Tier IV

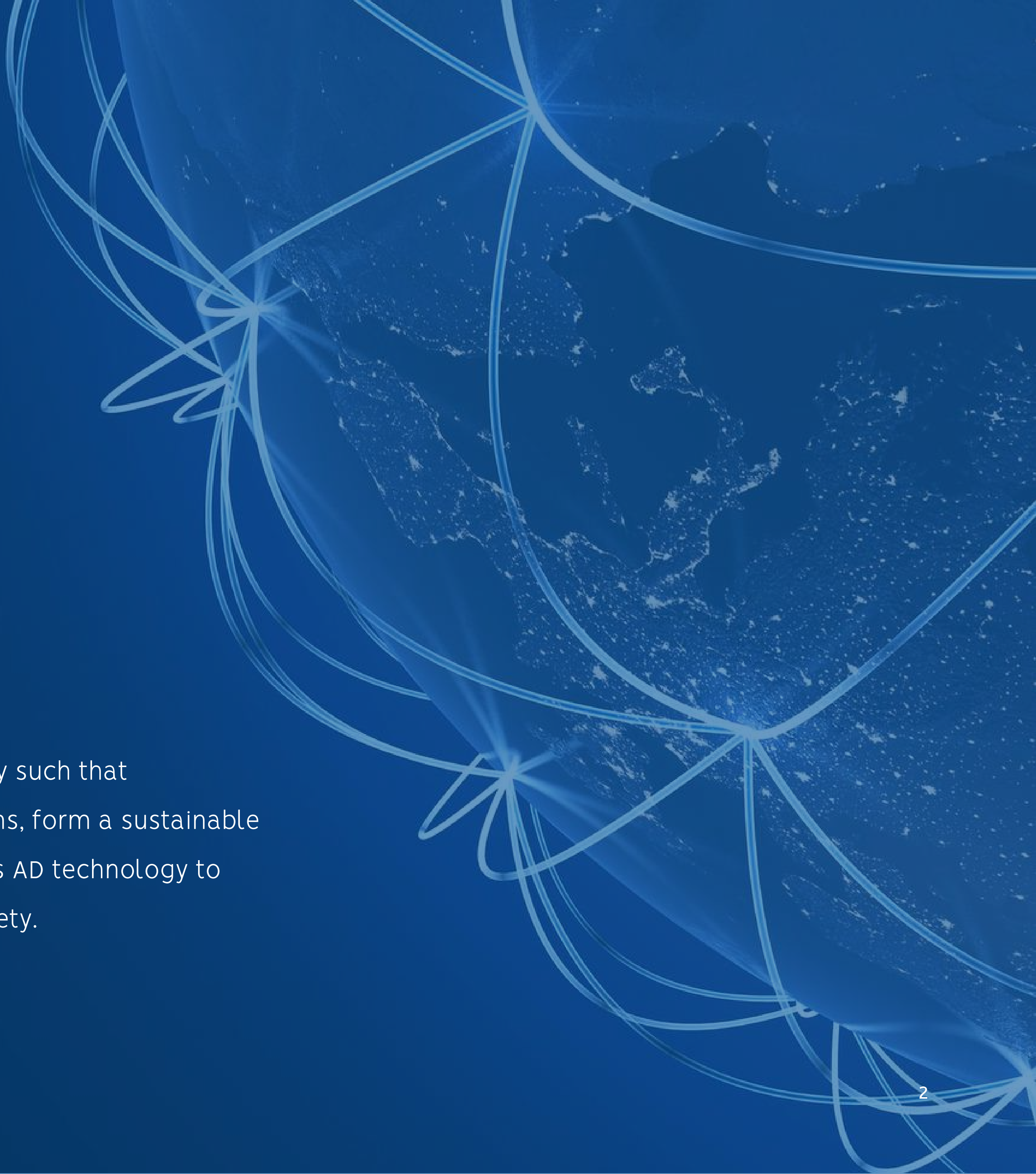
# SAFETY REPORT

2020

# TIER IV'S VISION

— Intelligent Vehicles for Everyone

We provide open access to AD technology such that everyone, from individuals to organizations, form a sustainable ecosystem that contributes to and applies AD technology to Intelligent Vehicles for the benefit of society.



# EXECUTIVE SUMMARY

## Introduction

Tier IV aims to establish the sustainable ecosystem for autonomous driving to which various organizations and individuals can contribute in terms of development, and wherein society can enjoy the benefits. Tier IV offers open access to technologies contributing to autonomous driving. and calls this concept "Intelligent Vehicles for Everyone". The greatest challenge is to ensure a socially acceptable level of safety at reasonable cost.

Autonomous driving requires a composite platform which integrates various software, cloud infrastructure and services in addition to the in-vehicle AD systems. There is a need for a horizontally collaborative development approach based on an open source platform that ensures a level of safety that satisfies society at a reasonable cost. In order to realize this, Tier IV is promoting (1) Autoware*, an open source autonomous driving software, (2) AD System Reference Designs based on ODD categorization, and (3) Deep-tech R&D of AD systems.

*Registered trademark of the Autoware Foundation

## Real-World Road Testing Activities and Approach

In Japan, Tier IV has performed real-world road testing on public roads in about 50 municipalities across 18 prefectures. Outside Japan, Tier IV supports customers and partners in real-world road testing of Autoware installed vehicles.

Real-world road testing is performed with a combination of multiple vehicle and sensor configurations in various driving environments, also known as Operational Design Domains (ODDs). Tier IV classifies these ODDs and provides the corresponding Reference Design, which covers the combination of vehicles and sensors for the service types of each ODD. Tier IV is showcasing its process of conducting the real-world road testing, and in doing so provides methods for risk assessment and incident response by citing applicable cases.

## Future Technology Development

The democratization of autonomous driving technology invites a diverse set of players to participate and share a knowledge base of safety in autonomous driving to a greater degree than any single organization can achieve alone. Tier IV aims to realize this by establishing an ecosystem centered around Autoware, which is the open standard from Japan. Collaborating on the development of Autoware will help industry players enhance safety to levels never realized before.

As Autoware is used by various players worldwide, ODDs from various parts of the world are collected, a common Reference Design is developed, and the edge cases are addressed in an effective manner. This all combines to form the transparent open standard regarding the safety of the autonomous driving system based on Autoware.

Based on extensive experience, Tier IV focuses its technology development direction under the four pillars of: (1) Expansion of the perception scope and the prediction of the motion/intention of moving objects, (2) Estimation of the risk level which is not directly captured by the sensor output, (3) Quantification of the addressable risk levels, and (4) The Fail Safe functionality for the cases where the risk level threshold is exceeded.

## Future Preparation of Enterprise/Societal Environments

As outlined in Japan's national autonomous driving technology roadmap, the timeline will make it is difficult for Tier IV or any other single organization to introduce autonomous driving technology to society while maintaining business sustainability.

As a next step, government consensus is required to address challenges such as the formulation of standards for (1) government approvals and licenses(i.e. simulation based evaluation methods for AD system driving capability), (2) AD system operation (i.e. pragmatic standards for remote monitoring personnel), and (3) ensuring social security (i.e. a basic method of insurance).

# CONTENTS

SECTION 1

# INTRODUCTION

# INTELLIGENT VEHICLES FOR EVERYONE

## How does AD create a better Society?

By enabling a Society...

- without traffic accidents that put those involved in a difficult situation.
- with a smart and efficient mobility system, utilizing cutting-edge IT.
- where AD vehicles coexist with and are indispensable to citizens as an integral part of their lives.

Tier IV, working as an inspired team, is aiming to realize "Intelligent Vehicles for Everyone" in society to create value for humanity from these three perspectives.

## How can we make AD a reality?

The automotive industry has evolved into a hierarchical structure where OEMs at the top level are supported by suppliers designated as Tier 1, Tier 2, etc. AD technology, however, is based on an integrated platform of diverse functionality that extends beyond the autonomous vehicle itself from the view point of hardware, software and usage environment. Therefore, AD system development requires cooperative contribution by multiple players.

The "Intelligent Vehicle (IV)" of Tier IV expresses our aspiration for a revolutionized ecosystem structure enabling access to AD technology for everyone in the industry. In this way, individuals can enjoy the benefits of AD technology while also contributing to its advancement.

To achieve social acceptance of AD, we foremost prioritize ensuring a level of safety that satisfies society at a reasonable cost. Tier IV will continue to advance cutting-edge AD technology and safety features.

## The Need for Autonomous Driving

The realization of AD can solve the following transportation issues.

## Social Issues that can be solved with AD*

### Worldwide Issues

- Many victims of traffic accidents
- Time wasted due to traffic congestion
- Many disabled people cannot travel

### Issues in Japan

- Limitation of Public Transportation
  - Shortage/aging of drivers
  - Bad financial situation
- Insufficient Mobility for Elderly
  - More elderly individuals are going out
  - Eldery individuals mainly use cars for mobility
  - Increase of fatal accidents caused by elderly drivers

*See appendix

## Intelligent Vehicle for Everyone

Tier IV's approach to realize autonomous driving consists of three core elements.

### 1. Development and Alliance of AD Software "Autoware"

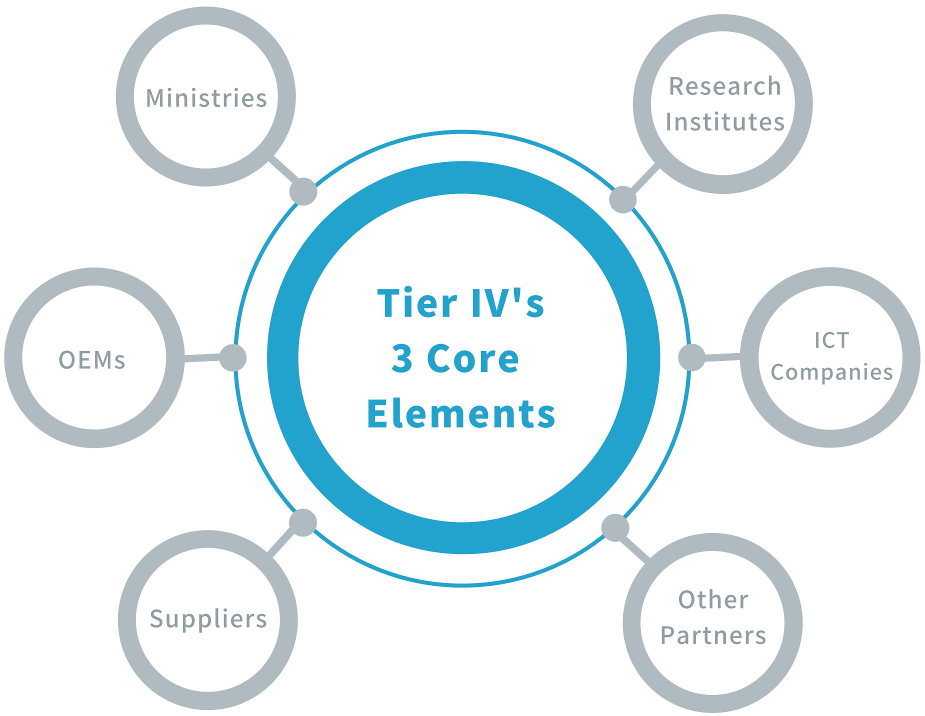
Autoware's code is open source and anyone can participate in its development. The collaboration of Autoware and the Autoware Foundation constitutes a system in which organizations and individuals around the world can get involved.

### 2. ODD Classification and Reference Design Provisioning

With clear ODD classifications, everyone can understand where AD fits into complex real-world traffic environments. Furthermore, by presenting a suitable "Reference Design" for each ODD, Tier IV simplifies the preparation process in AD and lowers the difficulty threshold for demonstration and implementation.

### 3. R&D as a Deep-tech Company

Deep-tech is cutting edge technology enabled by significant financial and time investment with the goal of positively impacting society. As an academic startup and the creator of Autoware, Tier IV aims to advance deep-tech R&D for AD technology development in the industry.



# AUTOWARE – Architecture and Features

In general, AD software performs perception (localization and surrounding environment recognition), prediction, planning (path-planning and path-following) and final vehicle control (steering angles and brake/accelerator pedal usage). This process uses sensing information from common sensors such as LiDAR, cameras, GNSS, IMU, etc. In AD levels 1 and 2, the human driver and the AD software work together to operate the vehicle; at level 3 and above, the AD software basically replaces the human driver.

Autoware is aligned with these principles and Tier IV breaks down the functionality of Autoware into six parts. Details can be found on the Autoware GitHub page*.

*https://github.com/tier4/AutowareArchitectureProposal

## Autoware's Features

### Sensing
Collect information from external (LiDAR, cameras, GNSS, etc.) and internal sensors (IMU, etc.).

### Localization
Localize the vehicle and sensor information within a high resolution 3D map obtained in advance.

### Perception
Detect objects, track them in time series and predict motion of moving objects.

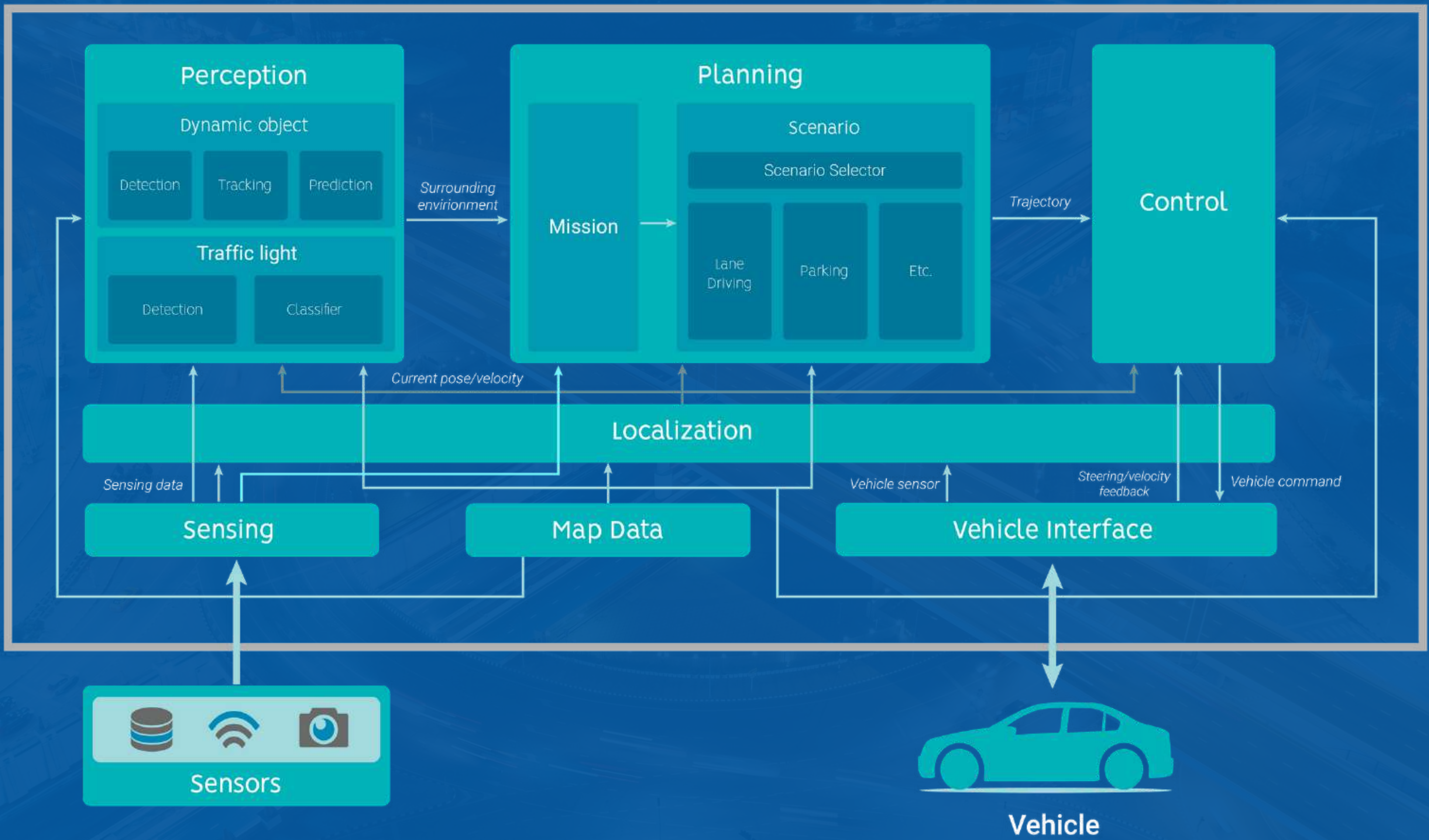
### Planning
Calculate path including the avoidance of obstacles and parking maneuvers.

### Control
Generate control signals for the vehicle to follow the planned path.

### Vehicle Interface
Convert the control signals into commands according to various vehicle characteristics.

### Map Data
Utilize high-precision 3D mapping with environmental data

# Autoware's Component Architecture



# Autoware as a Platform
# – Open, Agile and Scalable

Autoware is free open-source software specialized for AD. It can be used by anyone for any vehicle type, with the aim of increasing the penetration of AD into society. More than 200 companies in over 10 countries have already started using Autoware.

Tier IV aims to realize its vision through the use of vehicles with a variety of application/usage covering a wide range of possible ODDs. To achieve this goal, Tier IV continues to develop Autoware with openness and expandability in mind, and implements real-world road testing by designing systems corresponding to different types of environments.

# Autoware as a Foundation
# – For Everyone

The Autoware Foundation, an international organization of 44* leading companies in the industry, aims to promote the development of Autoware. The development community platform, Discourse*, advances open discussions on Autoware and drives progress on a daily basis. For example, Discourse collaboration facilitates the knowledge accumulation of new functions/algorithms and the promotion of compatibility with new devices. Even developers without an autonomous vehicle can use Autoware and run simulations with real data on their own computer. The provisioning of such data is enabled by Autoware's developers accumulating and sharing data from real-world road testing, and opening parts of it to the public. Through such collaboration Autoware contributes to the global development of AD independent of vehicle type and region.

*As of May 2020

*https://discourse.ros.org/c/autoware/


SECTION 2

# REAL-WORLD ROAD TESTING ACTIVITIES AND APPROACH

# REAL-WORLD ROAD TESTING ACTIVITIES

## Tier IV promotes real-world road testing in Japan and across the world to realize Intelligent Vehicles for Everyone

Tier IV has completed real world road testing on public roads in about 50 municipalities across 18 prefectures in Japan. It has achieved more than 70 ODD cases, and is in Japan's top tier of AD technology leadership.

Tier IV is expanding its presence worldwide, particularly in Asia and North America. In the United States, the "Intelligent Vehicles for Everyone" concept with open-source software has come to be widely accepted and proof-of-concept testing with Autoware-equipped vehicles has begun.

Tier IV continues real-world road testing across the world and is contributing to the expansion of safe and secure AD, backed by knowledge collected through real life testing experience

Major real-world road testing activities in Japan

# Major Activities Worldwide

## Estonia

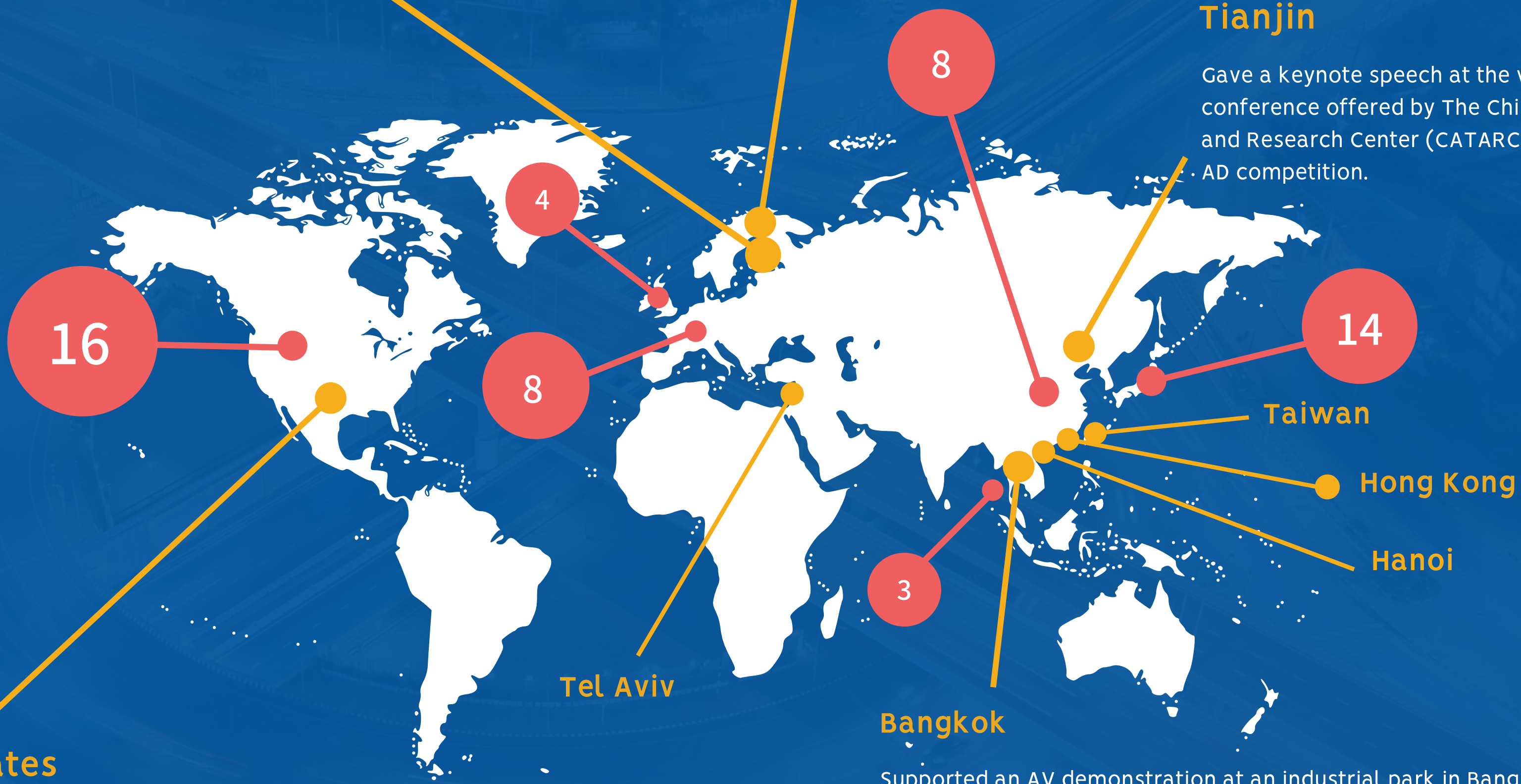
At Tallin University of Technologies, 18 professors and students created their own autonomous vehicles in a short period of time. Autoware contributed to their work

## Sweden

NEVS has launched a pilot of the PONS mobility service using Autoware enabled shuttles.

## Tianjin

Gave a keynote speech at the world-renowned AD conference offered by The China Automotive Technology and Research Center (CATARC). Completed the course in an AD competition.




## United States

The US Department of Transportation's Federal Highway Administration adopted Autoware as the AD platform for its CARMA traffic system and implemented driving tests with Autoware based vehicles.

## Bangkok

Supported an AV demonstration at an industrial park in Bangkok in an ASEAN event. Implemented trial rides for senior government officials and ministers

● ··············· No. of AWF members (as of July 2020)

# ODD CLASSIFICATION AND REFERENCE DESIGN

## ODD classification for AD diffusion

ODD classification and specification is a precondition for the AD system to work safely. Safety is ensured because the AD technology is applied only to specific ODDs with well understood requirements and specifications.

Conditions defined by ODDs depend on the road environment, such as vehicles, pedestrians, route complexity and road regulations. Tier IV classifies the ODD according to the technical complexity as shown in the table below, which also takes player type and business model into consideration.

Tier IV implements a wide variety of real-world road testing within each ODD classification. We are continuously improving the way ODDs are classified so that AD is introduced into society in a safe manner.

## ODD 1

Slow speed use cases supported by short range and minimal sensing. No other vehicles or pedestrians.

### AD dedicated envirionment

Activities

- Test driving
- AD in research institutes

## ODD 2

Use cases supported by short range sensing. All vehicles are slow.

### Logistics roads inside factories

Activitites

- Component transportation within Yamaha's manufacturing plant* (cart)

### Cyclic routes inside facilities

Activitites

- A loop line bus in Moricoro Park (small-sized EV)
- Facility to facility automated transportation in Shimizu-Kensetsu's factory  (small-sized EV)
- A loop line bus at the Olympic Village (bus)

*Implemented as eve autonomy, a joint venture with Yamaha Motor

## Reference Design

Autoware requires connection to various components, data and networks. For example, it is necessary to establish connection to in-vehicle hardware components, external data such as 3D maps, and software offered by service providers. It also needs to coordinate with road environment regulations.

To secure all necessary connections and ensure AD safety, every Reference Design must consider the peripheral components and networks.

Rooted in our vision of Democratizing AD, Tier IV creates an Autoware based Reference Design including state of the art AD software algorithms, and does so with close collaboration with partners in the Autoware Foundation.

# ODD 3

Use cases supported by long range sensing.
Vehicles are mid to high speed.

### Cyclic routes in suburban areas

Activities

- Public roads in Sakado-shi, Saitama (bus)
- Local roads  in Tokyo coastal area (passenger car)

### Mountain areas

Activities

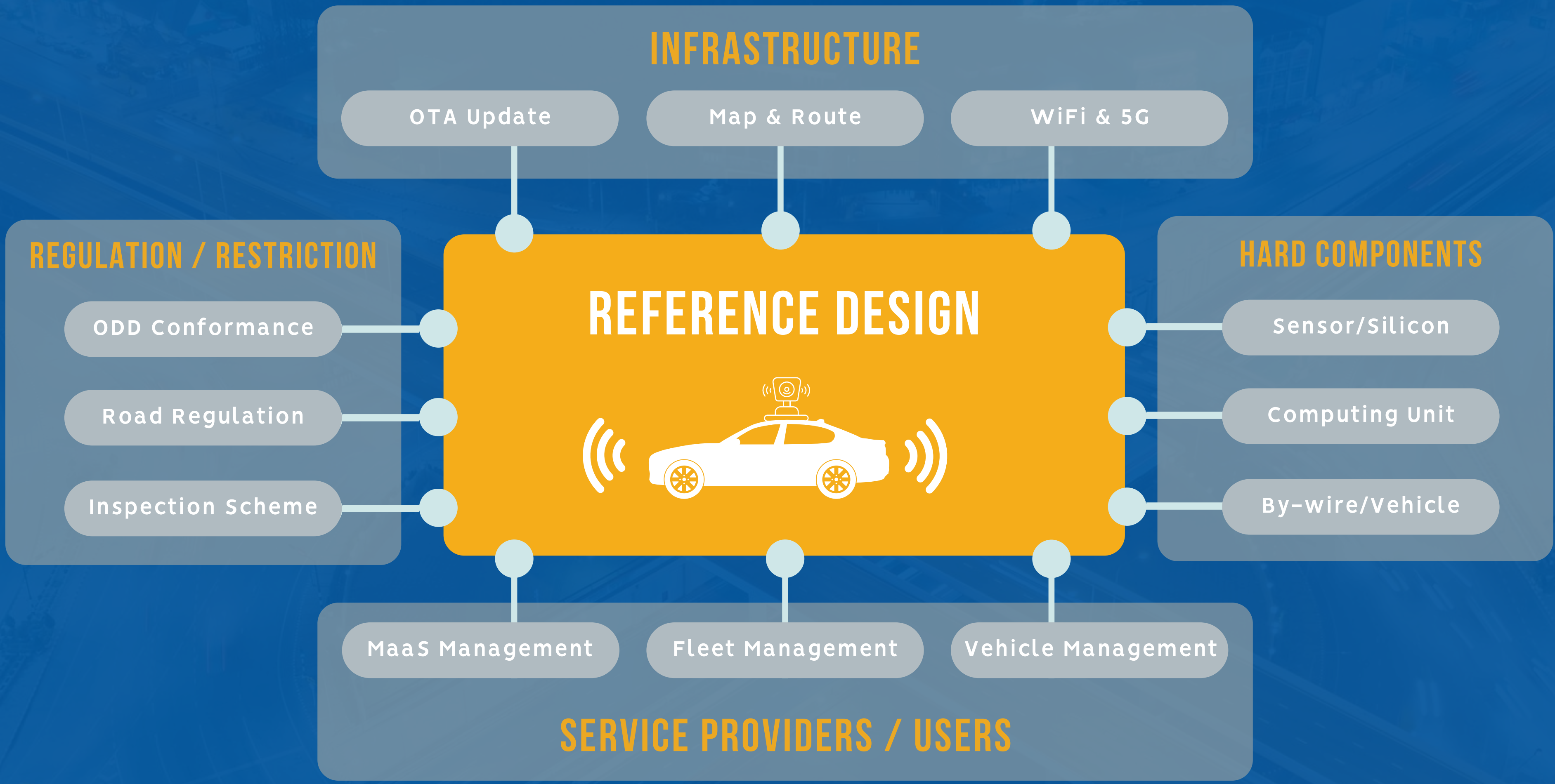
- One-mile transportation in mountain areas such as Ube-shi, Yamaguchi (passenger car)
- Regional transportation at Tobishima-mura, Aichi (passenger car)
- Tourism-oriented MaaS in Himaka-jima (bus)

### Urban areas

Activities

- Shinjuku city area (passenger car)

## Reference Design ensures AD safeness



## ODD Optimized Reference Designs

Tier IV seeks to achieve the optimal sensor configuration in vehicles for each ODD classification. With the optimal configuration, we can ensure safety at reasonable cost in various real-world driving environments.

The actual design is based on the diverse set of detailed ODD specifications and the intended transportation use case so that everyone can easily conduct real-world road testing for AD.

## Reference Design for each ODDs

| | Sensor configuration | Number of LiDARs* | Number of cameras* |
|---|---|---|---|
| ODD 1 | Minimum system configuration required for AD | 1+ | 1+ |
| ODD 2 | Configuration for environments with slow and irregular moving objects which need mid range detection | 6+ | 6+ |
| ODD 3 | Configuration for environments with uncontrollable pedestrians, bicycles and fast-moving vehicles which need short to long range detection. | 6+ | 12+ |

*See appendix

# FIELD TEST PREPARATION AND INCIDENT ASSESSMENT

## Field Test Preparation

To ensure safety, Tier IV conducts extensive evaluation processes before implementing real-world road testing.

### 1. Simulation

Validate safety by driving along the planned route in virtual space.

### 2. Closed space test

Perform real-world vehicle driving tests on a dedicated road to check vehicle functions and safety, as well as to conduct safety driver training.

### 3. Driving course risk assessment

Identify potentially hazardous events in advance, and consider countermeasures that ensure safety.

### 4. Test review

A risk management committee reviews the real-world test plans and authorizes testing to take place.

### 5. Manual/adjustment driving of test course

Manually pre-drive the course to confirm sufficient safety conditions and driver aptitude in order to finalize AD system parameters. Furthermore, pre-drive with adjusting the system parameters.

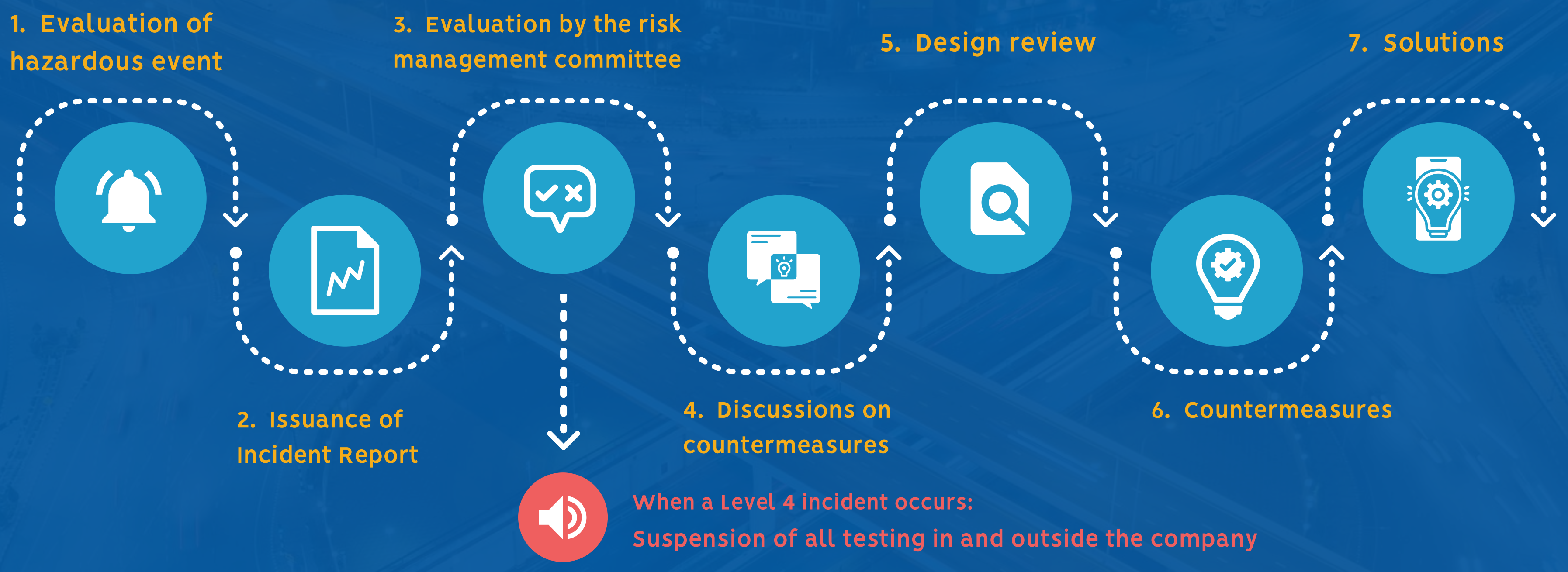
### 6. Execution

Implement the real-world driving test depending on weather and course conditions.

# Incident Assessment Procedure

Tier IV's safety evaluation process is characterized by risk management at the occurrence of an "incident". Although incidents in general are defined as accidents, Tier IV's definition of an incident is more stringent, and includes the events potentially leading to accidents. As soon as an incident is observed, Tier IV assesses the validity of countermeasures and solutions, as well as the suspension of the real-world road testing.

Based on extensive experience, designers or implementors issue an incident report to the risk management committee when an event defined as an incident is observed. Software/hardware engineers, safety specialists and implementers, as a team, evaluate the risk against four levels. If the highest risk level (Level 4) is observed, all internal and real-world testing activities are suspended.




Tier IV then discusses countermeasures to secure the necessary level of safety. Designers discuss solutions for fundamental revisions to the system implementation and/or configuration. Tier IV removes the suspension on testing once a design review, conducted by designers and the risk management committee, confirms that safety is ensured by the countermeasures. Ultimately, Tier IV takes steps to implement and execute the identified solutions.

Through a thorough process for incident risk management, Tier IV has established and maintained the highest level of safety during real-world road testing.

# Remote monitoring operation

The Japanese government understands the necessity for AD and is supporting its realization, but it will take some time to fully address the legal aspects due to dependencies with international AD frameworks. As a temporary step, ministries have published guidelines related to AD and are conducting real road driving tests under the interpretation of the current law.

In parallel with the internal safety verification process, Tier IV is working together with the Ministry of Land, and the Police department on vehicle safety standards and road usage permissions respectively as follows.

## Collaboration with the MInistry of Land

– Regarding the road transport vehicle law

1. Mount the vehicle with sensors and controllindevices needed for AD [16]
2. Mount the vehicle with a controlling device, communications device, and sensors (cameras) for remote monitoring
3. Prior consulting with the Ministry of Land regarding the easing of safety standards
4. Acquire the certification to ease of safety standards
5. Confirm the AD drivable route
6. Select the real world driving test course

## Collaboration with the Police department

– regarding the road traffic law

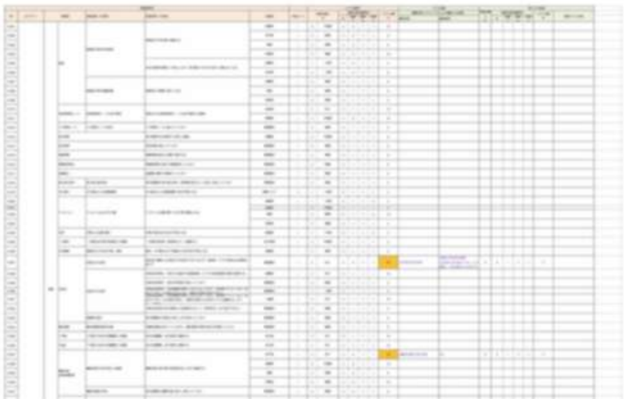
1. Draft a test plan and consult with the police agency [17]
2. Police department cooperates with the prefectural police
3. Apply to local police for road permission
4. Verity brake performance during remote operation inside closed space
5. Verification by police officer on whether or not it is safe to do testing [18]
6. Prior explanation to surrounding neighbor residents
7. Start real road testing

Since AD technology is still in the developing phase, accidents can lead to a loss of trust by society. Therefore, Tier IV cooperates with ministries in prior to conducting any testing and verifies safety and legal compliance.

# DRIVE ROUTE RISK ASSESSMENT

## Collaboration with Sompo Japan Insurance to establish driving route risk assessment methods

Drive route risk assessment methods are yet to be established around the world. Tier IV is collaborating with Sompo Japan Insurance Inc, who has extensive experience regarding traffic accidents. In this process, Through this process, we are establishing and applying practical risk assessment methodologies to ensure drive course safety as outlined in the following steps.



Rist assessment sheet by Sompo Japan

### 1. Assess test conditions

Study experimental conditions to ascertain potential for hazardous events

e.g. Testing period, time, objectives, driving route, driving road type (general road, freeway, etc.), presence of test drivers/operators, presence of passengers

### 2. Understand potential hazardous events

Potential hazardous events are assessed thoroughly by evaluating elements such as driving conditions, test drivers/operators, persons/goods to be transported as well as overall test operations management.

e.g. Left-turn accident involving bicycles and motorcycles, pedestrians rushing-out in front of vehicle, collision with an emergency vehicle

### 3. Evaluate risk-level

Risks are evaluated from two angles - hazard level (damage level, impact on business plan, etc.) and occurrence level (exposure frequency, probability of occurrence, risk avoidance).

## 4. Establish risk reduction measures

Countermeasures are studied and designed to reduce hazardous event risks.

e.g. Introduction of escort vehicle (front/rear), driver/operator intervention when hazardous events are observed, preparation of response manuals

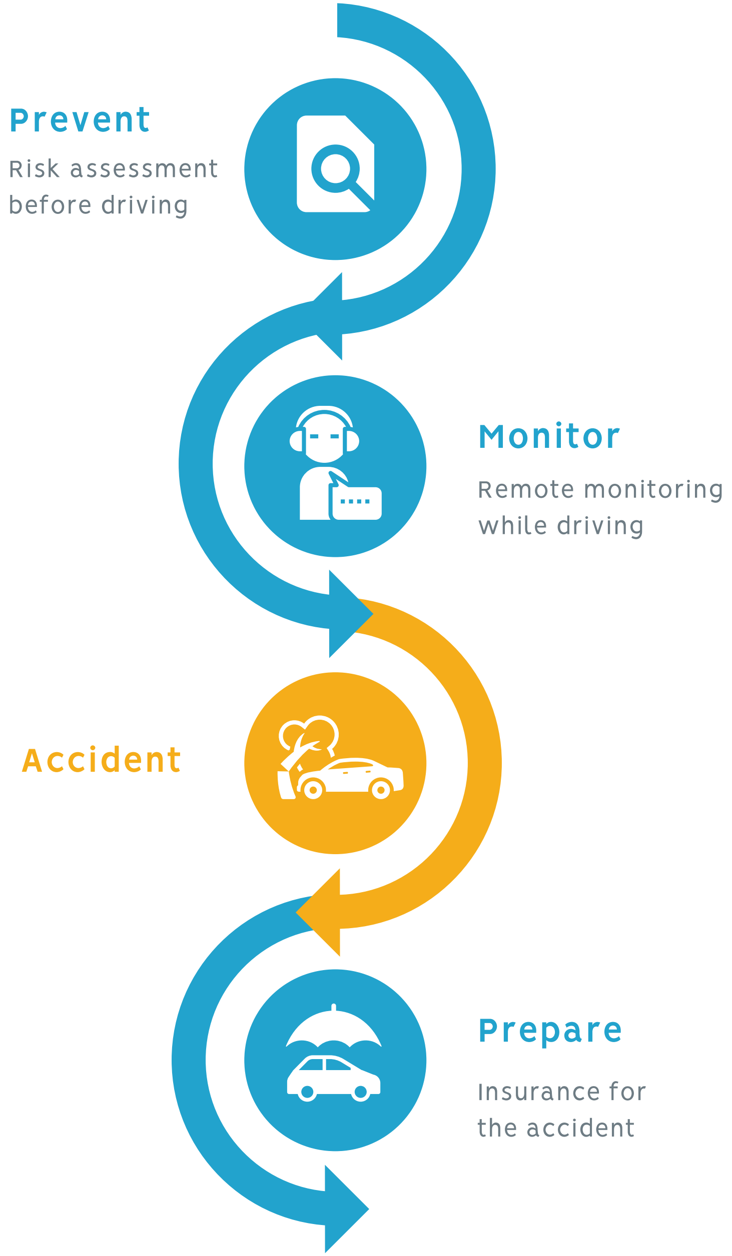
## 5. Reevaluate risk levels and measures against remaining risks

To reevaluate the risk of hazardous events after risk reduction measures have been applied, and if the risk remains at a high level, to establish additional measures to address.

# Level IV Discovery

To make safe AD widely available, it is necessary to "monitor" driving and "prepare" for accidents, as well as "prevent" accidents through prior risk assessment.

Tier IV, Sompo Japan Insurance and Aisan Technology have established "Level IV Discovery"* as a solution to this problem. To achieve AD acceptance throughout society, the solution is a risk management platform supporting AD safety and security. This platform covers risk assessment, remote monitoring and insurance as shown in the right.




*Level IV Discovery official website (Japanese): https://level4-discovery.org/

# INSIGHTS FROM THE RISK MANAGEMENT COMMITTEE

## Case: Setting the maximum driving speed

The initial test plan for an ODD 1 use case set the vehicles maximum running speed to 20 km/h. However, considering the relative speed to other vehicles and topographic factors leading to manual/adjustment driving in the real-world road testing course, it was considered to increase the set speed and re-evaluate the test examination to ensure safety.

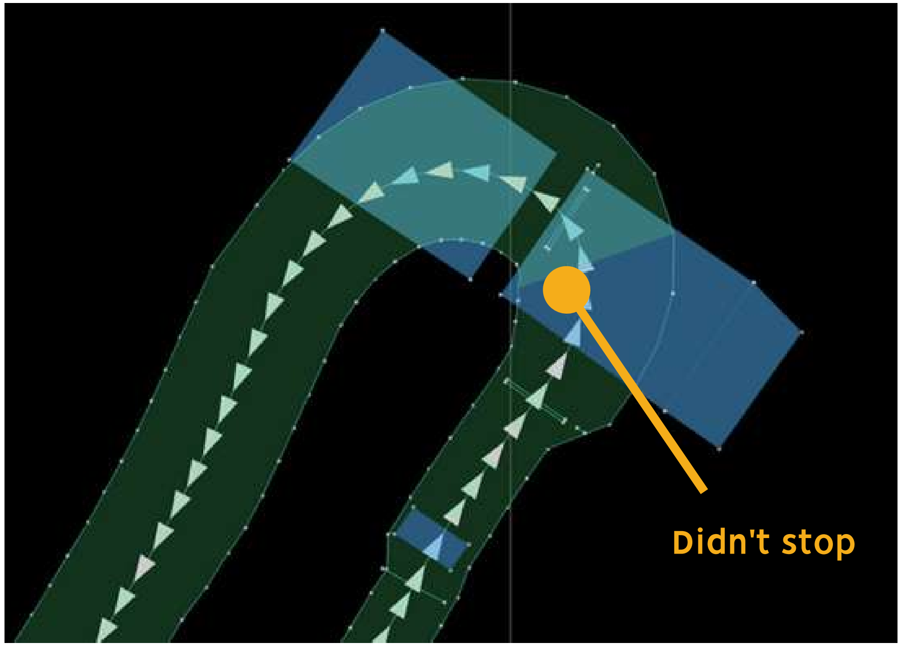
### Judgement and Response

The road-use permission standard relating to the real-world road testing states "to ensure safety and promote traffic smoothness according to road/traffic conditions", as well as to drive at "a speed not exceeding 20 km/h is assumed in principle, for the time being."

It was judged that driving at 20 km/h was too slow due to topographic factors and the relative speed with other vehicles, and that the maximum driving speed should be 30km/h so that the test vehicle could safely merge with the traffic flow. The test plan was changed and the test examination was conducted again.

## Case 1： Stop order error in high-precision 3D map

An order to stop at a dangerous place was embedded on a high-precision 3D map. However, it was found that this stop instruction was not obeyed during manual/adjustment driving in the real-world road testing course.




### Judgement and Response

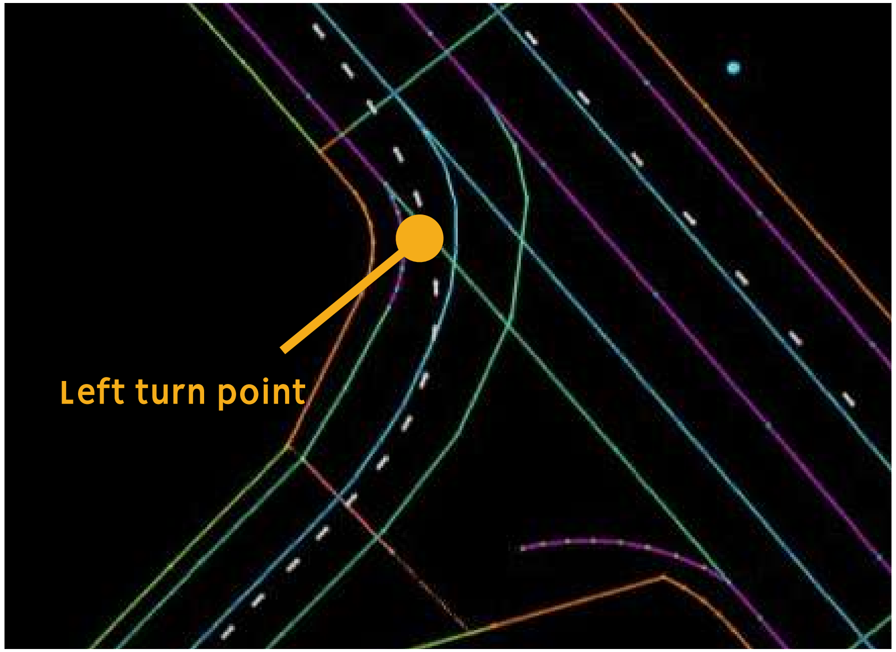
The fact that the high-precision 3D map order did not work is considered a serious incident. The verification test was suspended until the cause was identified and countermeasures were taken.

### Problem and solution

Although the stop order was confirmed on the high-precision 3D map, it was found that the stop order overlapped with other information on the user interface of the creation tool and was linked as another instruction due to this overlap. As a result, the stop order was not activated. As a permanent countermeasure, the user interface of the tool has been improved so that a warning will be issued if the stop order is not activated.

## Case 2：Minor collision with a road-related object during the real-world road testing

The incident occurred during the adjustment driving on the route running phase of the real-world road testing. The autonomous vehicle lightly collided with a road-related object when it turned left on the public road




### Judgement and Response

Real-world road testing was immediately suspended, and local authorities were notified. We then analyzed causes of the incident to discuss countermeasures for recurrence prevention.

After having reported on the incident as well as the implemented countermeasures, responsible parties gave permission to continue real-world road testing. The delay in the reporting process to the stakeholders brought to light the communication issues related to incident occurrence that had to be solved.

### Problem and solution

Emergency contact information was not placed in an appropriate position leading to the delayed notification of the incident by the driver. Also, the process of contacting the relevant parties took longer than expected.

Emergency contact information was repositioned where the driver can immediately see it and the contact procedures were changed to be more realistic and effective with immediate effect.

SECTION 3

# FUTURE TECHNOLOGY DEVELOPMENT

# ACHIEVING AD SYSTEM SAFETY THROUGH AN OPEN STANDARD

## Tier IV targets International standards for System Safety

Autonomous vehicles have significantly higher system complexity compared to traditional vehicles. The AD system of an autonomous vehicle must respond to the vehicle's operational environment, coordinate with external service platforms, and enhance capabilities via software update just to name a few examples which drive system complexity. This AD system complexity leads to a significant time and financial investment making development by individual industry players slow and difficult.

Ensuring the safety of an AD system across many operational environments and the issues observed is inefficient, let alone challenging, for an individual company. Industry players, as a community, must gather their knowledge of AD system safety. Open standards are required to advance collaborative development amongst the various specialized players in the AD ecosystem. Tier IV aims to achieve System Safety by enabling an ecosystem centered around Autoware, an AD OSS originating from Japan.  Autoware enables system safety based on international standards*.

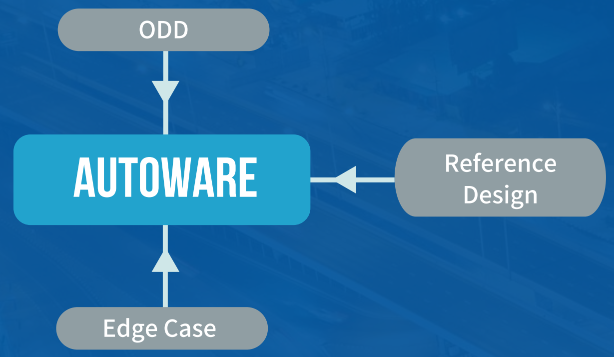
*ISO 21448、ISO26262、ISO21434、UL4600, etc.

## Components of system safety

\+ ··············· Can be covered
++ ··············· Main scope

| Design level | Target | Risk assessment | Use case analysis | Safety analysis | Simulation analysis | Real life testing |
|---|---|---|---|---|---|---|
| Service level | System coordination/remote monitoring/vehicle allocation | ++ | ++ | ++ | + | ++ |
| Vehicle level | Vehicle/surrounding environment | + | + | ++ | ++ | ++ |
| System level | Software/Hardware | | | ++ | ++ | + |
| Component level | Software/Hardware | | | ++ | ++ | + |

# Reinforce safety and lower cost with an Autoware centric ecosystem




- Add features
- Identify risk probability
- Discuss risk measures

### Knowledge accumulation from various users

### Safety verification by companies

1. Secure safety for features lacking in OSS
2. Add safety features lacking in ODD
3. Secure safety related to service expansion

### Share as an Open standard

### Social implementation

### Social reception

# TECHNICAL ISSUES OBSERVED IN REAL-WORLD ROAD TESTING

### Issue 1: Lack of ODD parameter coverage

Various real-world road tests conducted across Japan found a significantly complex driving environment for each route. It is therefore essential to assess real life driving environments on a case-by-case basis and to repeat cycles of elaboration and improvement of the ODD parameters and settings. Each cycle includes, but is not limited to, the process of simulation, driving course risk assessment and real-world road testing.

p32 Technology development 1:

**ODD Classification and Refinement**

### Issue 2: Inefficiency in development due to lack of road testing classification

Tier IV has performed real-world road-testing across diverse vehicle types and applications. However, evaluation of vehicle and sensor configurations is difficult to scale as it has to be done on a case-by-case basis. Together we need to combine and convert obtained system design knowledge from all real-world road testing into an open knowledge base. With this open knowledge base, industry players can accelerate the development and commercialization of AD.

p34 Technology development 1:

**Expansion of Reference Design**

### Issue 3: Need for enhanced Autoware functions

Real-world road testing shows that it is essential to further enhance the features and functionality of Autoware. For example, continuous improvement of perception and prediction AI accuracy for localization and detection of objects, as well as enhanced "Fail Safe" procedures to avoid accidents in the case of deviations from ODDs or unexpected errors.

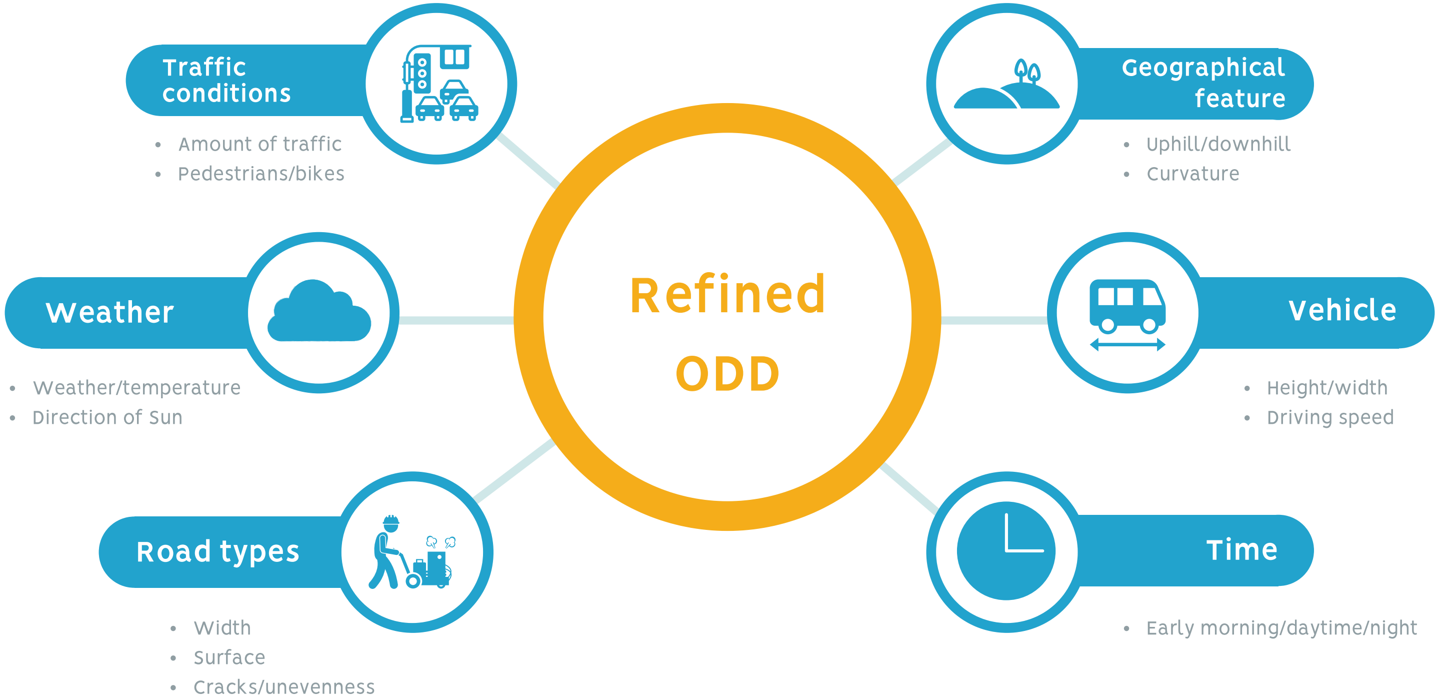
p34 Technology development 3:

**Advancement of Autoware**

# Technology development 1: ODD Classification and Refinement

Tier IV has classified ODDs according to both operational business models and driving environment technical requirements. These ODD classifications correspond to those defined in "Panel on Business Strategies for Automated Driving"[13]. Classification of ODDs is essential to develop optimized Reference Designs addressing ODD requirements and form an open knowledge base from real-world road-testing in each ODD.

AD System settings for individual ODDs include various elements such as traffic conditions, road conditions, vehicles, climate, geographic characteristics, time, etc. To improve safety, Tier IV continually breaks down system parameters and learns from real-world testing, assessing each incident occurrence in detail. In doing so, we continuously improve hardware and software functionality to cover an increasing range of ODDs.




* Panel on Business Strategies for Automated Driving: Created by the Ministry of Economy, Trade and Industry (Director-General of the Manufacturing Industries Bureau) and the Ministry of Land, Infrastructure, Transport and Tourism (Director-General of the Road Transport Bureau) in February 2015. This "industry-academia-government" panel discusses problems and actions so that the Japanese industry can become the leader of promoting AD and contributing to solve societal problems such as traffic accidents.

## Correspondence with ODD classification by the government

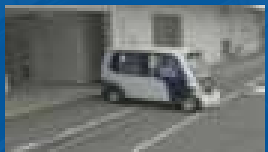
| Classification by Tier IV (technology and feature) | |
|---|---|
| ODD 1 | Use cases supported by short range and minimal sensing. Slow speed with no other vehicles or pedestrians. |
| ODD 2 | Use cases supported by short range sensing. Vehicles are slow speed. |
| ODD 3 | Use cases supported by long range sensing. Vehicles are mid to high speed. |

| Classification by government (restriction and environment) |
|---|
| Closed space |
| Restricted space |
| Driving only space |
| Traffic environment maintenance space |
| Mixed space |

## Classification by government

### Closed spaces

- Factories
- Airport

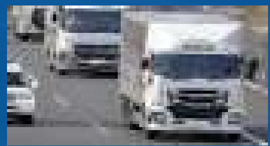


### Restricted spaces

- Abandoned road
- Bus Rapid Transit (BRT)

### Driving only spaces

- Freeway

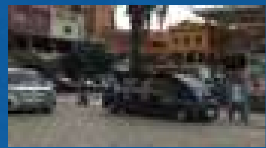


### Traffic environment maintenance spaces

- Highway

### Mixed spaces

- Community roads



## Technology development 2:
## Expansion of the AD System Reference Design

The broad adoption of Autoware is accelerating through optimized Reference Designs for vehicles suitable for operation in any place and application. Tier IV aims to expand ODD coverage across common transportation usages and further accumulate the experience and knowledge acquired from real-world drive-testing and service operation.

Tier IV expands the scope of the AD System Reference Design based on the experience accumulated across ODDs. The AD System Reference Design is specified and optimized against combinations of ODDs and vehicle applications. In addition, Tier IV seeks opportunities to openly share knowledge with other industry players.

## Technology Development 3:
## Advancement of Autoware

### Improving the accuracy of "perception/prediction" and "planning" functionality

"Perception/prediction" and "planning" are playing an important role in the quality of the overall AD functionality. In this context, accuracy improvement requires advanced AI research, and as there is a shortage of AI researchers in the industry, collaboration with academia is indispensable. AD system development requires collaboration amongst specialists in areas such AI, software engineering and automotive engineering. Tier IV improves the accuracy of "perception/prediction" and "planning" based on a multidisciplinary effort spanning business and academia.

### Reinforcing Fail Safe functionality

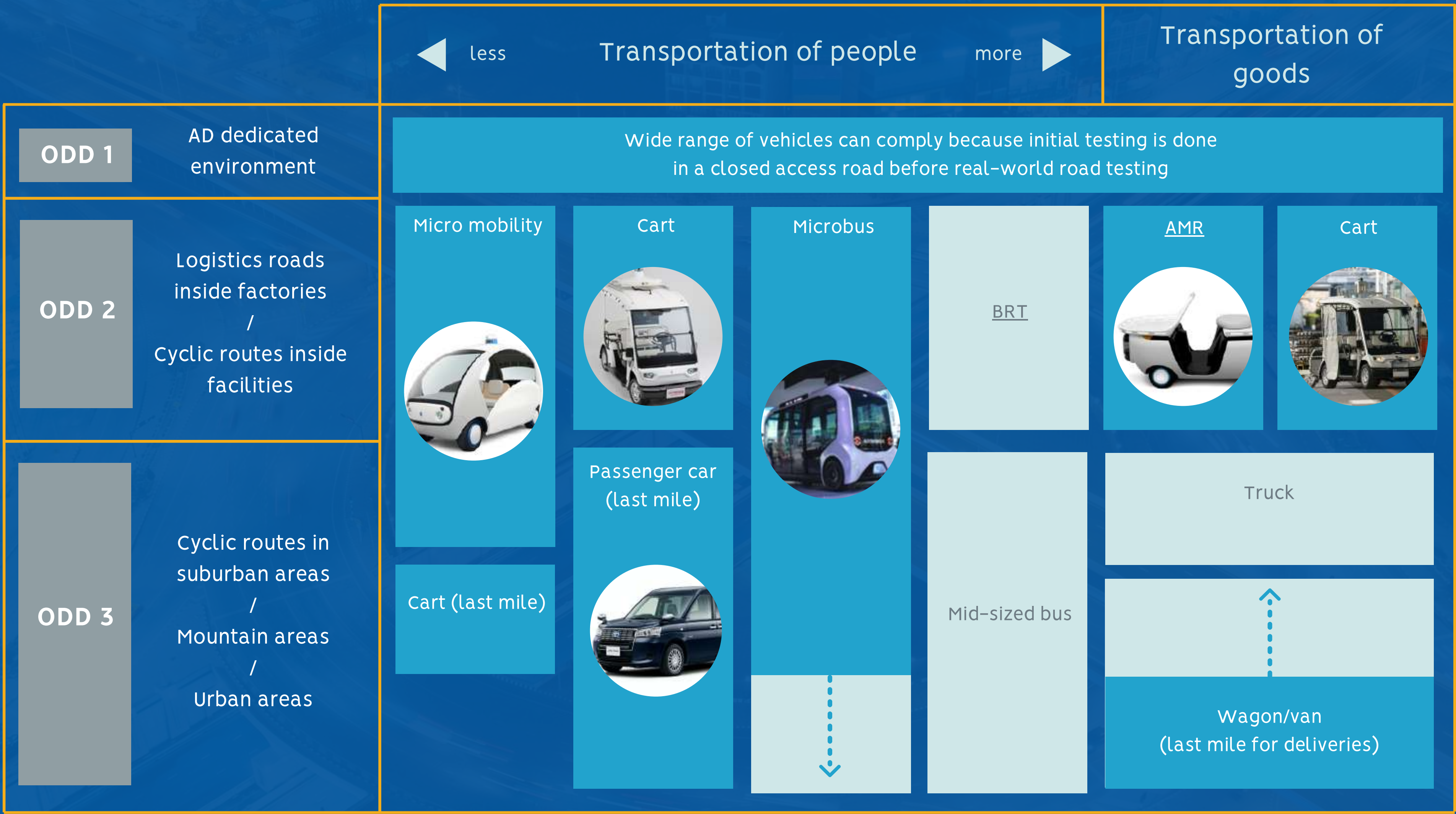
It is necessary to expand Autoware functions that notify of hazards at the time of system error occurrence. Moreover, it is required to set "Fail Safe" functions in advance to address known hazardous events.

Tier IV can partially check whether such functions work across various ODDs through simulation. The database from the PEGASUS Project, which was run in Germany from 2016 to 2019, can be utilized to examine the functions applied to general use cases. The SAKURA Project, a similar project which began in Japan during 2018, can be utilized to address use cases applicable to the road environment in Japan.

In addition, in order to comply with situations such as ODD deviation and other unexpected hazardous events, low probability hazard events must be translated into use cases, including those events that cannot be realized via simulation.

*PEGASUS Project： A project aimed to define the safety evaluation methods suitable for German OEMs. The project is based on a public-private partnership and established by 17 organizations including BMW, Daimler, Audi, and Bosch.
https://www.pegasusprojekt.de/en/about-PEGASUS
*SAKURA Project： Project aimed to develop the safety evaluation methods for AD suitable for Japan. It is based on a public-private partnership and promoted in collaboration with overseas projects including the PEGASUS project.

# Expanding Reference Design and ODDs classification using the knowledge from real-world road testing




Domain Tier IV have covered

Domains Tier IV hasn't covered yet

SECTION 3

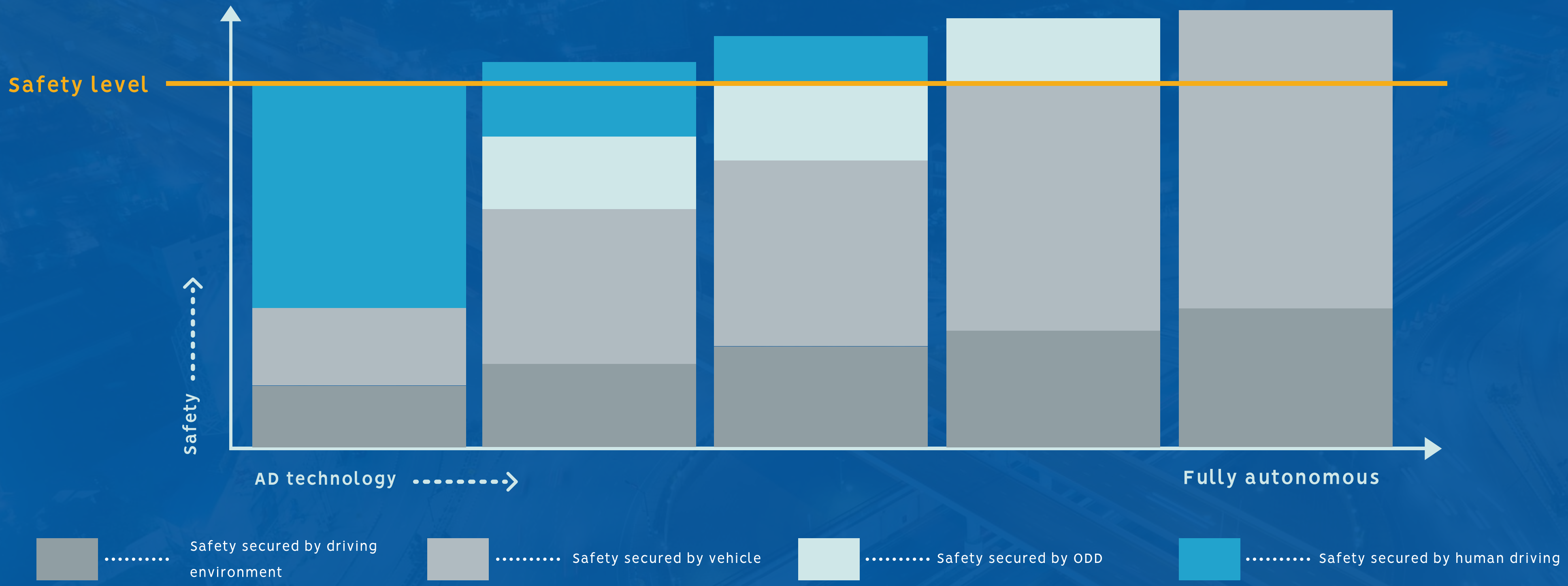
# FUTURE PREPARATION OF ENTERPRISE/SOCIETAL ENVIRONMENT

# GOVERNMENT POLICIES FOR AD

In May of 2020, the Japanese government's Panel on Business Strategies in Automated Driving published the roadmap for AD based on various road environments and service types[13]. To realize the AD roadmap, the government first classifies driving environments.

The next step is to discuss methods for ensuring safety in AD from the following perspectives; (1) design of objective standards for driving environment conditions and (2) discussion on safety standards for AD vehicles. Tier IV follows the government guidelines and ensures safety by challenging and addressing the issues of technology and the enterprise/societal environment.

## The Japanese government is ensuring safety in realizing the AD roadmap



# ISSUES OF ENTERPRISE/SOCIETAL ENVIRONMENTS

## Unlike overseas, real-world driving tests with multiple vehicles are not conducted in Japan

In Japan, real-world road testing is performed in many diverse areas, and the application for testing must be submitted to ministries and local governments in every instance of testing to be conducted. Testing is therefore conducted within a short period of time using only a small number of vehicles.

On the contrary, in the US more than 80 companies have conducted driving tests on public roads. As of June 2019, these companies have used more than 1,400 vehicles in 37 states over an extensive period of testing[15]. While this contributes to the accumulation of aggregate driving data in the US, the testing areas and vehicle types for real-world road testing are limited per company and learnings are not shared openly.

# It is essential to establish a common environment for AD System development and operation across the boundaries of individual companies

## Problem 1: Lack of simulation standards for authorization

Human drivers are awarded licenses based on their driving capability. These capabilities are tested under specific environments with clear standards of accepted performance. However, for AD Systems, there is as yet no authorization standard for driving capability based on simulation scenarios with agreed upon performance criteria. Driving authorization is awarded to companies on a case-by-case basis.

## Establishment of authorization standards

The driving capabilities of AD Systems are reproducibly quantified under specific scenarios by simulations. It is necessary to develop evaluation methods in simulation for the various aspects of driving capability and the respective authorization standards. This will enable a shorter time to authorization, allowing for a greater number of vehicles to be used in real-world road testing, and therefore, speeding the development of sophisticated AD technology.

## Problem 2: Lack of standards for operation

An operational system does not have standards for methods of dealing with hazardous events. Companies individually consider methods to deal with such events from the perspective of the probability of such hazardous events occurring, as well as the types of personnel systems and operational methods for remote monitoring.

## Establishment of rational operational standards

The system of "Fail Safe" functions, human drivers and remote monitoring by humans must deal with a vehicle's deviation from ODD specifications or unexpected errors. It is important to set rational standards for the personnel systems and operational methods established to respond to such situations. This will enable AD systems to curtail workforce shortages and solve societal issues such as the lack of drivers.

## Problem 3: Lack of insurance methods in case of accidents

Under any authorization standard or operational setting, unexpected risks exist for both human drivers and AD systems. For human drivers, automobile liability insurance exists as a basic insurance offering. However, basic insurance has yet to be established for AD systems.

## Establishment of basic insurance

The same as for human drivers, an AD system requires basic insurance. The insurance must cover the inevitable risk that the AD system operates outside the driving capability standards for which it was authorized. These risks remain even with the preparation of "Fail Safe" functions and remote monitoring systems.

# CONCLUSION

## Autonomous vehicles for everyone ——

Founded 5 years ago — Tier IV has continuously aimed to realize the goal of Intelligent Vehicles for Everyone. To achieve this goal, we develop AD technology with our open source AD software, "Autoware". We have performed many real-world road tests spanning various ODDs across the world. Our experience in real-world road testing is the best-in-class in Japan.

This Safety Report provides an overview of ODD classification and AD System Reference Design development against ODDs.  Based on this methodology, Tier IV shares with industry players real-world road-testing processes to ensure AD System safety. This report also addresses common issues in the areas of AD technology development and the business/societal environment for acceptance of AD technology and services.

AD systems extend well beyond the basic autonomous vehicle. AD Systems are built upon a unified platform of hardware and software applied to usage environments. It is essential that industry players contribute to AD's collaborative development across horizontal technology domains. This collaboration will lead to a sustainable ecosystem and enable the prompt realization of AD in society by establishing socially acceptable safety at reasonable costs.

We believe in AD's potential to decrease traffic accidents, provide increased mobility for the disabled and elderly, and support the sustainable use of public resources for transportation.

Tier IV continues to advance "Intelligent Vehicles for Everyone".

# APPENDIX

# DATA

Social Issues that lead to the need of AD

| | Worldwide | Japan | |
|---|---|---|---|
| Traffic fatalities (people/year) | 1.4 million | 4000 | *97% of fatal accidents are caused by human errors |
| Traffic injuries (people/year) | 20-50 million | 529,000 | |
| Time wasted in traffic jams | 20% of driving time | 40% of driving time | |
| Number of blind people | 36 million | 140,000 | |

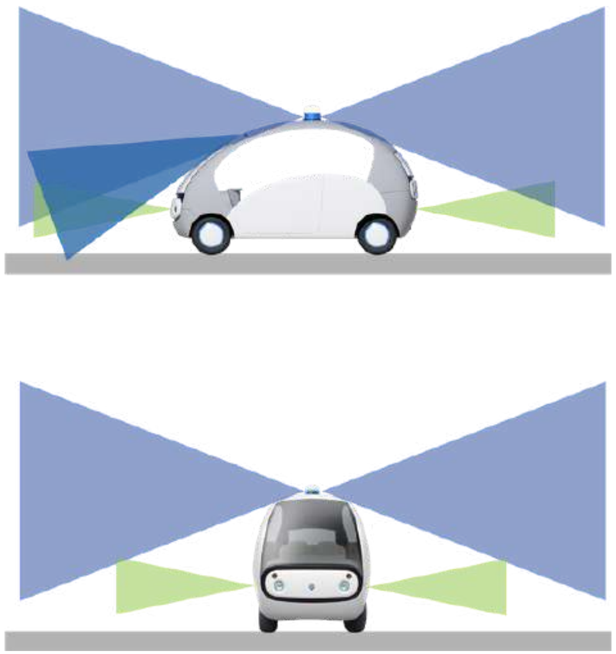
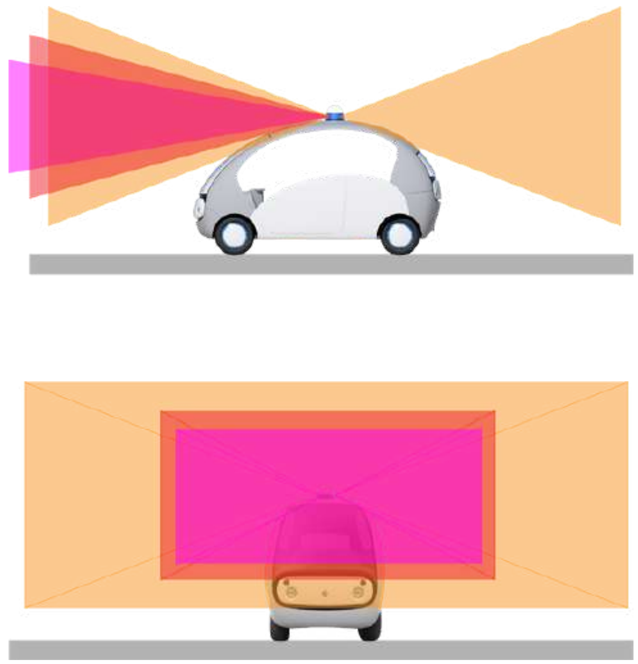
| | | |
|---|---|---|
| Heavy vehicle class 2 licensees | -20% ('09-'19) | *effective job offer rate in driving industry is twice as that of the average |
| Number of taxi drivers | -27% ('08-'18) | |
| Average bus driver's age | 51.2 (+8.7 from mean) | *grew by +4.4 in the last 10 years |
| Average taxi driver's age | 59.9 (+17.4 from mean) | |

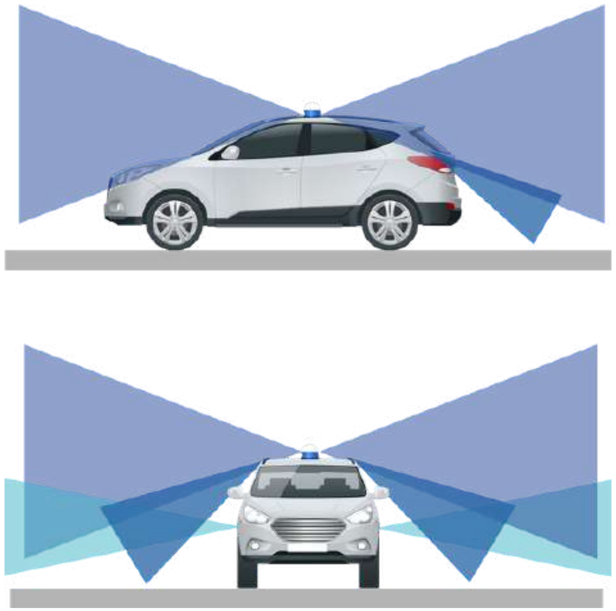
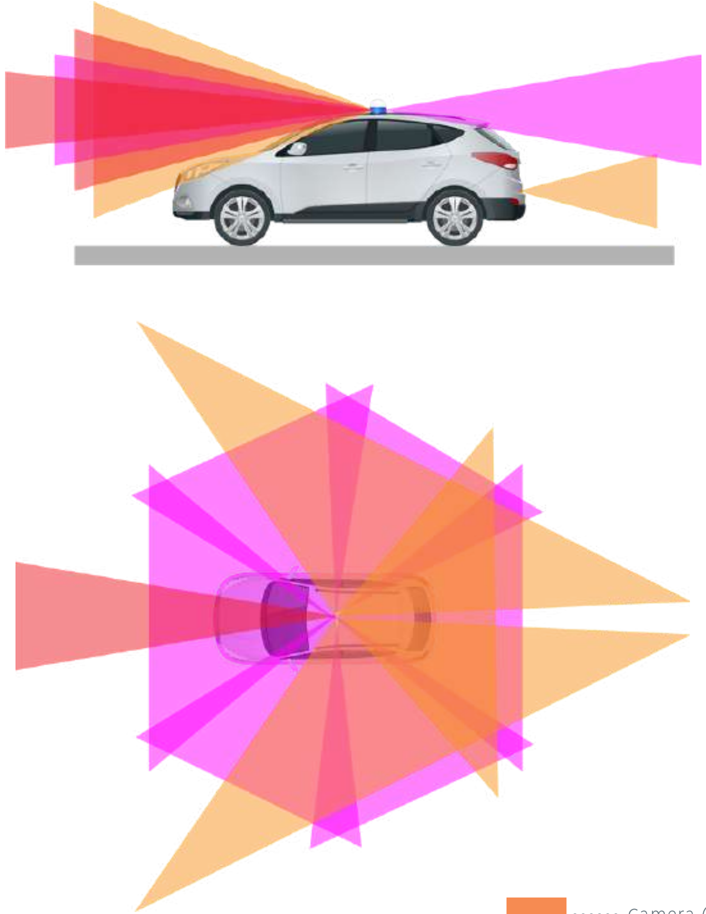
| | Bus | Regional railway |
|---|---|---|
| Number of deficit operator | 69% | 76% |
| Abandoned routes (km) | 13,391 ('07–'16) | 895 ('00–'19) |

| | Local cities | Metropolitan areas |
|---|---|---|
| Percentage of elderlies who mainly use cars | 55% | 36% |
| Percentage of elderlies going out | +21% ('87–'15) | |
| Percentage of fatal accidents caused by elderlies | +16% ('08–'18) | |

# Reference Design for each ODD

| | LiDAR configuration example | Camera configuration example |
|---|---|---|
| ODD 1 | <br><br>•••••• LiDAR (localization)<br>1 LiDAR<br>• Localization/360° long range object detection | <br><br>•••••• Camera (remote monitoring)<br>1 camera<br>• Remote monitoring of front side |

| | LiDAR configuration example | Camera configuration example |
|---|---|---|
| ODD 2 |  |  |
| | ······ LiDAR (localization)<br>······ LiDAR (short range)<br>······ LiDAR (mid range) | ······ Camera (remote monitoring)<br>······ Camera (object detection)<br>······ Camera (signal detection) |
| | 6 LiDARs<br>• Localization/360° long range object detection (1)<br>• 360° close to mid range object detection (5) | 6 cameras<br>• 360° remote monitoring (4)<br>• Object detection of front side (1)<br>• Signal detection of front side (1) |

| | LiDAR configuration example | Camera configuration example |
| --- | --- | --- |
| ODD 3 |  |  |

LiDAR (localization)

LiDAR (mid range)

LiDAR (long range)

6 LiDARs

- Localization/360° super long range object detection (1)
- Mid range object detection of rear side (1)
- Mid to long range detection of surrounding vehicles and humans (4)

Camera (remote monitoring)

Camera (object detection)

Camera (signal detection)

12 cameras

- 360° remote monitoring (4)
- 360° object detection of front side (6)
- Signal detection of front side (2)

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# GLOSSARY

| | |
|---|---|
| **ODD** | Operational Design Domain: the preconditions (e.g. driving environment) for autonomous driving systems to work safely. |
| **Reference Design** | The blueprint that Tier IV provides, along with other solution providers, to support the implementation of Autoware. |
| **Deep Tech** | The cutting-edge technology developed through great financial and time investment, which has a beneficial impact on society. |
| **Edge case** | The rare, hard-to-predict outlier case which can lead to the hazardous events. |
| **Fail safe** | One of the concepts which should be taken into consideration in the design of devices and systems to build a mechanism which transfers an autonomous vehicle to a safer condition when malfunction/abnormality occurs. |
| **LiDAR** | Light Detection and Ranging. A sensor that measures the distances to the targets using a beam of light, which is essential for AD. |
| **GNSS** | Global Navigation Satellite System. An umbrella term for the positioning systems that use satellites (e.g., GPS). |
| **IMU** | Inertial Measurement Unit. A device that measures vehicle's angular velocity and acceleration by combining a 3-axis gyroscope and accelerometer. |
| **AMR** | Autonomous Mobile Robot. A robot for internal transportation that avoids people or other obstacles autonomously. |
| **BRT** | Bus Rapid Transit. |

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