1 Cut-in

The object to be recognized enters the front of the own lane at a constant lateral speed from a position where the field of view is restricted by an attached object.





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[%])

Supplementary of Cut-in Scenario

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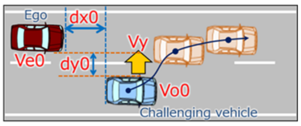
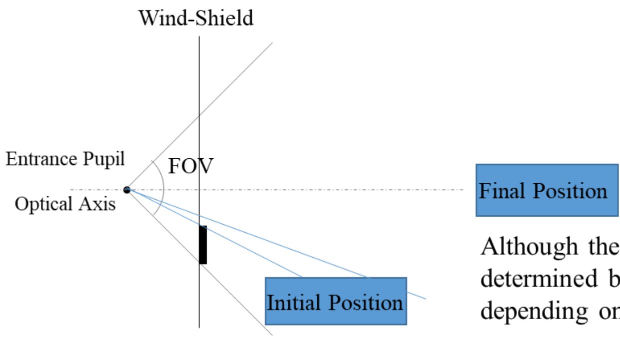
(image cut out)

In a cut-in scenario, consider a situation where a target that is partially or fully hidden becomes an ACC target by entering your lane.



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.

E.4.1.2.4.2 Cut-out

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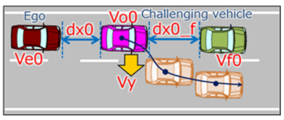
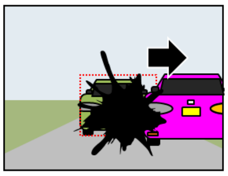
(image cut out)

The recognition target cuts out from the position where it is hidden. The recognition target in the foreground was partially visible, while the recognition target in the background, which exists farther away, is more shielded.



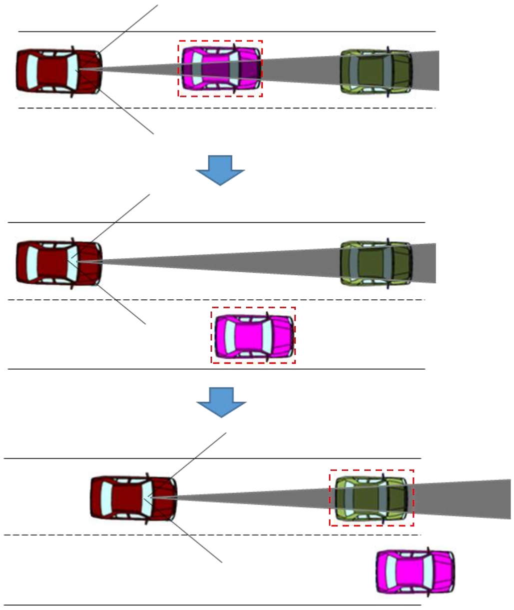


Parameter	Variable/Fixed	Range	Explanation
Distance to the target	Variable	Longitudinal position dx0 [m] Longitudinal position dx0_f [m]	Cut-out distance at the slowest speed to the maximum sensing distance of the sensor.
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph] Longitudinal velocity Vo0-Vf0 [kph] Lateral velocity Vy [kph]	The fastest and slowest speeds against the preventable criteria in the cut-out scenario.
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.

Hidden (image cut out)

Supplementary of Cut-out Scenario

In the cut-out scenario, when the vehicle in front that is partially hidden moves to the adjacent lane and the previous vehicle becomes the ACC target, it is evaluated that the partially hidden condition does not lead to a dangerous event.

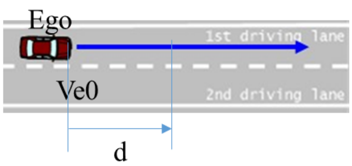


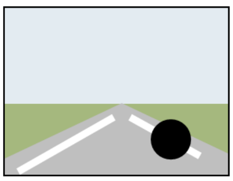
If the vehicle ahead is completely occluded, camera recognition is not possible, so this is another case such as the occlusion detection function. Since the problem here is the error in the output result of the position and distance to the recognition target due to the occlusion, the complete occlusion of the vehicle ahead is not included.

Hidden (image cut out)

E.4.1.2.4.3 Lane-Keep

Drive at a constant speed along your lane in a hidden situation.





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]	

E.4.1.2.4.4 Blind-spot (vertical)

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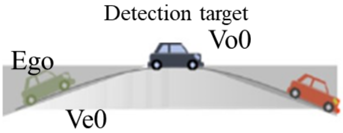
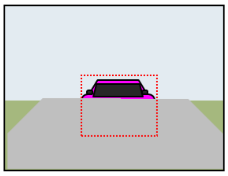
(image cut out)

While driving on a sloped road surface (convex shape), approaching the recognition target in front of own lane at a constant speed.





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.

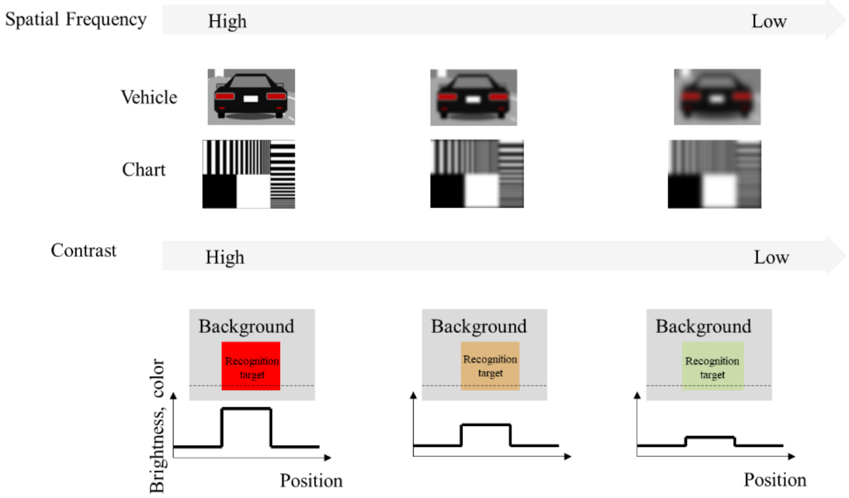
E.4.2 [Camera] Low spatial frequency / low contrast (caused by spatial obstruction)

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

E.4.2.1 Phenomenon and principle

E.4.2.1.1 Phenomenon

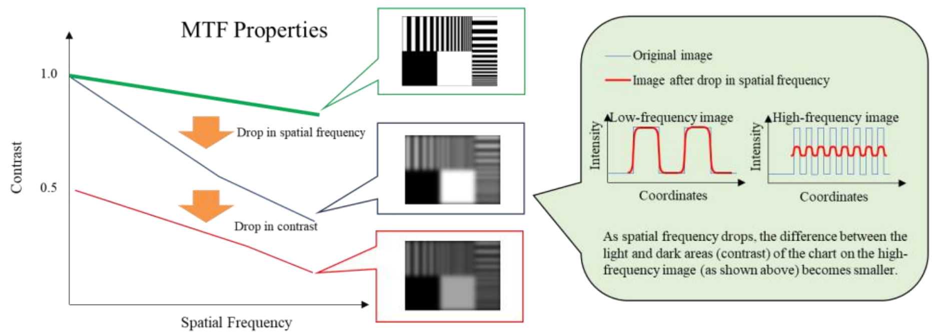
Rain, snow, and fog cause blurring of the contours of objects (decrease in spatial frequency).
At the same time, the contrast of the image is reduced.



Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

The degree of drop in spatial frequency and contrast of the image can be expressed with MTF.

A drop in spatial frequency can be expressed as a drop in the high frequency MTF (equivalent to blurring).
Contrast is the difference in brightness or chromaticity between the object and the background, and the overall contrast reduction in the image is expressed by the MTF reduction in all frequency bands.

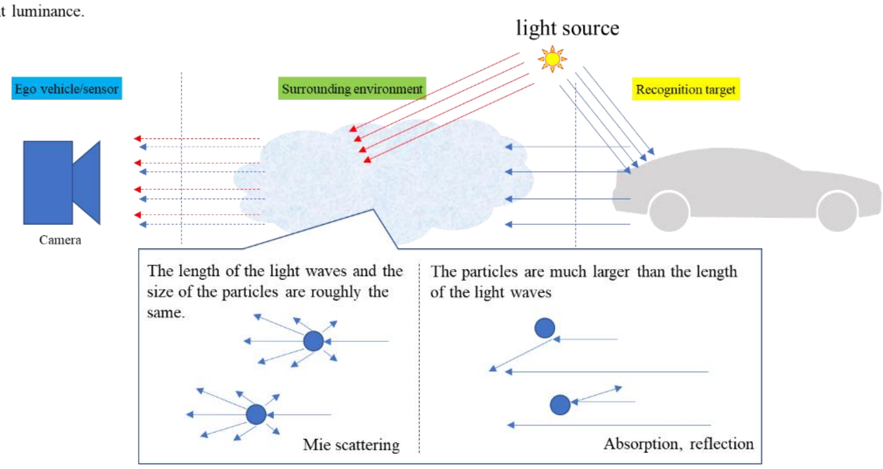


MTF (Modulation Transfer Function)
MTF is the amplitude ratio of the frequency and the input/output waves, when sine waves are input into the system.
It is the value representing the degree of gathering of light from a certain area of the recognition target, at the corresponding position in the image.
It allows to quantitavely test the performance of the lens, and allows testing of the image formation and contrast at the same time.

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

E.4.2.1.2 Outline of the principle

If there is an obstruction within the space of concern then the lights reflected from the recognition target can hit that obstruction (particles) within the space, causing scattering, absorption and reflection, resulting in attenuation prior to reaching the camera. (The degree of scattering, absorption and reflection, will depend on the size and concentration of the particles).
The luminance scattered by obstacles in the space due to the direct luminance from the light source is added to the attenuated luminance to become the camera incident luminance.

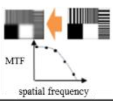


Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

Phenomenon Parameter

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

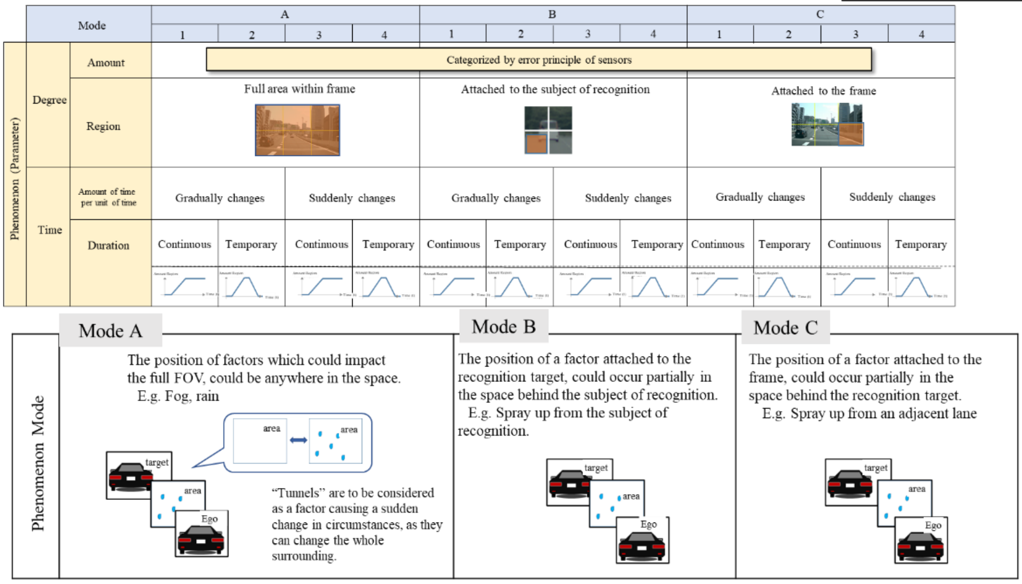
Exhibit: Pxhere.com: CC0 License

How it Affects Recognition/Controls

These can become a factor for error or prevent detection of the recognition target, when converting the image coordinates into positional information in the 3D space.

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

Classified into three modes according to the range of occurrence within the angle of view.

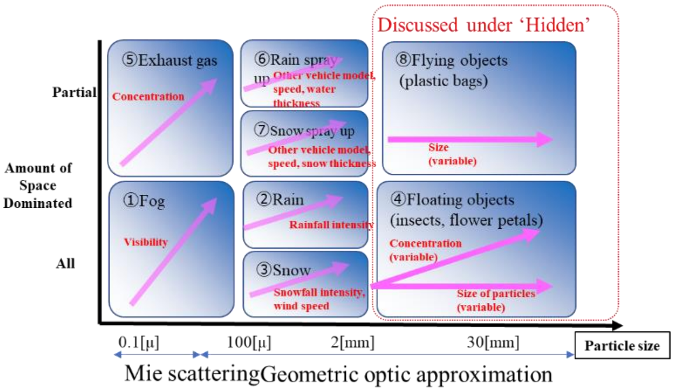


Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

Visibility drops due to spatial obstructions in accordance with the principle explained thus far.

There are various types of spatial obstructions. Here we have categorized them by the size of their particles according to previously mentioned principle. This is further categorized into "region", which is dealt with in the phenomenon mode (i.e. all or partial).

(Of these categories, ④ floating objects and ⑧ flying objects are looked at under the error mode "Hidden").

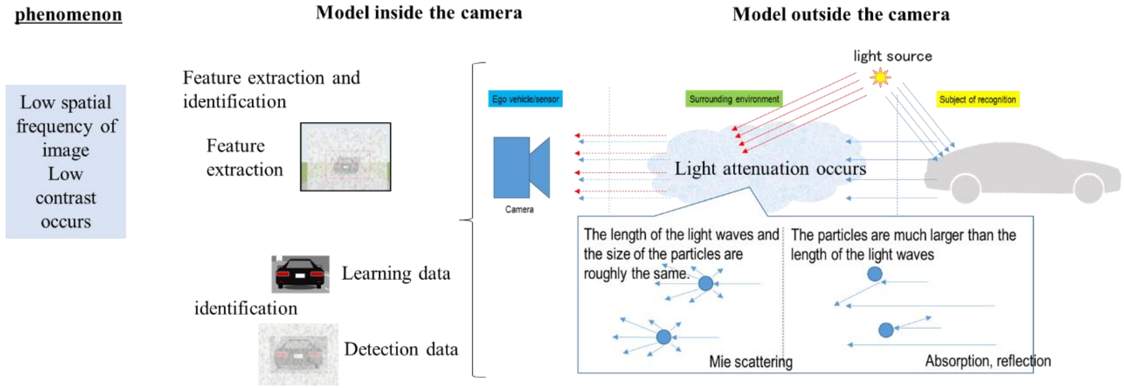


※Red font refers to the parameter of the disturbance

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

E.4.2.1.3 Principle Model

Relationship between internal and external models



Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

Internal to Camera

Several techniques exist for extracting trait information and for identification, and therefore cannot be specified. However, here we provide examples of some classic techniques.

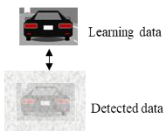
Extract trait information

【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 to Camera

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

According to Koschmieder's intensity attenuation model (below formula), when the attenuation coefficient (σ) (≒visibility) and distance (d) increase, the apparent intensity of the target becomes closer to the intensity of the surrounding environment (intensity of the background (sky)).

Source: Mori, "Fog Density Recognition by In-vehicle Camera and Millimeter Wave Radar", IJICIC vol.3, Num.5 Oct 2007

$$L = L_0 e^{-\sigma d} + L_f\left(1 - e^{-\sigma d}\right)$$

L : apparent intensity of the target
L_0 : targets intensity without scattering
L_f : brightness of surrounding environment (intensity of the sky)

Due to the attenuation of light in the atmosphere, the contrast C of an object when viewed from a distance d is as follows.

$$C = e^{-\sigma d}$$

σ: Light attenuation coefficient (dissipation coefficient) = the rate at which light intensity decays with distance

If the contrast identification limit is ε0, then the below can be expressed (Koschmieder's Law), with ε0 set at 0.02 or 0.05, etc. based on experience.

Source: Takata, 2004, 'Measuring Visibility', *Japan Society of Snow Engineering Journal*, Vol. 3 (20)
Takeuchi, 1991, 'Snow Particles in Space and Visibility', Journal of Geography, 100 (2), 264-272

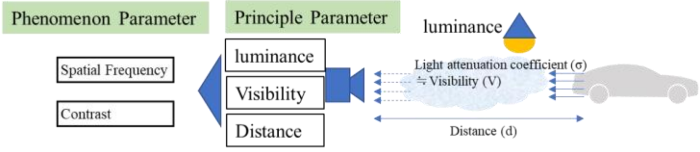
$$V = \frac{1}{\sigma}\ln\left(\frac{1}{\varepsilon 0}\right)$$

V: Visibility

$$V = \begin{cases} 3.912/\sigma & (\varepsilon 0 = 0.02) \\ 2.996/\sigma & (\varepsilon 0 = 0.05) \end{cases}$$

General visibility meters measure meteorological optical range (MOR) defined by the World Meteorological Organization (WMO).
MOR: the distance at which luminous flux in the collimated beam from an incandescent lamp of 2700K is reduced back to 5% of its original value

Therefore, the contrast is affected by the luminance of the light source, the light attenuation coefficient σ, and the distance d.
Since σ and the viewing distance V are uniquely corresponding values, and the viewing distance is generally used to measure the viewing distance, the principle parameters are as follows.



Different literature discuss the qualitative relationship between spatial obstructions and spatial frequency. However, none could be found
which look at the principle model, therefore, as with contrast, the parameters of
the principle have bee set as visibility and distance.

Mode A | Uniform Spatial Obstructions

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

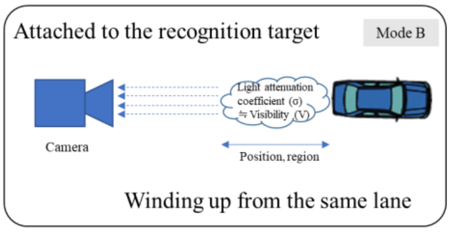
Causal factor parameter (underlined)

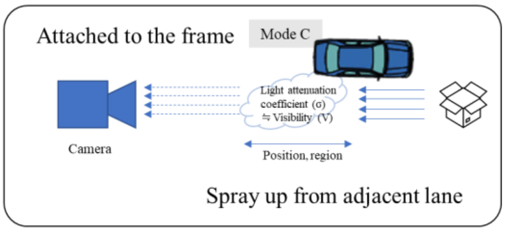
① **Fog**	The density of fog (attenuation coefficient) is generally expressed in terms of <u>**visibility**</u>, therefore the causal factor parameters will similarly be 'visibility'.
② **Rain**	There are several literature, however visibility will change according to the <u>**intensity of rainfall**</u>. 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 <u>**intensity of snowfall, wind speed**</u>, 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.

Mode B Mode C Local Spatial Obstructions

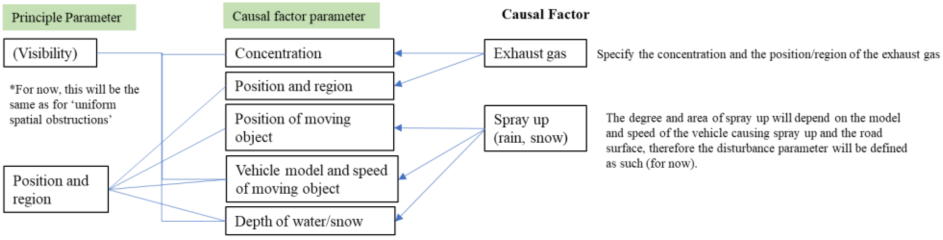
Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

The principle is the same as "uniform spatial obstructions," differing only in the limited scope.



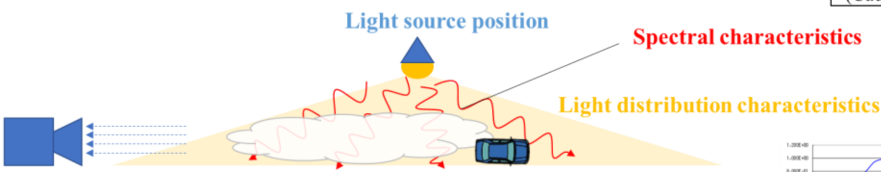


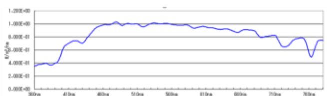
Exhaust gas and spray up (of rain or snow) have been listed as ‘disturbances’, with the parameters for the principle and disturbance being temporarily defined as below:

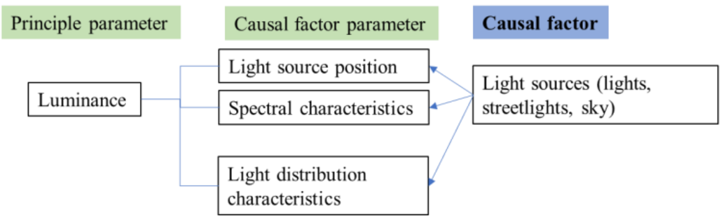


The luminance of a light source is determined by the spectral characteristics of the light source, the position of the light source, and the light distribution characteristics.

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)







Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

Impact of Light Source on Visibility

The light source from a target (tail lamps, etc.), can become the trait information used to detect the target (especially at night).
Spatial obstructions such as fog, etc. can cause veiling of the lights, causing the intensity distribution of the light veiling to become superimposed onto the intensity distribution of the actual light source.
(The intensity will gradually decrease as it extends out away from the light source).
The intensity ratio between the veiling and the actual light source, will change in constant relationship with fog density.
Further, if the difference in intensity between the light source and the background is large, the veiling will appear more prominent.

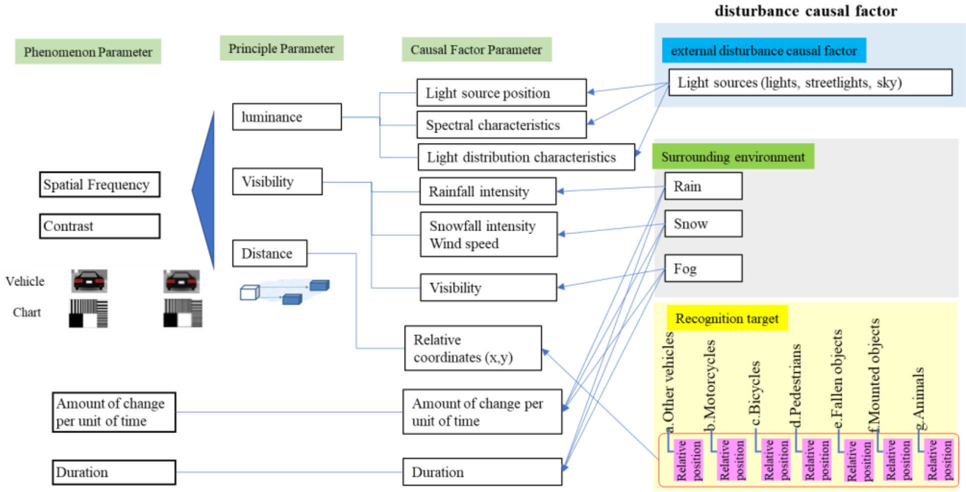
E4.2.2 Relationship Between Principle and Causal Factors of Perception Disturbance

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

E4.2.2.1 Causal factors based on the Principle

Mode A Full frame

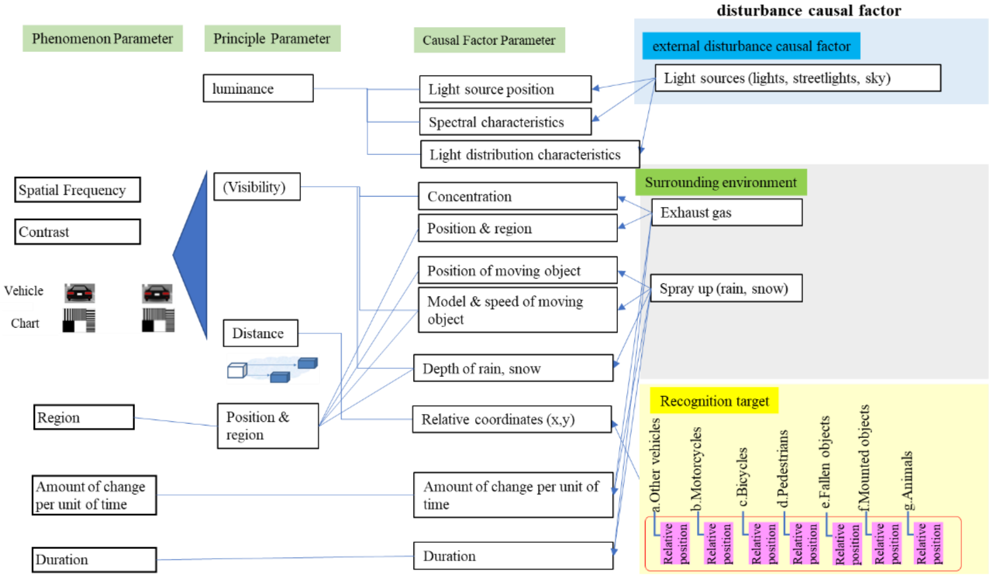
The below shows the relationship between disturbances (spatial obstructions) and their parameters.



Mode B **Attached to the recognition target** Mode C **Attached to the frame**

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

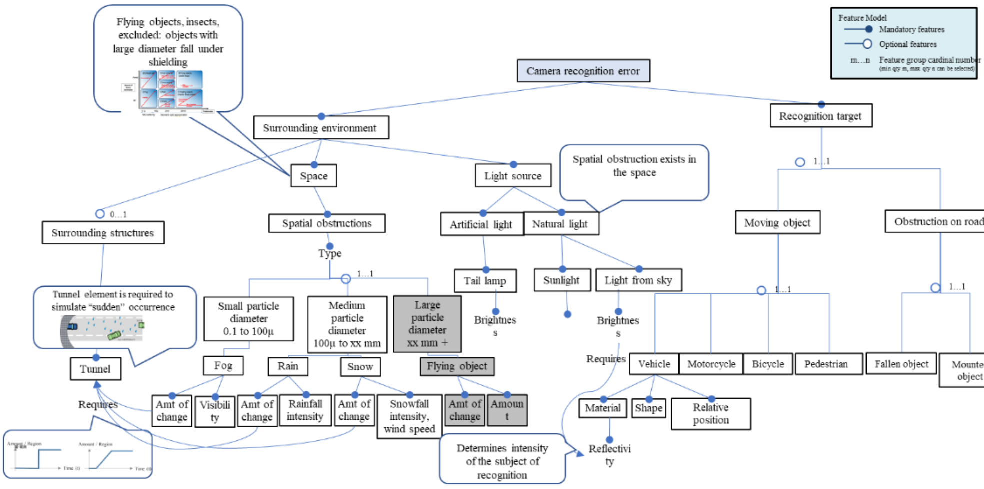
The below shows the relationship between disturbances (spatial obstructions) and their parameters.



Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

Hierarchy of disturbances based on disturbance causal factor

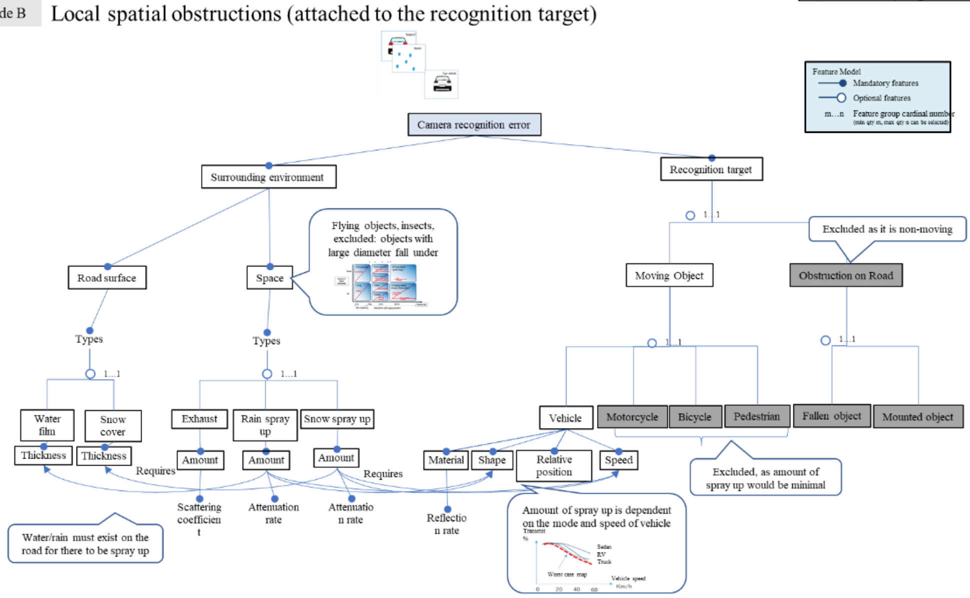
Mode A Full frame



Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

Hierarchy of disturbances based on disturbance causal factor

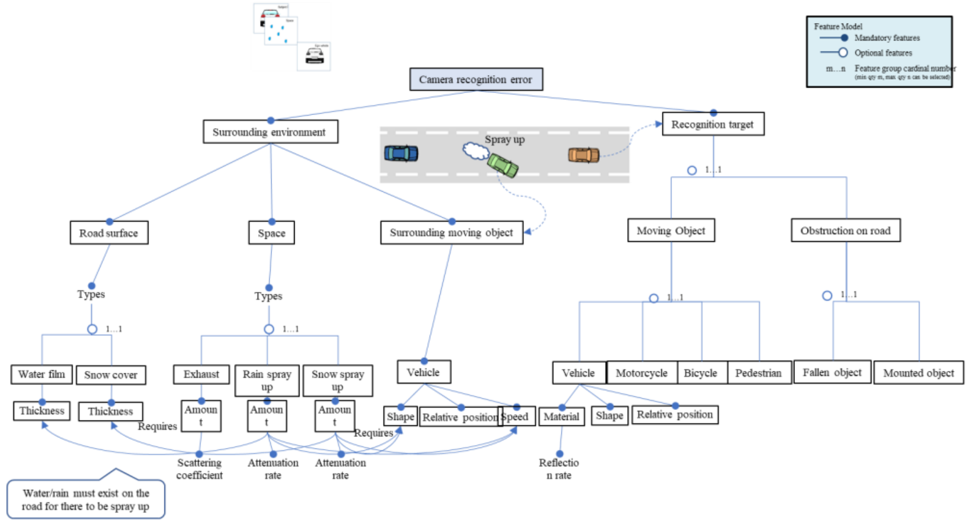
Mode B Local spatial obstructions (attached to the recognition target)



Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

Hierarchy of disturbances based on disturbance causal factor

Mode C　Local spatial obstructions (attached to the lane)



E4.2.2.2 Parameter Range

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

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

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

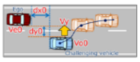
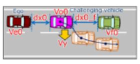
Explanation of the recognition targets

Targets that are similar in color to their background, have lower contrast, thus are more unfavourable (refer to the ‘low contrast’ error mode). Set the background as asphalt, concrete (black, gray) and snow (white), and select recognition target that are the same in colour.

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.

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

Derive the functional scenario by linking the ALKS scenario and the disturbance.

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.

Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)

E4.2.2.3. Evaluation Scenario

In the real world, disturbances can occur in combinations. Below are the combinations taken from the feature model.
Rain drop adherence to the front of the sensor during rain, leads to 'refraction' error, however it is included here as it may occur in conjunction with another.
*Multiple spatial obstructions could occur simultaneously, however they have been excluded for now.

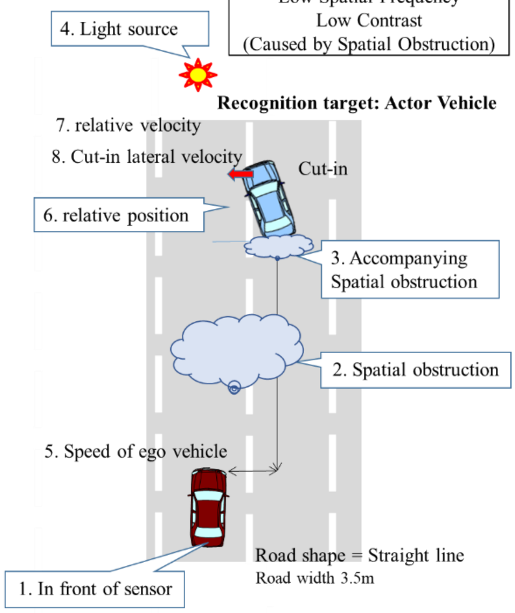
Scenario No.	Vehicle/Sensor		Surrounding environment						Notes	Mode
	In front of sensor		Spatial obstruction			Accompanying target		Light source		
	Rain drops (Refraction)	Snow (Shielding)	Fog	Rain	Snow	Spray up	Exhaust			
01	×	×	○	×	×	×	×	Day		A
02	×	×	○	×	×	×	×	Night		A
03	×	×	○	×	×	○	×	Day		A,B
04	×	×	○	×	×	○	×	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

Scenario F-1

Evaluation based on a 'Cut-in on a straight road' scenario

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		

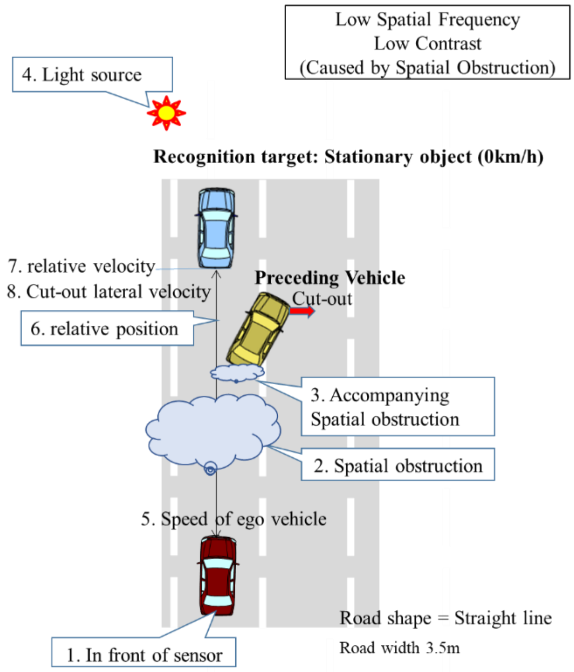
Low Spatial Frequency
Low Contrast
(Caused by Spatial Obstruction)



Scenario F-2

Evaluation based on a 'Cut-out on a straight road' scenario

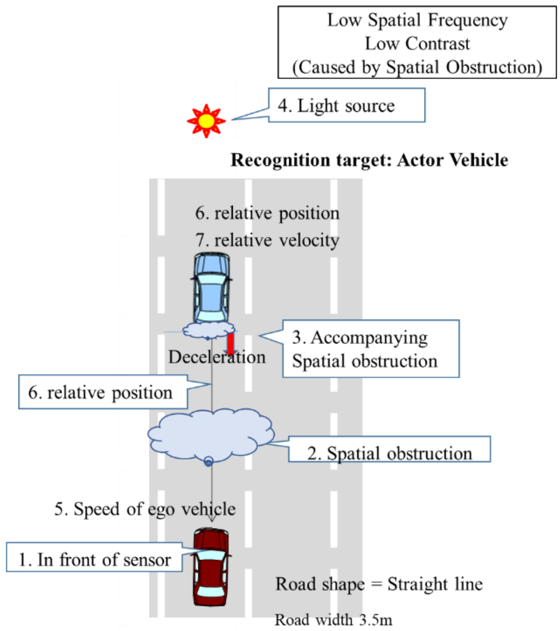
Causal factor parameter	1, In front of sensor	Rain drops
		Snow
	2. Spatial obstruction	Fog
		Rain
		Snow
	3. Accompanying Spatial obstruction	spray up
		Exhaust gas
	4.Light source	Day
		Night
Parameters required for evaluation	5. Speed of ego vehicle	Not decided here because of the scope of definition in the traffic flow scenario.
	6. relative position	
	7. relative velocity	
	8. Cut-out lateral velocity	



Scenario F-3

Evaluation based on a 'Deceleration on a straight-road scenario'

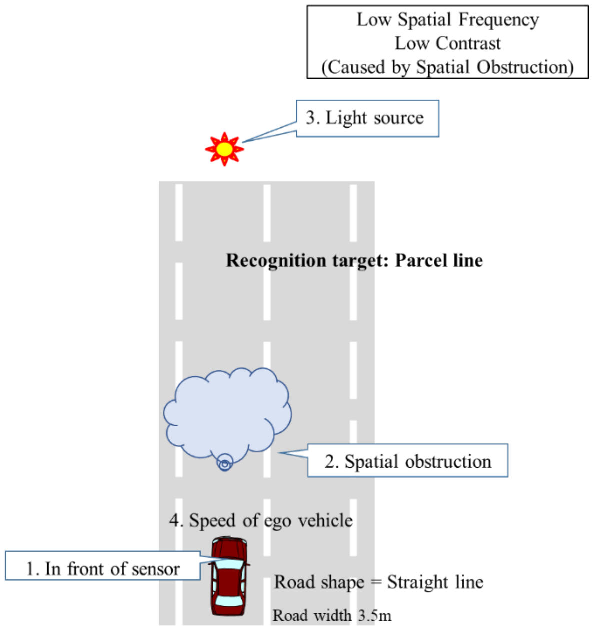
Causal factor parameter	1. In front of sensor	Rain drops
		Snow
	2. Spatial obstruction	Fog
		Rain
		Snow
	3. Accompanying Spatial obstruction	spray up
		Exhaust gas
	4. Light source	Day／Night
Parameters required for evaluation	5. Speed of ego vehicle	Not decided here because of the scope of definition in the traffic flow scenario.
	6. relative position	
	7. relative velocity	



Scenario F-B1-14

Evaluation based on a ‘Lane Keep on a straight road’ scenario

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 of the scope of definition in the traffic flow scenario.



E.4.3 [Camera] Overexposure

E.4.3.1 **Phenomenon and Principle**

Overexposure

E.4.3.1.1 Phenomenon

When the bright area within a frame exceeds the upper limit of intensity (upper limit of the dynamic range) which the camera can express, the camera will no longer be able to express the difference in intensity (tone) causing a deficiency in information and ultimately a non-detection.

Example

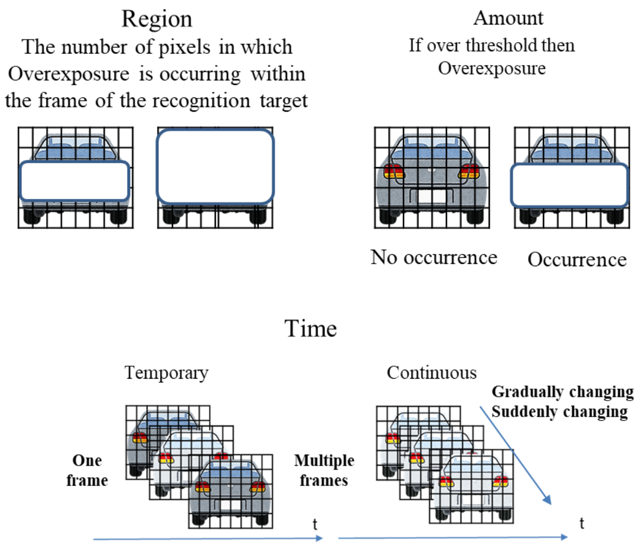
Overexposure of the vehicle ahead due to the reflection of the test vehicles headlamps

Overexposure caused by the sunlight at the exit point of a

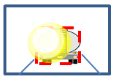
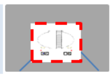
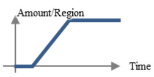
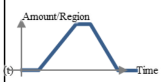
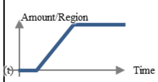
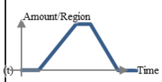
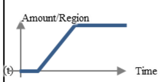
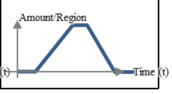
E.4.3.1.2 Outline of the principle

Overexposure

If Overexposure occurs in part of the recognition target, the recognition function of the camera may not be able to extract features correctly. Or, even if the features can be extracted, the identification may not be able to match the learning data, resulting in poor recognition (non-detection or classification error).

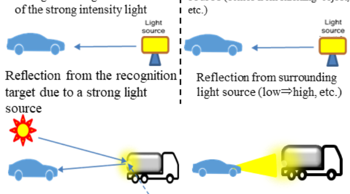


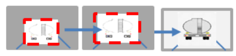
Causal factors of the disturbance based on the principle

Phenomenon Mode		A 1	A 2	B 1	B 2	C 1	C 2
Degree	Amount	Define by each principle of the sensor					
Degree	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					
Time	Duration	Continuous 	Temporary 	Continuous 	Temporary 	Continuous 	Temporary 

Causal factors and Evaluation Scenario

- A 1: 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.
- A 2: 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
- B 1: 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
- B 2: 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.)
- C: While overexposedCase where recognition target enters





Overexposure

E.4.3.1.3 Principle model

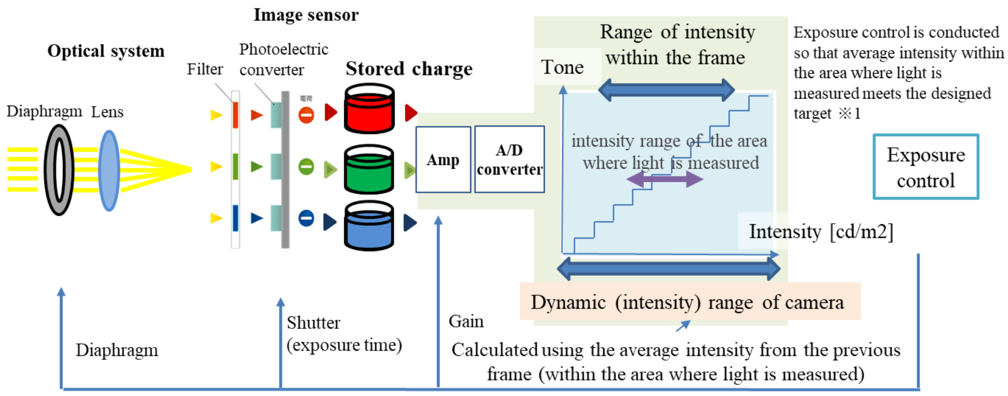
Outline of the principle

Overexposure is a phenomenon which occurs when the 'range of intensity in the scenery' is greater than the 'camera's dynamic (intensity) range' as adjusted by the exposure control.

Basic Principle

Exposure control identifies the difference in the average intensity of the previous frame (within the area where light is measured) to the target intensity, and determines the intensity range (Setting values for aperture, shutter-speed, gain, etc.).

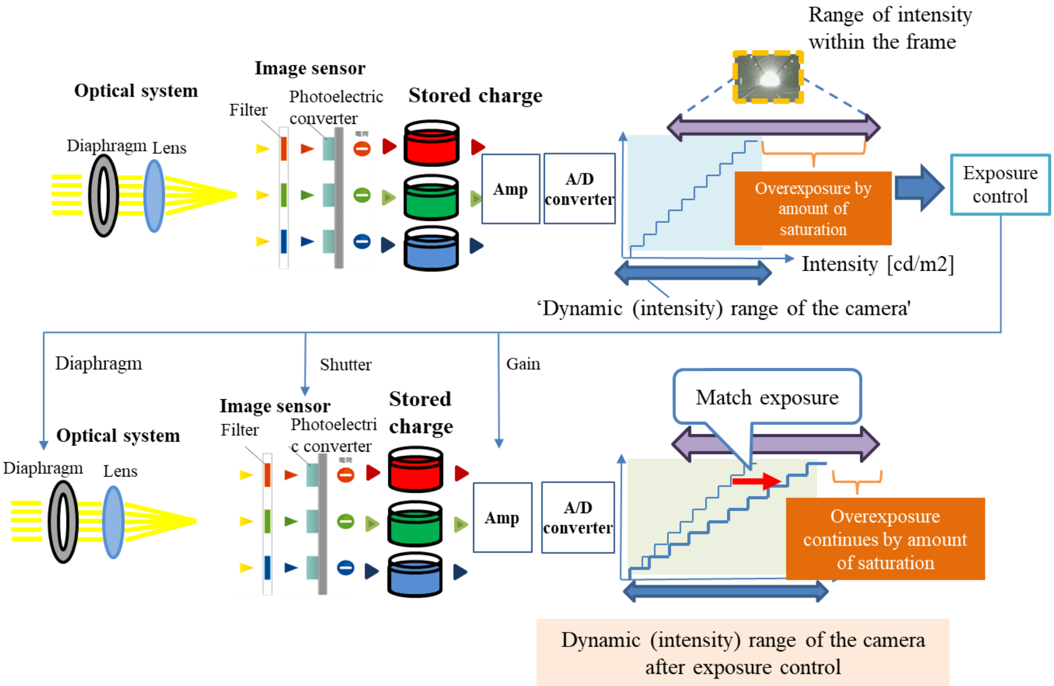
The intensity range within the frame is allocated to the above intensity range in order to express color.



※1 Details of control differs depending on manufacturer

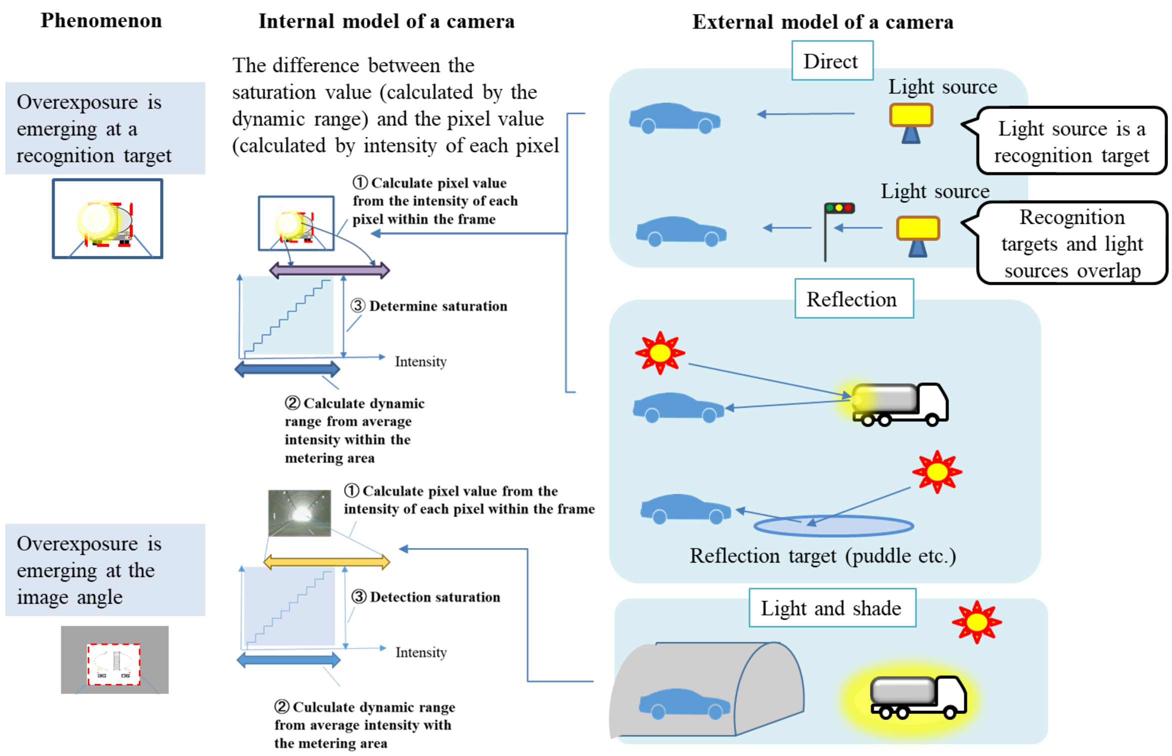
Overexposure

Mechanism of malfunction



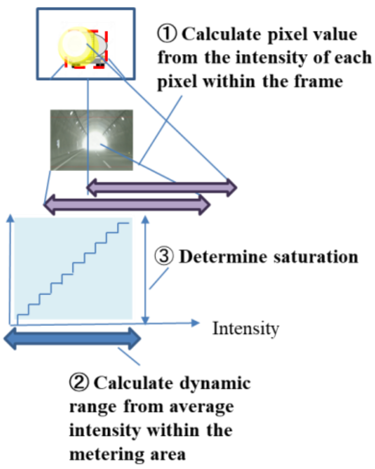
Overexposure

Relationship between internal and external models



Overexposure

Internal to Camera



① Calculating pixel value

Pixel value (R,G,B) =
Intensity of each pixel [cd/m2] x Rt[ms] × G × Wg x E x K

Rt : Exposure time [ms]
G : Gain z
Wg : White gain (fixed value)
E : Photoelectric converter coefficient (fixed value)
K : Color filter trasmittance

② Calculating dynamic range

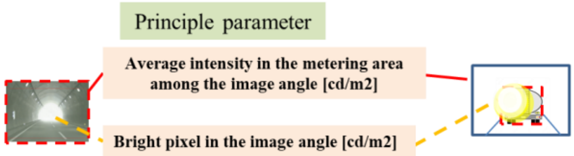
Dynamic range is determined by the average intensity of the previous frame (within the area where light is measured).

Average intensity within the frame (area where light is measured)
= ∑ pixel value / Number of pixels

③ Determining saturation

Brighter pixels than the saturation value (intensity) of each dynamic range will lead Overexposure.

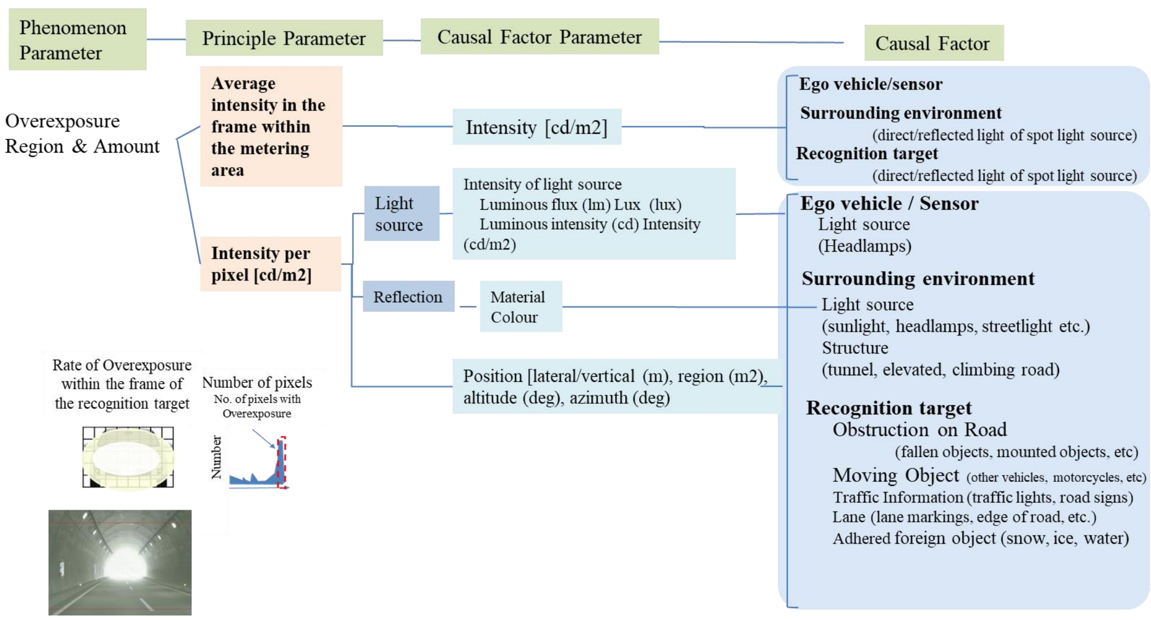
Bright pixel in the frame [cd/m2] > Saturation value



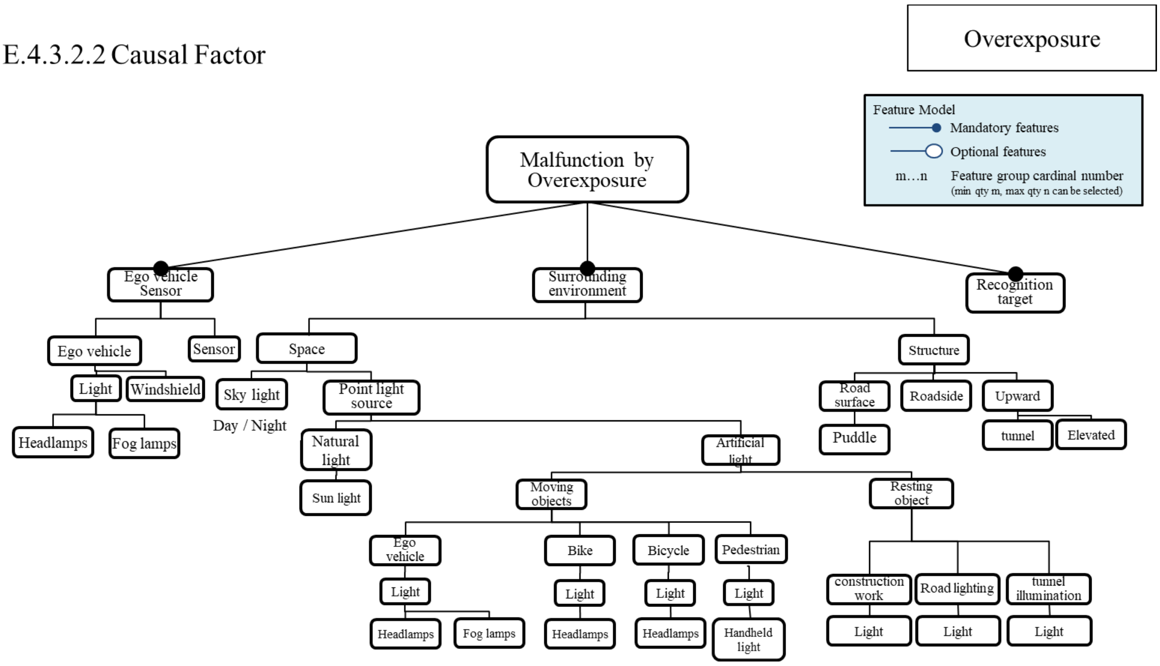
E.4.3.2 Relationship between the Principle and Causal Factors

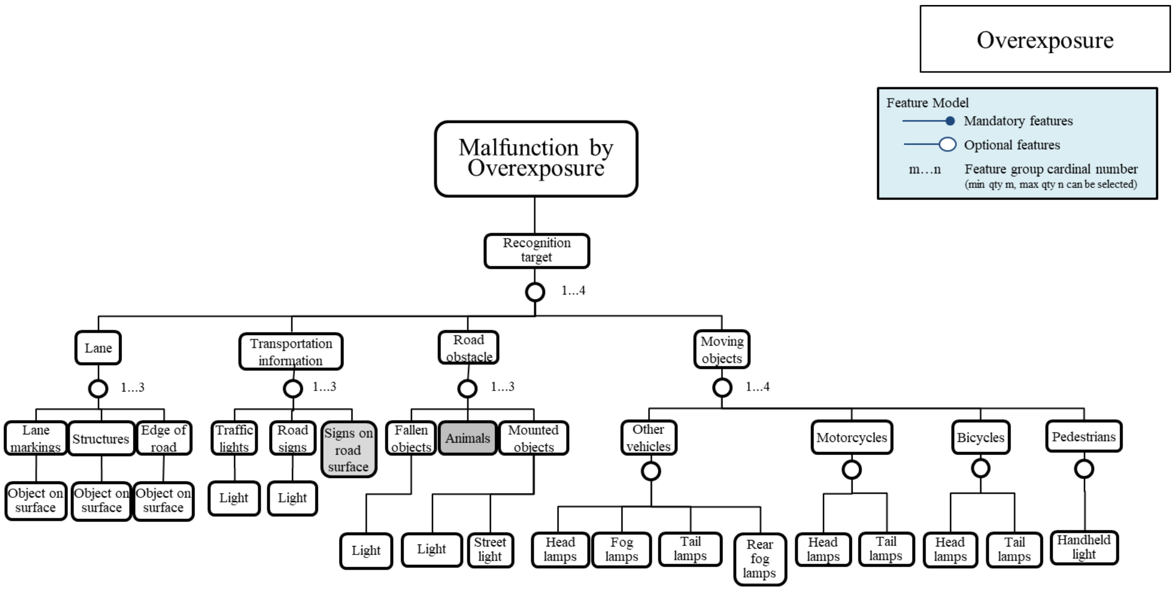
Overexposure

E.4.3.2.1 Causal Factors based on the Principle



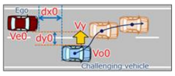
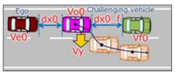
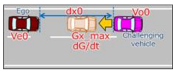
E.4.3.2.2 Causal Factor





Overexposure

Deriving the Functional Scenarios by connection between ALKS scenarios and causal factors

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		○	○	○	○	○	○								○	

E.4.3.2.3 Parameter Range

Overexposure

Ego vehicle /Sensor

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	

Overexposure

Surrounding environment

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[%]	

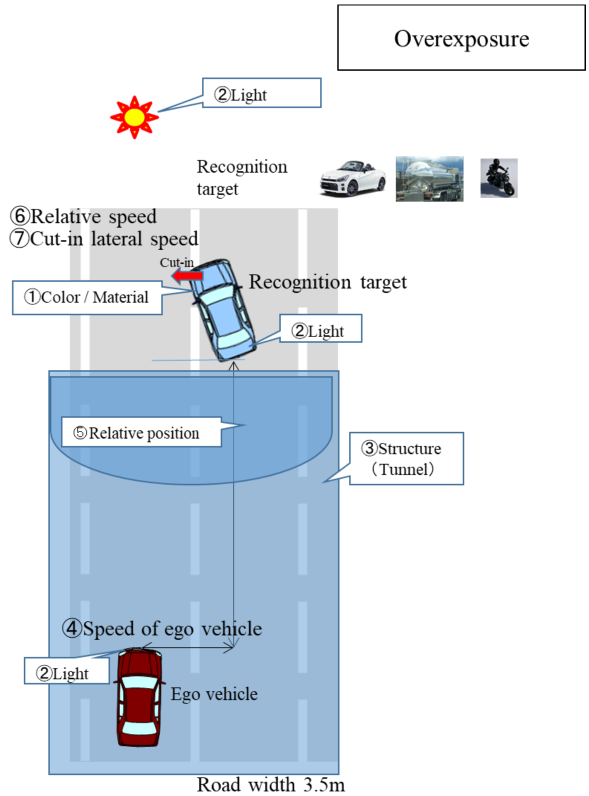
Overexposure

Recognition target

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.4.3.2.4 Evaluation Scenario

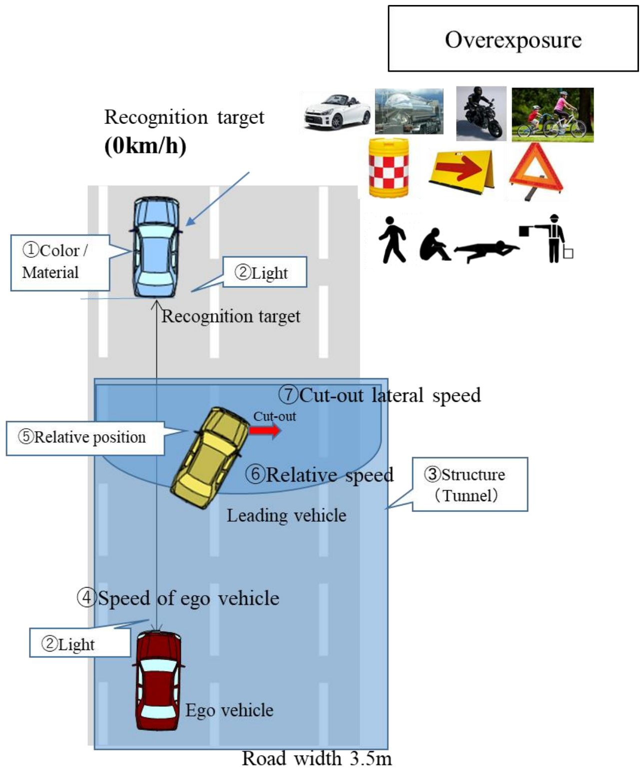
E.4.3.2.4.1 Cut-in



Evaluated in a Cut-in scenario on a straight road.

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	

E.4.3.2.4.2 Cut-out



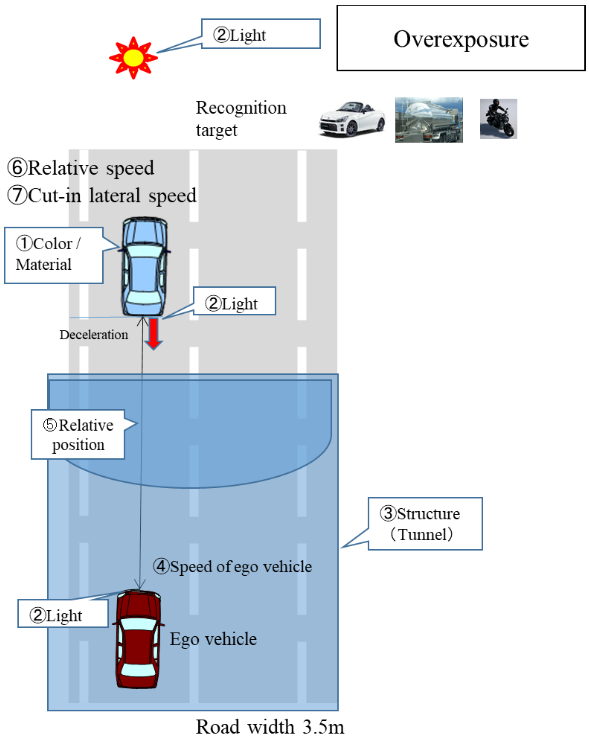
Evaluated in a Cut-out scenario on a straight road.

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	

E.4.3.2.4.3 Deceleration

Evaluated in the Deceleration scenario on a straight road.

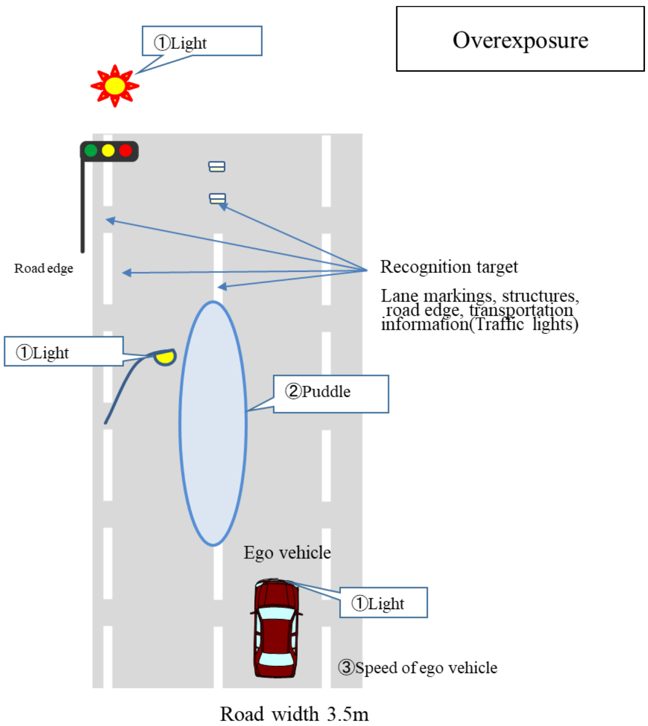
Causal factor parameter	①Color / Material	Color: White Material: Aluminum
	②Light	Natural light Sun light Artificial light Headlamps Tail lamps Rear fog lamps
	③Structure	Tunnel
Parameters required for evaluation	④Speed of ego vehicle	The range is defined by the traffic flow scenario, thus not defined here
	⑤Relative position	
	⑥Relative speed	
	⑦Deceleration	



E.4.3.2.4.4 Lane Keep

Evaluated in the Lane Keep scenario on a straight road.

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
Guideline for validation of virtual environment with perception disturbance

Generally, environment in which not only automated vehicle but also human drive vehicle will run is not limited to clear and good condition, that means bad weather like rain and fog situation should be considered. These conditions may cause recognition failure because sensor should receive perception disturbance. Safety evaluation of automated vehicle needs validation to consider these kinds of disturbance.

Simulation technology, that is remarkably progress especially in physical modelling, is a method to evaluate perception performance with disturbance. Validation in virtual environment is high convenience to apply but validity of virtual environment should be discussed.

This annex will clarify the requirement to be confirmed when principle of perception disturbance for each sensor (camera, millimeter radar, LiDAR) discussed in Annex E will be reproduced in virtual environment. Additionally, a method to validate developed environment will meet each requirement or not will be proposed.

The points to be discussed in this Annex are shown in fig.F-1.

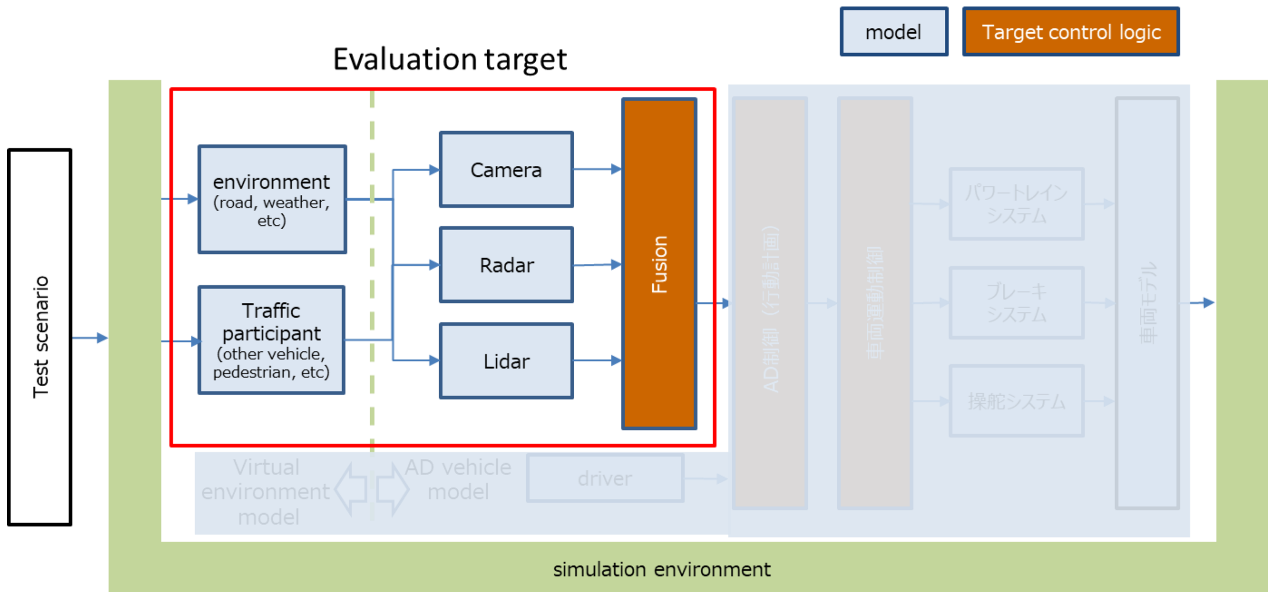


Figure F-1. area of this Annex

F.1 overview of requirements defined in this Annex

To judge whether perception performance evaluation in virtual environment will work well or not, it is necessary for relatives to have common understanding about how models and environment deployment will be validated. Final target would be to realize that evaluation result in virtual environment and real condition will be matched, thus we propose the definition of validation method in ideal condition (without perception disturbance) in advance to validation with perception disturbance. This means we can easily analyze the root cause of unmatch with disturbance (this is final target) by establishing validation method in ideal condition

We define requirement of validation in ideal condition as “A. Common requirement” and requirement of validation with perception disturbance as “B. perception disturbance reproducing requirement” (fig.F-2). Additionally, we propose each validation method about “A. Common requirement” and “B. perception disturbance reproducing requirement”

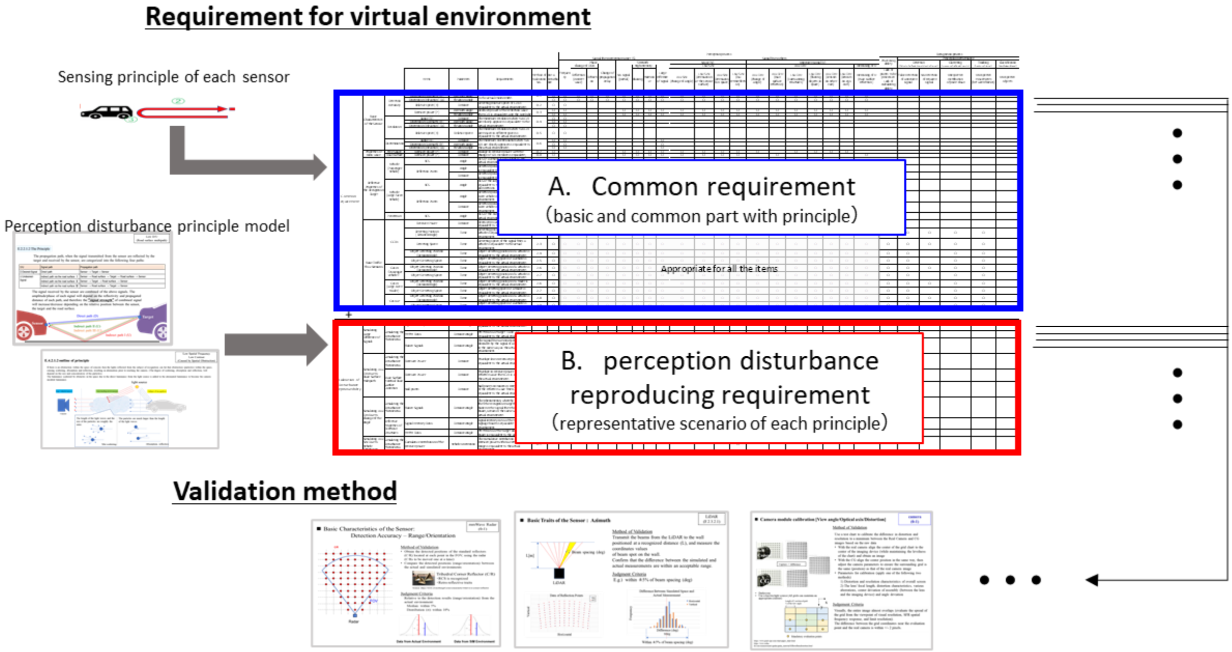


Figure F-2. overview of this Annex

A. Common requirement

- Define requirement to be confirmed in ideal condition (without perception disturbance) from each sensors' principle

B. perception disturbance reproducing requirement

- Define requirement to be confirmed with perception disturbance
- Clarify necessary principle parameter for reproducing disturbance and disturbance causal factor parameter by classifying various disturbance based on the principle and describe it as a model about each disturbance principle

F.2 Common requirement and reproductivity validation method

In this section items to be confirmed as common requirement and validation method are clarified. As a first step, clarifying the way of thinking about what items should be done as common requirement is shown. After that clarifying validation method for each sensor based on this way of thinking. This method is defined based on each sensors' principle thus it is necessary to clarify method when validating another principle's sensor following the way of thinking. This validation method shown below can be replaced by another method that can verify the same contents.

F.2.1 the way of thinking about common requirement

This section clarifies the way of thinking about the items to be set as common requirement. Component of object detection are defined as below elements as ①sensor/vehicle itself, ②space where the signal propagates

③recognition target(fig.F-3), and items to be validated and their criteria without perception disturbance for each element are clarified. Additionally the method to validate that recognition target can be detected under basic traffic disturbance scenario is defined to confirm this totally.

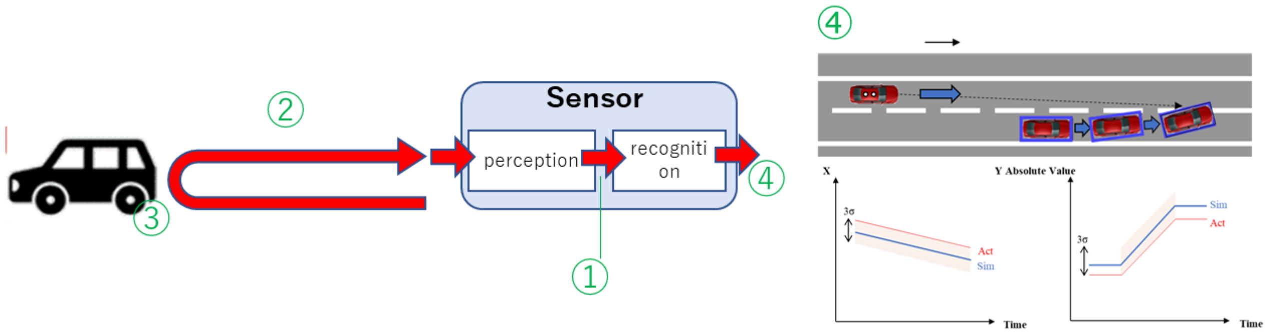


Figure F-3. element of common requirement

① sensor/vehicle basic characteristics

To confirm basic perception results like distance, direction, relative speed, signal intensity (items and condition differ in sensor principle) in ideal condition (without perception disturbance) as a sensor basic characteristic.

② characteristics of propagation, optical characteristics and so on

To confirm signal propagation from perception target to sensor in ideal condition would be reproduced.

③ reflection characteristics of perception target and so on

To confirm perception result would be reproduced. This is not only for perception result but also recognition result.

④ target recognition under traffic scenario

To confirm recognition result of the target under basic traffic scenario (following, cut-in, cut-out) would be reproduced.

F.2.2 The way of thinking about common requirement for each sensor

F.2.2.1 the way of thinking about common requirement for millimeter wave Radar

In accordance with the principles of the Radar perception, validates whether physical amount of distance, direction, relative speed and received wave intensity are reproduced (fig.F-4).

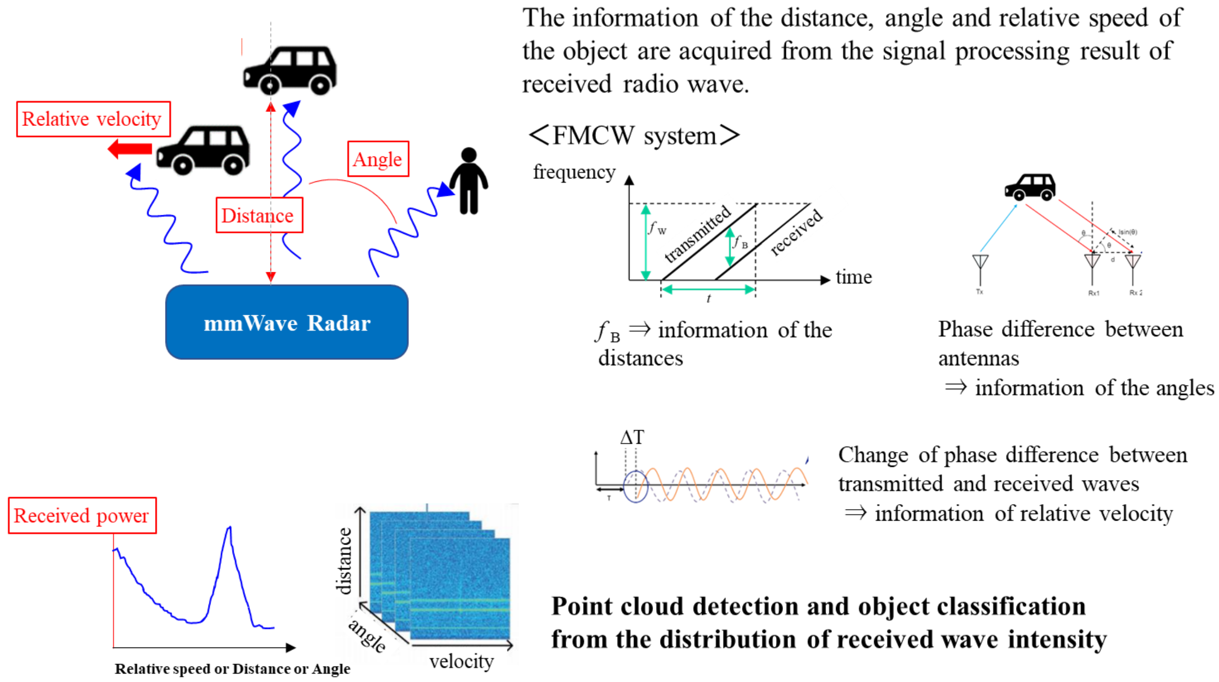


Figure F-4. the way of thinking about common requirement for millimeter wave Radar

Based on this way of thinking, list of actual requirement shown in table F-1 is clarified.

								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

Table F-1. List of common requirements for Radar

F.2.2.2 the way of thinking about common requirement for LiDAR

In accordance with the principles of the LiDAR perception, validates whether physical quantities like azimuth, range, strength, number of detection points and size are reproduced(fig.F-5).

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.

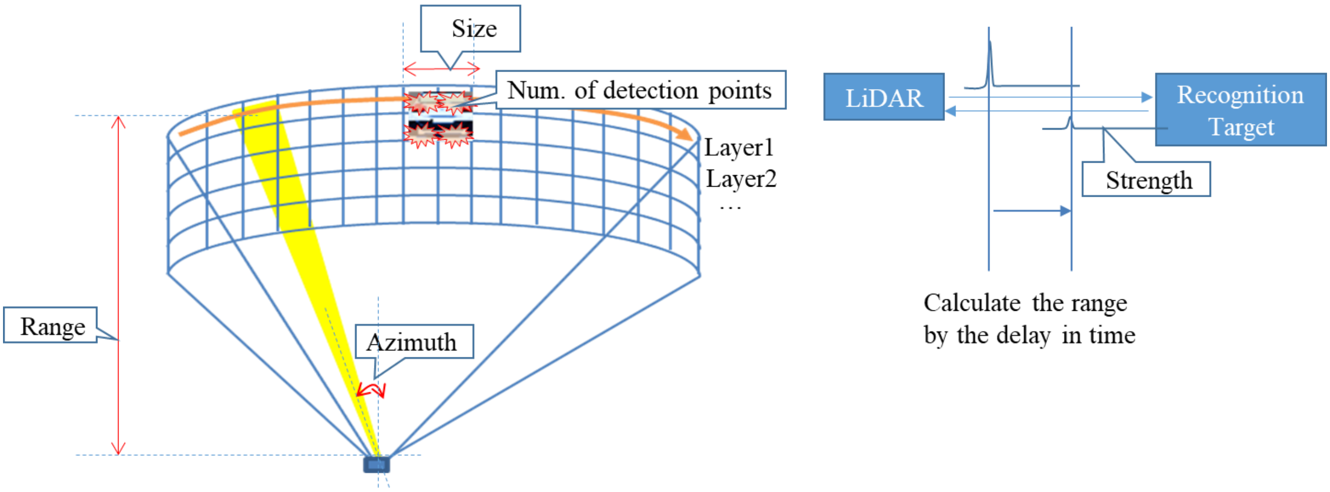


Figure F-5. LiDAR detection principle matrix

Based on this way of thinking, list of actual requirement shown in Table F-2 is clarified.

	Verification perspective		Explanation	target	item	Parameters	request	Validation Method No.	No disturbance	Perceptual part / Signal from recognition target (S) / Scan timing / Misalignment of overall spatial position	Scan timing / Misalignment of position of recognition target	S strength / Saturation of S	S strength / Attenuation of S / Low reflection of the recognition target	Attenuation of S / Adhesion to the recognition target	Attenuation of S / Rain/Snow/Fog	Attenuation of S / Exhaust gas/Hoisting	Attenuation of S / Adhesion to the sensor	S strength / No S due to occlusion	S Propagation direction / Reflection	S Propagation direction / Refraction	S speed / Arrival time of S	Signal from non-recognition target / N factor / Pulsed noise	N factor / DC noise	U factor / Multiple reflections	U factor / Signal from non-recognition target (Reflection)	U factor / Signal from non-recognition target (Refraction)
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	○	○	○									○						
						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	○				○	○	○	○	○	○				○	○	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。		
		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	○																	
						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	○	All items to be confirmed are applicable.																
					【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	○																	

Table F-2. List of common requirements for LiDAR

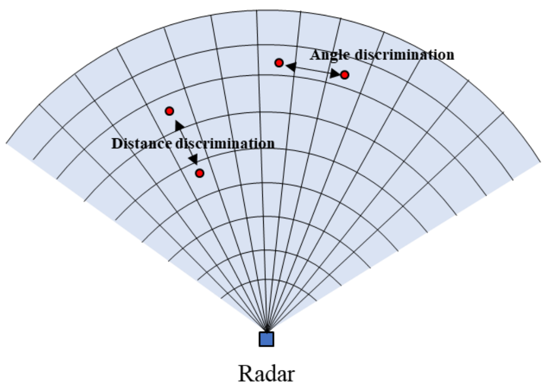
F.2.2.3 the way of thinking about common requirement for Camera

Camera sensor is different about perception principle from Radar and LiDAR, those are active type sensors and Camera is passive sensor which does not use signal from the sensor and uses surrounding light information, so that possible information differ from those 2 active sensors(fig.F-6). Camera can use colour information while active type sensors can detect distance information and camera cannot detect it in perception block. This comes from perception principle, that camera sensor uses flat plate light detecting sensor, so that this characteristic is very important to validate reproductivity.

Understanding the different between perception devices

Parameters to confirm to ensure consistency with sensor unit

Radar

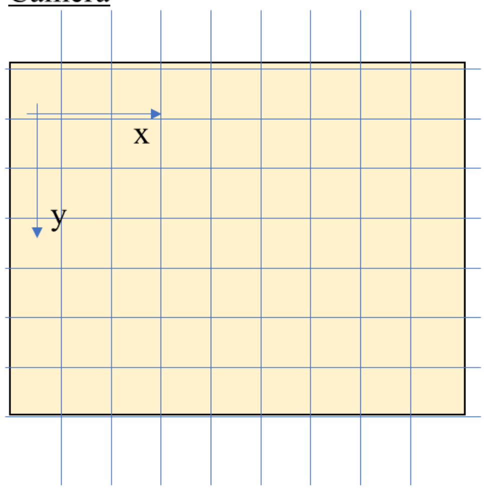


The radar/LiDAR sensors' perception data includes depth information

	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

Camera



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

× Range (FOV) Accuracy (positioning) Resolution (blurriness)

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 between active and passive sensor(camera)

Considering these characteristics, common requirement of camera perception process shown in below(fig.F-7) is clarified.

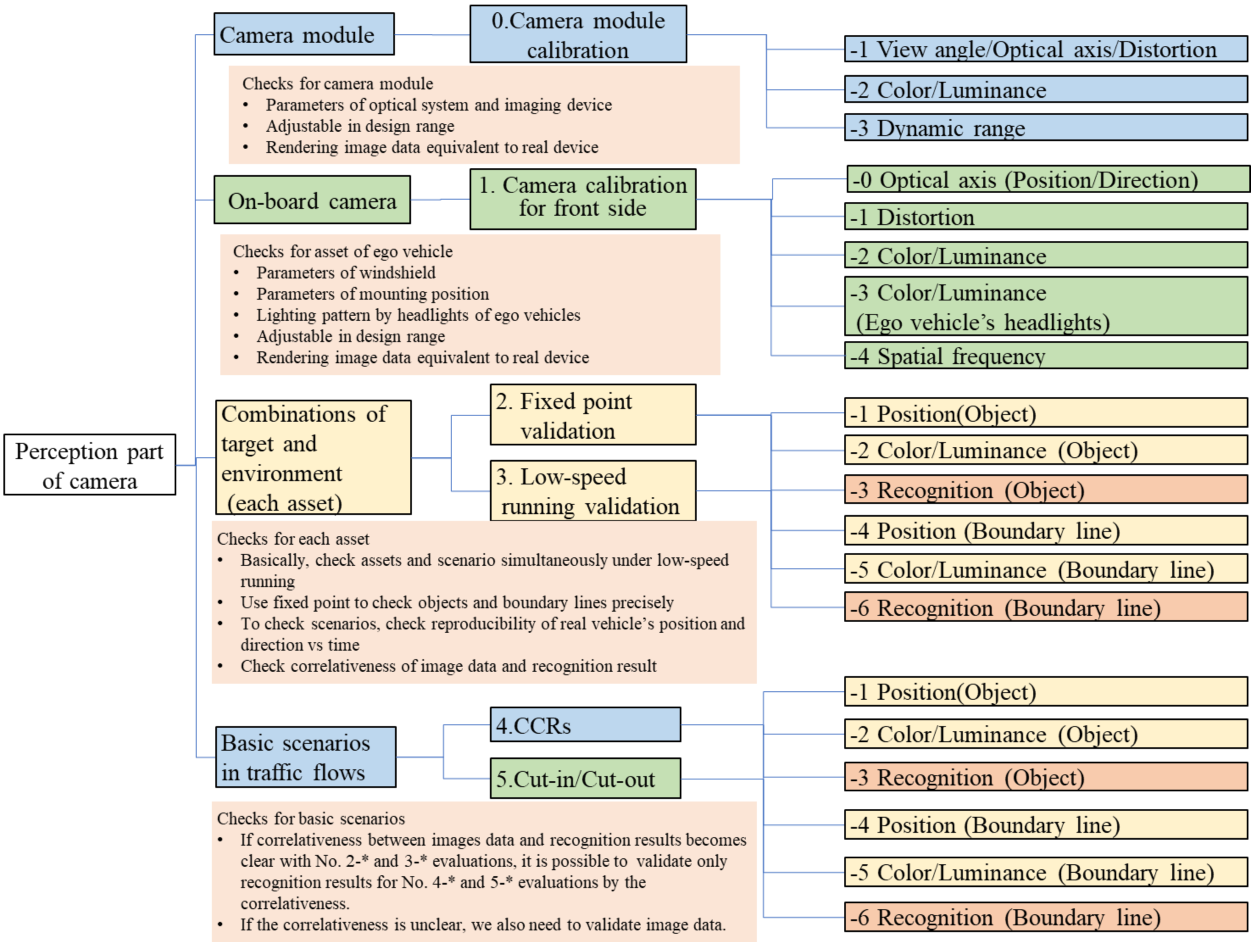


Figure F-7. common requirement of camera perception process

Camera perception process will be validated about sensor itself, resolution/color chart under on-vehicle condition, environment/target position reproductivity.

common requirement of camera recognition process shown in below(fig.F-8) is clarified.

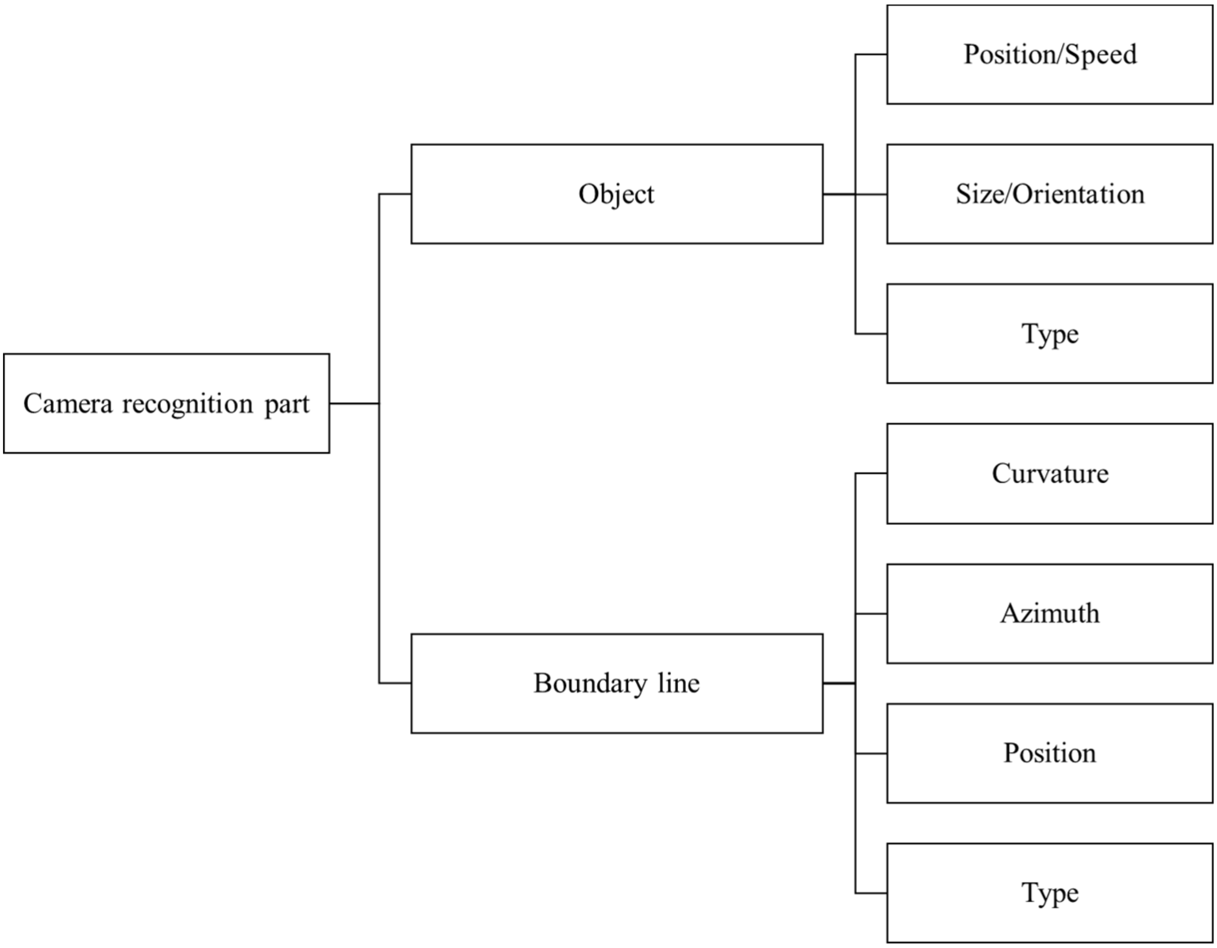


Figure F-8. common requirement of camera recognition process

Based on this way of thinking, list of actual requirement shown in Table.F-3 is clarified.

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	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	◎	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		(Lens)(CMOS)	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	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)	–	(◎)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		(Installed windshield)	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	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)	◎	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		(Pedestrians)	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)	–	○	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	–	–	–	–	–	–	–	–	–	–	–
		(Passenger cars: Prius) (Passenger car: NCAP dummy car) (Large vehicles)	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)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	○	–
		(Boundaries: white line, solid line, dashed line)		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)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	○	–
		(Road surface: straight, asphalt)		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)	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	◎	○	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		(Passenger car: Prius)	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	–	○	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	–	–	–	–	–	–	–	–	–	–	–
		(Road surface: straight, asphalt)	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	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	○	–
		(Surface: curved, asphalt)		Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	3-3-2	レ	レ	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	○	–
		(Boundaries: white line, solid line, dashed line)		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		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	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	–	–	–	–	–	–	–	–	–	–	–
		CCRs	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	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	○	◎	◎	–	–	○	–
			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	◎	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
		Cut-in (Passenger car) Cut-in (large vehicle) Cutout (Passenger car) Cutout (large vehicle)	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	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	○	–
		(Boundaries: white line, solid line, dashed line)		Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	5-3-2	レ	レ	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	○	–
		(Road surface: straight, asphalt)		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	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	○	◎	◎	–	–	○	–

Table F-3. List of common requirements for camera

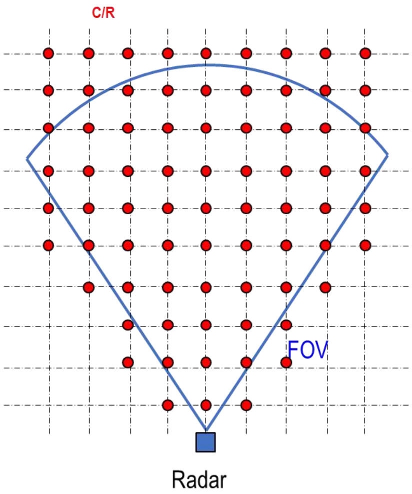
F.2.3 Validation method of common requirement

Validation method of each requirement for each sensor defined in section F.2.2 is shown in this section.

F.2.3.1 Validation method of common requirement of millimeter wave radar

mmWave Radar
(0-1)

■ Basic Characteristics of the Sensor:
Detection Accuracy – Range/Orientation



Method of Validation

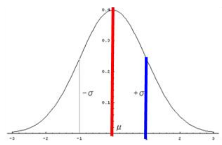
- Obtain the detected positions of the standard reflectors (C/R) located at each point in the FOV, using the radar (C/Rs to be moved one at a time)
- Compare the detected positions (range/orientation) between the actual and simulated environments

Trihedral Corner Reflector (C/R)
・RCS is recognized
・Retro reflective traits

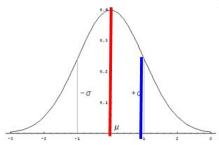
Source: https://www.everythingrf.com/community/what-is-a-corner-reflector

Judgment Criteria

Relative to the detection results (range/orientation) from the actual environment:
Median: within 5%
Distribution (σ): within 10%



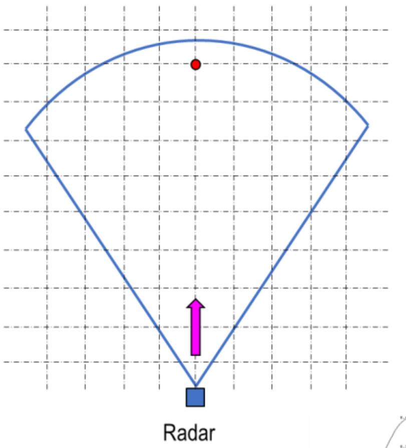
Data from Actual Environment



Data from SIM Environment

mmWave Radar
(0-2)

■ Basic Characteristics of the Sensor:
Detection Accuracy – Relative Speed

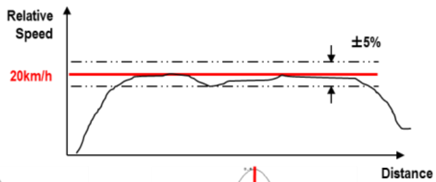


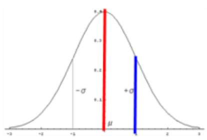
Method of Validation

- Place the C/R directly in front of the radar, and move the radar at a constant speed toward the C/R
- Compare the detected speed between the actual and simulated environments

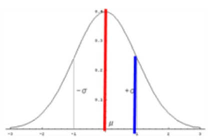
Judgment Criteria

Relative to the detection results from the actual environment:
Median: within 5%
Distribution (σ): within 10%





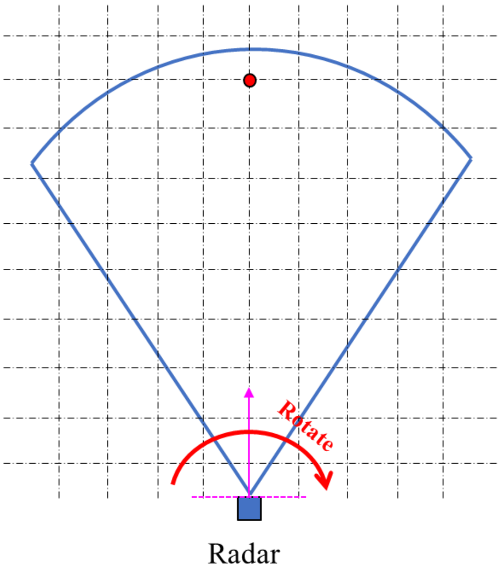
Data from Actual Environment



Data from SIM Environment

mmWave Radar
(0-3)

■ Basic Characteristics of the Sensor: Detection Accuracy - Received Power

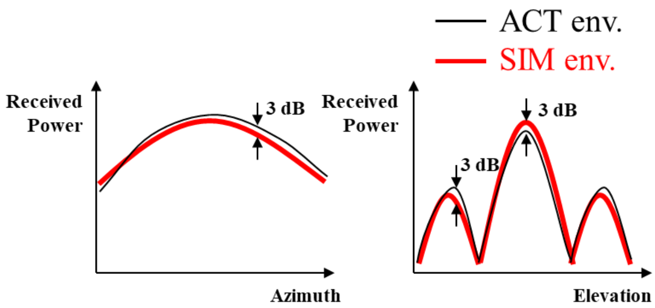


Method of Validation

- Place the C/R directly in front of the radar, and rotate the radar in the azimuth(horizontal) and elevation(vertical) angles, and measure the received power

Judgment Criteria

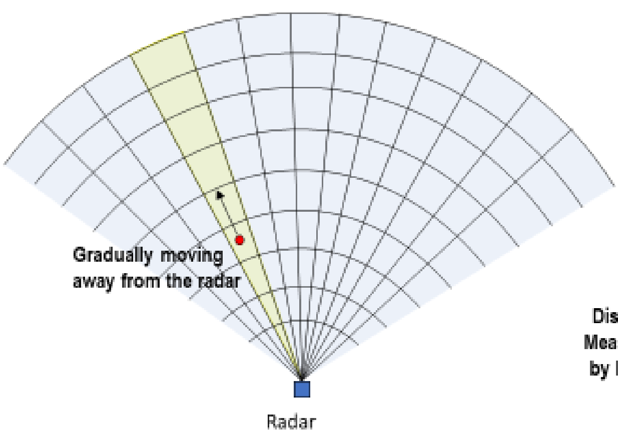
- Difference in the received power : 3 dB or less



mmWave radar
(0-4)

■ Basic Characteristics of the Sensor: Resolution - Range/Orientation

<Resolution Range>



Method of Validation

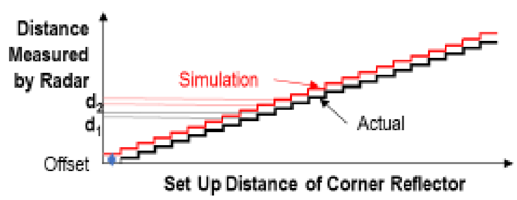
➢ Resolution Range

Validate the resolution range by placing the C/R within the radar's FOV, and gradually varying the distance away from the radar along the normal vector.

Judgment Criteria

◆ The number of steps in the stairs derived by the relationship between the set-up distance of the corner reflector and the distance measured by the radar, is to be the same for both the actual and simulated environments

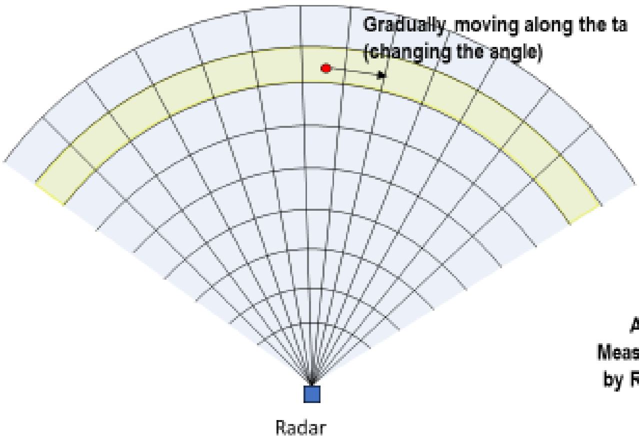
◆ The size of the steps d_1,d_2 shall not differ in size by more than 15% (provisional)



■ Basic Characteristics of the Sensor: Resolution - Range/Orientation

mmWave radar (0-4)

<Azimuth Resolution >



Method of Validation

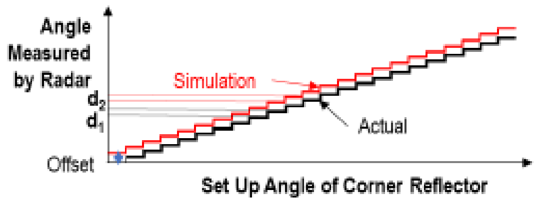
➢ Azimuth Angle Resolution

Place the C/R within the radar's FOV and gradually move it in the tangential direction. Validate the azimuth angle resolution by comparing the angle measured by the radar to the set-up angle of the C/R

Judgment Criteria

◆ The number of steps in the stairs derived by the relationship between the angle measured by the radar and the set-up angle of the C/R, is to be the same for both the actual and simulated environments.

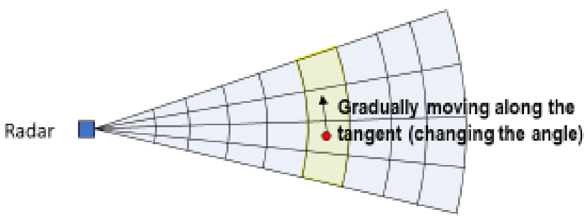
◆ The size of the steps d_1,d_2 shall not differ in size by more than 15% (provisional)



■ Basic Characteristics of the Sensor: Resolution - Range/Orientation

mmWave radar (0-4)

<Elevation Resolution >



Method of Validation

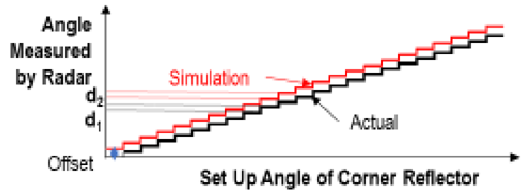
➢ Elevation Angle Resolution

Place the C/R within the radar's FOV and gradually move it in the tangential direction. Validate the elevation angle resolution by comparing the angle measured by the radar to the set-up angle of the C/R

Judgment Criteria

◆ The number of steps in the stairs derived by the relationship between the angle measured by the radar and the set-up angle of the C/R, is to be the same for both the actual and simulated environments.

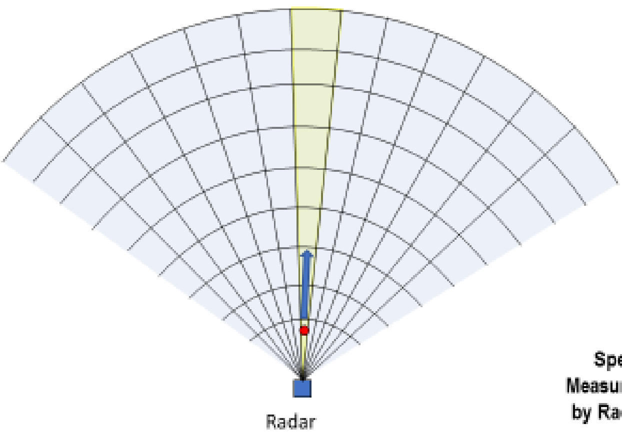
◆ The size of the steps d_1,d_2 shall not differ in size by more than 15% (provisional)



■ Basic Characteristics of the Sensor: Resolution - Relative Speed

mmWave radar (0-5)

<Speed Resolution>



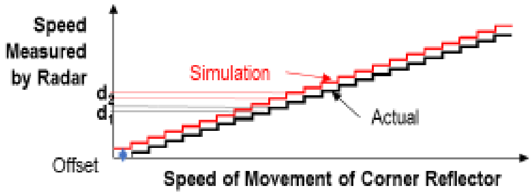
Method of Validation

➢ Speed Resolution

Place the C/R within the radar's FOV, and evaluate multiple times by keeping the speed of the reflector constant, and then changing the speed.

Judgment Criteria

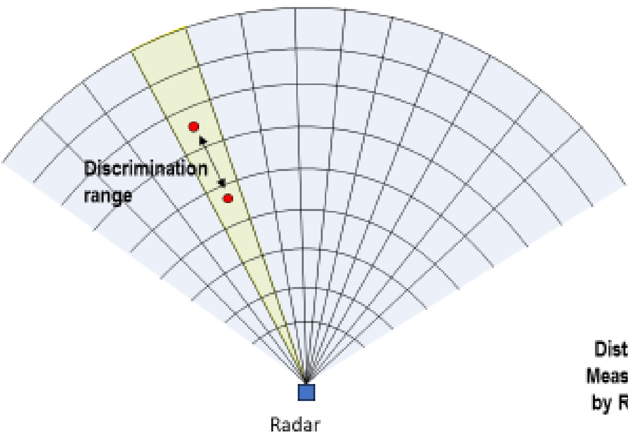
- The number of steps in the stairs derived by the relationship between the speed measured by the radar and the moving speed of the C/R, is to be the same for both the actual and simulated environments.
- The size of the steps d_1,d_2 shall not differ in size by more than 15% (provisional)



■ Basic Characteristics of the Sensor: Discrimination - Range/Orientation

mmWave radar (0-6)

<Discrimination Range>



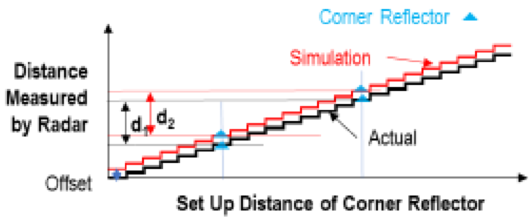
Method of Validation

➢ Resolution Range

Place 2 C/R's (of same spec) within the radar's FOV in close proximity to each other and validate the discrimination of each target. Then change the distance between the 2 C/R's and take further multiple measurements.

Judgment Criteria

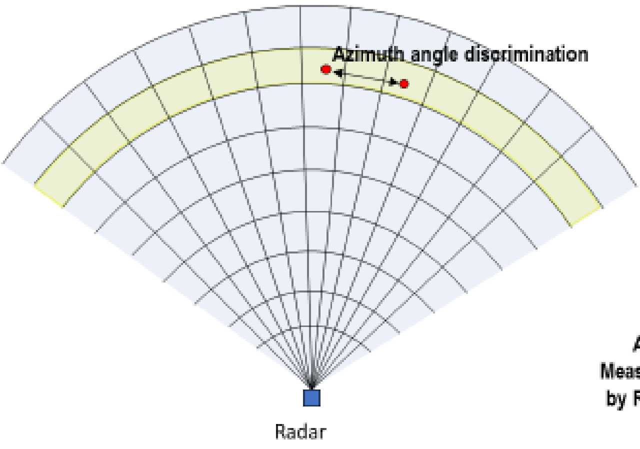
The calculated average distance of discrimination based on multiple measurements for the actual (d_1) and simulated (d_2) environments shall not differ in size by more than 15% (provisional)



■ Basic Characteristics of the Sensor: Resolution - Relative Speed

mmWave radar (0-6)

<Azimuth Discrimination>



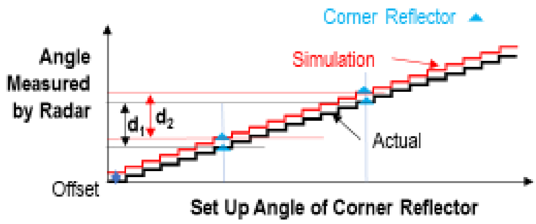
Method of Validation

➢ Azimuth Angle Resolution

Place 2 C/R's (of same spec) within the radar's FOV at the same distance and in close lateral proximity to each other. Validate the discrimination of each target. Then change the set-up angle of the 2 C/R's and take further multiple measurements.

Judgment Criteria

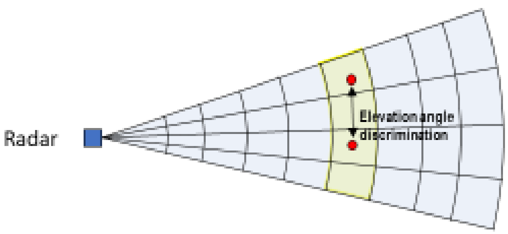
The calculated average angle of discrimination based on multiple measurements for the actual (d_1) and simulated (d_2) environments shall not differ in size by more than 15% (provisional)



■ Basic Characteristics of the Sensor: Resolution - Relative Speed

mmWave radar (0-6)

<Elevation Discrimination>



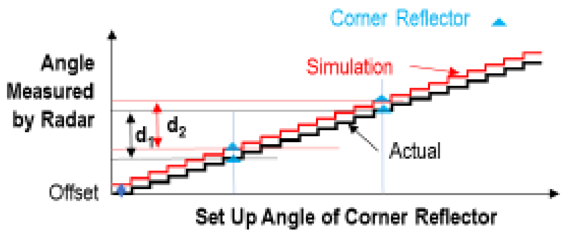
Method of Validation

➢ Elevation Angle Resolution

Place 2 C/R's (of same spec) within the radar's FOV at the same distance and in close vertical proximity to each other. Validate the discrimination of each target. Then change the set-up angle of the 2 C/R's and take further multiple measurements.

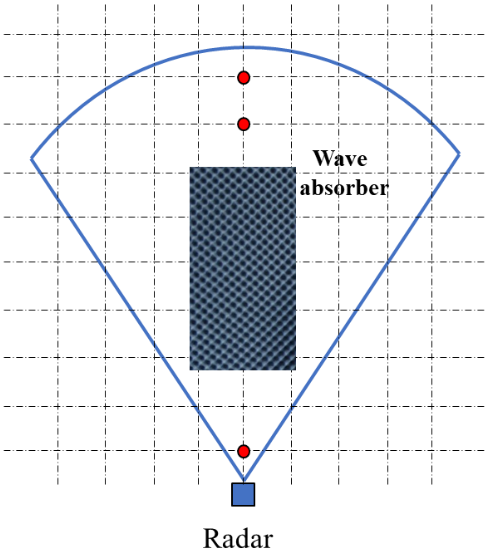
Judgment Criteria

The calculated average angle of discrimination based on multiple measurements for the actual (d_1) and simulated (d_2) environments shall not differ in size by more than 15% (provisional)



mmWave Radar
(0-7)

■ Properties of Radio Wave Propagation: Free-Space - Received Power

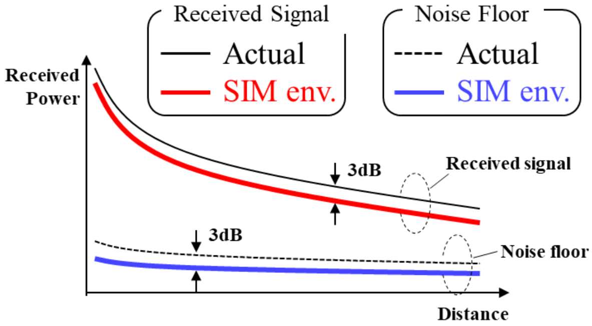


Method of Validation

- Place the C/R directly in front of the radar, then vary the set-up distance of the C/R and measure the received power at each distance
  (in order to eliminate the road surface reflection waves, set-up a wave absorber around the point where the road reflects)

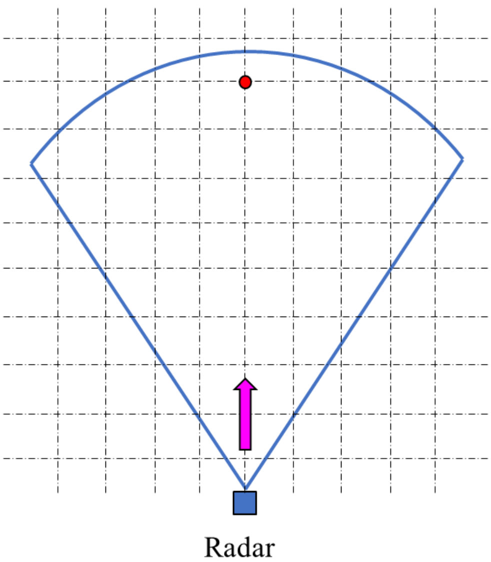
Judgment Criteria

・Difference in received power: 3 dB or less
・Difference in power of noise floor: 3 dB or less
・Difference in SNR: 3 dB or less



mmWave Radar
(0-8)

■ Properties of Radio Wave Propagation: Road Surface - Received Power

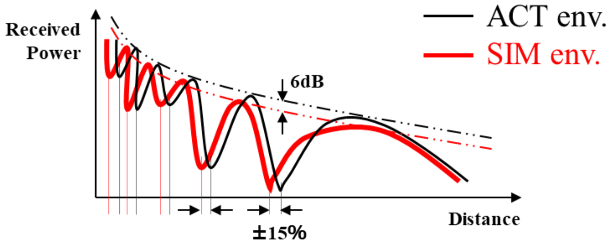


Method of Validation

- Place the C/R directly in front of the radar, and move the radar at a constant speed toward the C/R

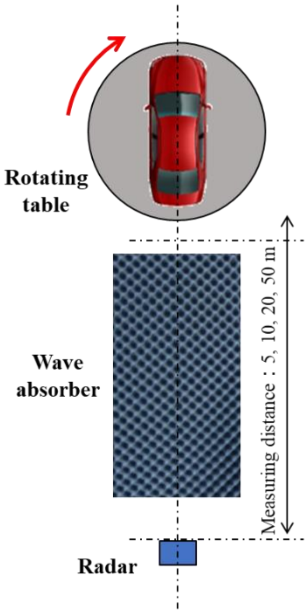
Judgment Criteria

- Difference in envelope: 6 dB or less
- Difference in null point distance: ±15% or less



■ Reflective Properties of the Recognition Target: Vehicle (Passenger Vehicle/Large-Sized Vehicle) RCS

mmWave Radar (1-1)

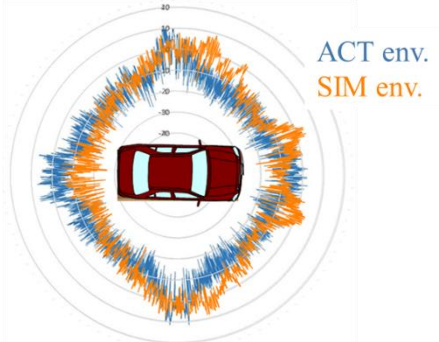


Method of Validation

- Direct the radio wave toward the vehicle on the rotating table.
- Rotate the passenger vehicle and plot the change in received power by the rotated angle.
- Measuring distance: 5, 10, 20, 50 (m)
- Type of vehicle: passenger vehicle, large-sized trailer
- Compare the received power between the actual and simulated environments

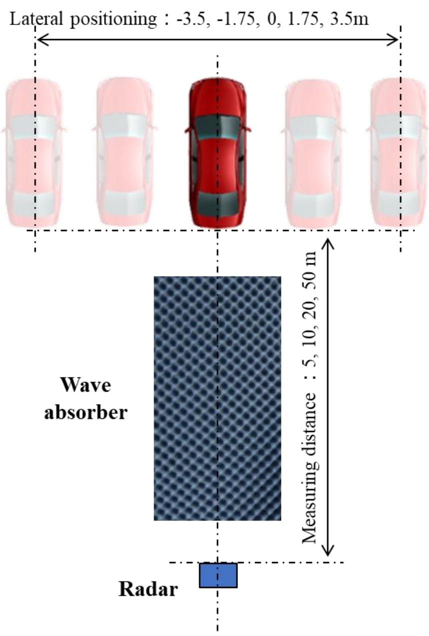
Judgment Criteria

- Difference in received power: 3 dB or less in all directions



■ Reflective Properties of the Recognition Target: Vehicle (Passenger Vehicle/Large-Sized Vehicle) Reflection Points

mmWave Radar (1-2)

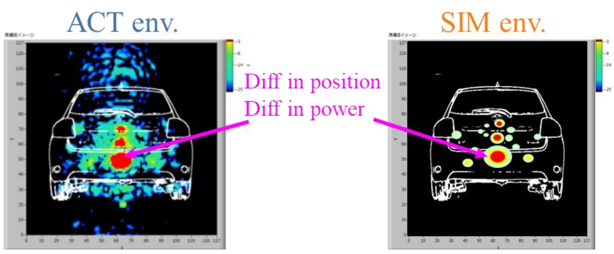


Method of Validation

- Direct the radio wave toward the vehicle from behind, and generate a radar image.
- Measuring distance: 5, 10, 20, 50 (m)
- Type of vehicle: passenger vehicle, large-sized trailer
- Lateral position of vehicle: 0, ±1.75, ±3.5 (m) (to simulate "in ego vehicle lane", "on lane marking" and "in adjacent lane")
- Compare the distributions of reflection intensity between the actual and simulated environment.

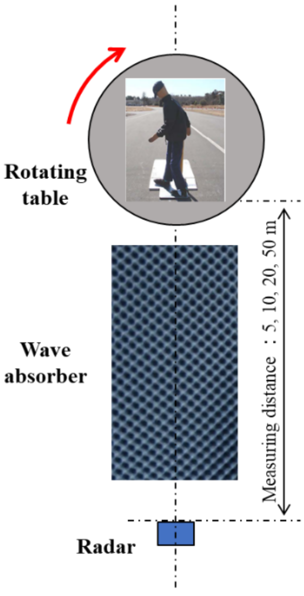
Judgment Criteria

- Difference in peak point of reflection intensity: within 3° of viewing angle
- Difference in received power at peak point: 3 dB or less



mmWave Radar (1-3)

■ Reflective Properties of the Recognition Target: Pedestrian RCS

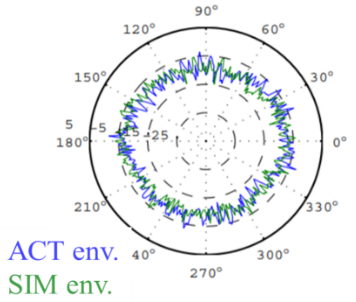


Method of Validation

- Direct the radio wave toward the pedestrian dummy on the rotating table.
- Rotate the dummy and plot the change in the received power by the rotated angle.
- Measuring distance: 5, 10, 20, 50 (m)
- Compare the received power between the actual and simulated environments.

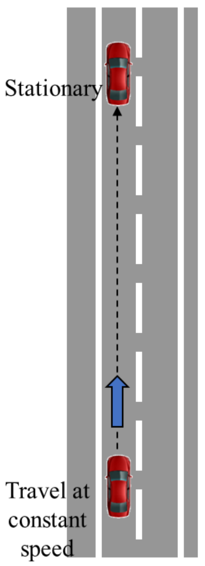
Judgment Criteria

- Difference in received power: 3 dB or less in all directions



mmWave Radar (2-1)

■ Basic Traffic Flow Scenario: CCRs Received Power

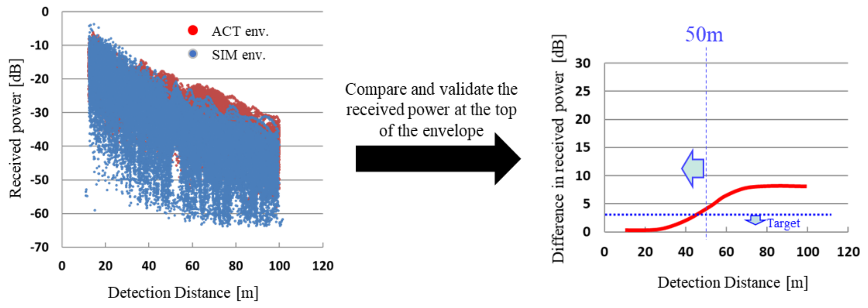


Method of Validation

- Simulate NCAP CCRs scenario
- Speed of ego vehicle: 2 points between 5 and 60 km/h (High/Low)
- Measure the received power from the stationary target vehicle ahead and plot the envelope line at the top of the curve.
- Compare the change in envelope lines between the actual and simulated environments.

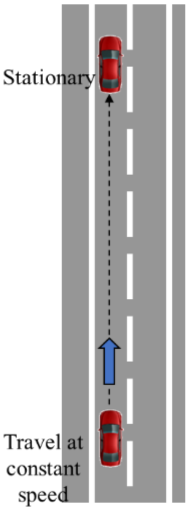
Judgment Criteria

- Difference in the envelope line of the received power at a relative distance of 50 m and below: 3 dB or less



■ Basic Traffic Flow Scenario: CCRs Detecting Position

mmWave Radar (2-2)

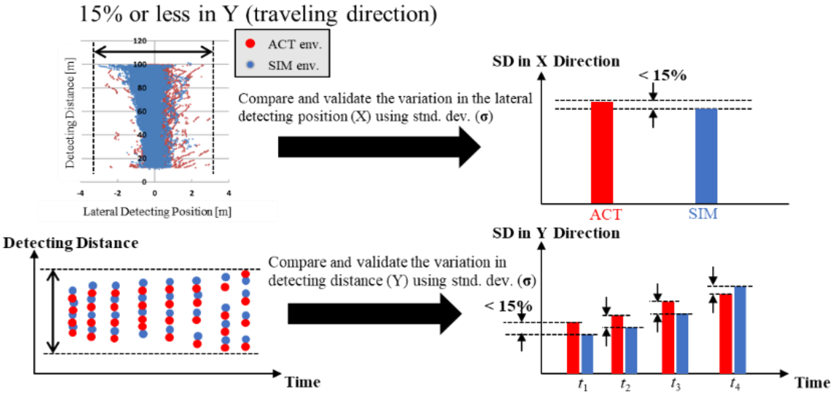


Method of Validation

- Simulate NCAP CCRs scenario
- Speed of ego vehicle: 2 points between 5 and 60 km/h (High/Low)
- Measure the position (X, Y) at which the reflection of the stationary target vehicle ahead is detected
- Compare the degree of variation in detecting positions between the actual and simulated environments

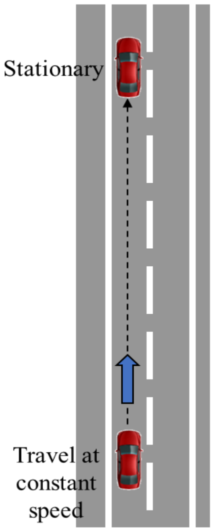
Judgment Criteria

- Difference in standard deviation at a relative distance of 50 m and below :
  15% or less in X (lateral direction)
  15% or less in Y (traveling direction)



■ Basic Traffic Flow Scenario: CCRs Detecting Speed

mmWave Radar (2-3)

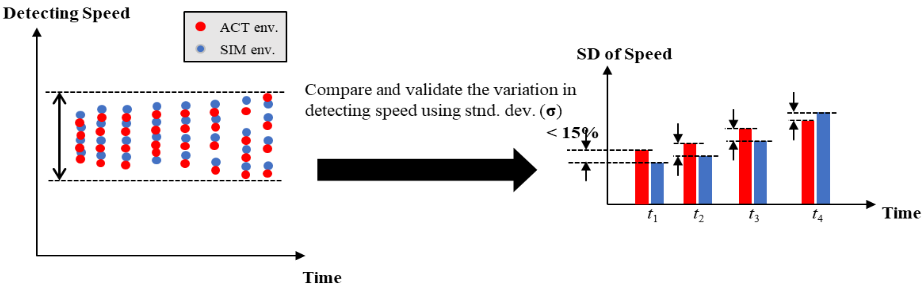


Method of Validation

- Simulate NCAP CCRs scenario
- Speed of ego vehicle: 2 points between 5 and 60 km/h (High/Low)
- Measure the speed at which the reflection of the stationary target vehicle ahead is detected (Y direction)
- Compare the degree of variation in detecting speeds between the actual and simulated environments

Judgment Criteria

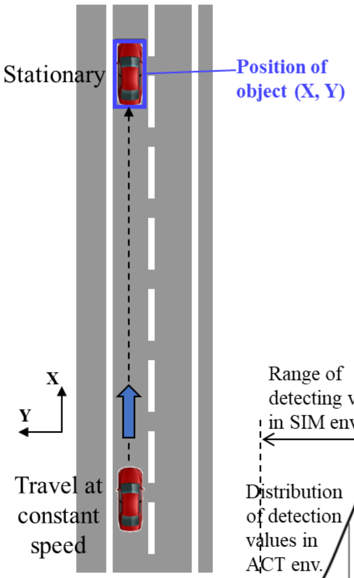
- Difference in standard deviation at a relative distance of 50 m and below: 15% or less



mmWave Radar
(2-4)

■ Basic Traffic Flow Scenario: CCRs

Object Detecting Position (Distance/Angle)



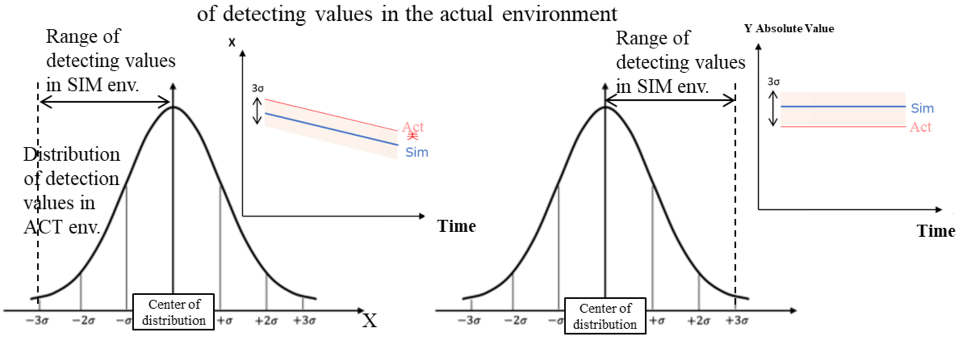
Method of Validation

- Simulate NCAP CCRs scenario
- Measure the position that the stationary target vehicle ahead is detected as an object.
- Speed of ego vehicle: 2 points between 5 and 60 km/h (High/Low)
- Compare the coordinates of the object (X-Y) between the actual and simulated environments

Judgment Criteria

At a relative distance of 50 m and below:

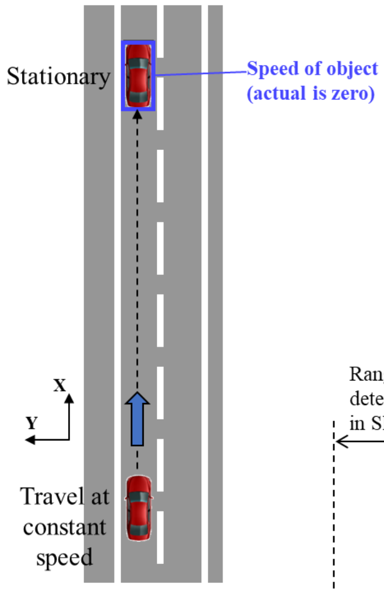
- X direction in SIM env.: within 3σ to the left (shorter distance) of the distribution of detecting values in the actual environment
- Y direction in SIM env.: within 3σ to the right (longer distance) of the distribution of detecting values in the actual environment



mmWave Radar
(2-5)

■ Basic Traffic Flow Scenario: CCRs

Object Detecting Speed



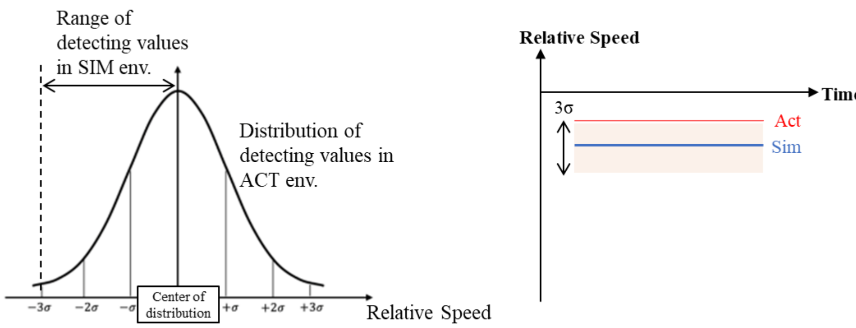
Method of Validation

- Simulate NCAP CCRs scenario
- Measure the speed that the stationary target vehicle ahead is detected as an object.
- Speed of ego vehicle: 2 points between 5 and 60 km/h (High/Low)
- Compare the object detecting speed between the actual and simulated environments

Judgment Criteria

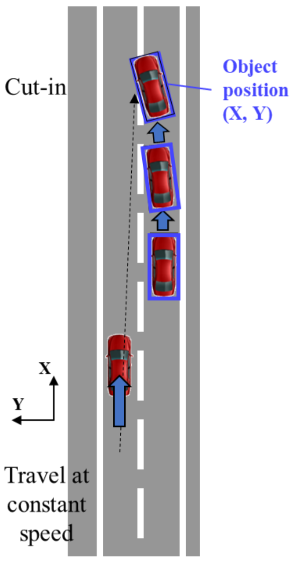
At a relative distance of 50 m and below:

Detecting value in SIM env.: within 3σ to the left (slower speed) of the distribution of detecting values in the actual environment



mmWave Radar
(2-6)

■ Basic Traffic Flow Scenario: Cut-in
Object Detecting Position (Distance/Angle)

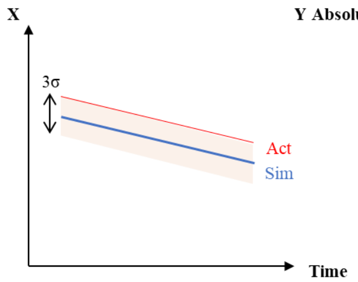


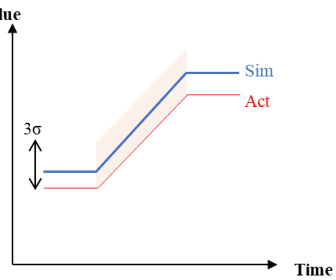
Method of Validation

- Plot the position at which the target vehicle is detected as an object, in the scenario whereby the vehicle cuts-in in front of the ego vehicle.
- Speed of ego vehicle: constant speed (e.g. 60 km/h)
- Target vehicle speed: constant in traveling direction (e.g. 40 km/h),
  3 points between 0.2 and 2.0 m/s in lateral direction
- Type of vehicle: passenger vehicle, large-sized trailer 
- Compare the detecting position between the actual and simulated environments

Judgment Criteria

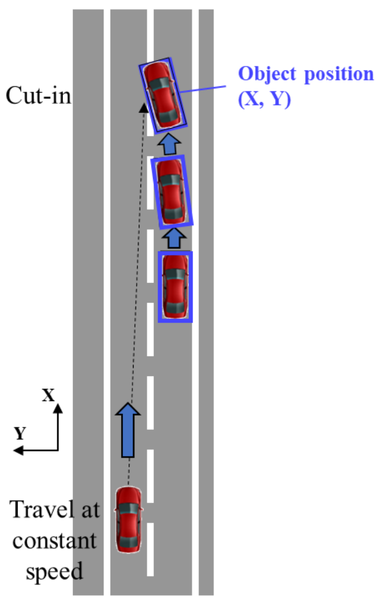
At a relative distance of 50 m and below:
- X direction in SIM env.: within 3σ to the left (shorter distance) of the distribution of detecting values in the actual environment
- Y direction in SIM env.: within 3σ to the right (longer distance) of the distribution of detecting values in the actual environment



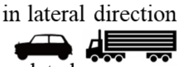


mmWave Radar
(2-7)

■ Basic Traffic Flow Scenario: Cut-in
Object Detecting Speed



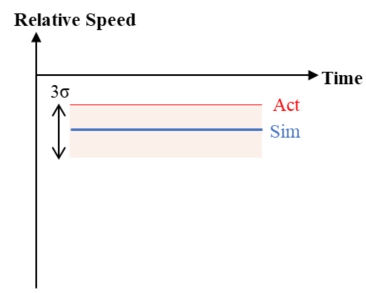
Method of Validation

- Plot the speed at which the target vehicle is detected as an object, in the scenario whereby the vehicle cuts-in in front of the ego vehicle.
- Speed of ego vehicle: constant speed (e.g. 60 km/h)
- Object vehicle speed: constant in traveling direction (e.g. 40 km/h),
  3 points between 0.2 and 2.0 m/s in lateral direction
- Type of vehicle: passenger vehicle, large-sized trailer 
- Compare the detecting speed between the actual and simulated environments

Judgment Criteria

At a relative distance of 50 m and below:

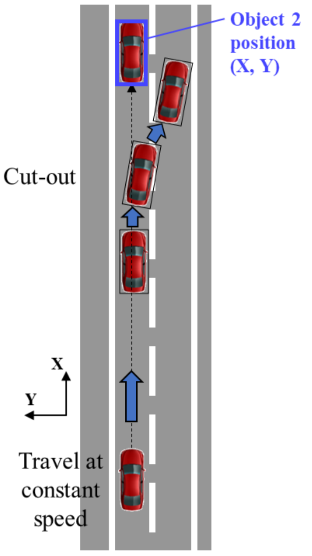
Detecting value in SIM env.: within 3σ to the left (slower speed) of the distribution of detecting values in the actual environment



mmWave Radar (2-8)

■Basic Traffic Flow Scenario: Cut-out

Object Detecting Position (Distance/Angle)



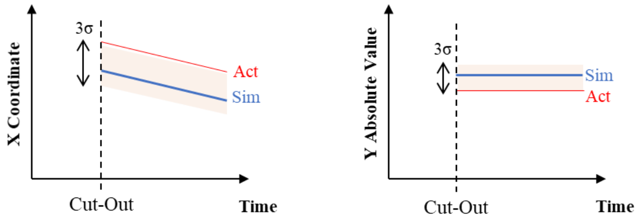
Method of Validation

- Plot the position at which the stationary vehicle (object 2) is detected as an object, in the scenario whereby there is a stationary vehicle in front of the preceding vehicle which cuts-out
- Speed of ego vehicle: constant speed (e.g. 60 km/h)
- Object 1 vehicle speed: constant in traveling direction (e.g. 40 km/h), nearly 1.0 m/s in lateral direction
- Object 1 type: passenger vehicle (vehicle which cuts out)
- Object 2 type: passenger vehicle (stationary vehicle)
- Compare the position at which object 2 is detected between the actual and simulated environments

Judgment Criteria

Detecting position after cutting out:

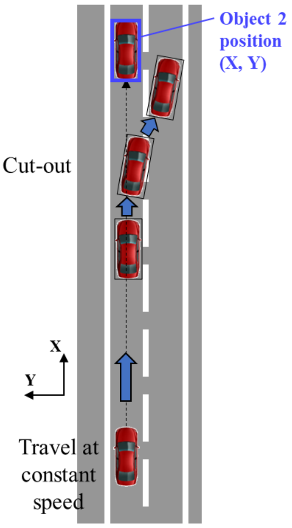
- X direction in SIM env. : within 3σ to the left (shorter distance) of the distribution of detecting values in the actual environment
- Y direction in SIM env. : within 3σ to the right (longer distance) of the distribution of detecting values in the actual environment



mmWave Radar (2-9)

■Basic Traffic Flow Scenario: Cut-out

Object Detecting Speed



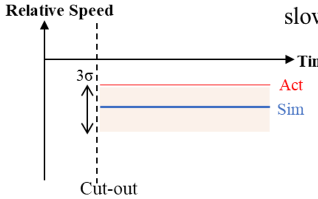
Method of Validation

- Plot the speed at which the stationary vehicle (object 2) is detected as an object, in the scenario whereby there is a stationary vehicle in front of the preceding vehicle which cuts-out
- Speed of ego vehicle: constant speed (e.g. 60 km/h)
- Object 1 vehicle speed: constant in traveling direction (e.g. 40 km/h), nearly 1.0 m/s in lateral direction
- Object 1 type: passenger vehicle (vehicle which cuts out)
- Object 2 type: passenger vehicle (stationary vehicle)
- Compare the speed at which object 2 is detected between the actual and simulated environments

Judgment Criteria

After cutting out:

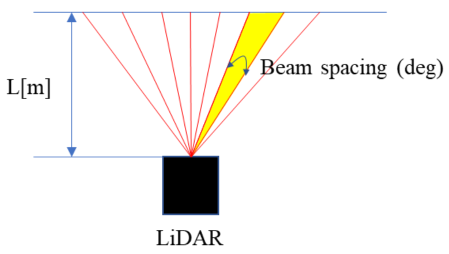
Detecting value in SIM env.: within 3σ of the distribution of detecting values in an actual environment (toward slower speed)



F.2.3.2 Validation method of common requirements of LiDAR

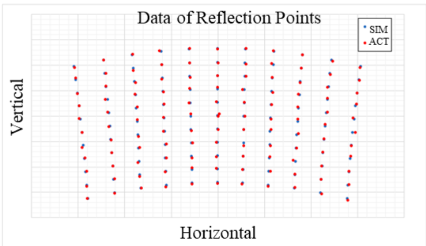
LiDAR
(F.2.3.2.1)

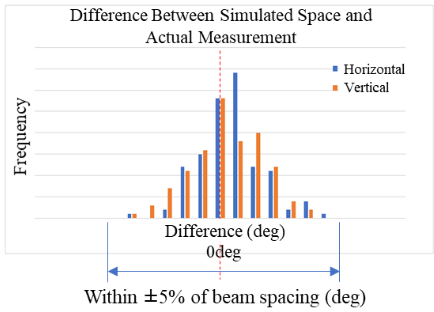
■ Basic characteristics of the sensor itself : Angle



<u>Method of Validation</u>
Transmit the beams from the LiDAR to the wall positioned at a recognized distance (L), and measure the coordinates values of beam spot on the wall.
Confirm that the difference between the simulated and actual measurements are within an acceptable range.

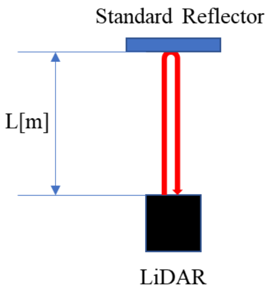
<u>Judgment Criteria</u>
within ±5% of beam spacing (deg)





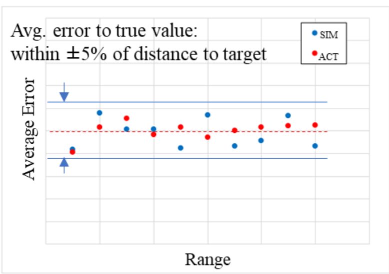
LiDAR
(F.2.3.2.1.1)

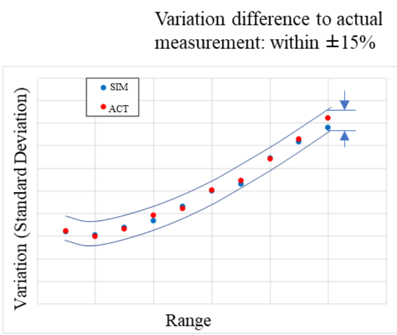
■ Basic characteristics of the sensor itself : Range



<u>Method of Validation</u>
Vary the distance between the LiDAR and the standard reflector and measure the distance error and variation.
Confirm that they are within an acceptable range.

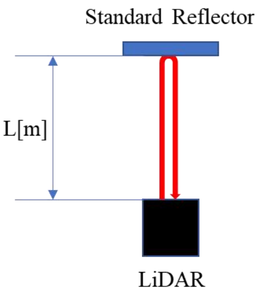
<u>Judgment Criteria</u>
Avg. error to true value: within ±5% of distance to target
Variation difference to actual measurement: within ±15%





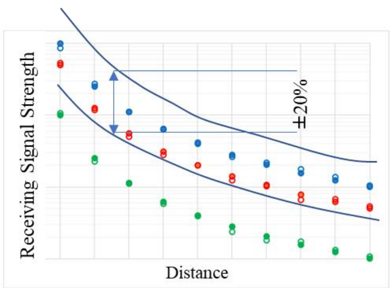
■ Basic characteristics of the sensor itself : Strength / Detection rate

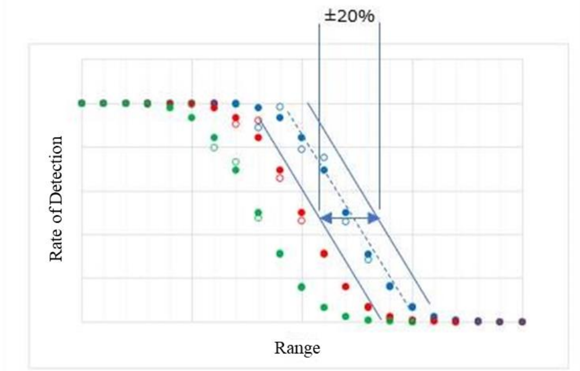
LiDAR
(F.2.3.2.1.2)
(F.2.3.2.1.3)



Method of Validation
Vary the distance between the LiDAR and the standard reflector, and measure the strength of reception and rate of detection.
Confirm that they are within an acceptable range.

Judgment Criteria
Intensity error in relation to actual measurement value: within ±20%
Difference in range to actual measurement @ 90% detection: within ±20%
Difference in range to actual measurement @ 50% detection: within ±20%
Difference in range to actual measurement @ 10% detection: within ±20%

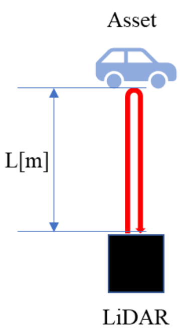




※Blue: reflectivity xx% Red: reflectivity xx% Green: reflectivity xx%
※●Actual ○Simulation

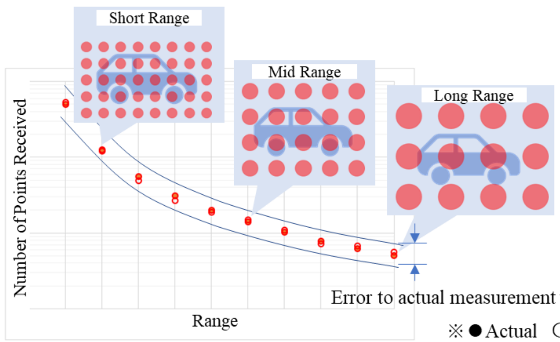
■ Reflection characteristics of the object to be recognized : Number of Detection Points

LiDAR
(F.2.3.2.2.1)



Method of Validation
Vary the distance between the LiDAR and the asset and measure the number of detection points.
Confirm that the difference in the number of detected points is within an acceptable range.

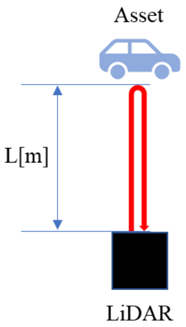
Judgment Criteria
Error to number of actual points to be within ±15%
(do not include large distances where the number of detected points reduces)



Error to actual measurement within ±15%
※●Actual ○Simulation

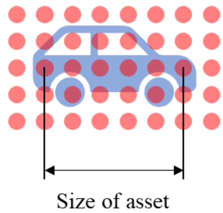
■ Reflection characteristics of the object to be recognized : Size

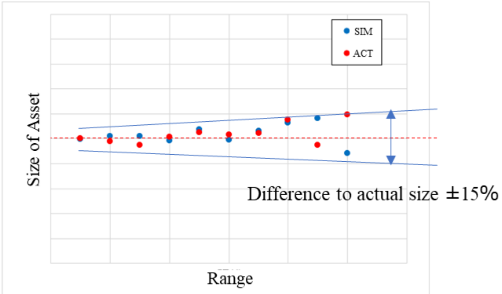
LiDAR
(F.2.3.2.2.2)



Method of Validation
Vary the distance between the LiDAR and the asset and measure the size of asset. Confirm that the difference in size is within an acceptable range.

Judgment Criteria
Difference to actual size within 15%

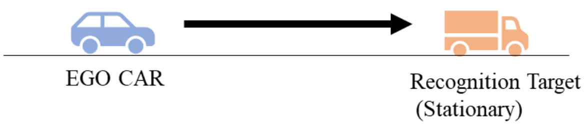


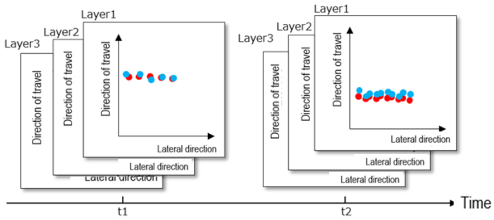


■ Reflection characteristics of the object to be recognized : Dynamic Validation【Pointcloud Data】

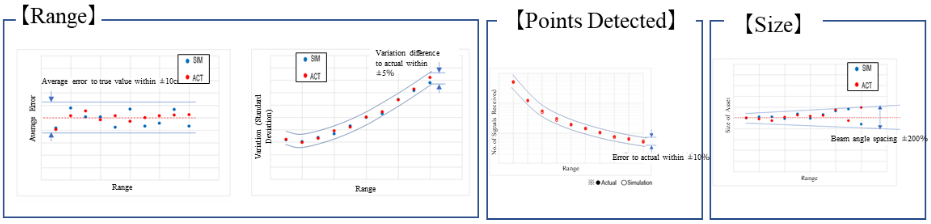
LiDAR
(F.2.3.2.2.3)

Method of Validation
Approach the stationary vehicle, and compare the change in azimuth, range, number of detection points, and size over time between the actual and the simulation. (E.g. approach the recognition target at 40 km/h, and apply the brakes when distance to the vehicle is 20 m and come to a stop)





Judgment Criteria
The range, number of detection points and size over time, are to satisfy previously mentioned criteria (F.2.3.2.1.1, F.2.3.2.2.1, F.2.3.2.2.2)

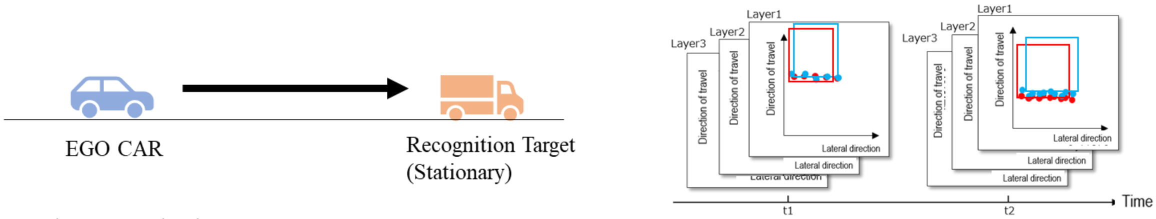


■ Reflection characteristics of the object to be recognized : Dynamic Validation【Object】

LiDAR
(F.2.3.2.2.4)

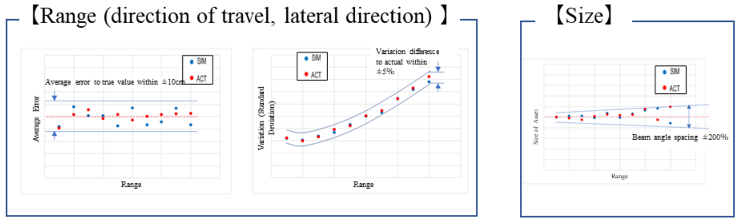
Method of Validation

Approach the stationary vehicle, and compare the change in the object's range and size over time between the actual and the simulation. (E.g. approach the recognition target at 40 km/h, and apply the brakes when distance to the vehicle is 20 m and come to a stop).



Judgment Criteria

The range (in the direction of travel and lateral direction) and size over time, are to satisfy previously mentioned criteria (F.2.3.2.1.1, F.2.3.2.2.2)

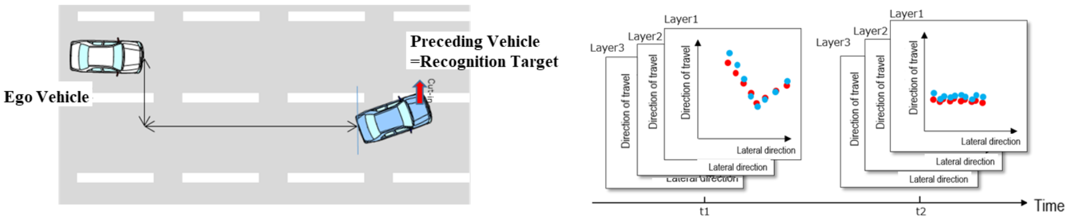


■ Basic Traffic Flow Scenario : Cut-In Scenario (Standard-sized Vehicle)【Pointcloud Data】

LiDAR
(F.2.3.2.3.1)

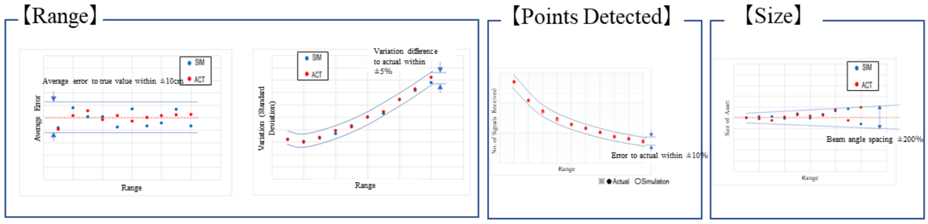
Method of Validation

Compare the change in azimuth, range, number of detection points and size over time between the actual and the simulation, for when a normal vehicle cuts in. (E.g. speed of ego vehicle 60 km/h and preceding vehicle to cut in at 40 km/h in the direction of travel and 1.0m/s in the lateral direction)



Judgment Criteria

The range, number of detection points and size over time, are to satisfy previously mentioned criteria (F.2.3.2.1.1, F.2.3.2.2.1, F.2.3.2.2.2)

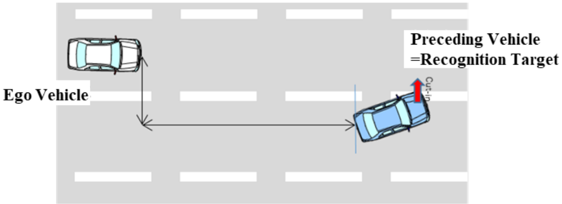


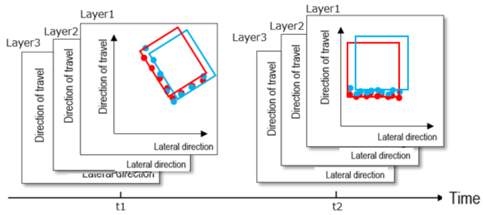
LiDAR
(F.2.3.2.3.2)

■ Basic Traffic Flow Scenario :
Cut-In Scenario (Standard-sized Vehicle)【Object】

<u>Method of Validation</u>

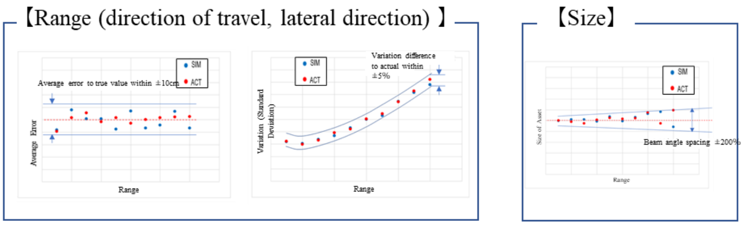
Compare the change in the object’s range and size over time between the actual and the simulation for when a normal vehicle cuts in. (E.g. speed of ego vehicle 60 km/h and preceding vehicle to cut in at 40km/h in the direction of travel and 1.0m/s in the lateral direction)





<u>Judgment Criteria</u>

The range (in the direction of travel and lateral direction) and size over time, are to satisfy previously mentioned criteria (F.2.3.2.1.1, F.2.3.2.2.2)

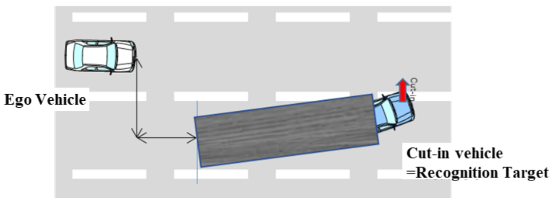


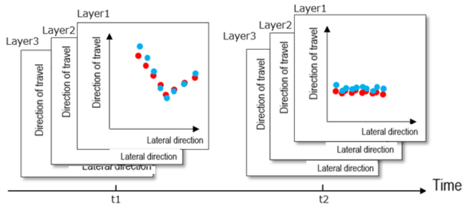
LiDAR
(F.2.3.2.3.3)

■ Basic Traffic Flow Scenario : Cut-In Scenario (Large-sized Vehicle)【Pointcloud Data】

<u>Method of Validation</u>

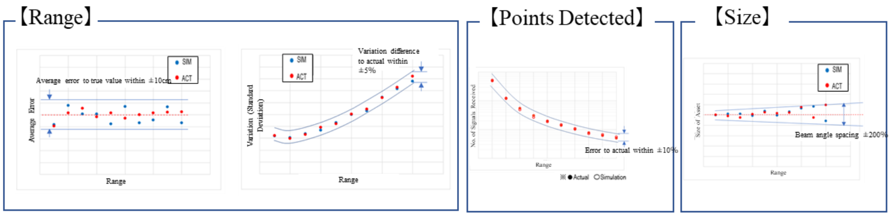
Compare the change in azimuth, range, number of detection points and size over time between the actual and the simulation, for when a large-sized vehicle cuts in. (E.g. speed of ego vehicle 60 km/h and preceding vehicle to cut in at 40 km/h in the direction of travel and 1.0 m/s in the lateral direction)





<u>Judgment Criteria</u>

The range, number of detection points and size over time, are to satisfy previously mentioned criteria (F.2.3.2.1.1, F.2.3.2.2.1, F.2.3.2.2.2)

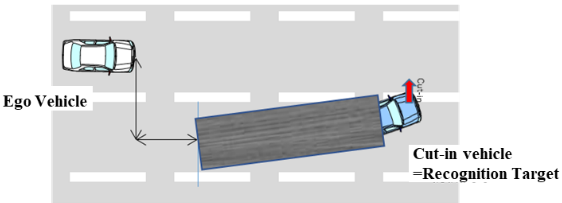


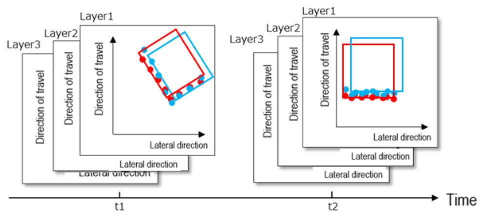
LiDAR
(F.2.3.2.3.4)

■ Basic Traffic Flow Scenario : Cut-In Scenario (Large-sized Vehicle)【Object】

Method of Validation

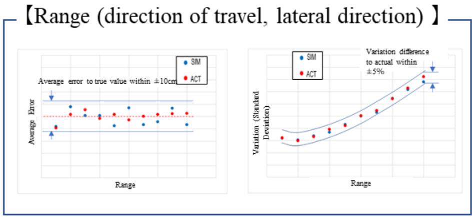
Compare the change in the object's range and size over time between the actual and the simulation, for when a large-sized vehicle cuts in. (E.g. speed of ego vehicle 60 km/h and preceding vehicle to cut in at 40 km/h in the direction of travel and 1.0 m/s in the lateral direction)

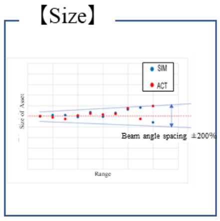




Judgment Criteria

The range (in the direction of travel and lateral direction) and size over time, are to satisfy previously mentioned criteria (F.2.3.2.1.1, F.2.3.2.2.2)



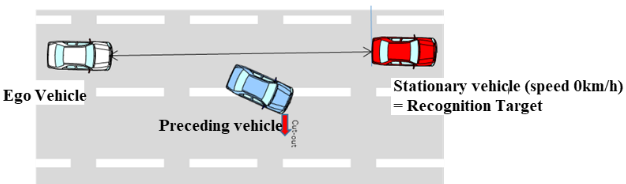


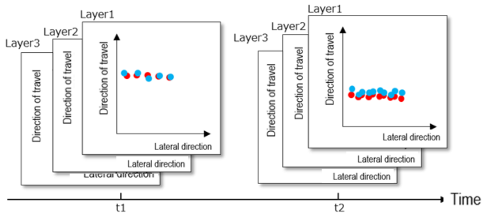
LiDAR
(F.2.3.2.3.5)

■ Basic Traffic Flow Scenario : Cut-Out Scenario【Pointcloud Data】

Method of Validation

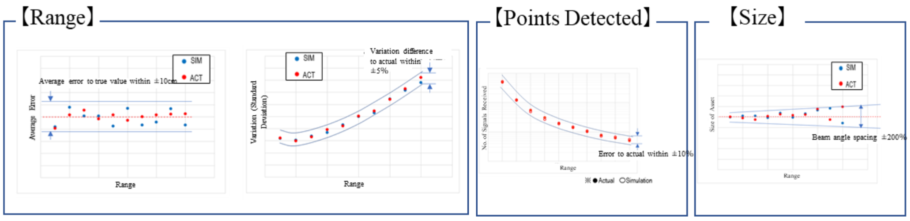
Compare the change in azimuth, range, number of detection points and size over time between the actual and the simulation, for when the preceding vehicle cuts out, resulting in the approach toward a stationary vehicle. (E.g. speed of ego vehicle while traveling behind the preceding vehicle is 40 km/h as it cuts out, then ego vehicle approaches the recognition target)





Judgment Criteria

The range, number of detection points and size over time, are to satisfy previously mentioned criteria (F.2.3.2.1.1, F.2.3.2.2.1, F.2.3.2.2.2)

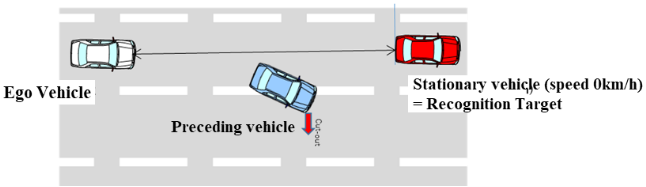


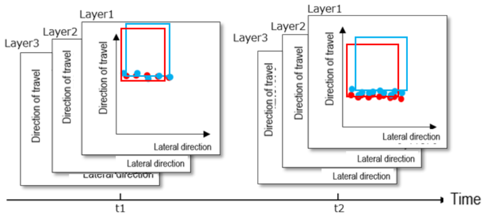
LiDAR
(F.2.3.2.3.6)

■ Basic Traffic Flow Scenario : Cut-Out Scenario【Object】

Method of Validation

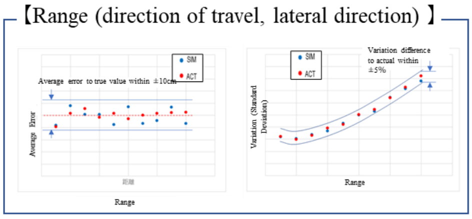
Compare the change in range and size over time between the actual and the simulation, for when the preceding vehicle cuts out, resulting in the approach toward a stationary vehicle. (E.g. speed of ego vehicle while traveling behind the preceding vehicle is 40 km/h as it cuts out, then ego vehicle approaches the recognition target)

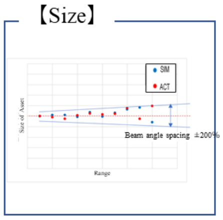




Judgment Criteria

The range (in the direction of travel and lateral direction) and size over time, are to satisfy previously mentioned criteria (F.2.3.2.1.1, F.2.3.2.2.2)

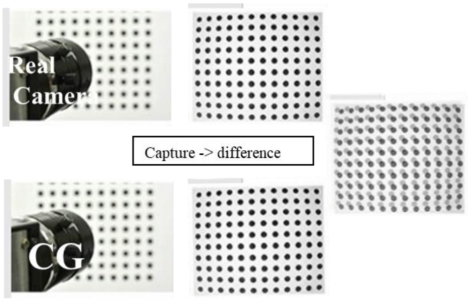




F.2.3.3 Validation method of common requirements of Camera

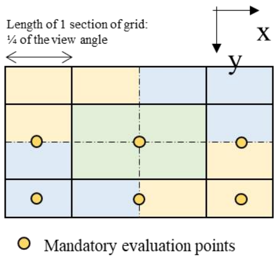
■ Camera module calibration [View angle/Optical axis/Distortion]

camera (0-1)



Source: https://www.seika-di.com/measurement/qanda/qanda_material/Effectoflensdistortion.html

[Measuring condition]
- Darkroom
- Known test chart
- Known light source
- Light source for validation (headlights, sun light)



Method of Validation

Use a test chart with glid lines or points, to minimize the difference between image taken with the real camera and CG based on the raw data in terms of distortion and resolution

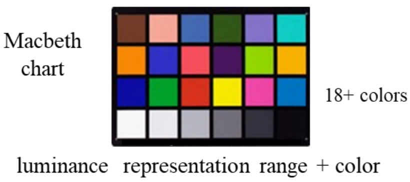
- With the real camera, align the center of the grid chart to the center of the imaging device (while maintaining the levelness of the chart) and obtain an image
- With the CG, align the center position in the same way, then adjust the camera parameters to ensure the surrounding grid is the same (position) as that of image taken with the real camera
- Adjustment Parameters (examples)
  - Distortion and resolution characteristics of overall screen
  - The lens' focal length, distortion characteristics, various aberrations, center deviation of assembly (between the lens and the imaging device) and angle deviation, etc.

Judgement Criteria

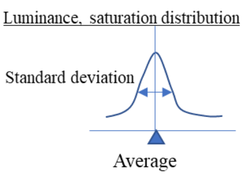
Visually, the entire image almost overlaps (evaluate the spread of the grid from the viewpoint of visual resolution, SFR spatial frequency response, and limit resolution).
The difference between the grid coordinates near the evaluation point and the real camera is 2 [pix] or less.

■ Camera module calibration [Color/Luminance]

camera (0-2)



[Measuring condition]
- Darkroom
- Known test chart
- Known light source
- Light source for validation (headlights, sun light)



Method of Validation

Use a test chart (for colors) to minimize the difference between image taken with the real camera and CG based on the raw data in terms of luminance representation and color

- Measure with each color block in the chart
- Measure statistics of 16 [pix] or more at the target image position (Brightness, average value of saturation, standard deviation)
- Adjust camera parameters to match up luminance representation and color reproducibility of general camera performance between image taken with the real camera and CG
- Adjustment parameters (examples):
  ・Photoelectric conversion characteristics of imaging device, etc.
  ・Transmittance of lenses, filter on imaging device, etc.
- Validation parameters (to check coincidence between real image and virtual image (CG image)):
  ・Exposure control characteristics, etc.
  ・HDR (high dynamic range) characteristics, etc.
  ・ISP (image signal processing) configuration parameters, etc.

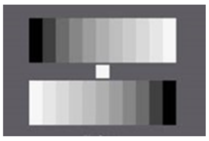
Judgement Criteria

For each item, the difference from the real camera is in the range of ±5[%]

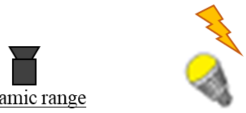
■ Camera module calibration [Dynamic range]

camera (0-3)

Gray chart

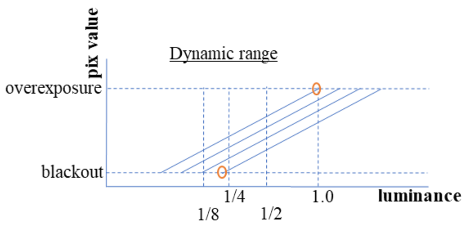


13+ steps



Validate dynamic range

[Measuring condition]
- Darkroom
- Known test chart
- Known light source
- Light source for validation (headlights, sun light)



Method of Validation

Minimize the difference between image taken with the real camera and CG based on the raw data by measuring the dynamic range of the camera for the luminance by gradually changing the luminance using the known lighting condition.

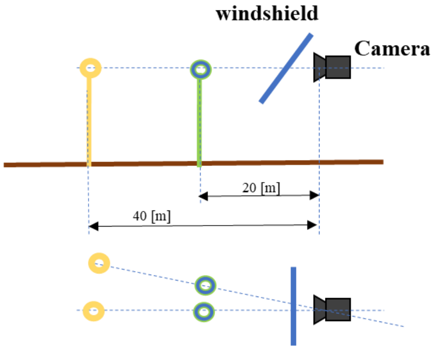
- Luminance vs. pixel value until overexposure
- The luminance hit to overexposure is handled as 1, and the luminance until blackout is compared at 6 or more steps.
- It is desirable that the measurement points have a geometric progression. (1/2, 1/4, 1/8, etc.)
- Adjust camera parameters to match up dynamic range characteristics
- Adjustment parameters (examples):
  ・Photoelectric conversion characteristics of imaging device, etc.
  ・HDR (high dynamic range) characteristics, etc.
- Validation parameters (to check coincidence between real image and virtual image (CG image)):
  ・ISP (image signal processing) configuration parameters, etc.

Judgement Criteria

- The difference of the luminance at the time of overexposure between image take with real camera and CG is 5 [%] or less.
- The difference of the luminance at the time of blackout between image take with real camera and CG is 5 [%] or less.

■ on-board Camera front calibration [Optical axis]

camera (1-0)



[Measuring condition]
- On-board
- Known target points
- Known light source
- Skylight (Sun light source)
- Known road surface (asphalt pavement, horizontal plane)

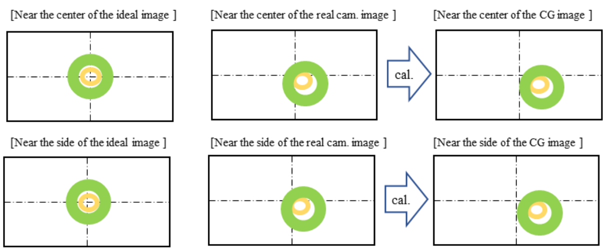
Method of Validation

Minimize mounting error using an aiming method under the assumption that optical axis is horizontal and parallel to axis of direction of forward movement.

- Adjust the mounting of camera to locate image of two target points on optical axis at the center of imaging device, and then locate image of target points on the right side of previous two target points on the horizontal line through the center of the device
- Adjust related parameters of camera model to render CG so that they are (positionally) equivalent even in CG.
- Adjustment parameters (examples):
  1) Height and orientation of camera mounting (yaw, roll, pitch)
  2) Curvature, inclination, and refractive index of the windshield

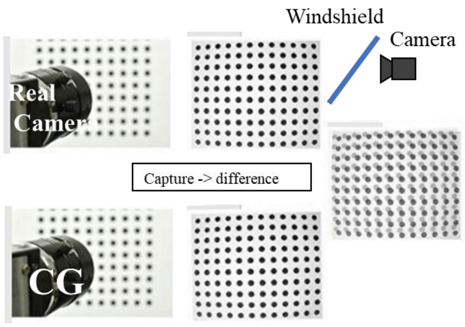
Judgement Criteria

At the position of the target point on the image, the difference from the real camera is in the range of ±5 [pix] or less.



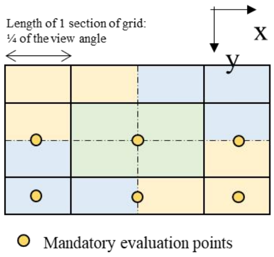
■ On-board Camera calibration for front side [Distortion]

camera (1-1)



Source: https://www.seika-di.com/measurement/qanda/qanda_material/Effectoflensdistortion.html

[Measuring condition]
- Darkroom
- Known test chart
- Known light source
- Light source for validation (headlights, sun light)



Method of Validation

Use a test chart with glid lines or points, to minimize the difference, caused by windshield, between image taken with the real camera and CG based on the raw data in terms of distortion and resolution

- With the real camera, align the center of the grid chart to the center of the imaging device (while maintaining the levelness of the chart) and obtain an image
- With the CG, align the center position in the same way, then adjust the camera parameters to ensure the surrounding grid is the same (position) as that of image taken with the real camera
- Adjustment Parameters (examples)
  - Distortion and resolution characteristics of overall screen
  - Height and orientation of camera mounting (yaw, roll, pitch) Curvature, inclination, and refractive index of the windshield, etc.

Judgement Criteria

- Visually, the entire image almost overlaps (evaluate the spread of the grid from the viewpoint of visual resolution, SFR spatial frequency response, and limit resolution).
- The difference between the grid coordinates near the evaluation point and the real camera is:
  - Near center: 5 [pix] or less
  - Peripheral: 30 [pix] or less

■ On-board Camera calibration for front side [Color/Luminance]

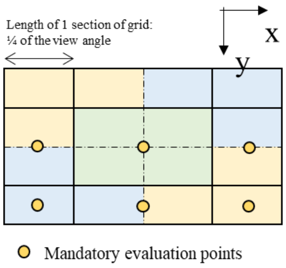
camera (1-2)

Macbeth chart

18+ colors

luminance representation range + color

[Measuring condition]
- Darkroom
- Known test chart
- Known light source
- Light source for validation (headlights, sun light)



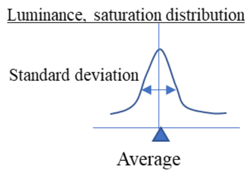
Method of Validation

Use a test chart (for colors) to minimize the difference, caused by windshield, between image taken with the real camera and CG based on the raw data in terms of luminance representation and color

- Measure with each color block in the chart
- Measure statistics of 16 [pix] or more at the target image position (Brightness, average value of saturation, standard deviation)
- Evaluate luminance representation and color reproducibility of general camera performance between image taken with the real camera and CG
- Adjustment parameters (examples):
  ・Photoelectric conversion characteristics of imaging device, etc.
  ・Wavelength-dependent reflectance and transmittance of windshield, etc.

Judgement Criteria

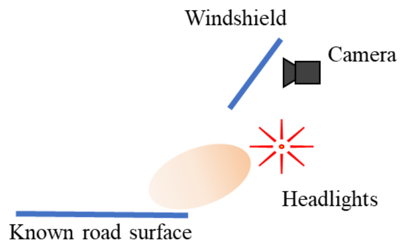
For each item at each evaluation point, the difference from the real camera is in the range of ±5 [%]



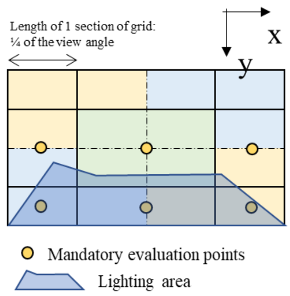
■ On-board camera calibration for front side

camera (1-3)

[Color/Luminance (headlights)]



[Measuring condition]
- Darkroom
- Known light source (headlights)
- Known reflection board (lambert reflector, vertical)
- Known road surface
  (asphalt pavement, horizontal plane)



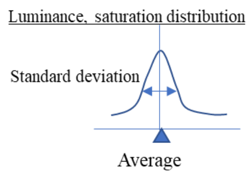
Method of Validation

Minimize the difference between image taken with the real camera and CG in terms of luminance representation and color at measuring points (5 or more in lighting area and 3 or more out of lighting area) by two steps (with known reflection board, then with known road surface)

- Measure statistics of 16 [pix] or more at the target image position (Brightness, average value of saturation, standard deviation)
- Adjustment parameters (examples):
  ･Known reflection board: color and luminance of light beam on each direction of headlight, etc.
  ･Known road surface: Reflectance of road surface, etc.

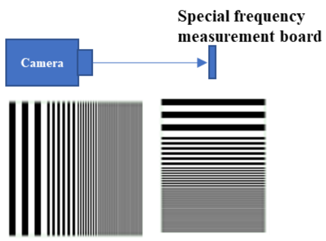
Judgement Criteria

For each item at each evaluation point, the difference from the real camera is in the range of ±5 [%]



camera (1-4)

■ On-board camera calibration [Special frequency]

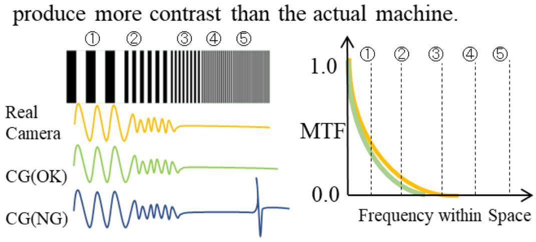


[Measurement conditions]
･dark room
･Use a specified light source
(The entire board must be able to maintain moderate contrast.)
･Use a frequency within space measurement board that can measure appropriate resolution
according to camera specifications.
･Place the board at a distance where you can focus.

Verification methods
Using a frequency within space measurement board , the gap of Frequency within space between the actual camera and the CG is the criterion for judgment. Adjust the model to meet your requirements.

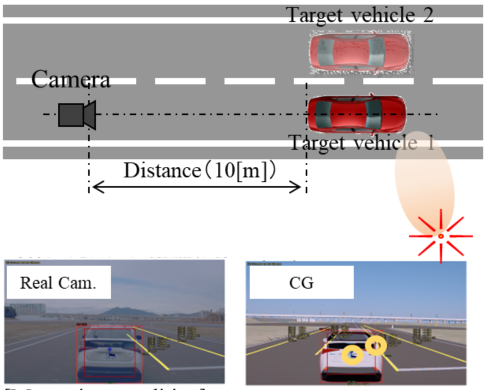
- In an actual camera, while maintaining the level of frequency within space measurement board, align the center point of the chart with the center point of the imaging device, acquire images, and calculate a horizontal / vertical MTF curve.
- Similarly, with a CG camera, the center points are aligned, the parameters of the vehicle orientation and mounting position are adjusted so that the position of the black line is positionally the same as the actual image, the image is acquired, and the horizontal / vertical MTF curve is calculated.

Judgment Criteria
The MTF difference is 5 [%] or less in areas other than 0 MTF.
In the region where the MTF is close to 0, the CG result does not produce more contrast than the actual machine.



■ Asset (ego-vehicle stopped) recognition target (vehicle) [Position]
■ Scenario recognition target (vehicle) [Position]

camera
(2-1/3-1)
(4-1/5-1)



[Measuring condition]
- On-board
- Known target points
- Known skylight (sun light, dark of the moon)
- Known road surface
  (asphalt pavement, horizontal plane)

※Reference information for judgement criteria near center of image
- Measure error of distance to target vehicle: 1[%]
- Image sensor horizontal pixels : 2880 [pix]
  size: 8.64 *10^-3[m]
- Lens parameter focal length: 7.9*10^-3[m]
  distortion ratio : 15%
- Vehicle width : 1.745[m]

<u>Method of Validation</u>

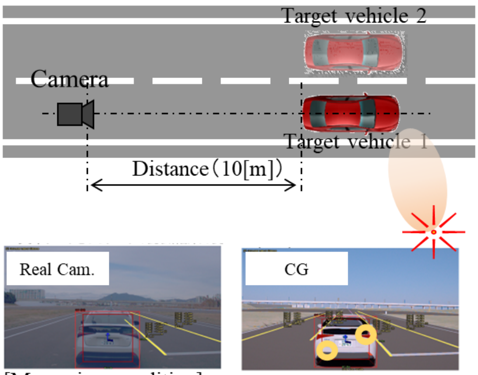
Check the position of target vehicles is the same between real and virtual environment
- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Speed of target vehicles: stopped, approximately 5[km/h] or [10km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle (If possible, use high-precision GPS)
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle (If possible, use high-precision GPS)
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance form ego vehicle
- Move target vehicle 2 to keep a distance form ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of distance (position), relative-speed, and images of both target vehicle 1 and 2 using real environment
- Render CG for the same scenario
- Compare positions of 3 or more feature points (gap of vehicle's body, etc.) of both images.

<u>Judgement Criteria</u>

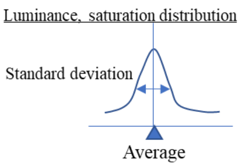
The differences of correspondent feature points between on image taken with the real camera and on CG
- Near center: 5 [pix] or less
- Peripheral: 30 [pix] or less

■ Asset (ego-vehicle stopped/low-speed) recognition target (vehicle) [Color/Luminance]
■ Scenario recognition target (vehicle) [Color/Luminance]

camera
(2-2/3-2)
(4-2/5-2)



[Measuring condition]
- On-board
- Known target points
- Known skylight (sun light, dark of the moon)
- Known road surface
  (asphalt pavement, horizontal plane)



<u>Judgement Criteria</u>

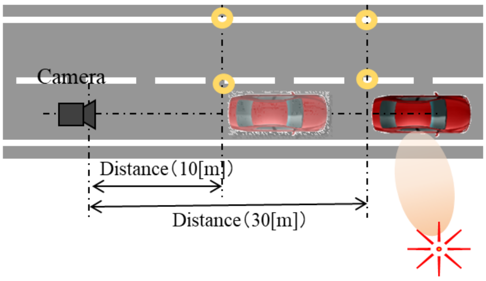
For each item, the difference from the real camera is in the range of ±20 [%]

<u>Method of Validation</u>

Check the luminance and color of target vehicles is the same between real and virtual environment
- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Speed of target vehicles: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle (If possible, use high-precision GPS)
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle (If possible, use high-precision GPS)
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance form ego vehicle
- Move target vehicle 2 to keep a distance form ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of distance (position), relative-speed, and images of both target vehicle 1 and 2 using real environment
- Render CG for the same scenario
- Measure the luminance and color expressions of the body, bumper, and preferably the tail lamps, when the sun is shining and when there is in shadow
- Measure statistics (brightness, average saturation, standard deviation) of 16 [pix] or more at the target image position, and then compare them

■ **Asset (ego-vehicle stopped/low-speed) recognition target (boundary)[Position]**
■ **Scenario recognition target (boundary) [Position]**

camera (2-4/3-4) (5-4)



[Measuring condition]
- On-board
- Known target points
- Known skylight (sun light, dark of the moon)
- Known road surface (asphalt pavement, horizontal plane)

※Reference information for judgement criteria near center of image
- Measure error of distance to target vehicle: 1[%]
- Image sensor horizontal pixels：2880 [pix]
  size: 8.64 *10^-3[m]
- Lens parameter focal length: 7.9*10^-3[m]
  distortion ratio：15%
- Vehicle width：1.745[m]

Method of Validation

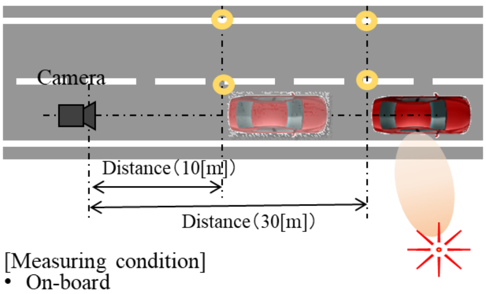
Check the position of target vehicles is the same between real and virtual environment
- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Speed of target vehicles: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle (If possible, use high-precision GPS)
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle (If possible, use high-precision GPS)
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance form ego vehicle
- Move target vehicle 2 to keep a distance form ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of distance (position), relative-speed, and images of both target vehicle 1 and 2 using real environment
- Render CG for the same scenario
- Measure the positions of the comparison positions on the boundary on the images, and then compare them

Judgement Criteria

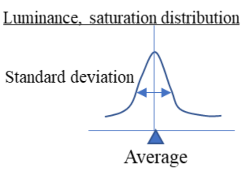
The differences of correspondent feature points between on image taken with the real camera and on CG
- Near center: 5 [pix] or less
- Peripheral: 30 [pix] or less

■ **Asset (ego-vehicle stopped/low-speed) recognition target (boundary) [Color/Luminance]**
■ **Scenario recognition target (boundary) [Color/Luminance]**

camera (2-5/3-5) (5-5)



[Measuring condition]
- On-board
- Known target points
- Known skylight (sun light, dark of the moon)
- Known road surface (asphalt pavement, horizontal plane)



Judgement Criteria

For each item, the difference from the real camera is in the range of ±20 [%]

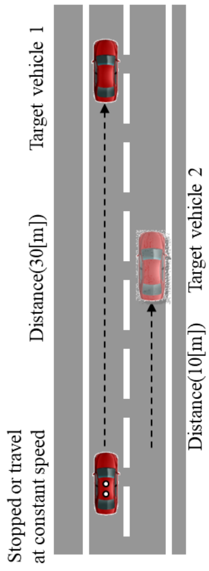
Method of Validation

Check the luminance and color of target of target vehicles is the same between real and virtual environment
- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Speed of target vehicles: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle (If possible, use high-precision GPS)
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle (If possible, use high-precision GPS)
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance form ego vehicle
- Move target vehicle 2 to keep a distance form ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of distance (position), relative-speed, and images of both target vehicle 1 and 2 using real environment
- Render CG for the same scenario
- Measure the luminance and color expressions of the lane marker and road, when the sun is shining and when there is in shadow.
- Measure statistics (brightness, average saturation, standard deviation) of 16 [pix] or more at the target image position, and then compare them.

■ **Asset (ego-vehicle stopped) recognition target (vehicle) [Distance/Speed]**

■ **Scenario recognition target (vehicle) [Distance/Speed]**

camera (2-3-1/2-3-3/3-3-1/3-3-3) (4-3-1/4-3-3/5-3-1/5-3-3)



Method of Validation

Check the recognition results is the same between real and virtual environment

- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Speed of target vehicles: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance form ego vehicle
- Move target vehicle 2 to keep a distance form ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of distance (position), relative-speed of target vehicle 1 and 2 using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data.

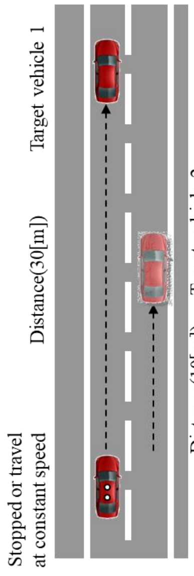
Judgement Criteria

- The difference of distance is in the range of ±5 [%] from real environment
- The difference of speed is in the range of ±10 [%] from real environment

■ **Asset (ego-vehicle stopped) recognition target (vehicle) [Size/Orientation]**

■ **Scenario recognition target (vehicle) [Size/Orientation]**

camera (2-3-2/3-3-2) (4-3-2/5-3-2)



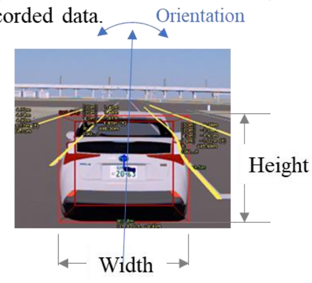
Method of Validation

Check the recognition results is the same between real and virtual environment

- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Speed of target vehicles: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance form ego vehicle
- Move target vehicle 2 to keep a distance form ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of height, width and orientation of target vehicle 1 and 2 using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data.

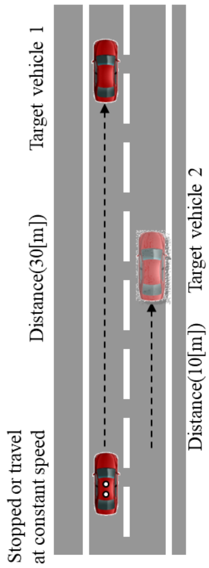
Judgement Criteria

- The difference of size is in the range of ±5 [%] from the real environment
- The difference of orientation is in the range of ±5 [%] from the real environment



- **Asset (ego-vehicle stopped) recognition target (vehicle) [Type]**
- **Scenario recognition target (vehicle) [Type]**

camera
(2-3-4/3-3-4)
(4-3-4/5-3-4)



Method of Validation

Check the recognition results is the same between real and virtual environment

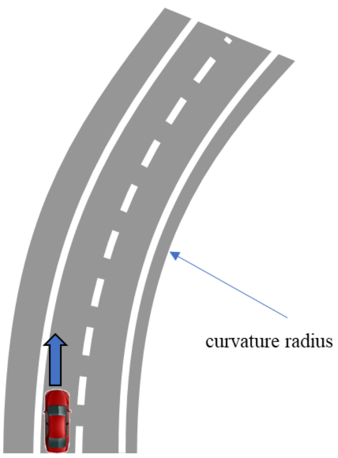
- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Speed of target vehicles: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance form ego vehicle
- Move target vehicle 2 to keep a distance form ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of types of target vehicle 1 and 2 using real and virtual environments, respectively, then compare those recorded data.
- Check type defined by the recognition process as the output

Judgement Criteria

- Target type is the same

- **Asset (ego-vehicle stopped/low-speed) recognition target (boundary) [Curvature]**
- **Scenario recognition target (boundary) [Curvature]**

camera
(2-6-1/3-6-1)
(5-6-1)



Method of Validation

Check the recognition results is the same between real and virtual environment

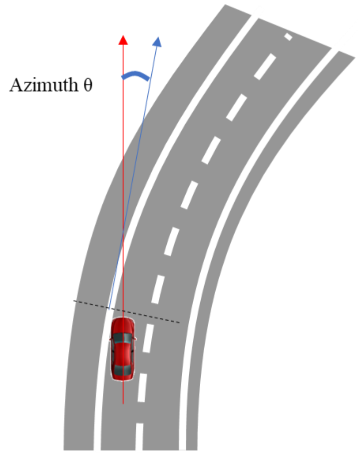
- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Record time series of curvature of boundary lines, which are parts of steady circles and from approximately 40[m] from ego vehicle, for ego lane using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data.

Judgement Criteria

- The difference of curvature is in the range of ±15 [%] from the real environment

- ■ **Asset (ego-vehicle stopped/low-speed) recognition target (boundary) [Azimuth]**
- ■ **Scenario recognition target (boundary) [Azimuth]**

camera
(2-6-2/3-6-2)
(5-6-2)



Method of Validation

Check the recognition results is the same between real and virtual environment

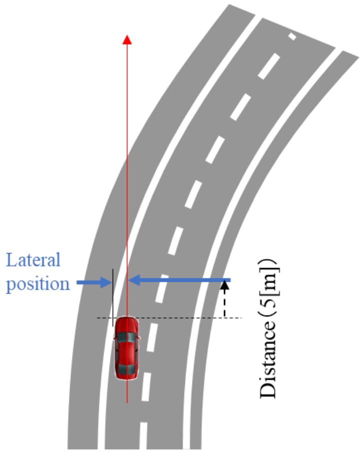
- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Record time series of azimuth of boundary lines for ego lane from the position of ego vehicle (e.g., head of the vehicle) using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data.

Judgement Criteria

- The difference of azimuth is in the range of ±10 [%] from the real environment

- ■ **Asset (ego-vehicle stopped/low-speed) recognition target (boundary) [Lateral position]**
- ■ **Scenario recognition target (boundary) [Lateral position]**

camera
(2-6-3/3-6-3)
(5-6-3)



Method of Validation

Check the recognition results is the same between real and virtual environment

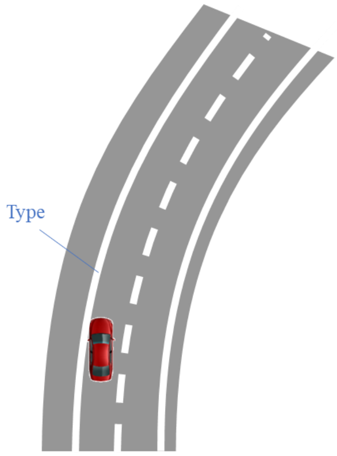
- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g. R100))
- Record time series of lateral positions of boundary lines for ego lane from the position of ego vehicle (e.g., 5[m] ahead of the vehicle) using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data
- Check both left and right boundary lines of ego lane

Judgement Criteria

- The difference of lateral position is in the range of ±5 [%] from the real environment

- **Asset (ego-vehicle stopped/low-speed) recognition target (boundary) [Type]**
- **Scenario recognition target (boundary) [Type]**

camera
(2-6-4/3-6-4)
(5-6-4)



Method of Validation

Check the recognition results is the same between real and virtual environment

- Speed of ego vehicle: stopped, approximately 5[km/h] or 10[km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Record time series of types of boundary lines using real and virtual environments, respectively, then compare those recorded data.
- Check type defined by the recognition process as the output (real line, broken line, line color, etc.)

Judgement Criteria

- Target type is the same

F.3 perception disturbance reproducing requirement and reproductivity validation method

In this section items to be confirmed as perception disturbance reproducing requirement and validation method are clarified. The way of study is the same as common requirement.

As a first step, clarifying the way of thinking about what items should be done as perception disturbance reproducing requirement is shown. After that clarifying validation method for each sensor based on this way of thinking. This method is defined based on each sensors' principle thus it is necessary to clarify method when validating another principle's sensor following the way of thinking. This validation method shown below can be replaced by another method that can verify the same contents.

F.3.1 Way of thinking about perception disturbance reproducing requirement

This section clarifies the way of thinking about the items to be set as perception disturbance reproducing requirement. Doing same process of common requirement, component of object detection are defined as below elements as ① sensor/vehicle itself, ② space where the signal propagates ③ recognition target(fig.F-3), and items to be validated and their criteria without perception disturbance for each element are clarified. Additionally the method to validate that recognition target can be detected under basic traffic disturbance scenario is defined to confirm this totally.

F.3.2 Way of thinking about perception disturbance reproducing requirement for each sensor

F.3.2.1 Way of thinking about perception disturbance reproducing requirement for millimeter ware Radar

In accordance with the principles of the Radar perception, validates whether physical amount of distance, direction, relative speed and received wave intensity are reproduced (fig.F-4)

Based on this way of thinking, list of actual requirement shown in table.F-4 is clarified.

								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													○													

Table F-4. perception disturbance of millimeter radar, reproductivity validation and disturbance principle

F.3.2.2 The way of thinking about perception disturbance reproducing requirement for LiDAR

In accordance with the principles of the LiDAR perception, validates whether physical quantities like azimuth, range, strength, number of detection points and size are reproduced(fig.F-5).

Based on this way of thinking, list of actual requirement shown in table.F-5 is clarified.

Verification perspective			Explanation	target	item	Parameters	request	Validation Method No.	No disturbance	Perceptual part / Signal from recognition target (S) / Scan timing / Misalignment of overall spatial position	Scan timing / Misalignment of position of recognition target	S strength / Saturation of S	S strength / Attenuation of S / Low reflection of the recognition target	Attenuation of S / Adhesion to the recognition target	Attenuation of S / Rain/Snow/Fog	Attenuation of S / Exhaust gas/Hoisting	Attenuation of S / Adhesion to the sensor	S strength / No S due to occlusion	S Propagation direction / Reflection	S Propagation direction / Refraction	S speed / Arrival time of S	Signal from non-recognition target / N factor / Pulsed noise	N factor / DC noise	U factor / Multiple reflections	U factor / Signal from non-recognition target (Reflection)	U factor / Signal from non-recognition target (Refraction)
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/mm^2. (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/mm^2. (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/mm^2. (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					○													

Table F-5. perception disturbance of LiDAR, reproductivity validation and disturbance principle

F.3.2.3 The way of thinking about perception disturbance reproducing requirement for Camera

As shown in the section about common requirement, camera can use color information while active type sensors can detect distance information and camera cannot detect it in perception block, so that this characteristic is very important to validate reproductivity under perception disturbance.

Based on this way of thinking, list of actual requirement shown in Table.F-6 is clarified.

Verification	Items/ Target Parts	Measurement items	Parameters	Requirement	Requirement ID	Normal condition(Day)	Normal condition(Night)	Perception: Optics: Refraction (Blur, Dislocation, Distortion)	Reflection (Flare, Artifact, Mirrored Objects)	Scattering (Flare)	Diffraction (Linear Flare)	Absorption (Vignetting)	Perception: Imager: Noise (Random, Fixed-pattern)	Color filter (Fade)	Exposure time (Shaked Image)	Exposure period (Flicker)	Time rag for exposure (Distortion depended on Rolling-shutter)	Overexposure (Clipped whites (Too long exposure time))	Overexposure (Clipped whites + Flare (Backlight))	Underexposure (Crushed shadows)	Lack of Gradation (Crushed shadows)	Perception: Image: Brightness (Out of correct exposure)	Hue (WB deviation)	Chroma	Recognition: Feature: Hidden ((Invisible))	Low spatial frequency ((Solid color)/(Flattish surface))	Low contrast ((Weak edge)/(Similar colors))	Recognition: Detection,: No classification ((No classification))	Detection or classification error ((False positive detection))	Detection or classification error ((False negative detection, or classification error))	Recognition: Positioning: Base-position error ((Self-position)/(Target-position))	Target-position error ((Size, position, or direction error(s)))	Recognition: Tracking: Tracking error ((Lost)/(Change to another object))	Velocity error ((Orientation error)/(Magnitude error))
perception disturbance reproducing requirement	shielding	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	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	–	–	–	–
	(Shelter: mud, water droplets)	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	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	–	–	–	–
	(passenger cars, large vehicles)	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	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	–	–	–	–
	(boundary lines: white, solid, dashed)	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	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	–	–	–	–
	(surface: curved, asphalt)	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	Spatial frequency	MTF	Adjust spatial frequency characteristics to meet judgement criteria based on RAW images of real and virtual (CG) environment	B-2-1	✓	–	○	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	◎	–	–	–	–	–	–	–
	(Fog)	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	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	○	–
	(passenger cars, large vehicles)		Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-2	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	○	–
	(boundary lines: white, solid, dashed)		Relative velocity	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-2-2-3	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	○	–
	(surface: curved, asphalt)		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)	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	✓	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	○	–	–	–	–	○	–	–	–	–	–	–	–
	(Tunnel)	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	✓	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	–	–	–	○	–	–	–	–	–	–	–
	(passenger cars, large vehicles)		Size, Direction	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-3-2	✓	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	–	–	–	○	–	–	–	–	–	–	–
	(boundary lines: white, solid, dashed)		Relative velocity	Recognized parameter values of the recognition target in virtual environment are similar to ones in real environment.	B-3-3-3	✓	–	–	–	–	–	–	–	–	–	–	–	◎	–	–	–	–	–	–	–	–	○	–	–	–	–	–	–	–
	(Road surface: straight, asphalt)		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	✓	–	–	–	–	–	–	–	–	–	–	–	◎	◎	–	–	–	–	–	–	–	○	–	–	–	–	–	–	–

Table F-6. perception disturbance of camera, reproductivity validation and disturbance principle

F.3.3 Validation method of perception disturbance reproducing requirement

Validation method of each requirement for each sensor defined in section F.3.2 is shown in this section.

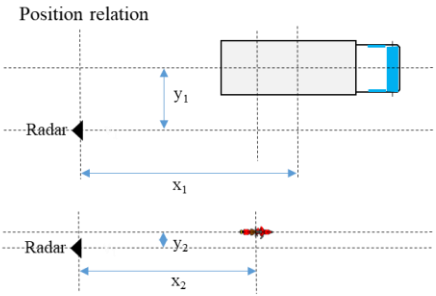
F.3.3.1 Validation method of perception disturbance reproducing requirement of millimeter wave Radar

■Reproduction of large difference of signal

Reproduction of disturbance phenomena

Signal Strength Ratio / Half Width Ratio

mmWave radar (3-1/3-2)



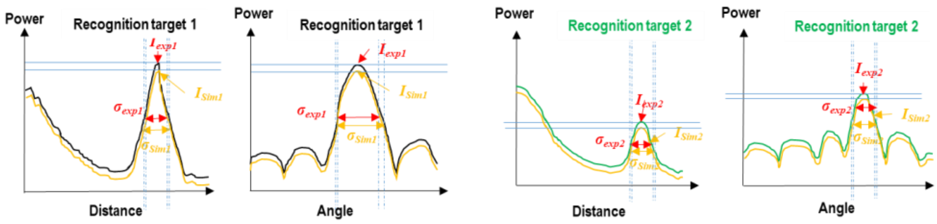
Validation Method

- Evaluate using subjects of differing degrees of reflectance large-sized motor vehicle such as a truck (recognition target 1) and small-sized recognition target such as a motorcycle (recognition target 2)
- Evaluate in a stationary state at a speed (0km/h) with the recognition target on a horizontal straight road
- Evaluate recognition target 1 and recognition target 2 separately
- Position of recognition target
  x_1:140(m) x_2:150(m) y_1:3.5(m) y_2:1(m)
- Compare to the signal strength ratio I_{exp1}/I_{exp2} I_{Sim1}/I_{Sim2} and the half-width ratio $\sigma_{exp1}/\sigma_{exp2}$ $\sigma_{Sim1}/\sigma_{Sim2}$ of the truck and the motorcycle in the actual and simulated environment

exp :actual environment *sim* :simulated environment

Judgement Criteria

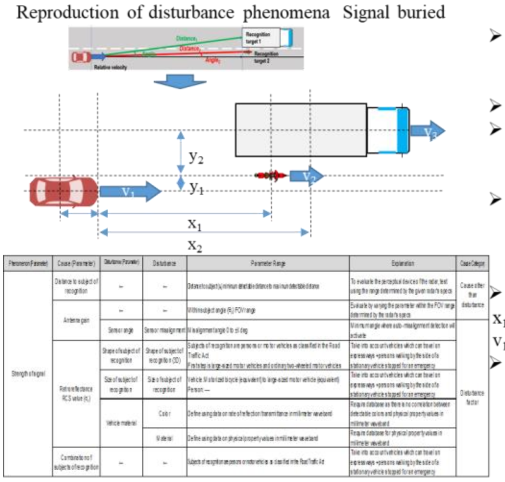
The signal strength ratio I_{exp1}/I_{exp2} I_{Sim1}/I_{Sim2} and the half-width ratio $\sigma_{exp1}/\sigma_{exp2}$ $\sigma_{Sim1}/\sigma_{Sim2}$ between the actual environment and simulated environment must be ±5% or less.



■Reproduction of large difference of signal

Reproduction of disturbance phenomena Signal buried

mmWave radar (3-3)



Validation Method

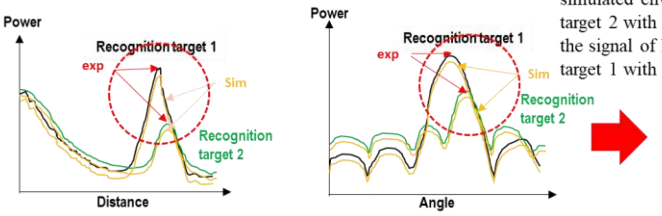
- Evaluate using targets of differing degrees of reflectance large-sized motor vehicle such as a truck (recognition target 1) and small vehicles such as a motorcycle(recognition target 2)
- Evaluated by driving on a straight road
- Evaluate with recognition target 1 and recognition target 2 traveling parallel in adjacent lanes, and in the direction of approach of the ego vehicle
- Evaluate two scenarios (scenario one is where the relative velocity of recognition target 1 and recognition target 2 is the same as that of the ego vehicle, and scenario two is where relative velocity differs)
- Initial position and initial velocity (Reference)

x_1:140(m) x_2:150(m) y_1:1(m) y_2:2.5(m) Relative velocity: v_1- v_2=Approx.10(km/h) v_2-v_3=0~Approx.10(km/h)

- Evaluate whether recognition target 2 with low signal strength are buried by the signals of high signal strength recognition target 1 in real and virtual

Judgement Criteria

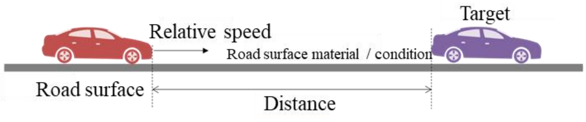
The ability to reproduce the phenomenon in simulated environment where a recognition target 2 with a low signal strength is obscured by the signal of high signal strength recognition target 1 with a high signal strength.



The red frame is an example of this situation, where the signal of recognition target 2 is buried in the signal of recognition target 1.

■ Simulating Low D/U due to Road Surface Multipath: Simulating the Disturbance Phenomenon - Received Power

mmWave Radar (4-1)



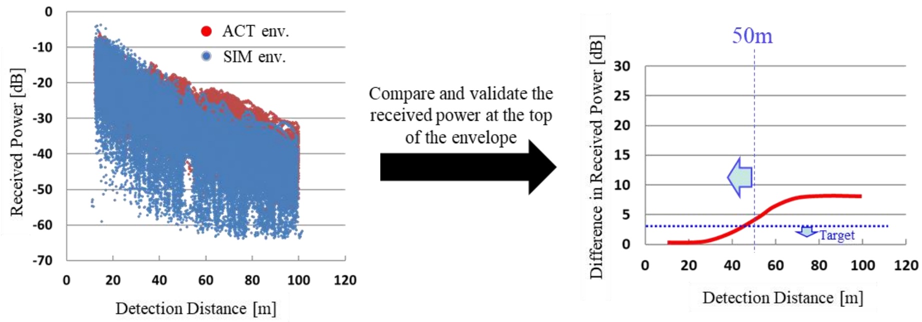
Parameter Item	Variable/Fixed	Range	Explanation
Distance to target	Variable	Min to Max detection Range	Min to max range detectable by the sensor
Relative speed	Fixed	Max speed within ODD	
Target type	Fixed	Large-sized vehicle (height : high) Normal vehicle (height : medium) Small-sized vehicle (height : 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

Method of Validation

- Simulate evaluation scenario for "low D/U (road surface multipath)" :
  - ➢ Approach the recognition target (stationary vehicle) ahead in the same lane as the ego vehicle
- Distance to the target : Sensor min. detectable distance to max. detectable distance
- Relative speed : constant (ex. about 20km/h)
- Type of target : passenger vehicle / large-sized trailer
- Road surface material : asphalt / metal plate
- Road surface condition : dry / wet

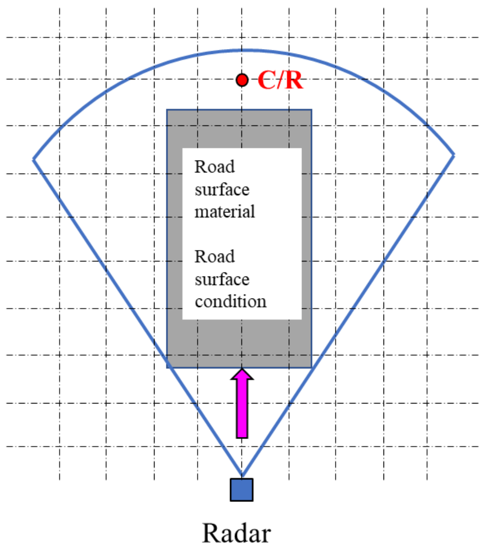
Judgment Criteria

- Difference in the envelope line of the received power at a relative distance of 50 m and below: 3 dB or less



■ Simulating Low D/U due to Road Surface Multipath: Road Surface Material/Road Surface Condition - Received Power/Null points

mmWave Radar (4-2/4-3)



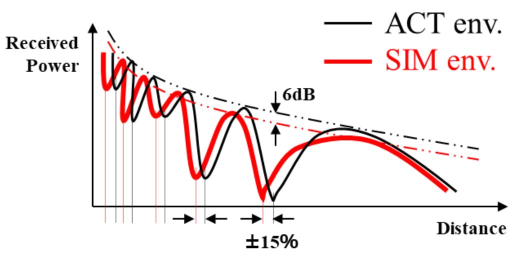
Method of Validation

- Place C/R in front of radar, and move radar toward C/R
- Road surface material : asphalt / metal plate
- Road surface condition : dry / wet

Judgement Criteria

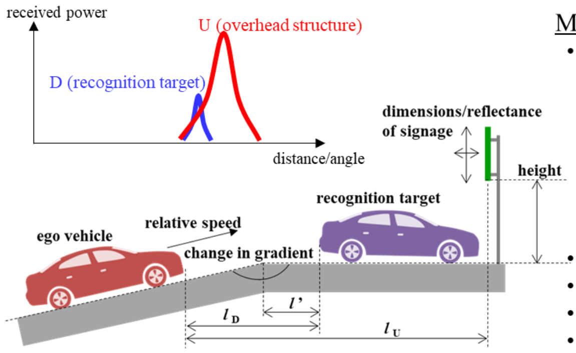
Plot the received power of the maximum reflection point at each distance

- Difference in envelope : 6 dB or less
- Difference in null point distance : ±15% or less



mmWave Radar
(5-1)

■ Simulating Low D/U Due to Change of the Angle: Simulating the Disturbance Phenomena – Buried Signals



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

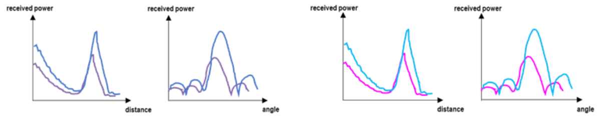
Method of Validation

- Simulate the scenario "Low D/U due to change of the angle":
  - ➢ Traveling a road with a change in gradient (concave down)
  - ➢ A metallic signage board ahead after the inflection point
  - ➢ The ego vehicle is to approach the stationary vehicle stopped nearby the signage board ahead.
  - ※Gradient: Substitution with equivalent conditions (such as changing the mounting angle of the radar) is allowed.
- Change in gradient： 2 points between 3 and 10 (°)
- l' ： 5 (m) fixed
- l_D initial value： 15 (m)
- l_U initial value： 20 (m)
- Type of the recognition target：a passenger vehicle
- Comparing the ratio I_D/I_U in the real and virtual environment

Judgment Criteria

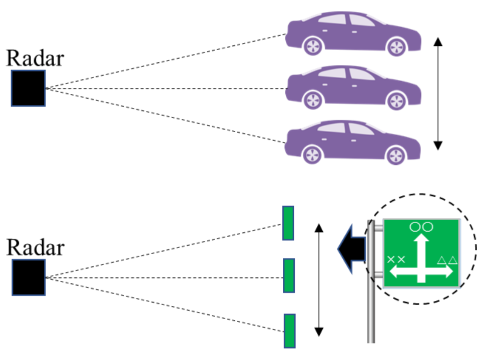
The phenomenon, whereby the signal from the recognition target becomes buried in the signal from the signage board, occurs in the same way in both the actual and the simulated environments.

Actual Environment　　Simulated Environment



mmWave Radar
(5-2/5-3)

■ Simulating Low D/U Due to Change of the Angle: Reflective Properties of Overhead Structures – Signal Intensity Ratio / HMFW



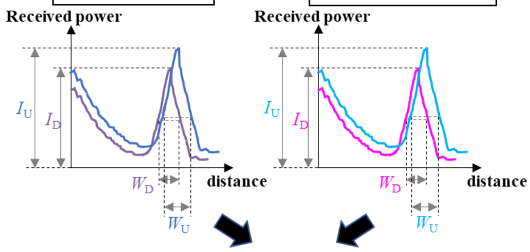
Method of Validation

- Direct the radio wave toward the recognition target (passenger vehicle) and the signage board (flat area)
- Vary the angle of the vehicle/board and the radar within the vertical plane
- Measurement angles： 0°, ±5°, ±10°
- Measurement distance： 15, 20 (m)
- Compare the ratio of peak intensity I_D/I_U and the HMFW W_D/W_U between the actual and simulated environments

Judgment Criteria

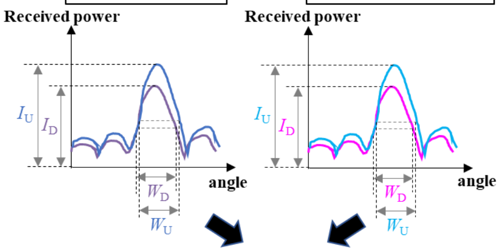
Difference in I_D/I_U , W_D/W_U between actual and simulated environments： within ±5%

Actual Environment　　Simulated Environment



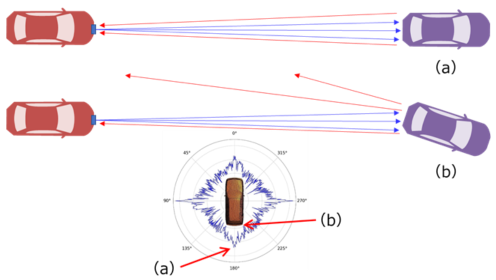
within ±5%

Actual Environment　　Simulated Environment



within ±5%

■Simulating Low S/N Due to Vehicle Orientation: Simulating the Disturbance Phenomenon



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

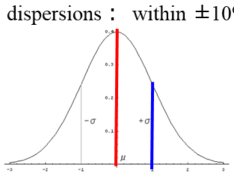
Method of Validation

- Simulate the scenario for evaluating "low S/N due to vehicle orientation":
  - ➢ Place a stationary vehicle up ahead on a straight road, and approach it at a slow speed
  - ➢ Change the orientation of the vehicle ahead and travel

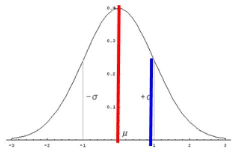
- Vehicle angle: 0 to 30 deg. (constant)
- Initial distance between vehicles: 150 m
- Vehicle speed: 20 km/h and below (constant)
- Type of recognition target: passenger vehicle
- Record the received power in both the actual and simulated environments

Judgment Criteria

Show the **cumulative distribution of the received power (dBm)** within a certain distance range between vehicles (e.g. 10 to 20 m), and compare the averages and dispersions: within ±10%



Cumulative Distribution of the Received power (ACTUAL)



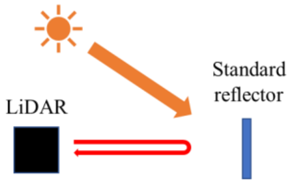
Cumulative Distribution of the Received power (SIM)

F.3.3.2 Validation method of perception disturbance reproducing requirement of LiDAR

■ Noise：Average error and dispersion of the range

LiDAR (F.2.4.2.1)

This validation corresponds to the evaluation scenario of 'disturbance light originated in reflected light' written in E.3.2.2.2.



Method of Validation

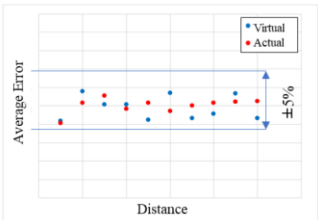
Place a standard reflector in front of the LiDAR and vary the distance to measure the average error and standard deviation, to ensure the difference to the actual measurement falls within the judgment criteria.

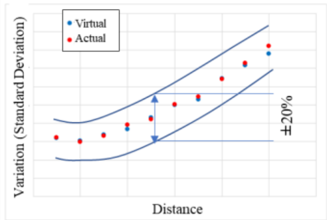
Judgment Criteria

Average error : within ±5% of distance to a target

σ : within ±20%

Causal Factors			Causal Factor Parameter	Range	Basis (or reasons)
Space	Light source	Halogen lights, etc.	Elevation angle	20 to 90 degrees	i.q. Annex.E
			Azimuth angle	-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.



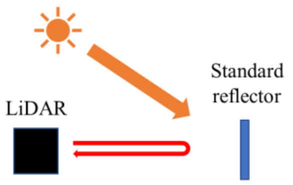


- The validation should be carried out in the condition of the maximum irradiance on the target surface within the parameter range above.
- A validation with fixed incidence is also acceptable if the noise level is properly reproduced.

■ Noise： Strength of signal and Detection rate

LiDAR (F.2.4.2.2)

This validation corresponds to the evaluation scenario of 'disturbance light originated in reflected light' written in E.3.2.2.2.



Method f of Validation

Place a standard reflector in front of the LiDAR and vary the distance to measure the intensity of the signal and detection rate, to ensure the difference to the actual measurement falls within the judgment criteria.

Judgment Criteria

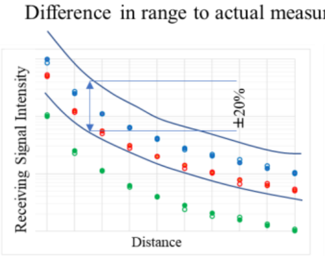
Intensity error in relation to actual measurement value: within ±20%

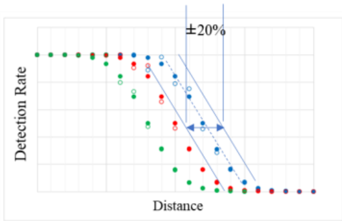
Difference in range to actual measurement @ 90% detection: within ±20%

Difference in range to actual measurement @ 50% detection: within ±20%

Difference in range to actual measurement @ 10% detection: within ±20%

Causal Factors			Causal Factor Parameter	Range	Basis (or reasons)
Space	Light source	Halogen lights, etc.	Elevation angle	20 to 90 degrees	i.q. Annex.E
			Azimuth angle	-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.





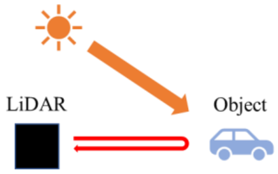
※Blue: reflectivity xx% Red: reflectivity xx% Green: reflectivity xx% ※●Actual ○Virtual

- The validation should be carried out in the condition of the maximum irradiance on the target surface within the parameter range above.
- A validation with fixed incidence is also acceptable if the noise level is properly reproduced.

■ **Noise： Number of Detection Points**

LiDAR
(F.2.4.2.3)

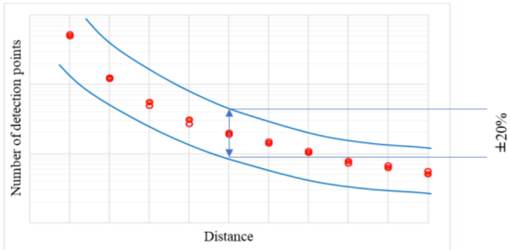
This validation corresponds to the evaluation scenario of ‘disturbance light originated in reflected light’ written in E.3.2.2.2.



Causal Factors			Causal Factor Parameter	Range	Basis (or reasons)
Space	Light source	Halogen lights, etc.	Elevation angle	20 to 90 degrees	i.q. Annex.E
			Azimuth angle	-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.

Method of Validation
Place the object in front of the LiDAR and vary the distance to validate the difference in number of detection points

Judgment Criteria
Error in relation to number of detection points in actual measurement to be within ±20%
(Do not include large distances where the number of detected points decreases)



- The validation should be carried out in the condition of the maximum irradiance on the target surface within the parameter range above.

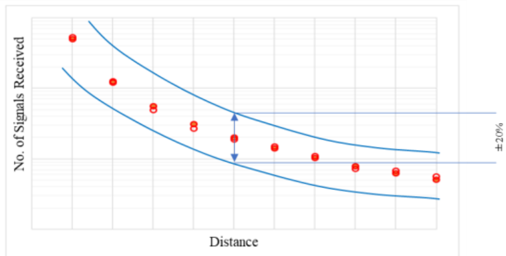
■ **Attenuation of S： Reproduction of attenuation of the signal from the recognition target**

LiDAR
(F.2.4.2.4)

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

Method
Place an object in front of the LiDAR and vary the distance, to verify the difference in the number of signals received

Judgment Criteria
Error in relation to actual points measured to be within ±20%
(Do not include large distances where number of signals reduces)

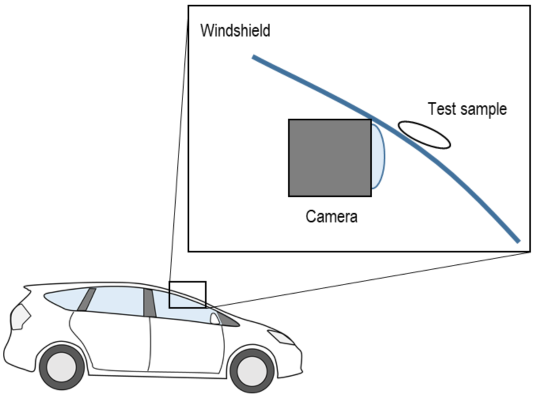


F.3.3.3 Validation method of perception disturbance reproducing requirement of LiDAR

■ Hidden Placement verification (hidden)/ color luminance verification (hidden)

Camera (B-1-1-1 B-1-1-2)

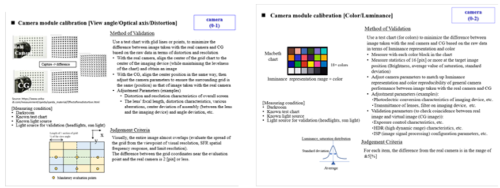
1. Object adheres to front of sensor: consistency of perception device



The sample to be attached should be completely hidden (not allowing light to transparent).

Method

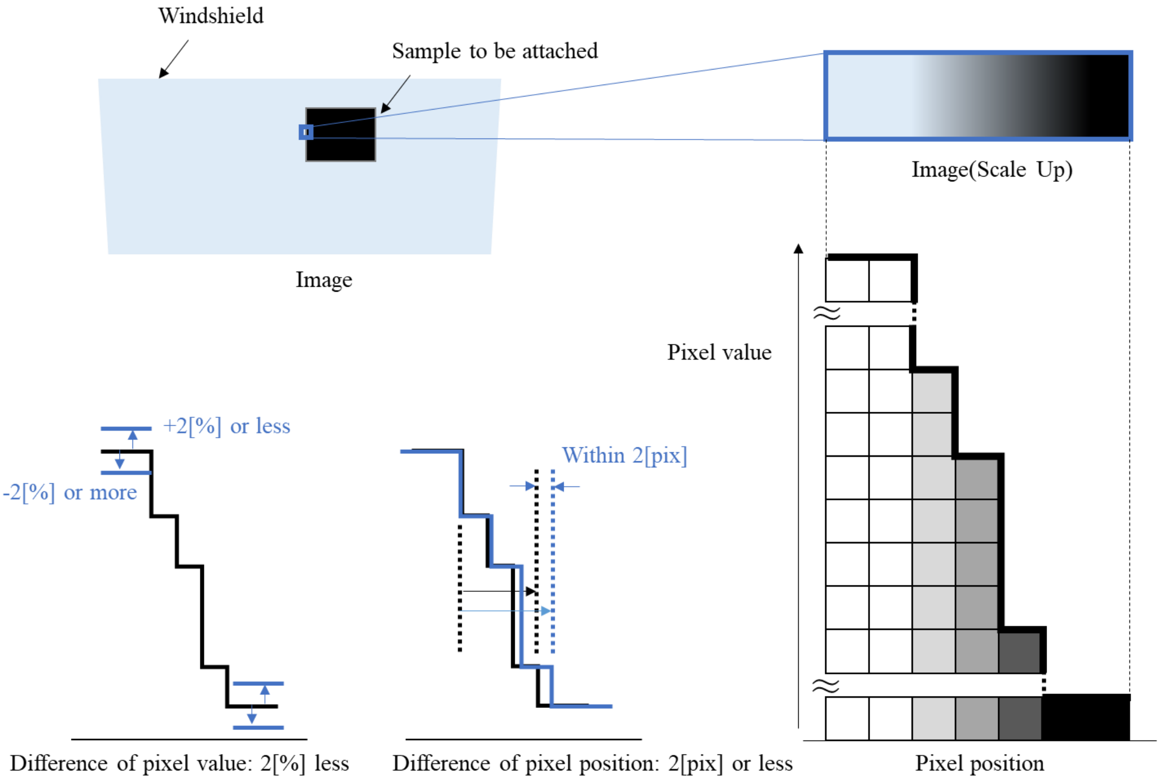
A test sample is applied to the windshield of the vehicle (while in a stationary state), and validation is conducted by evaluating the strength of the signal and color. However, if physical alignment of the sample is difficult, a comparison may be made with a profile of pixel values at the edge of the hidden part.



Judgment Criteria

The difference from the image taken by real camera as the pixel value is 2[%] or less in each of the hidden and unhidden areas.
and
The difference in distance on the image between the hidden and unhidden areas is 2 [pix] or less.

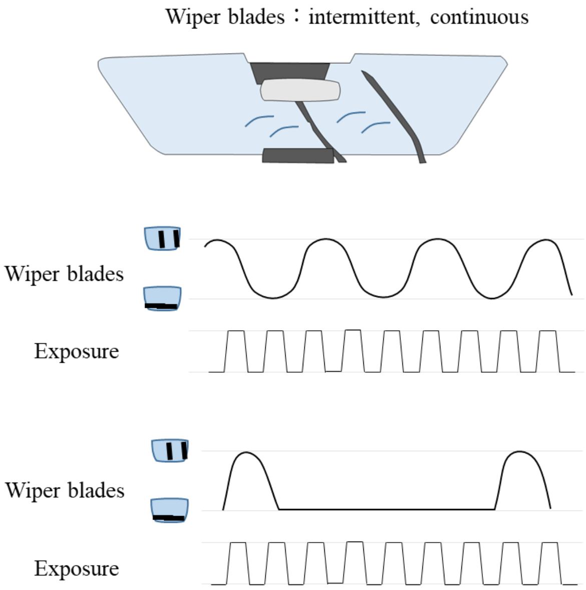
Supplementary for judgement criteria



■ Hidden　Placement verification (hidden)/ color luminance verification (hidden)

Camera
(B-1-1-1
B-1-1-2)

2. Obstruction in front of sensor: consistency of perception device



<u>Method</u>

Study the simulation of the image of wiper blades, as an element which can change over time as opposed to the adherence of a foreign object as seen in 1.
Evaluate the items that can change over time such as the movement of the wiper blades and the shutter speed.

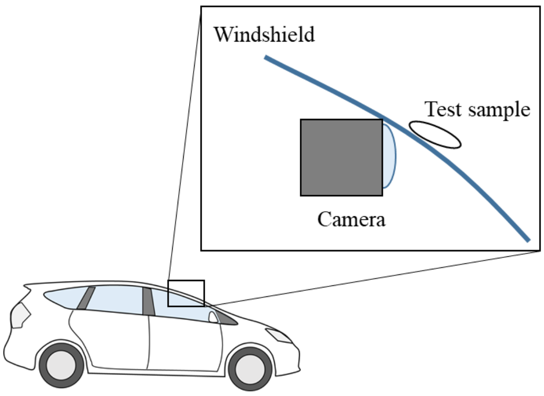
<u>Judgment Criteria</u>

- The changes match in regard to the exposure over time and wiper blade movement
- Difference in pixel value with an image of the same condition: 5[%] or less

■ Hidden　Placement verification (Object)/ color luminance verification (Object)

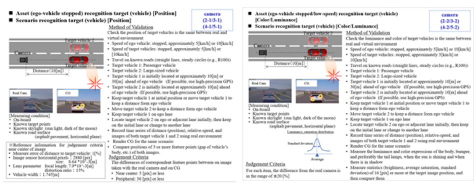
Camera
(B-1-2-1
B-1-2-2)

1. Object adheres to front of sensor: consistency of perception device



<u>Method</u>

A test sample is applied to the windshield of the vehicle (while in a stationary state), and validation is conducted by evaluating the strength of the signal and color.



<u>Judgment Criteria</u>

The difference from the real image taken by camera as the pixel value is 2[%] or less in each of the hidden and unhidden areas.
and
The difference in distance on the image between the hidden and unhidden areas is 2 [pix]　or less.

■Hidden　Recognition result (Object)

Camera (B-1-3)

Disturbance causal factor							Recognition part / Feature extraction / Hidden		
						Disturbance outline	(Invisible)		
Model class		Causal factor group			Causal factor item	Disturbance (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	⑤ 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)		◎	–

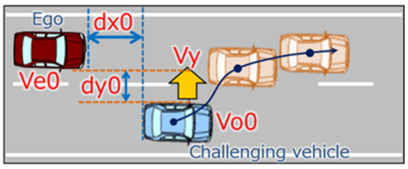
（Taken from Phenomenon and Cause Matrix）

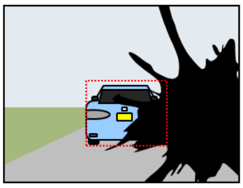
Validation method to be identified for each of the above 5 categories

■Hidden　Recognition result (Object)

Camera (B-1-3)

1. Object adheres to front of sensor　Cut-in scenario





Method

The recognition target cuts into the lane of the ego vehicle (in front) at a constant side-way speed, whilst vision is impaired due to the adherence of a foreign object.

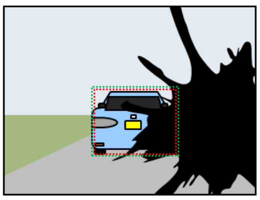
Judgment Criteria

- Difference in longitudinal distance: 5[%] or less
- Difference in lateral distance: 5[%] or less
- Difference in longitudinal relative speed: 10[%] or less
- Difference in lateral relative speed: 10[%] or less
- Difference in width/height: 5[pix] or less

However, judgment is made only on frames that are detected.

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%*

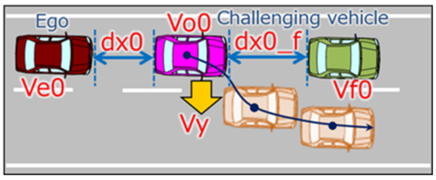


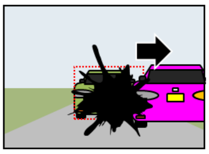
Real image
Virtual image

■Hidden　Recognition result (Object)

Camera (B-1-3)

1. Object adheres to front of sensor　Cut-out scenario





<u>Method</u>

The vehicle traveling in front cuts-out from the shielded position. The vehicle traveling in front, and the vehicle in front of that, are both the recognition targets.

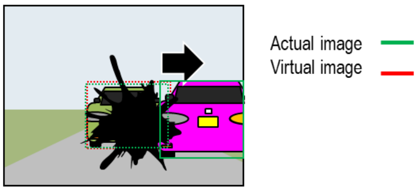
<u>Judgment Criteria</u>

- Difference in longitudinal distance: 5[%] or less
- Difference in lateral distance: 5[%] or less
- Difference in longitudinal relative speed: 10[%] or less
- Difference in lateral relative speed: 10[%] or less
- Difference in width/height: 5[pix] or less

However, judgment is made only on frames that are detected.

Reference: Parameters of Validation Scenario

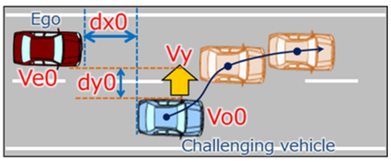
Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 [m]
		Longitudinal position dx0_f [m]
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph]
		Longitudinal velocity Vo0-Vf0 [kph]
		Lateral velocity Vy [kph]
Type of the target	Fixed	Shape: 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%



■Hidden　Recognition result (Object)

Camera (B-1-3)

2. Obstruction in front of sensor　Cut-in scenario



<u>Method</u>

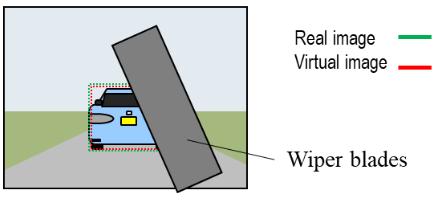
The recognition target cuts into the lane of the ego vehicle (in front) at a constant side-way speed, whilst wiper blades are in motion.

<u>Judgment Criteria</u>

- Difference in longitudinal distance: 5[%] or less
- Difference in lateral distance: 5[%] or less
- Difference in longitudinal relative speed: 10[%] or less
- Difference in lateral relative speed: 10[%] or less
- Difference in width/height: 5[pix] or less

Reference: Parameters of Validation Scenario

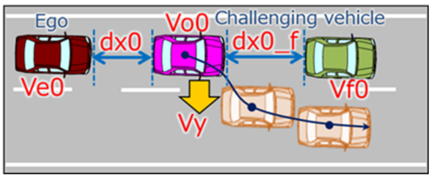
Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 [m]
		Lateral position y0 : 3.5m
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph] Lateral velocity Vy [kph]
Type of the target	Fixed	Shape: sedan Color: White
Wiper blade movement	Fixed	1. Intermittent 2. Continuous



■Hidden　Recognition result (Object)

Camera (B-1-3)

2. Obstruction in front of sensor　Cut-out scenario



Method

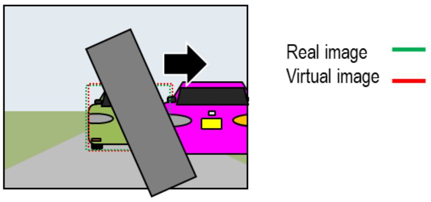
The recognition target cuts out while wiper blades are in motion.

Judgment Criteria

- Difference in longitudinal distance: 5[%] or less
- Difference in lateral distance: 5[%] or less
- Difference in longitudinal relative speed: 10[%] or less
- Difference in lateral relative speed: 10[%] or less
- Difference in width/height: 5[pix] or less

Reference: Parameters of Validation Scenario

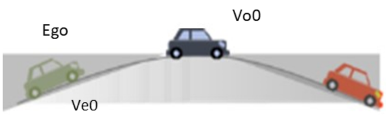
Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 [m]
		Longitudinal position dx0_f [m]
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph] Longitudinal velocity Vo0-Vf0 [kph] Lateral velocity Vy [kph]
Type of the target	Fixed	Shape: sedan Color: White
Wiper blade movement	Fixed	1. Intermittent 2. Continuous

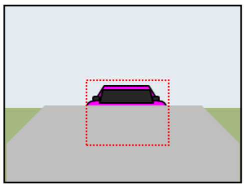


■Hidden　Recognition result (Object)

Camera (B-1-3)

3. Road surface shape incline　Blind-spot (vertical) scenario





Method

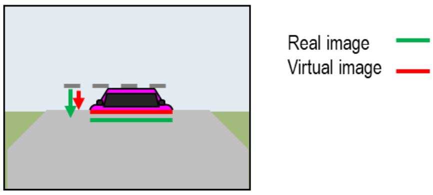
The ego vehicle travels along a road with a vertical incline (hump shape), and approaches the recognition target up ahead (in the ego-vehicle's driving lane), at a constant speed.

Judgment Criteria

- Difference in longitudinal distance: 5[%] or less
- Difference in lateral distance: 5[%] or less
- Difference in longitudinal relative speed: 10[%] or less
- Difference in lateral relative speed: 10[%] or less
- Difference in width/height: 5[pix] or less

Reference: Parameters of Validation Scenario

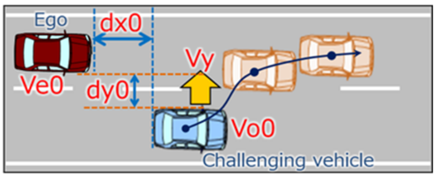
Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 [m]
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 [kph]
Type of the target	Fixed	Shape: sedan Color: White
Road structure vertical incline	Fixed	Vertical cross sectional incline: 6%



■Hidden　Recognition result (Object)

Camera (B-1-3)

4. Shielding by nearby moving objects (flying objects)　Cut-in scenario



__Method__

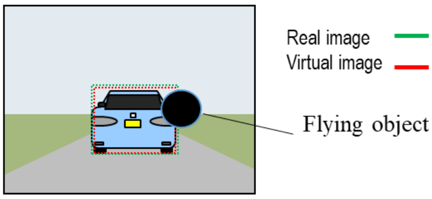
The recognition target cuts into the lane of the ego vehicle (in front) at a constant side-way speed, whilst a flying object crosses in front of the ego vehicle. Flying objects are assumed to be moving objects except traffic participants. It may be in contact with the ground, but it must be possible to move it in such a way that conceals part of the recognition target.

__Judgment Criteria__

- Difference in longitudinal distance: 5[%] or less
- Difference in lateral distance: 5[%] or less
- Difference in longitudinal relative speed: 10[%] or less
- Difference in lateral relative speed: 10[%] or less
- Difference in width/height: 5[pix] or less

Reference: Parameters of Validation Scenario

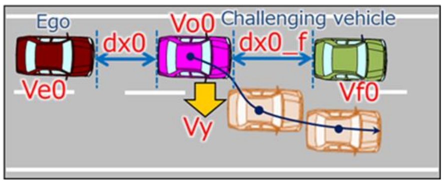
Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 : ○○～△△m
		Lateral position y0 : 3.5m
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 : ○○～△△kph Lateral velocity Vy　: ○○kph
Type of the target	Fixed	Shape: sedan Color: White
Flying object	Variable	Size (diameter): ○○ to △△ cm Sideways velocity: ○○kph

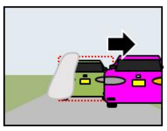


■Hidden　Recognition result (Object)

Camera (B-1-3)

5. Adherence of foreign object to other vehicle　Cut-out scenario





__Method__

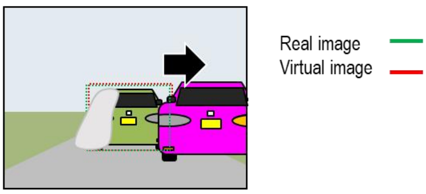
A vehicle traveling behind a recognition target which is covered by a cover, cuts out.

__Judgment Criteria__

- Difference in longitudinal distance: 5[%] or less
- Difference in lateral distance: 5[%] or less
- Difference in longitudinal relative speed: 10[%] or less
- Difference in lateral relative speed: 10[%] or less
- Difference in width/height: 5[pix] or less

Reference: Parameters of Validation Scenario

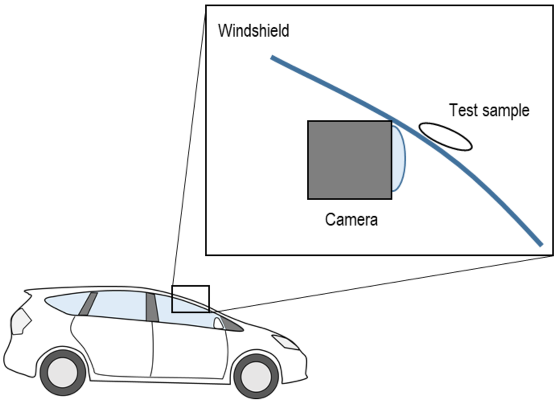
Parameter	Variable／Fixed	Range
Distance to the target	Variable	Longitudinal position dx0 : ○○～△△m
		Longitudinal position dx0_f : ○○～△△m
Relative velocity to the target	Variable	Longitudinal velocity Vo0-Ve0 : ○○～△△kph Longitudinal velocity Vo0-Vf0 : ○○～△△kph Lateral velocity Vy　: ○○kph
Type of the target	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



■Hidden　Placement verification (boundary line)/ color luminance verification (boundary line)

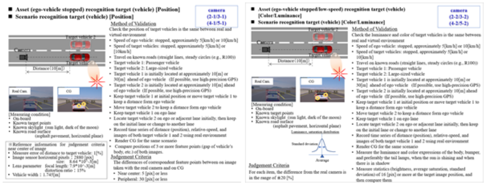
Camera (B-1-4 B-1-5)

1. Object adheres to front of sensor: consistency of perception device



Method

A test sample is applied to the windshield of the vehicle (while in a stationary state), and validation is conducted by evaluating the strength of the signal and color.



Judgment Criteria

The difference from the real camera as the pixel value is 2[%] or less in each of the shielded and unshielded areas.
and
The difference in distance on the image between the shielded and unshielded areas is 2 [pix] or less.

■Hidden　Recognition result (Object)

Camera (B-1-3)

(◎: large impact, ○: middle impact, △: small impact)

Disturbance causal factor					Disturbance outline	Recognition part / Feature extraction / Hidden (Invisible)		
Model class		Causal factor group		Causal factor item	Disturbance (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	⑤ 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)		◎	–

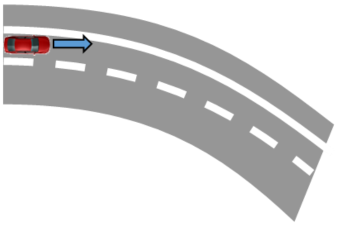
(Taken from Phenomenon and Cause Matrix)

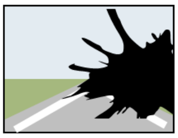
Validation method to be identified for each of the above 5 categories

■Hidden　Recognition result (boundary line)

Camera
(B-1-6)

1. Object adheres to front of sensor: Lane-keeping scenario





Method

The ego vehicle travels at a constant speed keeping to it's driving lane, whilst vision is impaired due to the adherence of a foreign object.

Judgment Criteria

- Difference in radius of curvature： 5[%] or less
- Difference in orientation： 5[%] or less
- Difference in position： 5[%] or less
- Target type is matching

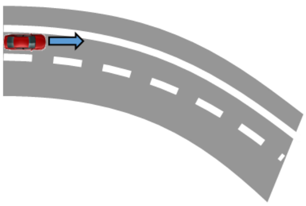
Reference: Parameters of Validation Scenario

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%

■Hidden　Recognition result (boundary line)

Camera
(B-1-6)

2. Obstruction in front of sensor : Lane-keeping scenario



Method

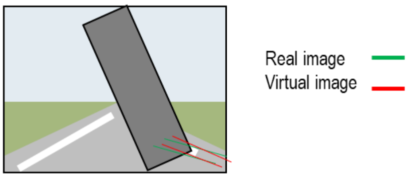
The ego vehicle travels at a constant speed, staying in its driving lane, whilst the wiper blades are in motion.

Judgment Criteria

- Difference in radius of curvature： 5[%] or less
- Difference in orientation： 5[%] or less
- Difference in position： 5[%] or less
- Target type is matching

Reference: Parameters of Validation Scenario

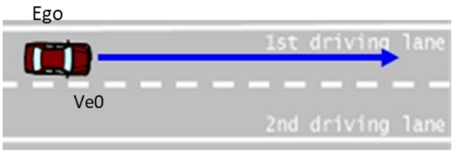
Parameter	Variable／Fixed	Range
Velocity of ego vehicle	Fixed	Ve0 : 120kph
Width of driving lane	Fixed	3.5m
Curvature of lane	Fixed	R〇〇
Type of the target	Variable	Shape: solid line, dotted line Color: white, yellow
Wiper blade movement	Fixed	1. Intermittent 2. Continuous

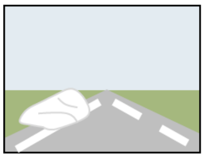


■Hidden　Recognition result (boundary line)

Camera
(B-1-6)

3. Dirty marking line: Lane-keeping scenario





Method

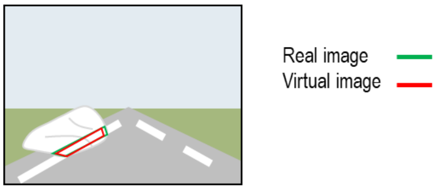
The ego vehicle travels at a constant speed keeping to it's driving lane, whilst sections of the lane marking line are shielded by fallen leaves on the road, piles of snow, etc.
The object shall be shielded so that the maximum shielding ratio of the object is 50%.

Judgment Criteria

- Difference in amount of shielding of marking line : pixels 5[%] or less
- Difference in radius of curvature : 5[%] or less
- Difference in orientation : 5[%] or less
- Difference in position : 5[%] or less
- Target type is matching

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 shielding due to adherence of a foreign object (disturbance)	Fixed	Amount of shielding: 50%



■Camera: Low Spatial Frequency Low Contrast – Simulating the Disturbance Phenomenon

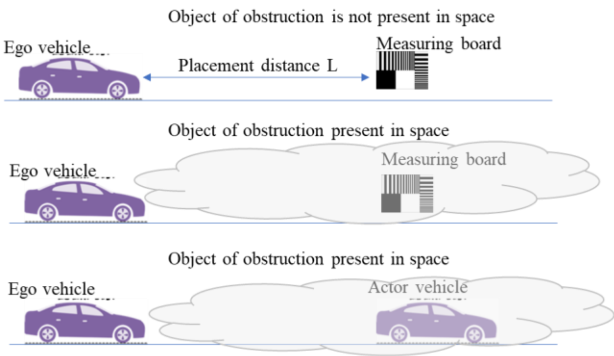
Camera
(B-2)

Validation Method

・The evaluation scenario assumes validation is conducted with varied disturbance parameters to create conditions such as performance limitation(s)
・The tool is a combination of disturbance parameters in the scenario that can be supported (=can be measured in actual conditions) and confirmation the disturbances are reproduced

(Validation 1) From Perception Device
Spatial frequency and contrast are verified by placing a dedicated measurement board and swinging a disturbance factor parameter
*Confirmed by checking the RAW data for brightness

(Validation 2) From Recognition Unit
The ego vehicle approaches the stationary actor vehicle, and the recognition results are checked and swinging a disturbance factor parameter



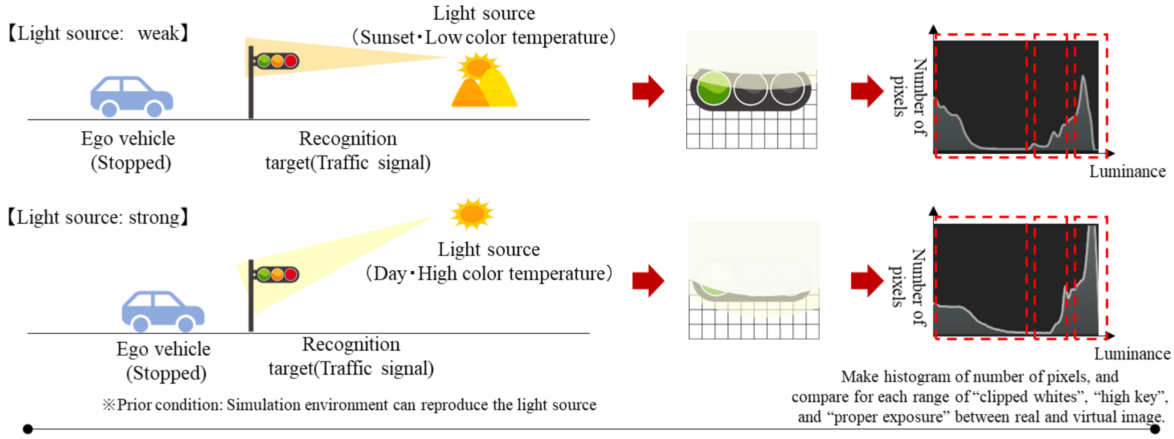
Judgement Criteria
(Validation 1) Difference in spatial frequency and contrast between SIM & Actual to be within ±5[%] deviation
Measuring conditions: average measured value and theoretical value to fall within ±5]%] deviation
(Validation 2) Difference in distance at which the vehicle can "recognize" between SIM & actual to be within ±5[%] deviation

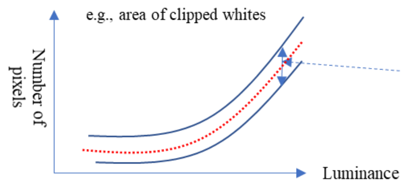
■Overexposure dynamic range

camera (B-3-1)

Method of Validation: ①-1 Check dynamic range

Check histogram of images, which may include clipped whites, etc., in the angle of view of target (traffic signal) with light source in front of ego vehicle.





Judgement Criteria

In each range of luminance, check the difference of number of pixels between real and virtual images for N (e.g., 3) times. The differences are 5 [%] or less.
If possible, it is better to check with various strength of light source.

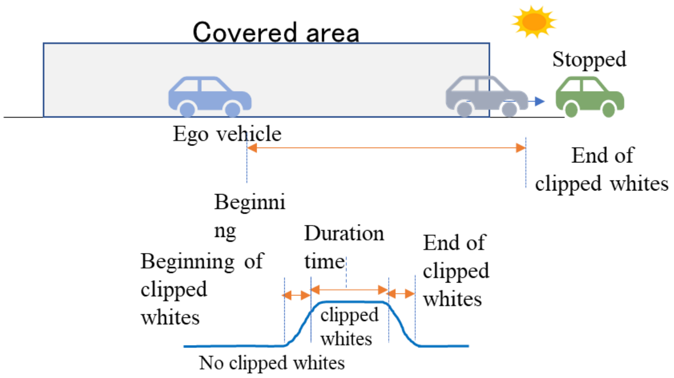
■Overexposure duration time

camera (B-3-2)

Method of Validation

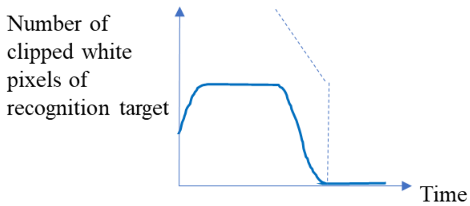
Definition of clipped whites: 80 [%] or more of maximum pixel value, or affect to recognition process
Check time change of number of clipped white pixels from beginning of clipped whites to end of them in covered area

- Speed of ego vehicle: approximately 10[km/h] or 30[km/h]
- Target vehicle: Type: Large-sized vehicle, etc. Speed: stopped
- Put target vehicle ahead of exit of known road (Covered area (Tunnel, etc.): Straight), then move ego vehicle to the target with constant speed
- Test for N (e.g., 3) times for each combination of light strength (fair sky, obscured sky, etc.) and vehicle speed (approximately 10 [km/h], 30[km/h], etc.)
- Record time series of distance (position), relative-speed, and images of target vehicle in front of ego vehicle using real environment
- Render CG for the same scenario
- Compare number of clipped white pixels between real environment and virtual environment (CG) from beginning of clipped whites near target vehicle to end of them.



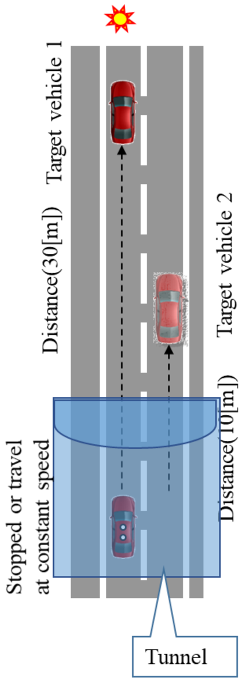
Judgement Criteria

Each time, difference of number of clipped white pixels between real and virtual environment is 5 [pix] or less



■ Scenario recognition target (vehicle) [Distance/Speed]

camera (B-3-3-1)



<u>Method of Validation</u>

Check the recognition results is the same between real and virtual environment

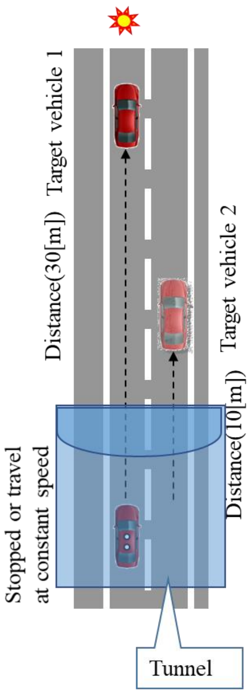
- Properly put disturbance factors (Tunnel, Light source) (In real environment, the phenomenon occurs)
- Speed of ego vehicle: stopped, approximately 5 [km/h] or 10 [km/h]
- Speed of target vehicles: stopped, approximately 5 [km/h] or 10 [km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance from ego vehicle
- Move target vehicle 2 to keep a distance from ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of distance (position), relative-speed of target vehicle 1 and 2 using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data.

<u>Judgement Criteria</u>

- The difference of distance is in the range of ±5 [%] from real environment
- The difference of speed is in the range of ± 10 [%] from real environment

■ Scenario recognition target (vehicle) [Size/Orientation]

camera (B-3-3-2)



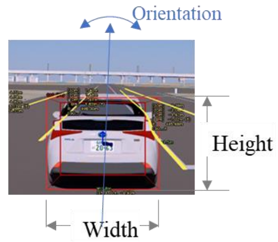
<u>Method of Validation</u>

Check the recognition results is the same between real and virtual environment

- Properly put disturbance factors (Tunnel, Light source) (In real environment, the phenomenon occurs)
- Speed of ego vehicle: stopped, approximately 5 [km/h] or 10 [km/h]
- Speed of target vehicles: stopped, approximately 5 [km/h] or 10 [km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance from ego vehicle
- Move target vehicle 2 to keep a distance from ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of height, width and orientation of target vehicle 1 and 2 using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data.

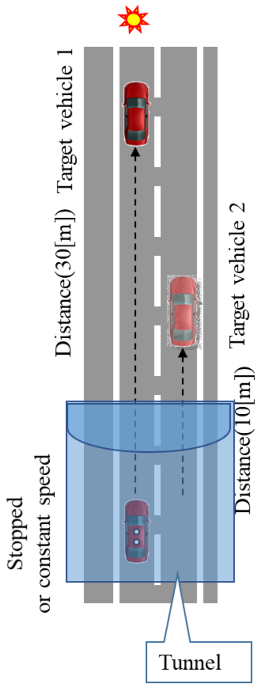
<u>Judgement Criteria</u>

- The difference of size is in the range of ±5 [%] from the real environment
- The difference of orientation is in the range of ±5 [%] from the real environment



■ Scenario recognition target (vehicle) [Type]

camera
(B-3-3-4)



<u>Method of Validation</u>

Check the recognition results is the same between real and virtual environment

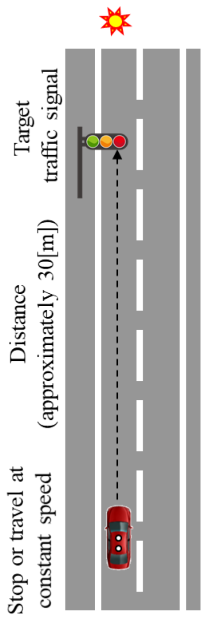
- Properly put disturbance factors (Tunnel, Light source) (In real environment, the phenomenon occurs)
- Speed of ego vehicle: stopped, approximately 5 [km/h] or 10 [km/h]
- Speed of target vehicles: stopped, approximately 5 [km/h] or 10 [km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Target vehicle 1: Passenger vehicle
- Target vehicle 2: Large-sized vehicle
- Target vehicle 1 is initially located at approximately 10[m] or 30[m] ahead of ego vehicle
- Target vehicle 2 is initially located at approximately 10[m] ahead of ego vehicle
- Keep target vehicle 1 at initial position or move target vehicle 1 to keep a distance from ego vehicle
- Move target vehicle 2 to keep a distance from ego vehicle
- Keep target vehicle 1 on ego lane
- Locate target vehicle 2 on ego or adjacent lane initially, then keep on the initial lane or change to another lane
- Record time series of types of target vehicle 1 and 2 using real and virtual environments, respectively, then compare those recorded data.
- Check type defined by the recognition process as the output

<u>Judgement Criteria</u>

- Target type is the same

■ Scenario recognition target (traffic signal) [Type]

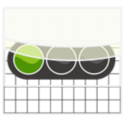
camera
(B-3-3-5)



<u>Method of Validation</u>

Check the recognition results is the same between real and virtual environment

- Properly put disturbance factors (Light source) (In real environment, the phenomenon occurs)
- Speed of ego vehicle: stopped, approximately 5 [km/h]
- On the known road (straight lines), stopped or travel
- Target is traffic light in front of ego vehicle
- Keep ego vehicle on ego lane
- Record time series of type (lighting status of traffic signal) in front of ego vehicle on ego lane, and then compare the types between virtual and real environment.
- The type is green, yellow, red, and others which are defined as output of recognition process.



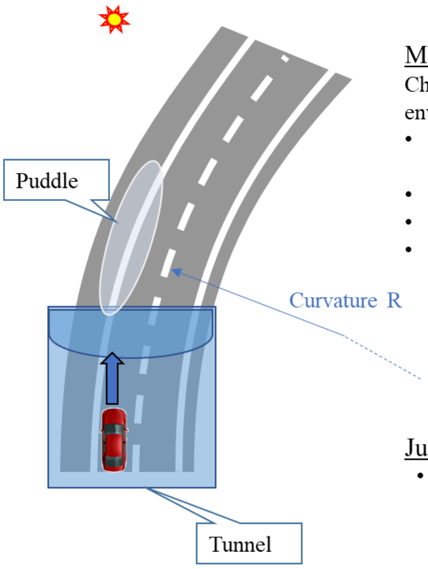
In the validation process, include scenes in which entire or a part of target image is clipped whites because the target is existed in front of light source (sun)

<u>Judgement Criteria</u>

- Target type is the same

camera (B-3-4-1)

■ Scenario recognition target (boundary) [Curvature]



Method of Validation

Check the recognition results is the same between real and virtual environment

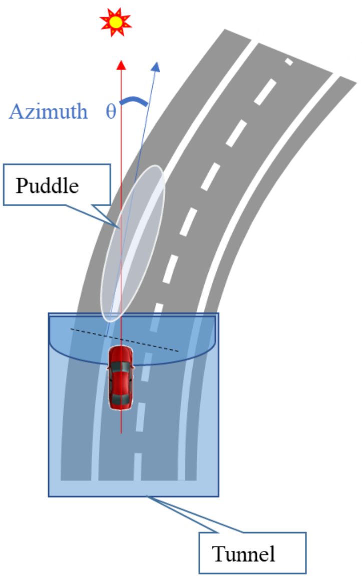
- Properly put disturbance factors (Tunnel, Light source, Puddle) (In real environment, the phenomenon occurs)
- Speed of ego vehicle: stopped, approximately 5 [km/h] or 10 [km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Record time series of curvature of boundary lines, which are parts of steady circles and from approximately 40[m] from ego vehicle, for ego lane using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data.

Judgement Criteria

- The difference of curvature is in the range of ±15 [%] from the real environment

camera (B-3-4-2)

■ Scenario recognition target (boundary) [Azimuth]



Method of Validation

Check the recognition results is the same between real and virtual environment

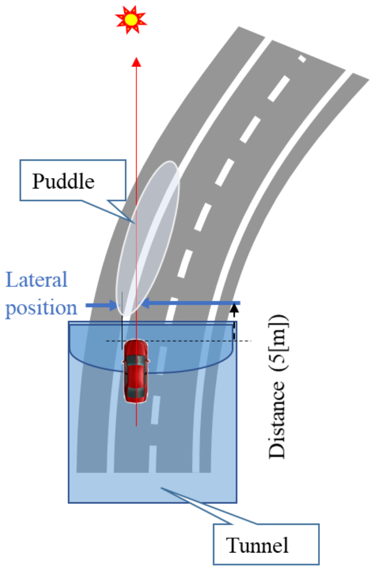
- Properly put disturbance factors (Tunnel, Light source, Puddle) (In real environment, the phenomenon occurs)
- Speed of ego vehicle: stopped, approximately 5 [km/h] or 10 [km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Record time series of azimuth of boundary lines for ego lane from the position of ego vehicle (e.g., head of the vehicle) using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data.

Judgement Criteria

- The difference of azimuth is in the range of ±10 [%] from the real environment

camera (B-3-4-3)

■ Scenario recognition target (boundary) [Lateral position]



Method of Validation

Check the recognition results is the same between real and virtual environment

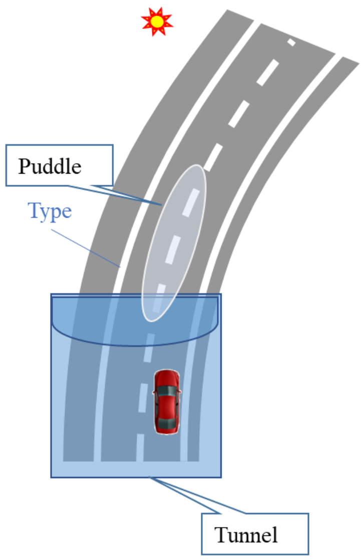
- Properly put disturbance factors (Tunnel, Light source, Puddle) (In real environment, the phenomenon occurs)
- Speed of ego vehicle: stopped, approximately 5 [km/h] or 10 [km/h]
- Travel on known roads (straight lines, steady circles (e.g. R100))
- Record time series of lateral positions of boundary lines for ego lane from the position of ego vehicle (e.g., 5[m] ahead of the vehicle) using real and virtual environments, respectively. If there is constant offset, get the offset from correlativity and cancel the effect from that if need, then compare those recorded data
- Check both left and right boundary lines of ego lane

Judgement Criteria

- The difference of lateral position is in the range of ±5 [%] from the real environment

camera (B-3-4-4)

■ Scenario recognition target (boundary) [Type]



Method of Validation

Check the recognition results is the same between real and virtual environment

- Properly put disturbance factors (Tunnel, Light source, Puddle) (In real environment, the phenomenon occurs)
- Speed of ego vehicle: stopped, approximately 5 [km/h] or 10 [km/h]
- Travel on known roads (straight lines, steady circles (e.g., R100))
- Record time series of types of boundary lines using real and virtual environments, respectively, then compare those recorded data.
- Check type defined by the recognition process as the output (real line, broken line, line color, etc.)

Judgement Criteria

- Target type is the same

Annex G

Validation of Simulation Tools and Simulation Test Methods Related to UN Regulation No. 157

G.1 Purpose and Scope

To summarize the concepts behind the validation technique for simulation tools and simulation test methods used in compliance testing for the traffic disturbance scenario defined in UN Regulation No. 157 (low-velocity ALKS). Note that errors in the perception unit are not taken into account (100% recognition is assumed), with the subjects of evaluation being the main AD control system (Planer) and vehicle motion control system (Fig. G-1).

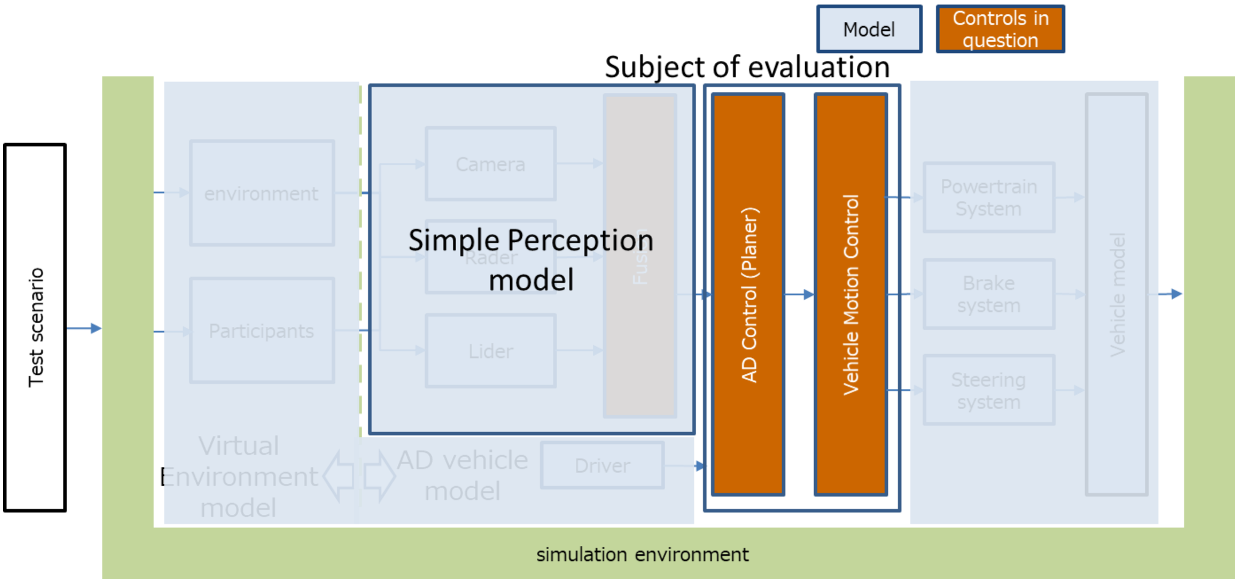


Figure G-1. Control Systems (Subject of Evaluation) in the Traffic Disturbance Scenario

G.2 Terminology

Following are the definitions of the terminology used in this chapter.

(A) Automated Driving System (ADS)
A system that has the function to perform a part or all of the driving required by the driver on behalf of the driver by performing a part or all of a dynamic driving task (DDT) by automatically identifying driving conditions, making decisions, and controlling the steering.

(B) Parameters
Physical quantities (e.g., vehicle velocity and distance) used for measuring data, conducting simulations, etc.

(C) Calculated Value
Value determined from the results of calculations performed using the simulation tool.

(D)Provided Value
Value provided by the scenario.

(E)Scenario

A scene that incorporates one (or more) ADS and one (or more) target vehicle while performing a specified DDT and the narrative of the subsequent interactions that arise thereafter.

In this section, this is the narrative formed by the evaluation conditions when conducting actual tests and simulations, including the initial conditions of the ego and other vehicles (vehicle velocity, longitudinal distance, etc.), behavior of other vehicles (cut-in, etc.), and road conditions (number of driving lanes, road width, etc.).

(F)Preventable Threshold

The threshold between "no collision" and "everything other than no collision (collision, etc.)" shown by the graphs under "5. Reference" in Appendix 3 Guidance on Traffic disturbance critical scenarios for ALKS of the UNR-157.

G.3 Method for Validating the Simulation Tool

G.3.1 Purpose of This Chapter

This chapter describes the process and requirements for determining whether the simulation tool can accurately reflect an actual test. Before running a simulation test, this confirmation must be completed.

G.3.2 Validation Method and Criteria

Following parts describe the method and criteria used for validating simulation tools, along with justification.

Validation Method

Apply the same environmental information from the actual test for the selected scenario to the simulation and then compare the relative distance to other vehicles (hereinafter "longitudinal distance").

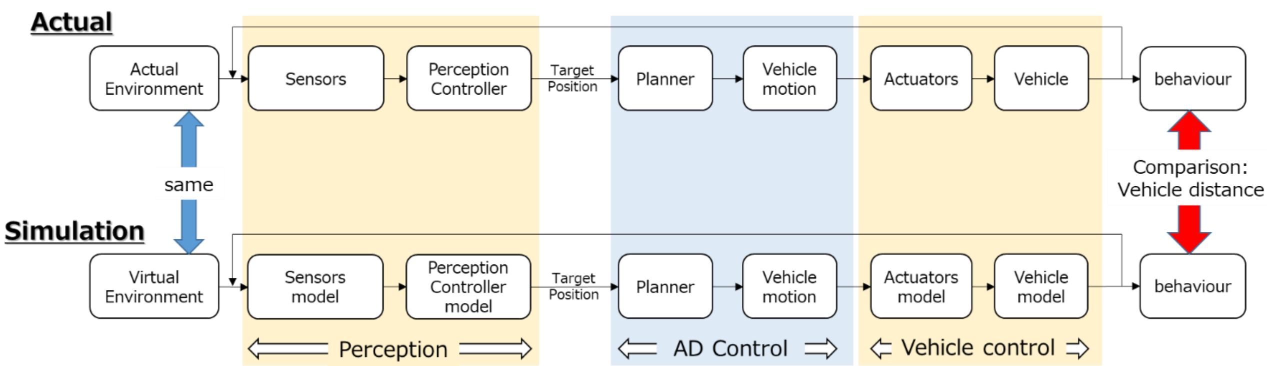


Figure G-2. ADS Structure

Justification of the Concept:

The compliance test in question determines whether the ego vehicle will (or will not) collide with other vehicle. Therefore, the simulation tool must be capable of accurately simulating longitudinal distances (physical quantification for determining whether a collision has or has not occurred). Furthermore, the ambient circumstances that compose the "inputs," such as the location of the preceding vehicle, must be equal to accurately compare the outcomes of the acutual test and simulation. Based on this, it is possible to conclude that the aforementioned validation method can demonstrate the simulation tool's suitability for this purpose.

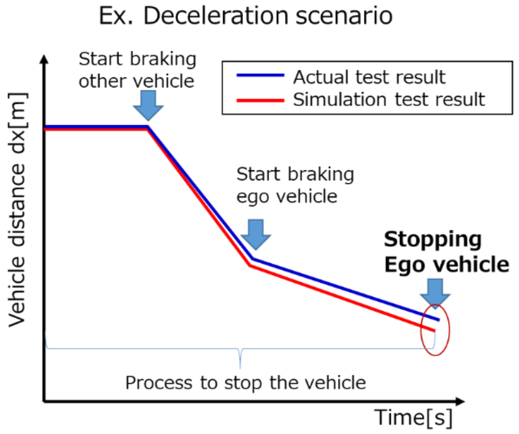
Criteria

When the ego vehicle reaches a stationary or steady state[1], the resulting longitudinal distance[2] between the ego and target vehicles for which the collision is being avoided must be greater in the actual test than that in the simulation tool. Here, we compare the "no-collision (preventable)" territory and process leading up to the ego vehicle reaching a stationary or steady state to be used as a reference.

Furthermore, to demonstrate that the above criteria have been met, the simulation tool itself must first satisfy "3.3 Simulation Tool Requirements."

[1] "Steady state" refers to the state where there is no longer a difference in velocity between the ego and target vehicles as a result of the ego vehicle's collision avoidance behavior.

[2] Longitudinal distance refers to the length of the perpendicular distance line created from the front end of the ego vehicle to the rear end of the target vehicle.



Justification of the Concept:

To "confirm that the test results for collision/non-collision by the ADS are always superior to the results of the criteria for collision/non-collision (i.e., the purpose of the compliance test)," the success or failure of actual avoidance performance for a particular test scenario can be demonstrated by showing that results calculated using the simulation tool are always superior to the criteria, as long as the simulation test results show that the actual test results will always perform better.

G.3.3 Simulation Tool Requirements

The simulation tool must conform to the following two requirements to be valid.

Requirement 1: The simulation tool must calculate and output the parameters that influence the determination of whether a collision occurred.

(For the parameters that contribute to each scenario, refer to "Attachment 1. Scenario-Specific Parameters of Impact")

Requirement 2: To be able to compare calculation results, it must be proved that "a correlation exists[1]" between the parameters calculated and that assessed via actual tests.

[1] "A correlation exists" does not mean that the calculated parameter values perfectly match, but rather that the changes in the parameters vary in a similar way.

G.4 Procedure for Validating the Simulation Tool

G.4.1 Purpose of This Chapter

This chapter describes the steps that lead to validating the simulation tools using the technique described in the previous chapter.

G.4.2 Procedure for Validating the Simulation Tool

① Choose the Scenario and Parameters that will be Used to Confirm the Validity
From the list of scenarios necessary for the compliance test, select the scenario(s) and parameters to be used to confirm the validity (refer to G.5 ADS Safety Performance Evaluation Simulation Method).

INPUT: the scenario and parameter range listed under “G.5 ADS Safety Performance Evaluation Simulation Method.”

OUTPUT: chosen scenario and parameters for validation

NOTE: For low-velocity ALKS, ADS avoidance behavior is limited to “deceleration” (avoidance by steering does not occur); therefore, a scenario and characteristics that demonstrate the correlation in ADS deceleration performance between the actual and simulation tests should be chosen. The maximum deceleration by ADS “G” should ideally be included in the range of deceleration performance to be compared.

② Preliminary Actual Test
Perform an actual test before conducting a validation test to measure each parameter required to be input/adjusted in the simulation tool.

INPUT: selected performance characteristics that impact the results of the simulation tool

OUTPUT: actual test data to be used for adjusting the characteristics of the vehicle model

③ Input and Adjust the Settings for the Simulation Tool and Environment
Input and adjust the settings (e.g., braking performance) based on the specifications of the target vehicle to be used in the simulation (e.g., vehicle weight) and the data obtained from “② Preliminary Actual Test.”

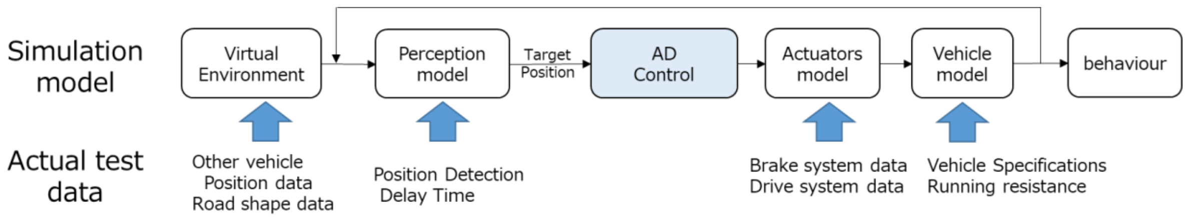
INPUT: actual test data to be used for adjusting the characteristics of the vehicle model

OUTPUT: the simulation tool and environment where the settings have been input and adjusted

NOTE: Adjusting the simulation tool refers to adjusting the perception and vehicle unit models from the preadjusted state to the state where they are aligned with the actual conditions to satisfy the criteria and simulation tool requirements for validation described in Chapter 3.

An example of inputting and adjusting settings

Input and adjust the settings of the perception and vehicle unit models using the measurement data obtained from “② Preliminary Actual Test.”



NOTE: If the perception unit's responsiveness is based on a "time delay," correlation (validity) must be confirmed by matching the increase/decrease in the timing of the longitudinal/lateral position and velocity of the target vehicle as recognized by the actual perception unit to the actual physical measurements of the position and velocity of the target vehicle.

④ Actual Test for Confirming Validity
Conduct an actual test based on the scenario selected in "① Choose the Scenario to be Used to Confirm Validity" above.

INPUT: test scenario and parameters (test conditions) under which the actual test will be performed

OUTPUT: actual measurement data to be used for confirming the validity of the respective test scenario

⑤ Simulation for Confirming Validity
Conduct simulation based on the scenario selected in "① Choose the Scenario to be Used to Confirm Validity" above.

INPUT: actual test measurement parameters for respective test scenarios, simulation, and environment for which settings have been input and adjusted

OUTPUT: simulation data to be used for confirming the validity of respective test scenarios

NOTE: Information on other vehicles to be input into the simulation can be created based on the position data of each test vehicle positioned using GNSS, for example, during the actual test conducted in ④.

⑥ Confirming the Validity of the Simulation Environment
Compare the results from ④ and ⑤ to confirm the validity of the simulation environment.

INPUT: actual measurement and simulation data for confirming the validity of each respective test scenario

OUTPUT: the result of confirming the validity of the simulation environment

NOTE: The procedure does not necessarily proceed in order from ① to ⑤, but rather it may repeat from ② to ⑤ until the judgment criteria are satisfied.

G.5 ADS Safety Performance Evaluation Simulation Method

G.5.1 Purpose of This Chapter

To discuss the simulation test method used to ensure that the compliance test's pass/fail criteria are met (i.e., confirm that the test results for collision/non-collision by the ADS are always superior to the results of the criteria for collision/non-collision) using the validated simulation tool.

G.5.2 Test Method

Adopt the environment described in "Simulation tools and implementation environment (G.6 Submission Documents-3)," with the simulation input comprising a combination of the following two items:

1. The scenario, in other words, the allocation and behavior of the ADS-equipped ego vehicle (hereinafter "ego vehicle") and surrounding vehicles (hereinafter "other vehicles").

Following are the eligible scenarios:

(a) Cut-in scenario [No.1]

(b) Cut-out scenario [No.2]

(c) Deceleration scenario [No.4]

*The number within the [ ] corresponds to the numbers within the Figures in Attachment 2 "Hazardous Scenarios."

2. The parameters of the ego and other vehicles within the scenario

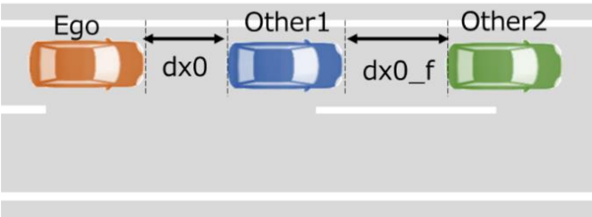
① The velocity of the ego and other vehicles
② Acceleration/deceleration velocity of the ego and other vehicles
③ Distance between the ego and other vehicles

Next are the definitions of each scenario used above and parameters of the ego and other vehicles within the given scenarios.

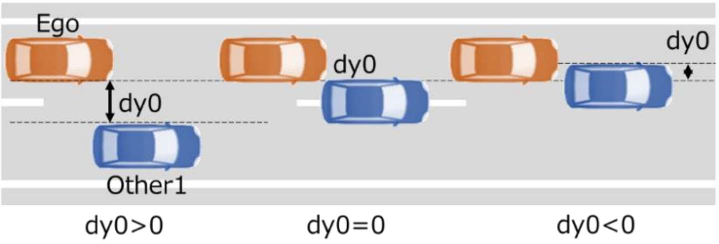
G.5.3 Definition of the Parameters of the Ego and Other Vehicles

① Basic Definition of Initial Longitudinal Distance (dx0)
The initial longitudinal distance is the length of the perpendicular distance line created from the front end of one vehicle to the rear end of another.

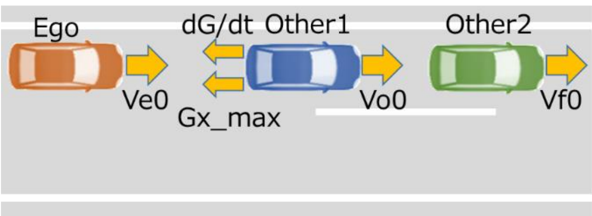
The distance between the ego vehicle and the vehicle in front of the ego vehicle ("other vehicle 1") is shown as dx0 (m), with the distance between "other vehicle 1" and the vehicle in front ("other vehicle 2") shown as dx0_f (m).



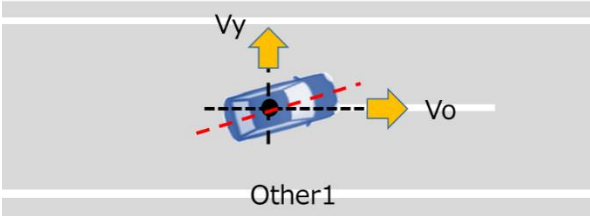
② Basic Definition of Initial Lateral Distance (dy0)
Lateral distance is the length between the edge lines of the adjacent sides of two vehicles. The sign preceding the value will be "plus" if the "other vehicle 1" does not overlap with the ego vehicle and "minus" if there is an overlap. Thus, if the value is "0," the two perpendicular distance lines perfectly overlap.



③ Basic Definition of Initial Velocity
Ve0 (km/h): initial velocity of the ego vehicle
Vo0 (km/h): initial velocity of the preceding vehicle (other vehicles 1) in the ego lane or adjacent lane
Vf0 (km/h): initial velocity of other vehicles 2
Gx max (G): deceleration rate of other vehicles 1
dG/dt: change over time in the deceleration rate of other vehicles 1



④ Basic Definition of Lateral Velocity
Vy (m/s): lateral velocity of other vehicle 1 and the velocity perpendicular to the lane line

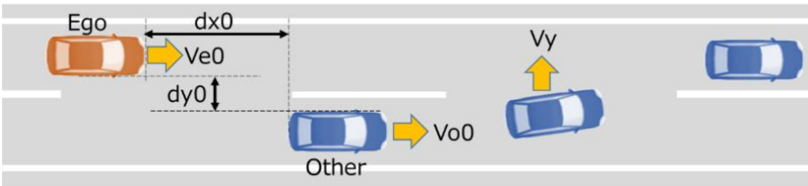


*Refer to Attachment 3, "Definition of the Behavior of Other Vehicles," for more details

G.5.4 Definition of Each Scenario

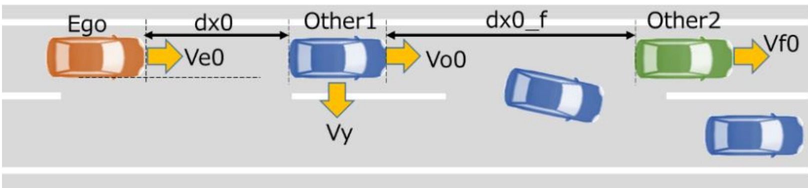
(a) Cut-in Scenario

The "parameters of the ego and other vehicles" as defined in G.4.2 are used as follows:



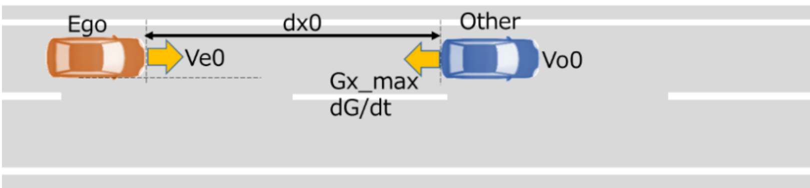
(b) Cut-out scenario

In this scenario, the "parameters of the ego vehicle, other vehicles 1, and other vehicles 2" as defined in G.4.2 are used as follows:



(c) Deceleration scenario

In this scenario, the "parameters of the ego and other vehicles" as defined in G.4.2 are used as follows:



G.5.5 Criteria for Pass or Fail

The collision must not occur within the preventable range (no-collision territory) as defined in "5. Reference" in Appendix 3 Guidance on Traffic disturbance critical scenarios for the ALKS of UNR-157.

G.5.6 Parameter Range for Simulations

① Parameter Values and Ranges Common Across 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 parameters

Vehicle Parameters	Ego Vehicle	Other Vehicle 1	Other Vehicle 2
Vehicle width	(According to the application vehicle)	1.9 m	1.9 m
Vehicle length	(According to the application vehicle)	5.3 m	5.3 m
Shape	Rectangular	Rectangular	Rectangular
Position of travel	Middle of the lane	Middle of the lane	Stationary in the middle of the lane

② Scenario-Specific Parameter Ranges

The parameter ranges listed under (1) to (3) below form the basic parameter ranges. However, this can be individually set based on the applicant's driving environment conditions, etc.

(1) Parameter ranges for 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

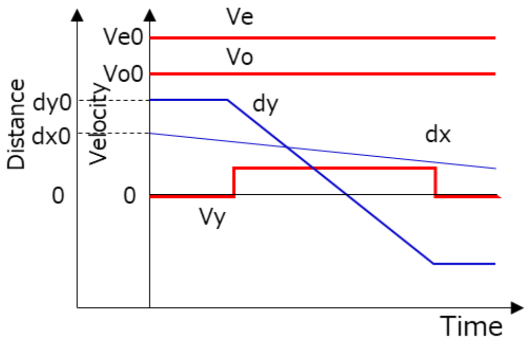
The value given in [ ] is the maximum designed velocity of the ego vehicle

*1 Do not include cases where the velocity of the cut-in vehicle is greater than the velocity of the ego vehicle.

Note: When the cut-in vehicle's velocity is slower, do not include lateral velocity values, which are physically impossible. (For example, a combination such as "vehicle velocity 10 km/h (2.78 m/s) wherein the lateral velocity is 3 m/s.")

Note: When the range of movement of autonomous driving (the subject of application) is limited to only when the ego vehicle is tracking the vehicle in front, do not include the combinations of the lateral velocity and longitudinal distance of the cut-in vehicle for which cut-in would occur in front of the preceding vehicle or "into" the preceding vehicle (collision).

E.g., the change in cut-in parameters over time.



*Refer to Attachment 1(a) for the parameters over a time series

(2) Parameter ranges for 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

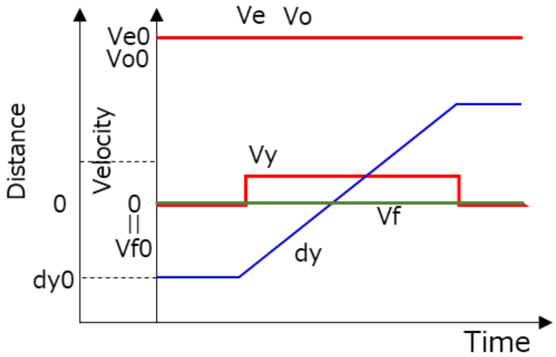
The value given in [ ] is the maximum designed velocity of the ego vehicle

[*2] Velocity of the preceding vehicle = velocity of the ego vehicle

Note: When the velocity of the cut-out vehicle is slower, do not include lateral velocity values that are physically impossible. (For example, a combination such as “vehicle velocity 10 km/h (2.78 m/s) wherein the lateral velocity is 3 m/s.”)

Note: When considering the “longitudinal distance,” do not include conditions where the cut-out vehicle collides with the stationary vehicle.

E.g., the change in cut-out parameters over time.



*Refer to Attachment 1(b) for the parameter over a time series

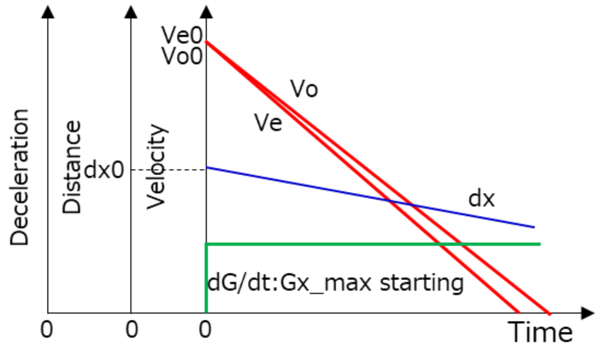
(3) Parameter ranges for deceleration scenario

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

The value given in [ ] is the maximum designed velocity of the ego vehicle

[*3] Velocity of the preceding vehicle = velocity of the ego vehicle

E.g., the change in deceleration parameters over time.



*Refer to Attachment 1(c) for the parameter over a time series

G.5.7 Conducting Simulation

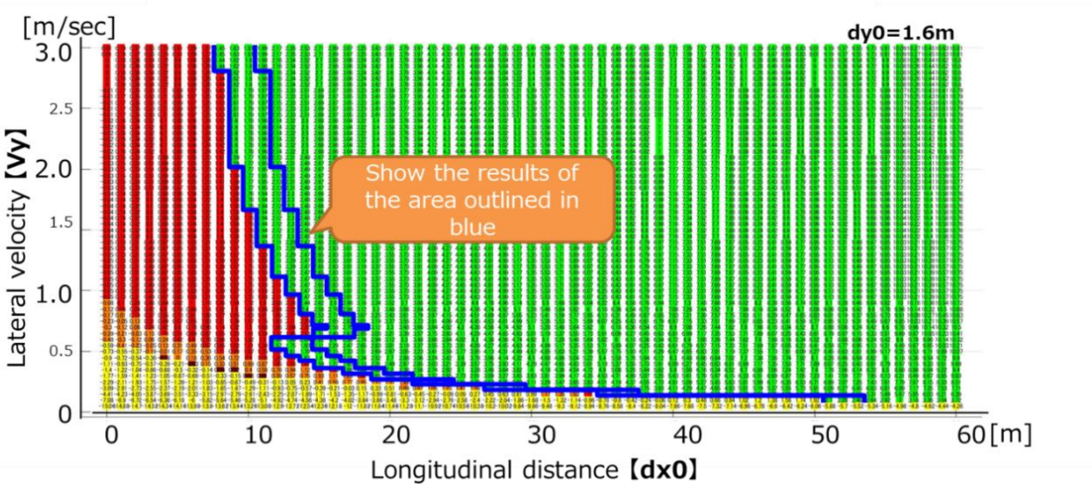
Conduct simulations based on the following ranges.

(1) Close to the Preventable/Unpreventable Threshold

Concerning the cut-in and cut-out scenarios, confirmation is to be conducted at +1 and +2 m from the threshold line from the borderline of pass/fail toward the direction in which the longitudinal distance becomes greater to confirm a broader range of collision/avoidance (not only limited to nearby the threshold line).

NOTE: The minimum increment of the lateral velocity is 0.1 m/s intervals.

Example of cut-in: ego vehicle velocity (Ve0) = 30 km/h, other vehicle velocity (Vo0) = 10 km/h.



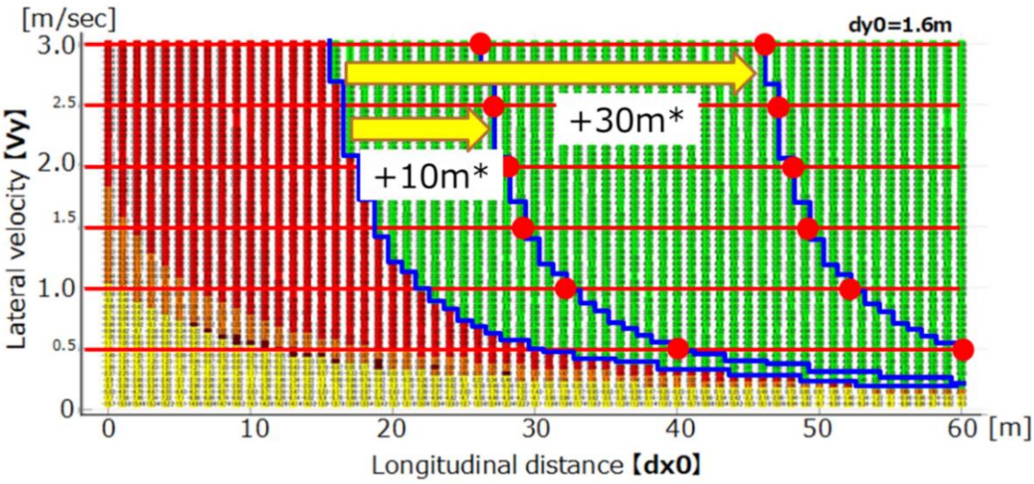
(2) Preventable Territory

Concerning the cut-in and cut-out scenarios, to also confirm that collision will not occur at random points within the preventable territory other than solely near the threshold line of preventable and unpreventable (i.e., to ensure a complete result), confirmation is to be additionally conducted at expanding intervals from the threshold line between unpreventable and preventable (pass/fail criteria) at +10 and +30 m. The reason for selecting “+10 m” and “+30 m” is to ensure that confirmation is not only in a limited number of points close to the center of the preventable range but also points at which the distance between vehicles is large.

Furthermore, the ego vehicle velocity and relative velocity combination cover the full range of combinations possible within the ODD range.

NOTE: Lateral velocity is to be at the increments of 0.5 m/s; if these increments are impossible, conduct based on possible increments.

Example of cut-in: ego vehicle velocity (Ve0) = 60 km/h, other vehicle velocity (Vo0) = 30 km/h.



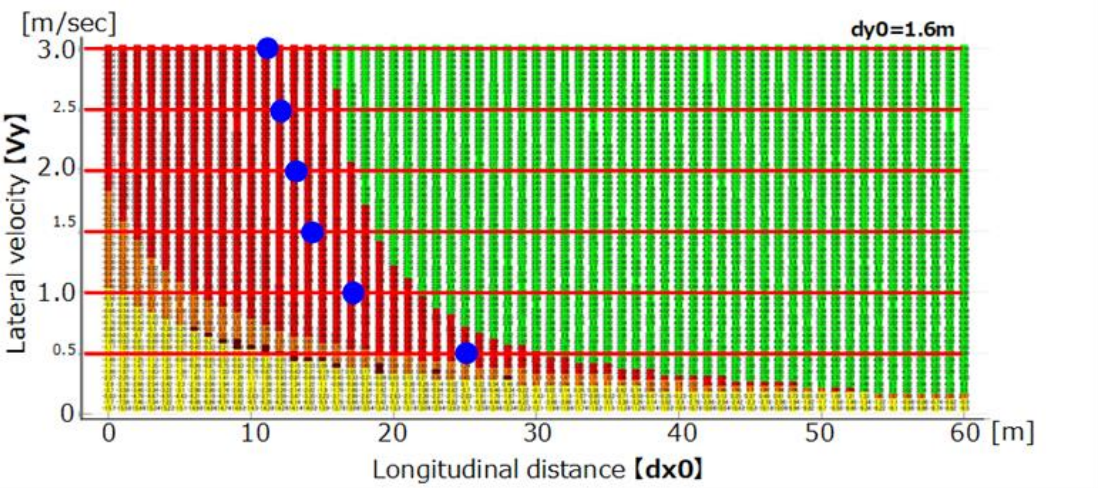
(3) Unpreventable (Collision) Territory

Confirm (for cut-in only) that best effort (=controls for collision avoidance are not stopped) within the unpreventable territory. The points to be used for the distance between vehicles within the unpreventable territory are up to each company's discretion.

Further, the ego vehicle velocity and relative velocity combination is to cover the full range of combinations possible within the ODD range.

NOTE: Lateral velocity is to be at the increments of 0.5 m/s. Avoidance is allowed.

Example of cut-in: ego vehicle velocity (Ve0) = 60 km/h, other vehicle velocity (Vo0) = 30 km/h.



In this example, if considerably distant from the preventable/unpreventable threshold, the higher is the likelihood that side collision or collision before deceleration will occur; thus, the points selected here for the distance between vehicles are, beginning from the threshold line, uniformly shortened at 5 m increments based on the average vehicle length of 5 m.

G.6 Submission Documents

The following documents must be submitted when conducting the compliance test.

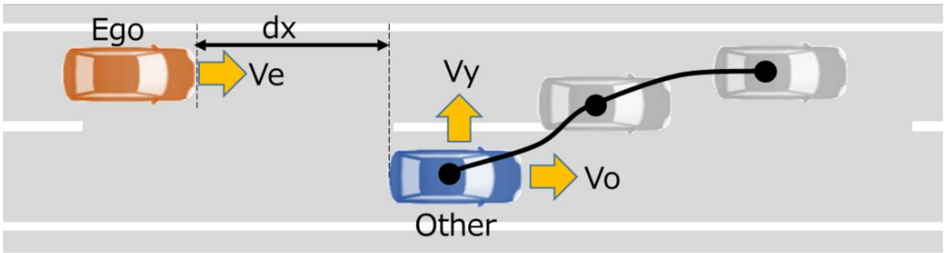
1. Test results confirming the validity of the simulation tool (Chapter G.4)
2. Simulation test and judgment results related to the ADS safety evaluation (Chapter G.5.7)
3. Simulation tools and implementation environment
   Structure of the hardware and software and structure of the simulation test tool and model

NOTE: Detailed information related to the test vehicle is explained under TRIAS 48-J122-01, TRIAS 48-R157-01 Appendix 1 "1. Test Vehicle and Test Conditions."

Attachment 1. Scenario-Specific Parameters of Impact

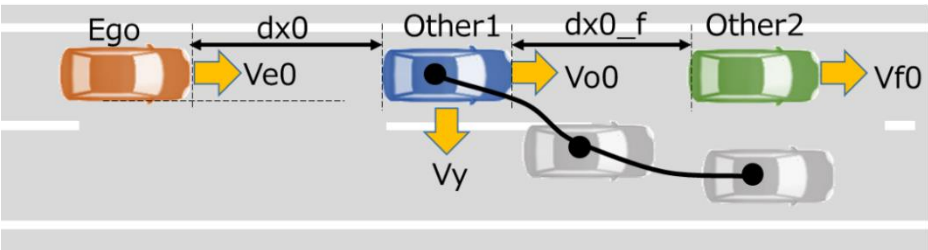
(a) Cut-in Scenario

Parameter	Attribute
Ego vehicle velocity [Ve]	Calculated value
Longitudinal distance between the ego and other vehicles [dx]	Calculated value
Other vehicle lateral velocity [Vy]	Provided value
Other vehicle velocity [Vo]	Provided value



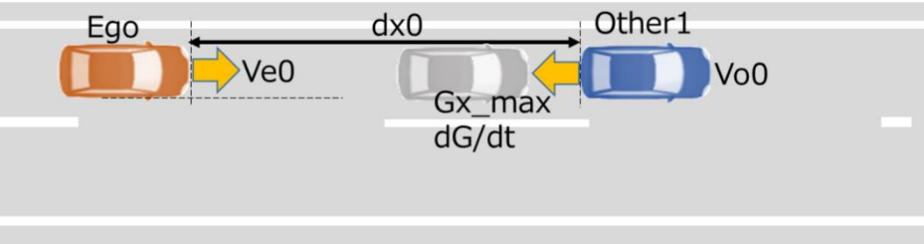
(b) Cut-Out Scenario

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
Other vehicle 1 lateral velocity [Vy]	Provided value
Other vehicle 1 velocity [Vo]	Provided value



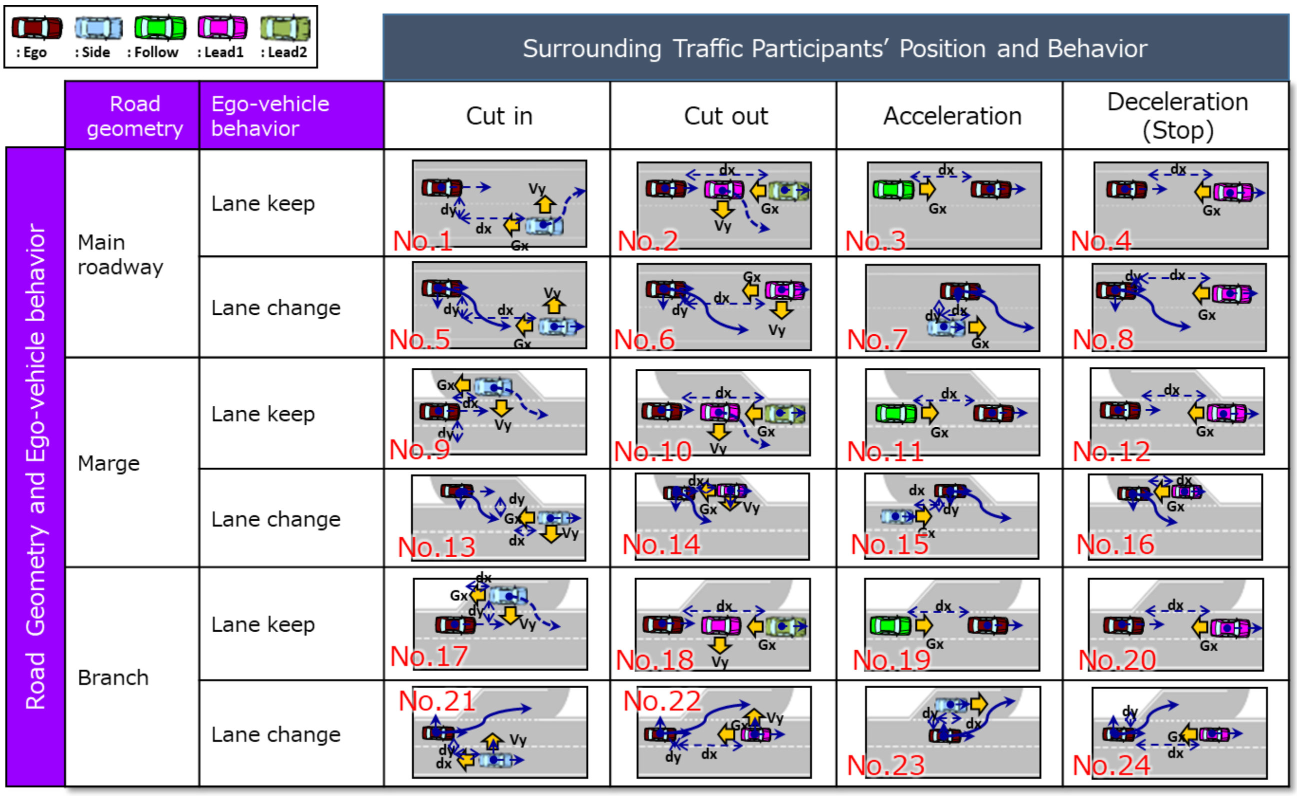
(c) Deceleration Scenario

Parameter	Attribute
Longitudinal distance between the ego and other vehicles [dx]	Calculated value
Ego vehicle velocity [Ve]	Calculated value
Other vehicle deceleration velocity [Gx_max]	Provided value
Other vehicle velocity [Vo]	Provided value



The tool must be equipped with the simulation elements required to calculate and output the above

Attachment 2. Hazardous Scenarios



Attachment 3. Definition of the Behavior of Other Vehicles

This evaluation compares the ADS and preventable and unpreventable criteria when dealing with the behavior of other vehicles that obstruct the ego vehicle. Thus, the behavior of the other vehicles must be applied under the same conditions. The following defines the model and behavior of the other vehicle(s) to align them with the graph as shown in the “5. Reference” of Appendix 3 of UN-R157.

- “Other vehicle(s)” are to be mass models
- Lateral speed for cut-in and cut-out is applied using a step function
- Initial velocity (Vo0) is to be maintained for the longitudinal velocity during cut-in and cut-out
- Deceleration rate in the deceleration scenario is to be applied using the step function (jerk [dG/dt] is ∞)
- The direction of travel (the orientation of the composite vector formed by Vo and Vy) is to be taken as the orientation of the vehicle during cut-in and cut-out