**Strategic Innovation Promotion Program (SIP)**
**Phase Two – Automated Driving**
**(Expansion of Systems and Services)**

# Research on the Enhancement of Technologies to Provide Traffic Signal Information toward the Realization of Automated Driving

Progress Report for Fiscal Year 2018

March 2019

UTMS Society of Japan

# 1. Outline of Research

## <Purpose>

With a view to contributing to the enhancement of **technologies to provide traffic signal information dedicated to automated driving vehicles**, the research will conduct a survey on cases of the real-time provision of traffic signal information from roadside infrastructure and their technology trends, as well as a **survey and examination of roadside infrastructure enhancement measures** based on opinions and requests from automobile manufacturers and other organizations.

## <Outline>

(1) Case survey
(2) Examination of measures for cases in which the number of remaining seconds of the current signal phase becomes inconsistent
(3) Examination of message sets for automated driving vehicles
(4) Examination of the linking of the road shape information with dynamic maps
(5) Examination aimed at enhancing the fail-safe function
(6) Identification of constraints to the provision of traffic signal information
(7) Development of specifications for ITS roadside radio equipment for automated driving

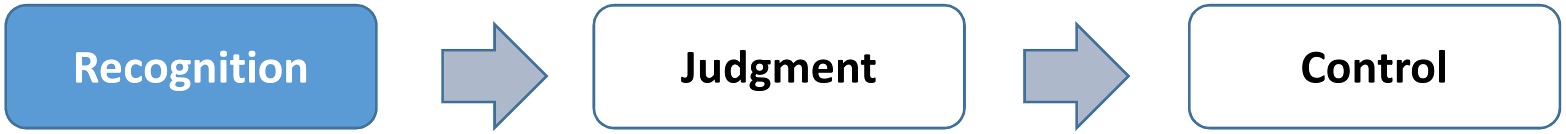
## <Participating members and others>

- Setting-up of a committee with participation from car makers, infrastructure makers, Japan Automobile Manufacturers Association, Inc. and others
- Cooperation with other SIP projects in respect of dynamic maps
- Implementation of experiments (an independent research) for the provision delay time and others and the utilization of experiment results

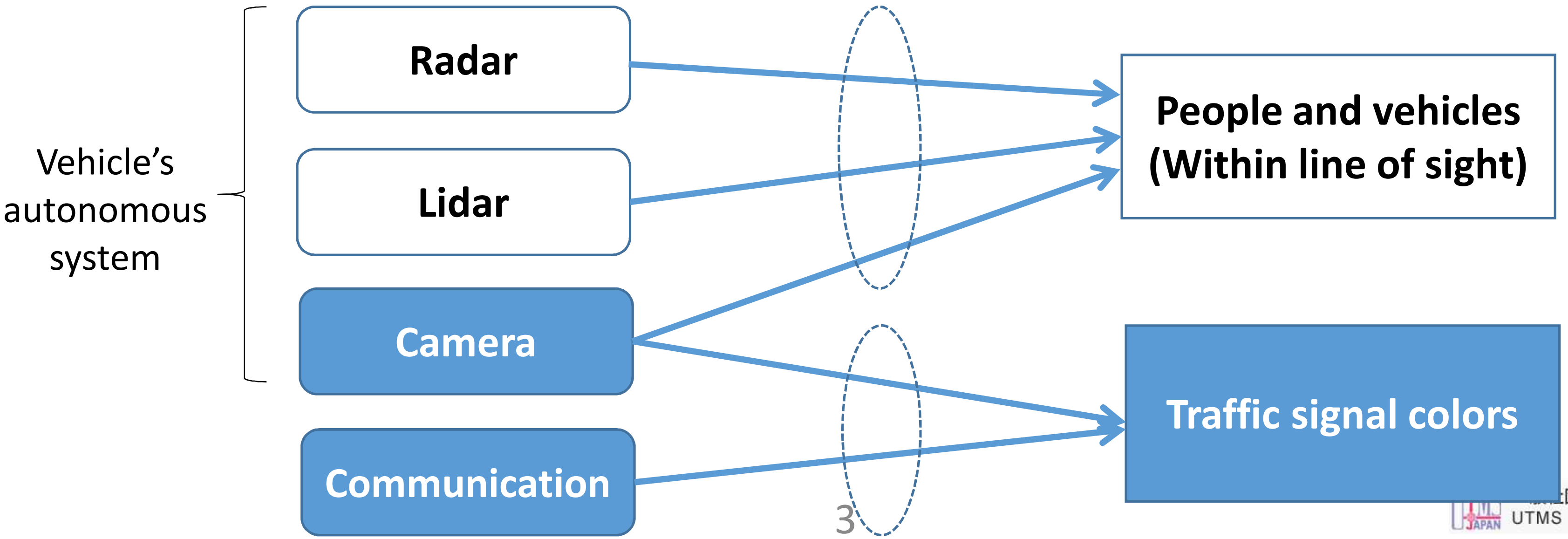
# 2.1 Need for signal information from infrastructure in automated driving

- Reliable recognition of surrounding conditions is essential for a safe automated driving control
  → The reliability is ensured through **<u>"multiplexing"</u>** of the recognition method
- Only cameras can recognize traffic lights in autonomous vehicle sensing
  → Traffic lights are reliably recognized through duplication of information obtained by autonomous cameras and by communication.

## ■ Driving process

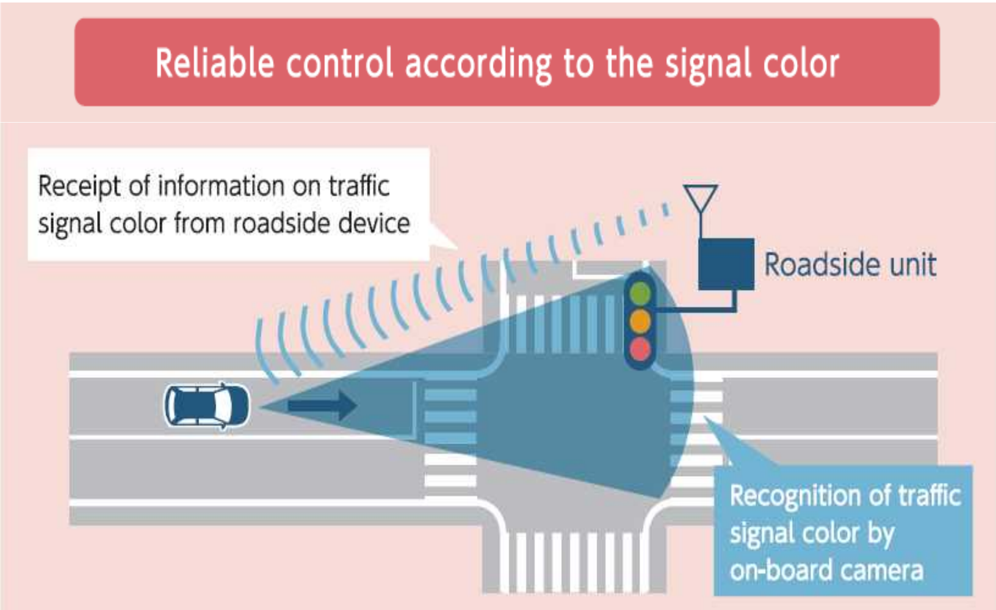


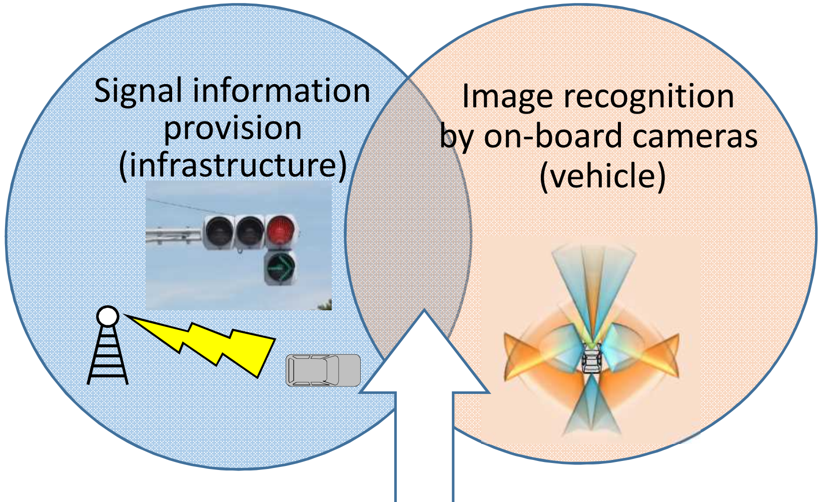

## ■ Recognition through a multiplex system



## 2.2 Scene in which information about present signal color is used

Achieves safe passage through intersections by reliably recognizing signal light colors through the duplex system of traffic signal information provided by infrastructure (via V2I/V2N) and on-board cameras.




Reliable recognition of traffic signal through the duplex system

(Reference)
# Scenes in which automated driving vehicles are particularly poor at recognizing traffic signal

Backlight

Long distance

Hand signals

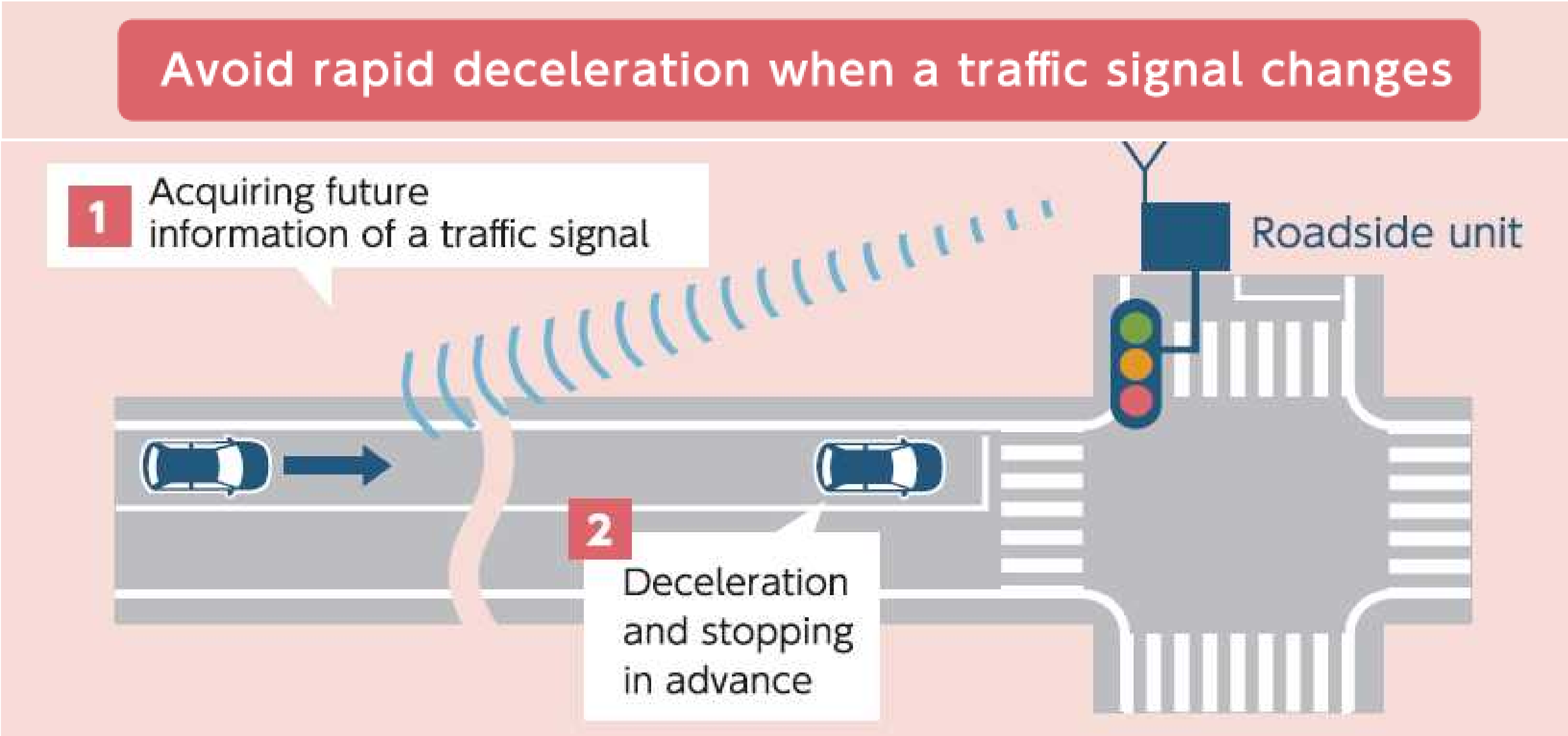
Lost in a background

Multiple traffic lights in an image

## 2.3 Scene in which future traffic signal information (number of remaining seconds) is utilized

Acquires future traffic signal information and decelerates in advance before a stop line, based on the prediction that the green signal changes to yellow/red.

⇒ Avoids rapid deceleration and reduces collision risk




**The Traffic signal cycle length needs to be fixed a certain period of time before the traffic signal light changes from green to yellow (red).**

# (Reference) A draft deceleration method to avoid dilemma zone

(1) In the case where maintaining the current speed will cause a vehicle to enter a dilemma zone, deceleration starts at a deceleration rate of D1(※1) ⊿t seconds before the signal color changes to yellow.

(2) After the signal color changes to yellow (※2), deceleration starts at a deceleration rate of D2(※3).

(3) Stopping before a stop line

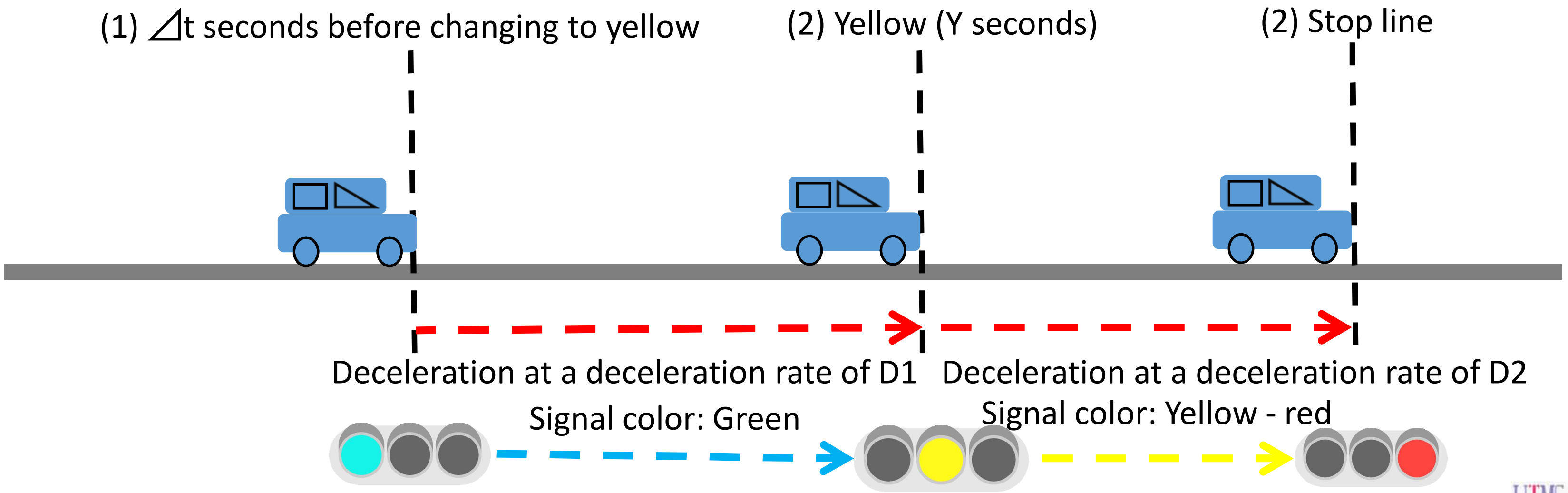
※1. At a deceleration rate that can obtain social acceptance judging from surrounding vehicles including following vehicles

⇒ The equivalent of engine braking (0.03 G) of ordinary vehicles is assumed

※2. When the signal light is judged to be yellow based on the information from both the on-board camera and communication

※3. Deceleration rate that allows safe stopping

⇒ A maximum of 0.2 G is assumed



# 3.1 Survey of foreign cases

On-site inspections and hearings on systems to provide traffic signal information to automated driving vehicles were conducted at five locations in the U.S., Europe and China.

| Locations surveyed | Outline of the survey |
|---|---|
| Las Vegas, the U.S. | <Project outline><br>● Project area: Old downtown districts that were designated as innovation districts<br>● Number of locations where DSRC is deployed: **DSRC (800 MHz) was deployed at 47 locations** (managed by the City of Las Vegas)<br>※ 4G and 5G are expected to be introduced in the future. Roadside units are planned to support multiple modes of communication including WiFi, Bluetooth, DSRC, 4G, 5G, etc.<br><Budgets for the activity><br>● The project is currently funded by the budget of Las Vegas. In 2019, the project is carried out under the federal budget (due to the project being part of the smart city projects).<br><Future developments><br>● The city will have a centralized system in the future toward building an environment in which roadside units can be remotely operated and troubleshooted. Also, smartphones will be utilized for pedestrians and cyclists. |
| Arizona, the U.S. | <Project outline><br>● Project area: Test bed in Anthem (about an hour's drive north of Phoenix)<br>● Number of locations where DSRC is deployed: **DSRC was deployed at 11 intersections on public roads** and a field operational test was conducted.<br>● Main use cases: Emergency vehicle and transit priority, calling attention to crossings and school zones, information on construction work<br>● Implementation system: **A government-academia partnership** (The University of Arizona and MCDOT have been in partnership for 20 years), in which the University of Arizona undertakes research and development, whereas administrative agencies implement policy measures.<br>● Related activities: Using connected vehicle data, the project implements signal control that provides hierarchical priority to traffic signal users of different traffic modes including rails, emergency vehicles, freight vehicles, buses, pedestrians, etc.<br><Project budget><br>● Highway Users Revenue Fund (HURF) derived from the state's **gasoline tax** (partially from federal funds)<br><Future developments><br>● The project results will be practically deployed for priority applications for emergency vehicles, then for transit vehicles and trucks and ultimately for ordinary vehicles. |

# 3.2 Survey of foreign cases

| Locations surveyed | Outline of the survey |
|---|---|
| The City of New York, the U.S. | <Project outline><br>• Project area: Midtown in Manhattan and parts of Brooklyn<br>• Number of locations where DSRC is deployed: **DSRC has already been installed at 350 intersections. 8,000 connected cars** are on the road. (of which about 3,000 are taxis and 700 buses)<br>• Use cases: **Red signal violation warning and others** in accordance with Vision Zero (a program to eliminate all traffic deaths on New York City streets by 2024)<br><Future developments><br>• A wider installation of roadside units is being prepared. Political decisions are expected to be made based on the results after two years. |
| The City of Vienna, Austria | <Project outline><br>• Project area: On the corridor connecting Rotterdam, Frankfurt and Vienna in **the Corridor Project**<br>The project started in 2013, **completed its evaluation phase 1 in 2017** and bidding was conducted in 2017 for the deployment phase 2.<br>• Use cases: Pedestrian priority traffic signal, **GLOSA**: (Green Light Optimum Speed Advisory) and **RLVW** (Red Light Violation Warning)<br>• Level of service: Provision of traffic signal information to drivers<br>(There are cases in which traffic signal information is used for autonomous mini-shuttle buses on fixed routes)<br><Future developments><br>• **Roadside infrastructure will be deployed by 2020. Actual operation is scheduled to start in or after 2020.**<br>• C-ITS use cases continue to be discussed with cities participating in the C-Roads project. New use case example: In addition to priority signal control (SSR, SRM) used for public transit, the project also assumes the use of these new message types for priority signal for police vehicles and fire engines.<br>• Expanded deployment is planned in the city of Vienna for traffic lights that are able to broadcast SPaT/MAP information (for the expansion of autonomous mini-shuttle bus service). |

# 3.3 Survey of foreign cases

| Locations surveyed | Outline of the survey |
|---|---|
| Anting town, China | <Project outline><br>• The idea for the development of the pilot zone was proposed in 2014 and the construction took place after receiving the development permission from the Ministry of Industry and Information Technology in 2015. It has been about two and half years since the start of operation of the pilot zone. The zone is classified by the following stages. Under the instruction of the country and Shanghai city, trial development of ICV (Intelligent Connected Vehicle) industries and pilot service provision were conducted.<br>1st stage: Development of closed test courses. Within the area, there are three closed test courses, zones for exhibition and education, as well as zones for application test projects and field operational tests for AI.<br>2nd stage: A test course on public roads. A 37.2 km course has been constructed with the support of Shanghai city.<br>3rd stage: A typical comprehensive pilot zone in the city. The entire Anting region serves as a pilot zone that has an average city population and traffic flow.<br>・There are **mainly two communication means, namely DSRC and LTE-V** on the test course. Emphasis is placed on the technology development using LTE-V, as it is expected to be replaced by 5G in the future. Tests for safety management, information services, the use of new energy and others can be performed.<br>• In the test area on public roads, **traffic signal information (cycle length information, count-down information for each direction) is provided at six intersections.**<br>• **The project has a global perspective and has been actively involved in activities** such as **participating in 5GAA.**<br>• **Society of Automotive Engineers of China has been promoting standardization** for communication protocol. Although not being the standard for the country or the region, it has already become an industry standard examined by all manufacturers and other organizations.<br>• **17 types of use cases have been determined**, in which five cases from DSSS are included.<br><Future developments><br>• The test course on public roads is planned to be further expanded.<br>• Both direct communication and communication via the Cloud are used for providing traffic signal information. Currently, decisions including the choice between the two communication methods have not been made, as the project is in the stage of collecting and analyzing test data. In the next stage, delay in providing information will be a major consideration. |

# (Reference) DSRC deployment status in U.S.

- SPaT Challenge (SPaT : Signal Phase and Timing)
  - ✓ The goal is to achieve deployment of DSRC infrastructure in at least one corridor or network (approximately 20 signalized intersections) in each of the 50 states by 2020.

https://transportationops.org/spatchallenge


SPaT deployment underway　SPaT deployment operational

| 26 | 216 | 2,121 |
| --- | --- | --- |
| States Committed | Signals Operating | Signals Planned |

# (Reference) DSRC (ITS-G5) deployment status in Europe

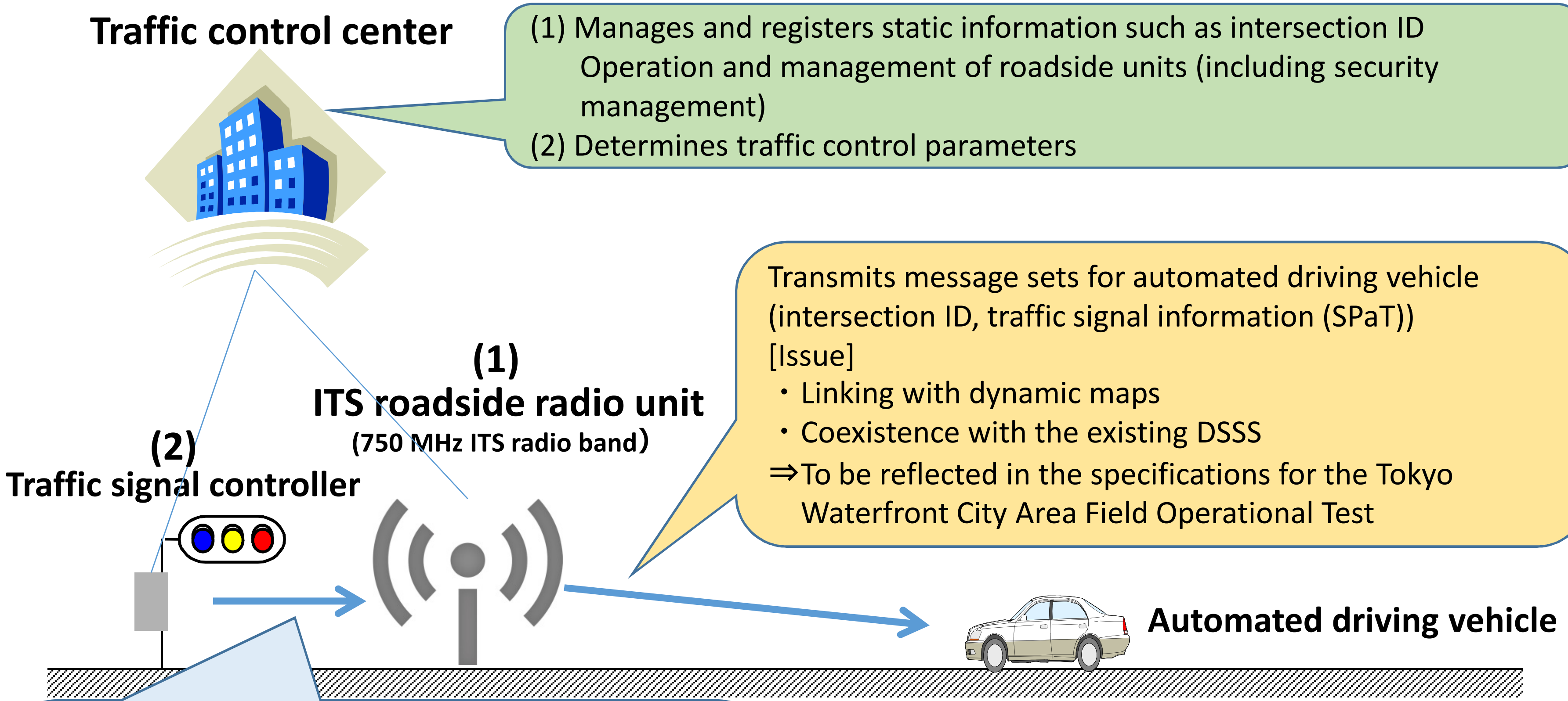
- The European Commission approved the use of “ITS-G5” as ITS stations and submitted a draft Regulation to the European Parliament.
  - ✓ Public comments invited (January 11 to February 8, 2019)
  - ✓ The Regulation will come into force on December 31, 2019.

- The Commission will review the Regulation after three years to consider new technologies.

  However, the new technologies (LTE-V2X and the Cellular 5G) must ensure interoperability with ITS-G5.

https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2017-2592333_en

# 4. Configuration a system to provide traffic signal information using ITS radio systems




(1) Manages and registers static information such as intersection ID
Operation and management of roadside units (including security management)
(2) Determines traffic control parameters

Transmits message sets for automated driving vehicle (intersection ID, traffic signal information (SPaT))
[Issue]
・Linking with dynamic maps
・Coexistence with the existing DSSS
⇒To be reflected in the specifications for the Tokyo Waterfront City Area Field Operational Test

Traffic signal information is output to ITS roadside radio unit.
[Issues]
・Events in which the number of remaining seconds of green time becomes uncertain.
・Fail-safe measures against failure of roadside units
⇒ Further examination, including the fabrication and verification of prototype, etc. is required in the next year and thereafter
・Provision delay/fluctuation time
⇒ Based on the experiment results, vehicle manufacturers agreed that the delays and fluctuations are within the allowable range.

Controls the vehicle speed and other conditions based on communication information, GPS information, dynamic maps, information of the vehicle (distance to the stop line, current speed and target deceleration speed).

# 5.1 Vehicle-to-infrastructure message sets for automated driving

- Achieve coexistence with DSSS

  **Share traffic signal information messages with DSSS** by effectively utilizing limited radio resources.

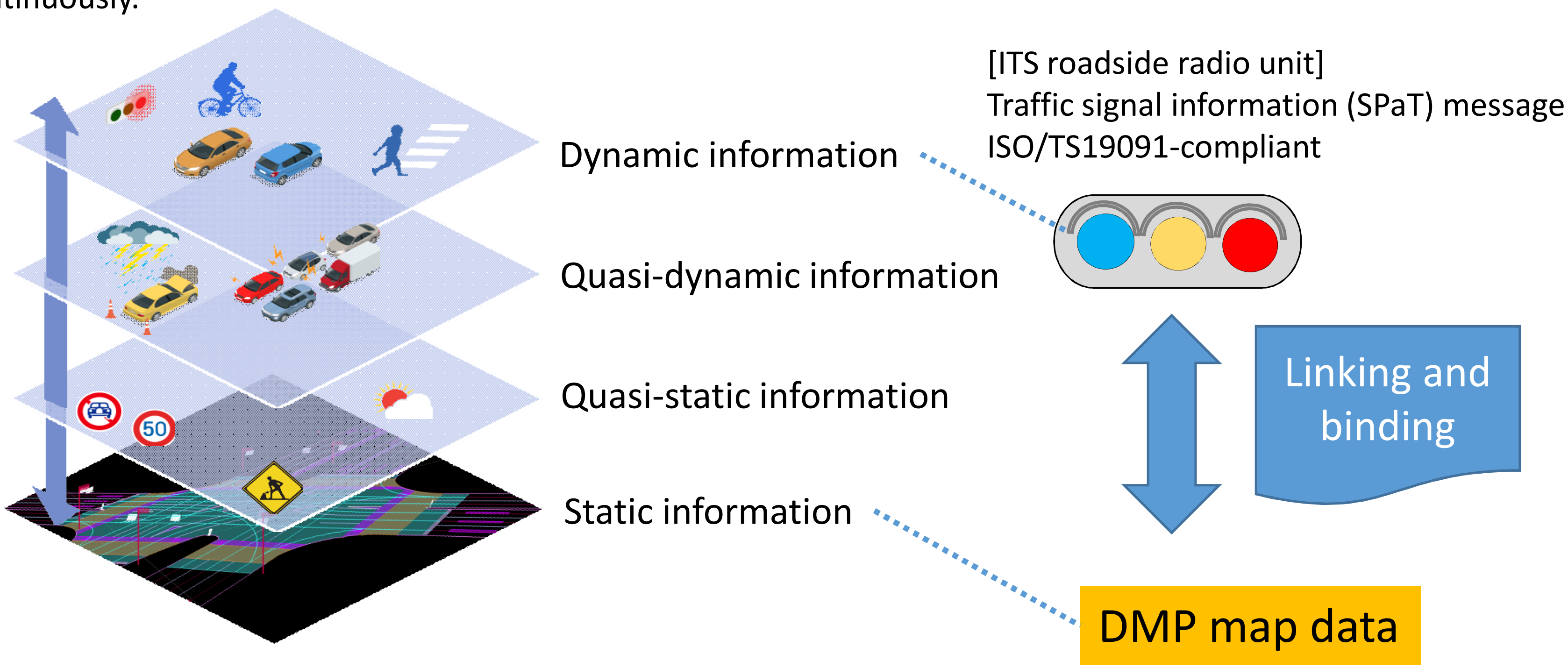
- Reduce the workload of preparing and maintaining road shape information which has been an issue faced by DSSS.

  **Link the information with dynamic maps and provide intersection identification information (such as IDs) instead of road shape information**

  **※ Evaluation during the Tokyo Waterfront City Area Field Operational Test**

- Additional issues to be examined in the future (under discussion with JAMA)

  Notification of special signal control modes that cause the number of remaining seconds of traffic light to change discontinuously.

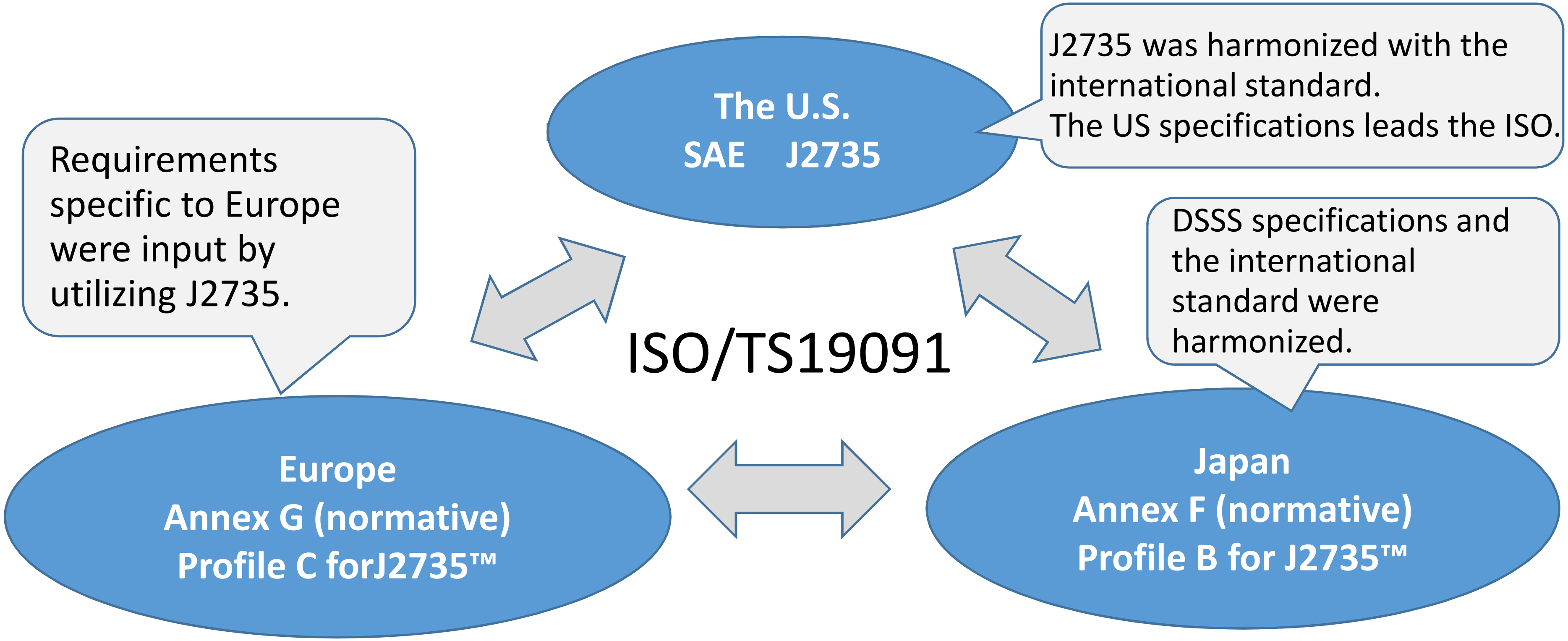



A concept of dynamic map

## 5.2 ISO/TS19091 (SPaT&MAP)

The standard was developed through ISO/TC204/WG18 (issued in March 2017: Editorial revisions are in progress)

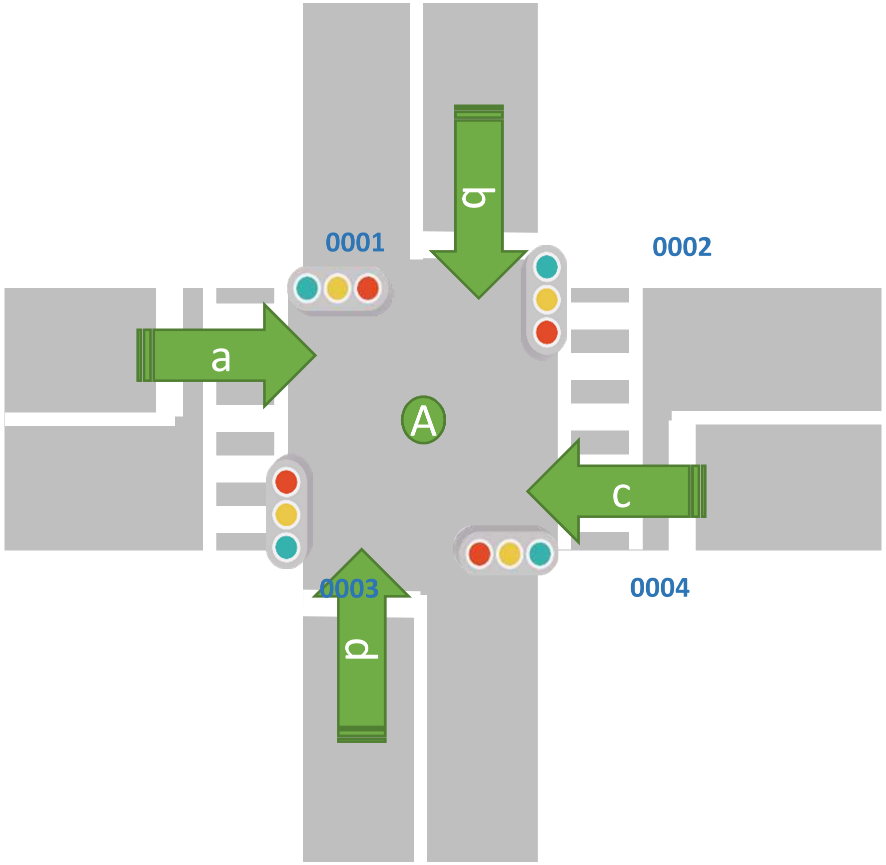
- Scope　Message set between vehicles and roadside equipment for cooperative systems (DSRC)
  Specifies data structure of traffic signal information (SPaT) and map information (MAP)
- Outline of the standard　Japanese and European specifications were input into the U.S. SAE Standard J2735.
  By referring to J2735, ISO specified individual profiles for each region.



# 5.3 Method of linking traffic signal information and DMP maps

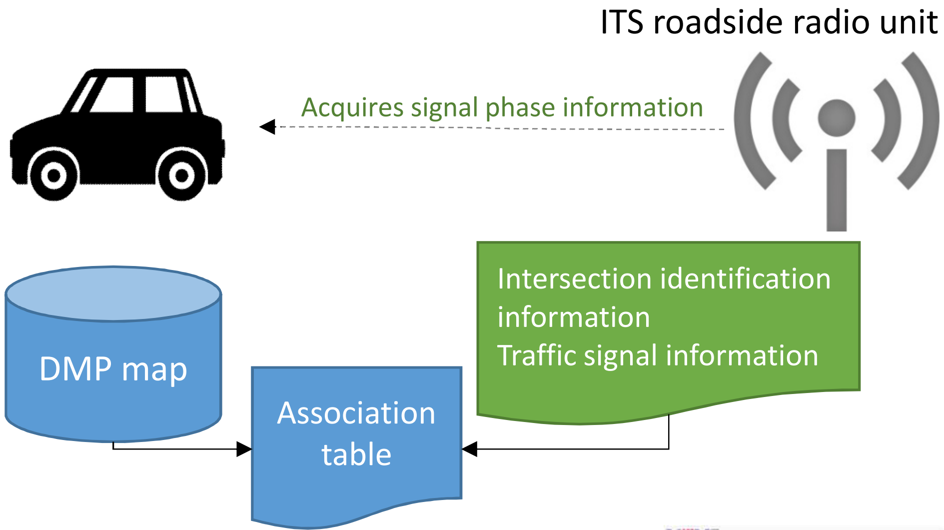
## ■ Linking method during the FOT before the Olympic and Paralympic Games

The association table between intersection identification information (intersection IDs, route IDs) provided from ITS roadside radio units and DMP traffic light information is held by the on-board unit.




**Association table between ITS radio and DMP**

| DMP Traffic light ID | DMP Mesh ID | ITS radio Intersection ID | ITS radio Route ID |
|---|---|---|---|
| 0001 | xxxx | A | d |
| 0002 | xxxx | A | a |
| 0003 | xxxx | A | c |
| 0004 | xxxx | A | b |



# 6.1 Examination to reduce events in which traffic signal information becomes uncertain

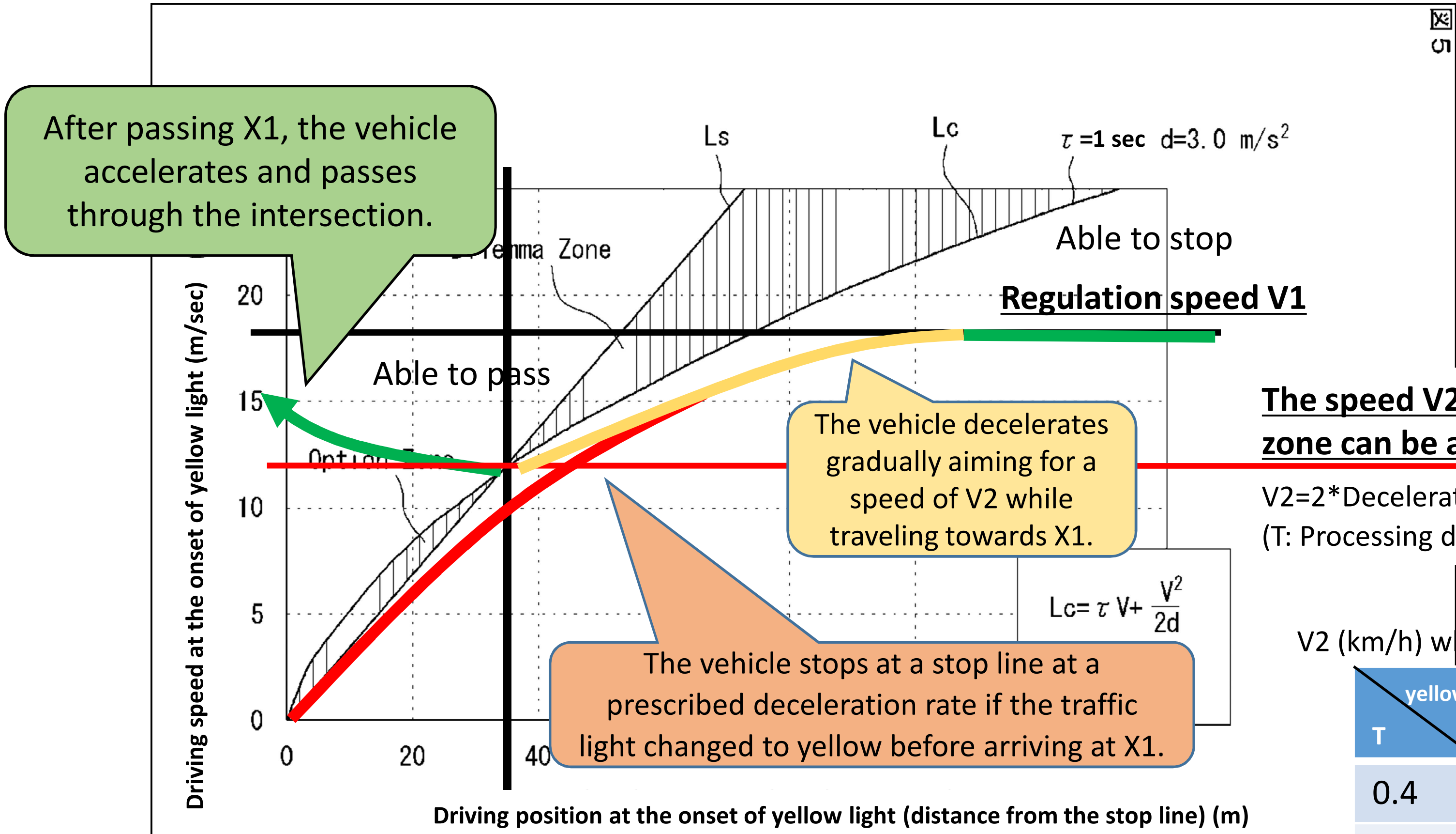
[Extraction of events in which traffic signal information becomes uncertain]

| No | Control type | Current status (DSSS specification) | Draft response policy |
|---|---|---|---|
| 1 | Push-button control | Unable to provide traffic signal information | Provision of current signal light color + analysis of the information that can be provided about the remaining number of seconds and examination of the possibility of the utilization of the information by the vehicle. |
| 2 | Interlocking slave unit | | Centralization of slave units through infrastructure-to-infrastructure communication via ITS radio system. |
| 3 | Step hold by manual operation | | Provision of current signal light color only. |
| 4 | Security operation Abnormal flashing | | Provision of traffic signal information is suspended due to fail mode. |
| 5 | Common traffic-actuated control | Provides minimum and maximum number of seconds<br>In the case of PR-actuated control, the signal changes to yellow when the minimum number of seconds of green time becomes 0. | • Recommendation of PG actuation and longer yellow time (4 seconds)<br>for intersections where regulation speed is high (dilemma tends to arise) |
| 6 | Emergency vehicle priority control | Only the current signal color is provided while the control is active. | Notification of the target intersection identification information and that actuation is active.<br>Provision of current signal light color + analysis of the information that can be provided about the remaining number of seconds and examination of the possibility of the utilization of the information by the vehicle. |
| 7 | Status change<br>・Blinking at night time<br>・Time difference control at peak times<br>・Responses in the event of disasters | Provides traffic signal information assuming that this status will continue during the next cycle. | Draft 1 Disclosure of information about intersections whose state is controlled.<br>Draft 2 Temporary suspension of operation before and after the status switching |

PG, PR: Vehicle green time consists of pedestrian green (PG), pedestrian flashing (PF) and pedestrian red (PR).

## 6.2 Driving model example when the vehicle cannot acquire future traffic signal information

(1) Starts preliminary deceleration during the green signal in order to avoid entering the dilemma zone.
(2) Accelerates immediately after passing the point X1 where the vehicle is confirmed to be able to enter the intersection and therefore can avoid entering the dilemma zone.




**Point X1 at which entering dilemma zone can be avoided**

X1 = Yellow time × V2

**The speed V2 at which dilemma zone can be avoided**

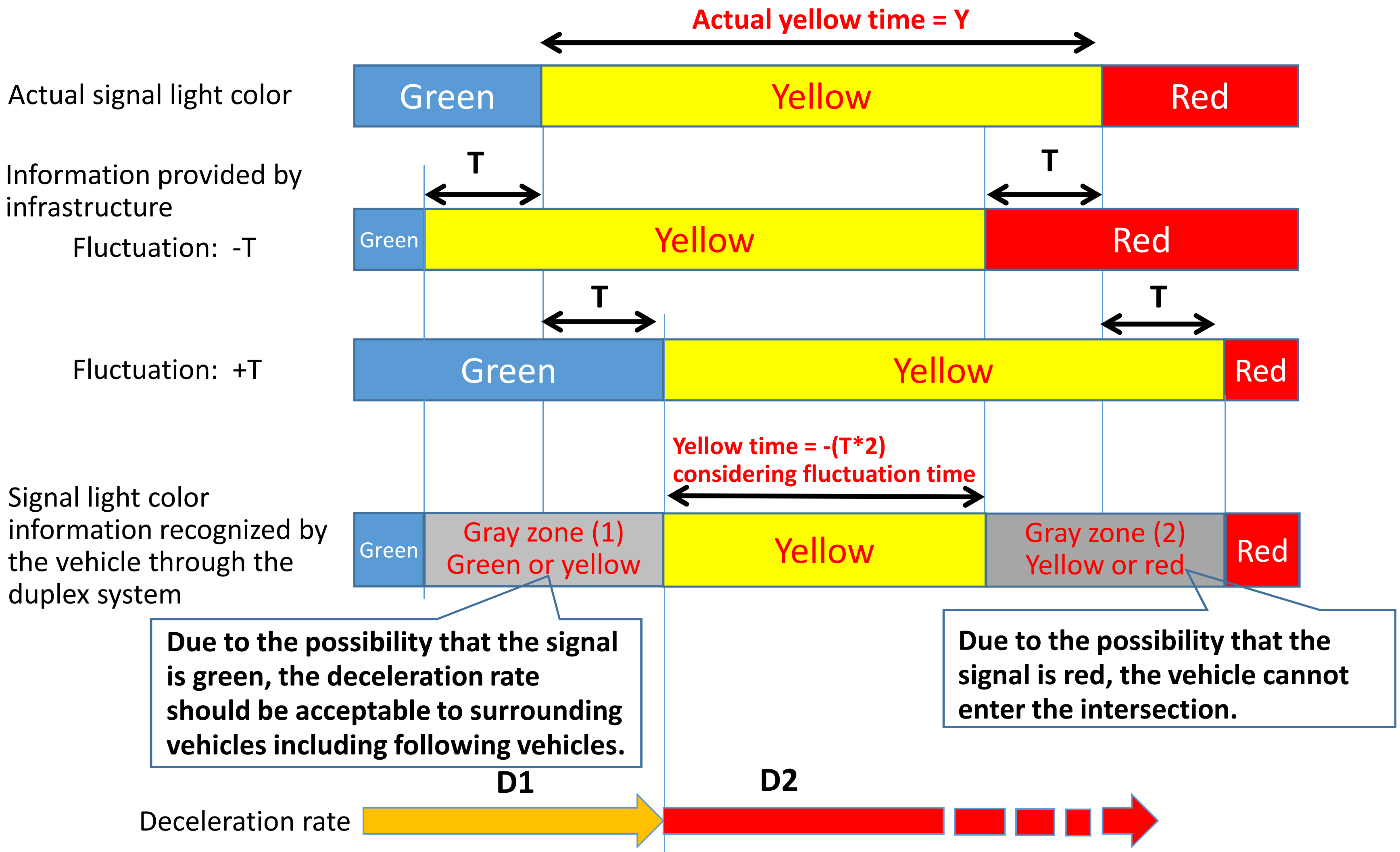
V2=2*Deceleration rate ×(yellow time - τ)
(T: Processing delay)

V2 (km/h) when deceleration rate = 1.8

| T \ yellow | 3 | 4 |
|---|---|---|
| 0.4 | 33.7 | 46.7 |
| 0.5 | 32.4 | 45.4 |

# 6.3 Driving model example that takes into account provision delays and time fluctuations

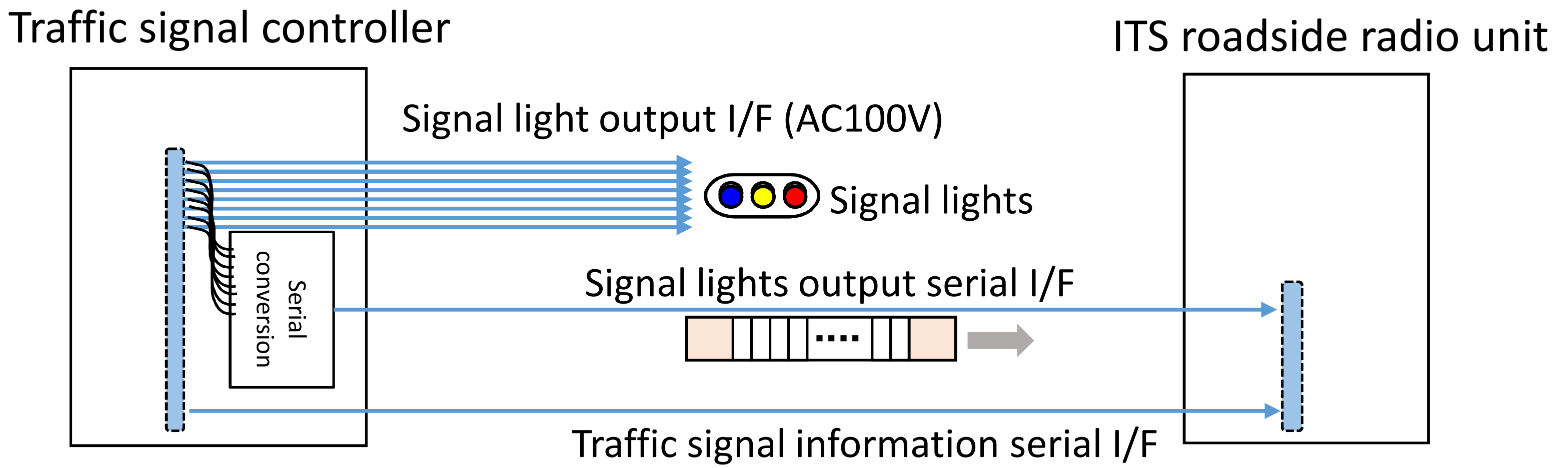
◆Assumptions: Remaining number of seconds are corrected by provision delay (experiment results example: approximately 0.4 seconds).
Automated driving is controlled in consideration of time fluctuation T (experiment results example: less than ± approximately 0.1 seconds).



# 7. Draft fail-safe specifications for roadside infrastructure

[Assumed requirements]

- Checks consistency between the lighting status of all green lamps and traffic signal information.
- Stops providing traffic signal information immediately if any inconsistency was detected.




(1) Traffic signal controller monitors the voltage of signal light outputs that control the lighting up of signal lights.
(2) The monitoring results are converted to serial data and transmitted to ITS roadside radio unit.
(3) Traffic signal information is transmitted via a circuit other than the one mentioned above.
(4) Consistency of both types of information is checked by ITS roadside radio unit.
(5) If inconsistency was detected, the roadside unit immediately stops providing traffic signal information (notifies the vehicle of the abnormal suspension).

# 8. Future issues

■ Issues in the Tokyo Waterfront City Area Field Operational Test

✓ Verification for the utility of traffic signal information provided by ITS roadside radio units in the automated driving environment

- Contributions to safety: Reduction in sudden decelerations for a stop light
- Contributions to smooth flow: Reduction in starting delays at the onset of green

✓ Verification of the acceptance to the assumed automated driving models.

- Public acceptance to the automated driving models such as preliminary deceleration and their impacts on surrounding vehicles

■ Future issues

✓ Finalization of requirements relating to the enhancement of roadside infrastructure, and its prototyping and verification

- Enhancement of the fail-safe function
- Measures for cases in which the number of remaining seconds of signal phase becomes uncertain

✓ Identification of guidelines for the operation of traffic signal control, including establishing operating rules for traffic-actuated control and determination of yellow time in response to the coexistence with automated driving.