Second Phase of Cross-Ministerial Strategic Innovation Promotion Program
— Innovation of Automated Driving for Universal Services
(System and Service Expansion)

# Study of the Impact of Automated Driving on Reducing Traffic Accidents and on Others

## Report (Summery)

## March 2020


The University of Tokyo
Doshisha University


Institute for Technology, Enterprise and Competitiveness

# Objective of study

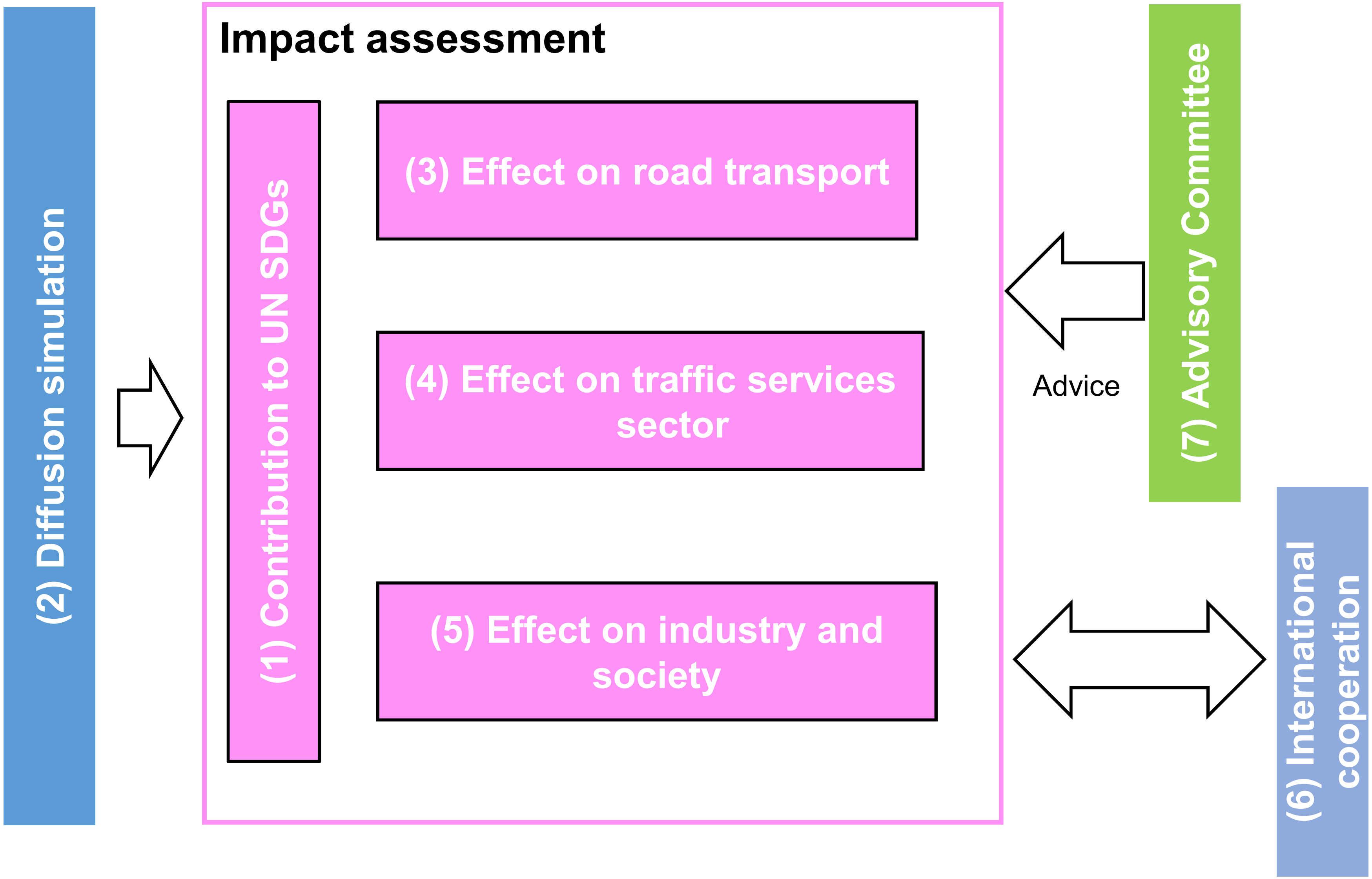
**Research and development plan for Second Phase of Cross-Ministerial Strategic Innovation Promotion Program — Innovation of Automated Driving for Universal Services (System and Service Expansion)**

Commercial development and increased diffusion of automated driving (AD) vehicles will help to reduce traffic accidents, alleviate traffic congestion, ensure mobility for vulnerable road users, resolve the driver shortage and reduce costs in logistics and transport services, and resolve other social problems. The aim is to achieve a society in which everyone is able to enjoy a high-quality life.

Quantification and monetary valuation of impact (benefits and potential risks) → Basic references for fostering social acceptance

Focus on differences in impact caused by governmental policies and/or manufactures' launching methods → Use in corporate management and policymaking

# Overall configuration of study



# Study items

## (1) Relevance of AD to SDGs

## (2) Simulation of AD vehicle diffusion

## (3) Effect on road transport

i. Estimation of effectiveness in reducing traffic accidents
ii. Estimation of reduction of traffic congestion and reduction of $CO_2$ emissions

## (4) Effect on traffic services sector

i. Ensuring mobility for vulnerable road users and in depopulated areas and other locations with poor access to transport
ii. Reduction of costs and resolution of driver shortage in logistics and transport services
iii. Change in ownership and usage of vehicle, and the structure of consumers' choice

## (5) Effect on industry and society

i. Effect on whole automobile industry due to change in vehicle ownership structure and other effects
ii. Contribution to growth of the total factor productivity of the Japanese economy

## (6) Formation of organization for international cooperation

## (7) Convening of Advisory Committee

# 1. Relevance of AD to SDGs

<Outline>

Organizing the relevance of AD to the UN's Sustainable Development Goals to establish a clear vision of how self-driving cars can help us build sustainable societies.

<Method>

Organizing the relevance based on the discussion within the Advisory Committee on the Relevance of AD to SDGs.

# Advisory Committee on the Relevance of AD to SDGs

**1) Meeting dates and venues:**

April 5, 2019, 1:00 - 3:30 PM, at Kambaikan meeting room of the Institute for Technology, Enterprise, and Competitiveness, Doshisha University

(Individual interview with Dr. Hiroto Inoi, member of the advisory committee, was conducted on
April 23, 2019, 1:00 - 2:30 PM, at Kambaikan meeting room of the Institute for Technology, Enterprise, and Competitiveness, Doshisha University)

**2) Advisory Committee members (without honorifics)**

| Name | Affiliation and Position |
|---|---|
| Chairman<br>Masanobu Kii | Professor, Faculty of Engineering and Design, Kagawa University |
| Member<br>Tateo Arimoto | Visiting Professor, National Graduate Institute for Policy Studies (GRIPS) / Principal Fellow, Japan Science and Technology Agency (JST), |
| Hiroto Inoi | Associate Professor, Faculty of Sustainable Design, Department of Civil Design and Engineering, University of Toyama |
| Yasuhiro Shiomi | Associate Professor, College of Science and Engineering, Department of Environmental Systems Engineering, Ritsumeikan University |
| Keii Gi | Senior Researcher, Systems Analysis Group, Research Institute of Innovative Technology for the Earth (RITE) |
| Keisuke Matsuhashi | Head, Center for Social and Environmental Systems Research（Environmental Policy Section), National Institute for Environmental Studies |

# Classifying impact (1)

**1) Direct and indirect impact**

**Direct impact** :  Effects exerted by AD, through the changes in mobility they enable, on SDG goals and targets.

The **Global Mobility Report 2017** prepared by Sustainable Mobility for All defines four sectors of sustainable mobility: *universal access, efficiency, safety,* and *green mobility.* Following this guidance, we considered potential impacts on each of the four sectors—*universal access, system efficiency, safety,* and *green mobility*—as well as synergies and tradeoffs arising between them.

**Indirect impact (ripple effects):** Effects exerted by AD—through the direct impact they have on SDG goals and targets—on other SDG goals and targets.  We identify three sectors: (1) Increased income and reduction of disparities, (2) improved sanitation, and (3) expanded educational opportunities.

# Classifying impact (2)

**2) Short-term and long-term impact**

***Short-term impact*** refers to factors influencing SDG goals and targets that will emerge when SAE level 1 or level 2 diffuse into society. This should be more or less achieved by 2030, the target year for achieving SDGs.

***Long-term impact*** refers to factors influencing SDG goals and targets that will emerge when SAE level 3 or level 4 ADs with sufficiently extended ODD, or SAE level 5 ADs, diffuse into society. This will be difficult to achieve by 2030.

3) Three categories of ADs for consideration of long-term impacts

For consideration of long-term impacts, it is useful to identify three distinct categories of applications for ADs: (i) Logistics / mobility services, (ii) Privately owned vehicles, and (iii) shared mobility.

# Conclusions (1)

- Through both direct impacts—including associated synergies—and indirect impacts, AD will make wide-ranging contributions toward achieving SDG targets and targets.
- On the other hand, there are several potential negative impacts, and tradeoffs may arise as described in the following examples:

1) Societies may suffer a decrease in resilience at the time of disaster, which may have negative impacts for targets 11 and 13.

→It is essential to promote the development of management technologies for AD vehicles.

# Conclusions（2）

2）If passengers’ AD cars are mainly by privately owned, a modal shift toward automobile transit and urban sprawl is expected.

If shared mobility becomes widely adopted, a modal shift toward automobile transit in urban transportation is expected.

These developments would have negative impacts for goals 3, 7, 8, 9, and 11.

→ Introduce an economic framework in which external diseconomies are internalized.

→ Need other initiatives, such as improved connectivity between AD vehicles and other modes of transit.

## 2 Simulation of AD vehicle diffusion

<Outline>

- Establish a simulation model to use the simulation results as common data for various impact assessments in this project.

<Method>

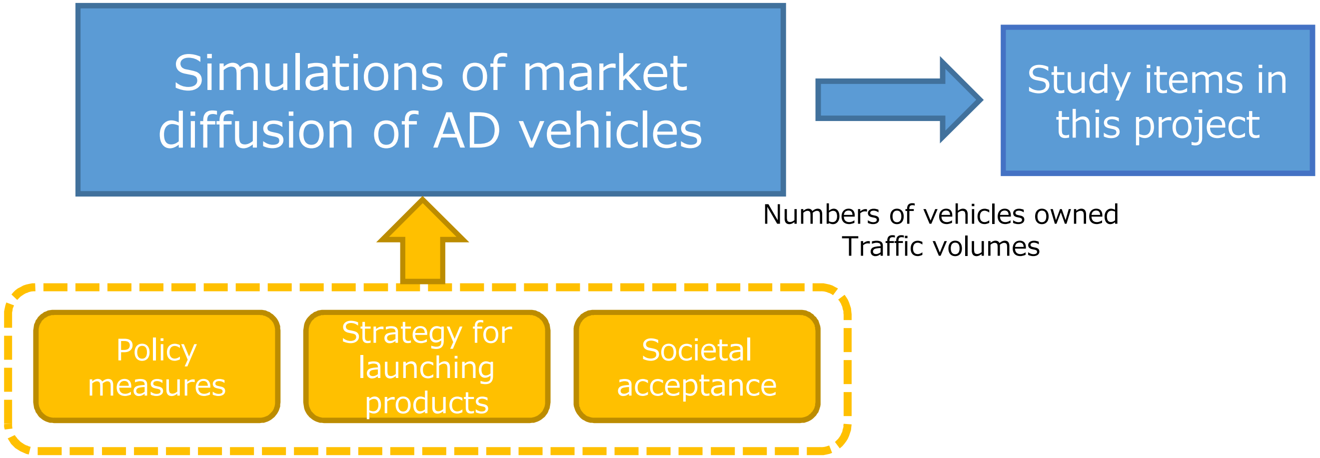
- Build element models such as car ownership models and consumer preference models.
- Construction of a system combining element models.
- Trial simulation targeting privately-owned passenger cars.

# Objectives of simulation

- Simulation results are used as common data for various impact assessments in this project.

- Evaluate the impact of the following factors on market diffusion of AD vehicles:
    1. Policy measures (economic incentives, mandatory installation of automated-driving devices, introduction of new types of driver licenses with relaxed conditions on license holders)
    2. OEM's strategy for launching products (when to launch into markets, at what price)

    3. Enhancement of societal acceptance



# Various classification schemes used in our simulations

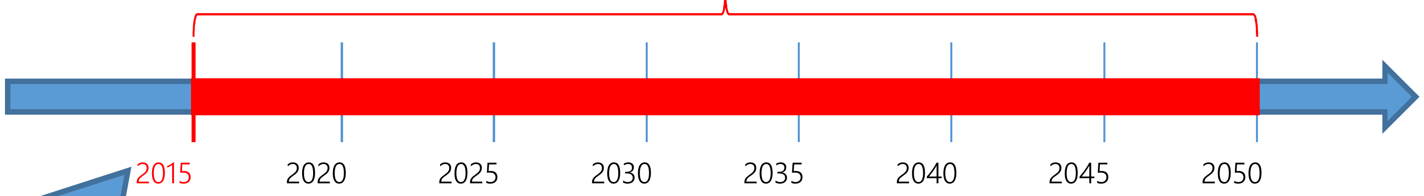
# Categories of vehicles and vehicle-based services, and Temporal extent of simulations

## 1. Categories of vehicles and vehicle-based services

| Category in this study | Outline of method for determining results | Outputs |
|---|---|---|
| Privately owned vehicle | • Use results of online surveys to model consumer's technology-related choices<br>• Incorporate results from the study *(4)-iii. Change in ownership and usage of vehicle, and the structure of consumers' choice* to model the transition from privately owned vehicle to mobility services | Numbers of vehicle owned<br><br>Numbers of new vehicle registrations<br><br>Traffic volumes |
| Mobility services | | |
| Logistics services | Use results from the study *(4)- ii . Reduction of costs and resolution of driver shortage in logistics and transport services* (University of Tokyo) | |

## 2. Temporal extent of simulations

Simulation period: 2015 - 2050, data output at 5-year intervals




2015 is the most recent year for which basic data are available for statistics including the Road Traffic Census

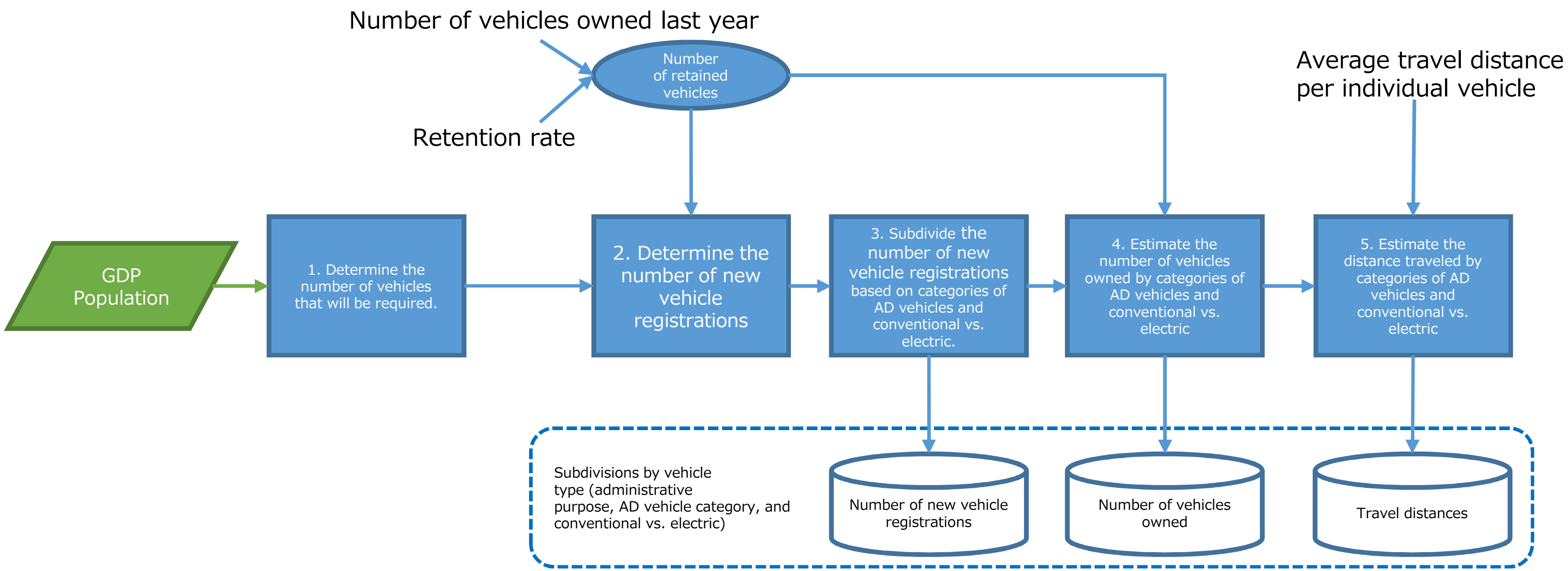
# Categories of AD vehicles considered in this study

| Category | Highways | General roads | Compatible technologies |
|---|---|---|---|
| C0 | SAE Lv.0 | SAE Lv.0 | No driving-support devices |
| C1 | SAE Lv.1<br>Driver assistance | SAE Lv.1 | ・Collision-damage-reducing brakes<br>・Acceleration limiters for accidental accelerations (due to driver error)<br>・Lane-departure warning system<br>・Car distance warning system |
| C2 | SAE Lv.2<br>Partial automation | SAE Lv.1 | In addition to C1:<br>・On highway, lane keeping systems (LKAS) + adaptive cruise control (ACC) applicable to all vehicle speed regimes, including low-speed motion and stopping<br>・Automatic lane changing on highway |
| C3 | SAE Lv.3<br>Conditional automation | SAE Lv.2 | In addition to C2:<br>・Lv.3 on highways<br>・Lv.2 on general roads |
| C4 | SAE Lv.4<br>High automation | SAE Lv.3<br>on major arteries and thoroughfares | In addition to C3:<br>・Lv.4 on highways<br>・Lv.3 on major general roads<br>・On general roads, take-over requests (TORs) for driving operations will be issued in response to system demand |
| C5 | SAE Lv.4<br>High automation | SAE Lv.4 on major arteries and thoroughfares | In addition to C4:<br>・Lv.4 on major general roads<br>・Take-over requests (TORs) will not be issued |
| C6 | SAE Lv.5<br>Fill automation | | |

# The logic of the simulations

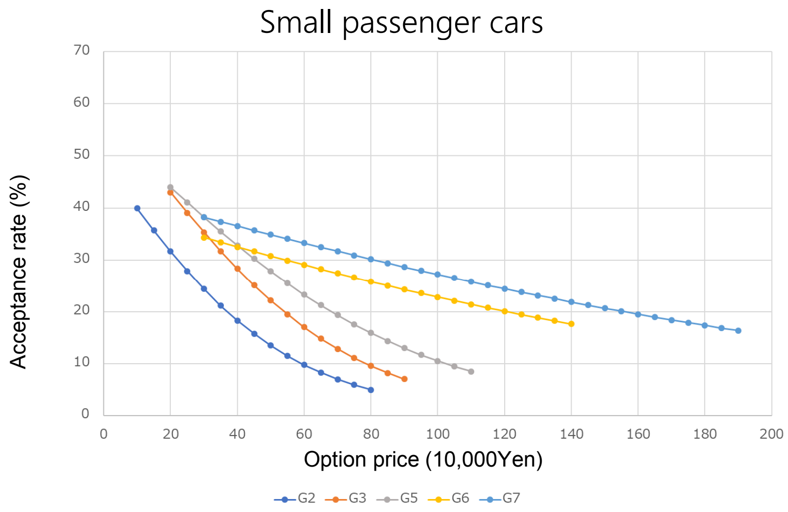
# Flowchart for AD vehicles market-diffusion simulations

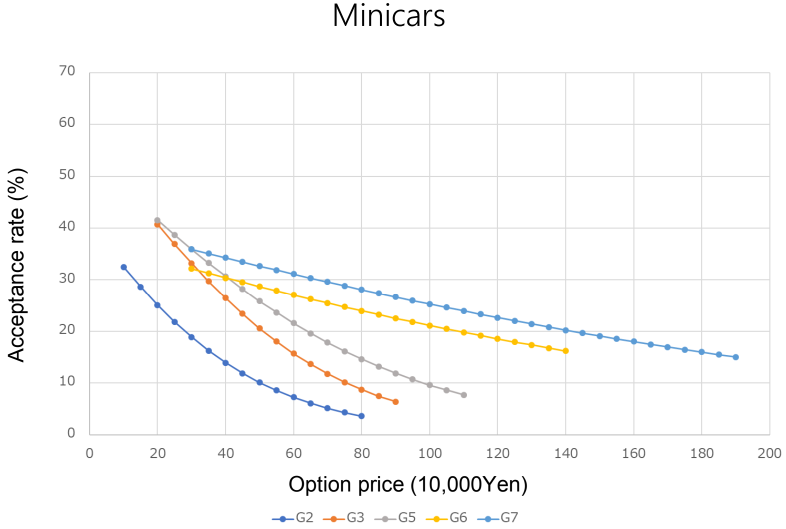
## For privately owned vehicles



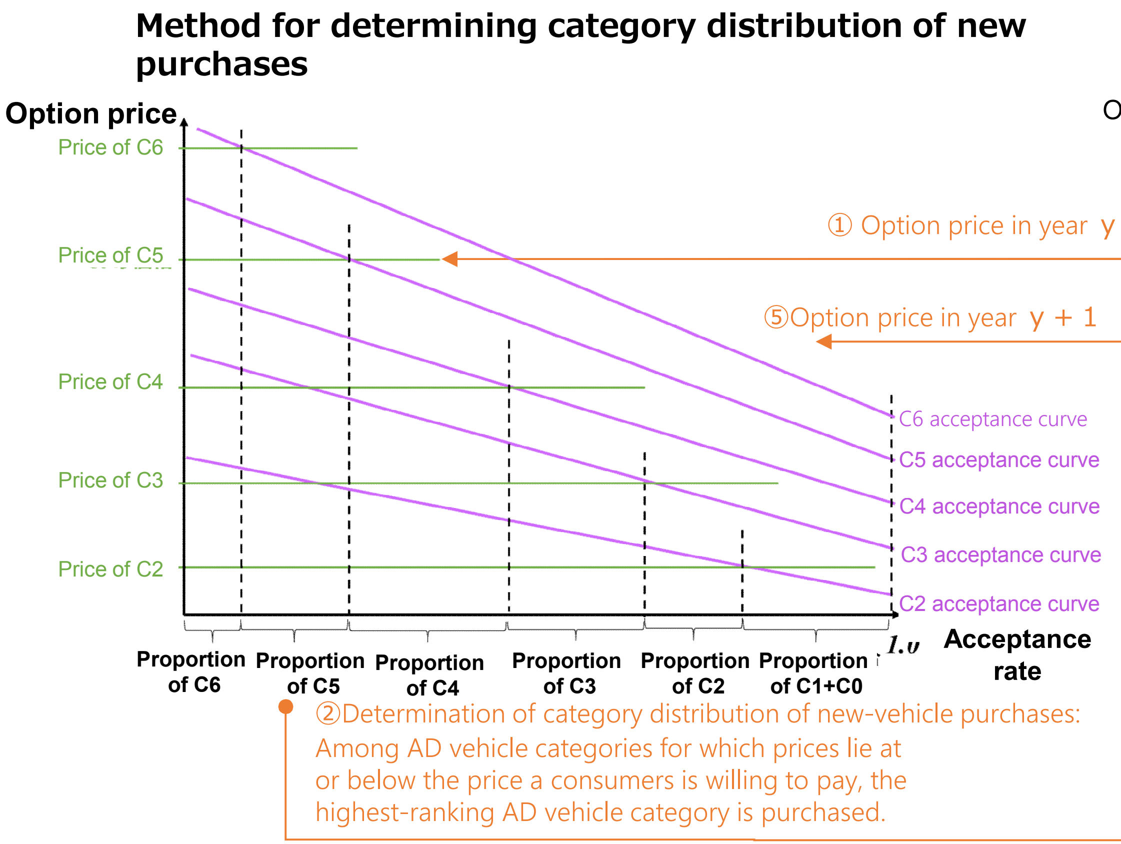
# Acceptance curves for various categories of AD vehicles

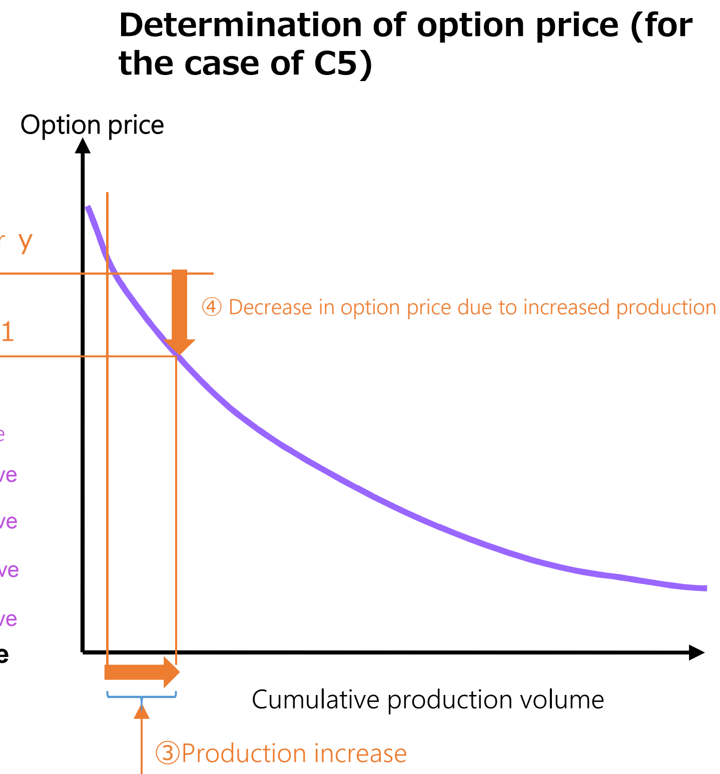
Acceptance curves for each self-driving vehicle category are constructed based on individual responses to online surveys.

# Distribution of AD vehicle categories among new purchases of privately owned (passenger) cars



# Market release times and initial option prices by AD vehicle category (for passenger cars)

- Market release times, initial option prices, and rates of price reduction due to production experience (progress ratio) are determined as follows.

*Progress ratio: Production cost ratio when cumulative production volume has doubled

| AD vehicle category | Year released to market | Initial option price (10,000 yen) | progress ratio* |
|---|---|---|---|
| C2 | 2019 | 41 | 0.9 |
| C3 | 2020 | 70 | |
| C4 | 2025 | 81 | |
| C5 | After 5 years 2030 | 93 | |
| C6 | After 10 years 2035 | 107 | |

Determined based on *Public and Private ITS Initiative / Roadmap 2019* and *Action Plan for realize the Automated Driving Version 2.0* (Panel on Business Strategies in Automated Driving, March 30, 2018)

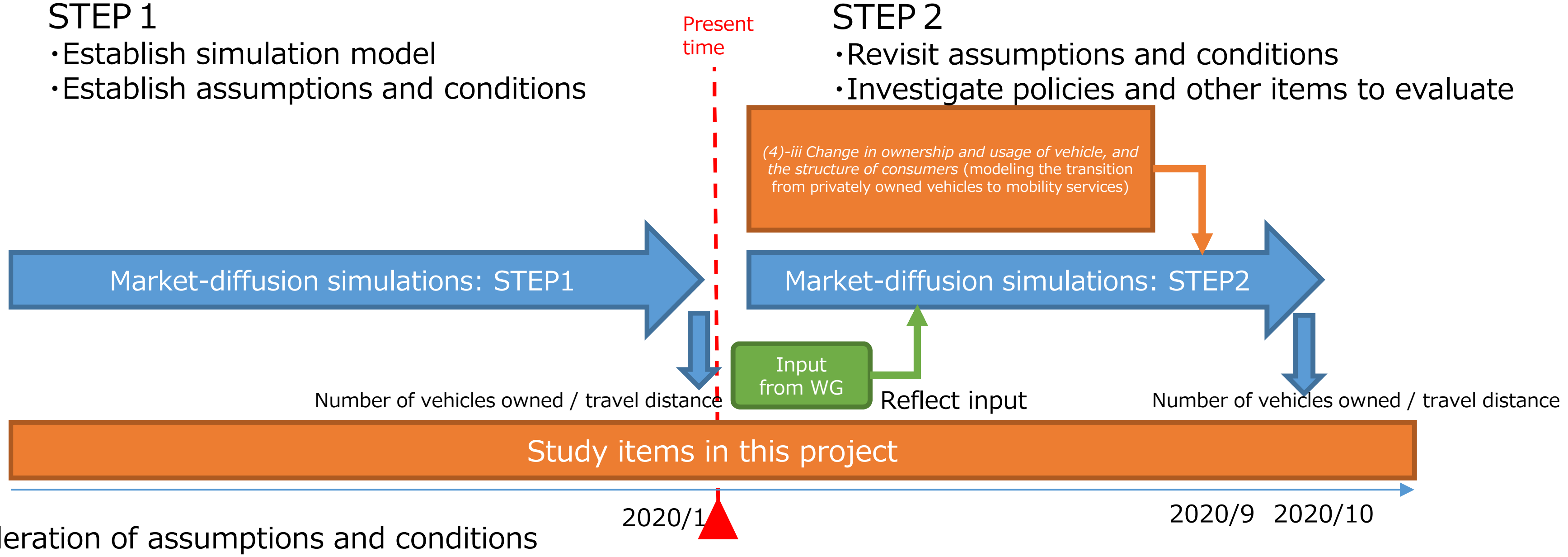
Determined in reference to literatures

Determined based on experience curves for automated braking systems

# Steps in the simulation procedure

STEP 1
・Establish simulation model
・Establish assumptions and conditions

STEP 2
・Revisit assumptions and conditions
・Investigate policies and other items to evaluate




Consideration of assumptions and conditions

| STEP | Transition from privately owned vehicles to mobility services | Change in vehicle lifetimes due to transition to AD vehicles / electric vehicles | Time and price of market appearance of AD vehicles | Selection of AD vehicle categories by consumers | Transition to electric vehicles | Scenario for introduction to cargo-transport services and mobility services | Change in travel distance due to transition to AD vehicles |
|---|---|---|---|---|---|---|---|
| STEP 1 (Fiscal year 2019) | Not considered | Vehicle lifetime unchanged from present value | Determined in reference to literature | Modeling of selection of AD vehicle categories by consumers | Determined independently of transition to AD vehicles | Not considered | Travel distance per vehicle unchanged from present value |
| STEP 2 (Fiscal year 2020) | Use results from the study 4)-iii *Change in ownership and usage of vehicle, and the structure of consumers* | Investigate change in vehicle lifetimes due to transition to AD vehicles/ electric vehicles | Determined with modifications appropriate to Japan | Setting scenarios for changes in acceptance rates | Investigate the relationship between transition to self-driving vehicles and transition to electric vehicles | Use results from the study *(4)- ii . Reduction of costs and resolution of driver shortage in logistics and transport services* (University of Tokyo) | Investigate changes in travel distance per vehicle due to transition to AD vehicles |

# 3-i. Estimation of effectiveness in reducing traffic accidents

<Outline>

- Another research, *Visualize the effects of reducing traffic accidents through Automated Driving and Driving Assistance,* sponsored by SIP-adus estimates the reduction of the number of accidents and casualties due to diffusion of AD vehicles. We estimate the monetary value of the impact of reduced traffic accidents.

<Method >

- The monetary value for the reduction in non-monetary losses (psychological burden) of perpetrator" due to avoidance of traffic accidents is estimated by means of web survey and economic experiments as part of this study. Economic experiments was conducted in this fiscal year.

# Results of economic experiments

- The participants in our experiments were 76 undergraduate students at Doshisha University.
- Non-monetary losses suffered by both victims and perpetrator are evaluated. Experiments consider only fatalities.
- The most important finding from the experiments is that the participants estimate non-monetary losses suffered as a perpetrator equal to or grater than non-monetary losses suffered as a victim.

# 3- ii. Estimation of reduction of traffic congestion and reduction of $CO_2$ emissions

<Outline>

- To estimate the reduction of traffic congestion and CO2 emissions by diffusing ADs

<Method>

- Almost sixty percent of traffic congestion on expressways nationwide are occurring at sag sections.
- ADs are supposed to contribute reduction of traffic congestion and CO2 because they promote vehicles' movement with proper headway and velocity.
- To prove the above idea, traffic simulation is used for two representing sections, a section with three-lane expressway and a section with two-lane expressway. AD diffusion rate are two cases, 20% and 90%.
- For ordinary roads, the idea is same as the above one and existing research results are referred.
- Then total amounts of reduction of traffic congestion and CO2 emissions nationwide are calculated.

# Trial calculation of reduction of traffic congestion and $CO_2$ emissions on expressways

- AD diffusion rate is forecasted as 25% in 2035 and 34% in 2050.
- Trial calculation result for expressways is as follows under many preconditions assumed this time. (Of course, if the preconditions are changed, result might be changed accordingly.)

✓Traffic congestion: 16% in 2035 and 17% in 2050 might be reduced compared to the present.

✓$CO_2$ emission: 1.9% in 2035 and 2.2% in 2050 might be reduced compared to the present.

## 4- i Ensuring mobility for vulnerable road users and in depopulated areas and other locations with poor access to transport

<Outline>

- To summarize possibilities of new business and life brought by AD technologies, particularly on remote areas

<Method>

- To implement interview surveys for staff of municipal governments in remote areas on use cases of AD technologies

# Possible use cases of ADs in remote areas

- Alternative of driving services
  - To substitute ADs for current driving services
    - Labor-saving (reduction of drivers’ work load)
    - Fully unmanned

- Expansion of administrative services
  - To enhance administrative services in poor level by AD technologies
    - Improvement of service frequency and expansion of service area
    - Improvement of service quality

→ Enhancement of service (Assist, Medical inspection, Attendance, Check of infrastructure, Disaster response)

- Improvement of those who are supported and occupants
- Check of infrastructure, Improvement of attention during response

- Creation of new administration services
  - Realization of new services
    - Additionally needed technologies and expectation

→ Automatic diagnosis identification (Check of infrastructure, Disaster response)

- Identification of diagnosis, Emergency treatment

# 4- ii Reduction of costs and resolution of driver shortage in logistics and transport services

<Outline>

- To estimate how ADs introduction will contribute the on-going shortage of truck drivers

<Method>

**1. Estimation of future truck drivers**

To calculate demand and supply of truck drives in the future

**2. Estimation of vehicle-km of trucks which can be covered by unmanned trucks**

To calculate future vehicle-km by vehicle type, region, route

**3. Trial calculation of replacement of truck drivers by ADs**

Trial calculation based on assumed diffusion scenarios

# Estimation method of truck drivers demand

<Outline>

- Firstly future freight demand is estimated, then number of drivers to satisfy those demand is calculated.

<Method>

- Generated freight flows are calculated using MLIT's future traffic demand estimation committee's method.
- Then, total freight vehicle-km are estimated using the mean capacity tonnage model and the mean haul distance model.

- Future truck drivers demand are calculated with the present truck driver number and the change ratio under the assumption that change of vehicle-km and change of driver demand are same.

# Estimation method of truck drivers supply

<Outline>

- Number of truck drivers are forecasted using the statistics on labor affair.

<Method>

- The number of current truck drivers by age-grade is calculated using the labor force survey and the basic survey on wage structure.
- Future number of truck drivers every 5 years is estimated by cohort method.

# Assumed diffusion scenario of ADs

The following scenarios are assumed based on the Public-Private ITS Initiative/Roadmaps 2019.

| Scenario | | 2025 | 2035 | 2040 |
|---|---|---|---|---|
| 1 | Fully automated driving of trucks on some specific sections of expressways | Commencement | ○ Achievement | |
| 2 | Fully automated driving of trucks on expressways with 4 lanes and more | | ○ | |
| 3 | Unmanned autonomous driving delivery service in specific areas (remote areas) | Commencement | ○ Achievement | |
| 4 | Unmanned autonomous driving delivery service in specific areas (all areas except urban and sub-urban areas) | | ○ | ○ |
| 5 | Fully automated driving of trucks on major ordinary highways | | | ○ |

# Trial calculation of replacement of truck drivers by ADs

- Trial calculation result is as follows under many preconditions assumed this time. (Of course, if the preconditions are changed, result might be changed accordingly.)

✓The gap between demand and supply of truck drivers might be 180 thousand persons and 230 thousand persons in 2035 and 2040 respectively.

✓In case there are proper provisions on roadways for unmanned trucks (i.e. expressways in near future and major highways in its following years), maximum 120 thousand persons and 200 thousand persons could be saved in 2035 and 2040 respectively.

# 4-iii.　Change in ownership and usage of vehicle, and the structure of consumers' choice

<Outline>

- Estimate how the structure of consumers' choice regarding the ownership and usage of vehicle, and mobility will change by introduction / diffusion of AD vehicles and MaaS.

<Method>

- Investigation of construction of consumer transportation choice model and cooperation with AD vehicle diffusion simulation
- Preliminary survey targeting students was conducted.

# Preliminary survey

- Preliminary survey targeting students was conducted regarding structure of consumer choice among 4 modes: 1) owned manual driving car, 2) owned AD vehicle, 3) 1-passenger self-driving taxi, 4) shared self-driving taxi.

- Estimation methodology is in the middle of reconsideration taking into account the opinions at Advisory Committee on the Social Impact of Automated Driving Systems.

## 5 Effect on industry and society
## ii Contribution to growth of the total factor productivity of the Japanese economy

<Outline>

- Classify the route of AD enhancing the total factor productivity (TFP) of Japanese economy. Then within each route, organize how automatic driving contributes to enhancing TFP by providing specific cases.
- Calculate the round number of how much the diffusion of AD vehicles will contribute to the enhancement of TFP growth rate.

<Method>

- This study will be conducted in FY 2020 on a full scale, while literature survey and planning of the study was started in FY2019. Results are partially described in the report.

# 6. Formation of organization for international cooperation

- Japanese-German cooperation
  - The joint research was commenced based on the Joint Declaration of Intent signed on January 12, 2017 by the Cabinet Office of the Japanese government and the German Federal Ministry of Education and Research (BMBF)
  - The first joint meeting was held in 7th and 8th October at German Aerospace Center, Berlin.
  - Research contents of both sides were presented and then mutual interesting research areas were shown and finally fields of information sharing and joint research were discussed.

# 7. Convening of Advisory Committee

- The meetings of the advisory committee were held on 26th June 2019, 1st October 2019 and 3rd February 2020.

**Members of the Advisory Committee on the Social Impact of Automated Driving Systems**

| Name | Affiliation | Speciality |
|---|---|---|
| **Masato Itohisa** | Associate Professor, Faculty of Social Science, Hosei University | Technology management |
| **Takeyoshi Imai** | Professor, Graduate School of Law, Hosei University | Criminal law |
| **Keisuke Uehara** | Associate Professor, Faculty Environment and Information Studies, Keio University | Iinformation technology |
| ○ **Takashi Oguchi** | Professor and Director, Advanced Mobility Research Center, Institute of Industrial Science, The University of Tokyo | Traffic control engineering |
| **Shusuke Kakiuchi** | Professor, Faculty of Law, Graduate Schools for Law and Politics, The University of Tokyo | Civil procedure law |
| **Masanobu Kii** | Professor, Faculty of Engineering and Design, Kagawa University | Urban and transportation planning |
| **Yuto Kitamura** | Associate Professor, Graduate School of Education, The University of Tokyo | Education |
| **Ryo Kurachi** | Specially Appointed Associate Professor, Center for Embedded Computing Systems, Graduate School of Informatics, Nagoya University | Cybersecurity |
| **Osamu Sakura** | Professor, Interfaculty Initiative in Information Studies, Graduate School of Interdisciplinary Information Studies, The University of Tokyo | Science, Technology and Society |
| **Yasuhiro Shiomi** | Associate Professor, Department of Civil and Environmental Engineering, College of Science and Engineering, Ritsumeikan University | Traffic engineering |
| **Naoki Suganuma** | Associate Professor, Automated Vehicle Research Unit, Future Society Creation Research Core, Institute for Frontier Science Initiative, Kanazawa University | Robotics engineering |
| **Satoshi Taguchi** | Professor, Faculty of Commerce and Director, Institute for Technology, Enterprise and Competitiveness, Doshisha University | Behavioral economics |
| ☆ **Akihiro Nakamura** | Professor, Graduate School of International Management, Yokohama City University | Public economics |
| **Pongsathorn Raksincharoensak** | Professor, Department of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology | Machine dynamics and control |
| **Hiroaki Miyoshi** | Professor, Faculty of Policy Studies and Director-General, Institute for Technology, Enterprise and Competitiveness, Doshisha University | Technology and public policy |
| **Akinori Morimoto** | Professor, Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Waseda University | Urban planning |
| **Goro Yamazaki** | Associate Professor, Center for the Study of Co Design, Osaka University | Cultural anthropology |