Cross-ministerial Strategic Innovation Promotion Program (SIP) Phase Two / Automated Driving for Universal Services / Update of High-precision Three-dimensional Map with Vehicle Probe Data

Final Results Report

March 2021
Dynamic Map Platform Company, Ltd.

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DMP-PD-OC-137

Table of Contents

Ref. FY2020 implementation results

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[Results and issues from last year]

- Camera image data (hereinafter “image data”)
  - In actual operation, the scheme outlined in blue would be best, but there are no mechanisms for vehicle-side processing.
  - The scheme outlined in red is well suited for rapid deployment, but the results could be affected by differences between drive recorders (erroneous detection due to the level of accuracy of GNSS positioning), etc.
- Vehicle probe data
  - In ideal environments, it could be possible to use this to identify road changes.
  - There are issues such as data scope and effectiveness issues that would present difficulties for rapid deployment.

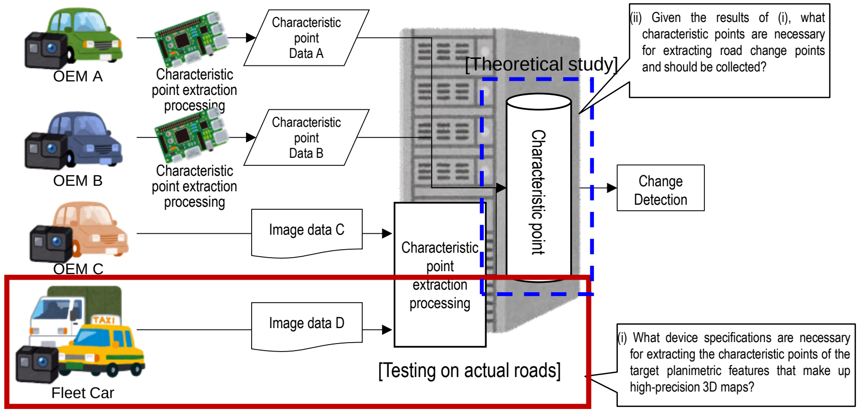

Fig. Schemes for collecting image data

[Contents of measures implemented this fiscal year]

- Image data
  - Deliberate regarding required specifications for devices such as drive recorders to collect the image data needed to extract characteristic points in order to deploy the scheme outlined in red (red box).
  - Consider characteristic point requirements and organize the approach to standardization, etc., with an eye towards deployment in the future (general roads/Global) (blue box).
- Vehicle probe data
  - Use the results of studies up to and including 2019 to organize information regarding issues involved in extracting road change points from vehicle probe data and explore the possibility of using vehicle probe data in actual operation.

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2. Schedule

■ The schedule for this fiscal year was as shown below.

<table>
<tr><th colspan="3" rowspan="2">Contents of implemented measures</th><th colspan="9">2020</th><th colspan="2">2021</th></tr>
<tr><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th></tr>
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<tr><td colspan="3">Future issues and prospects</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Examination of operational issues, etc., based on results of above technologies</td></tr>
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3. Implementation results

1) Deliberation of device specification requirements ((i) FOTs implementation/evaluation)

- The “results of visual confirmation by the map updater (true values)” and “results of identification of change points through the use of road change point extraction technologies (technology)” were used to confirm the accuracy of identified results, and precision and recall rates were calculated.
- There were some locations in which the map updater judged there as being no changes but the road change point extraction results judged that there were changes (shown in red). The results of confirmation of these locations are shown on the following page.

Table Comparison of results produced by road change point extraction technology and results of visual confirmation by map updater

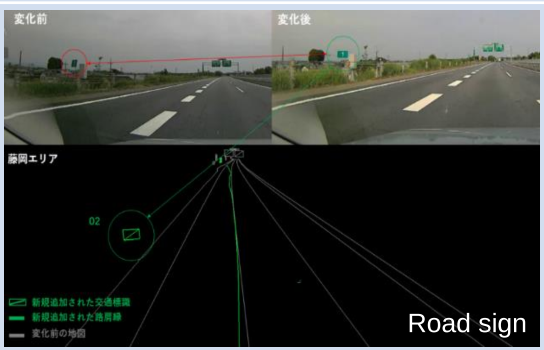
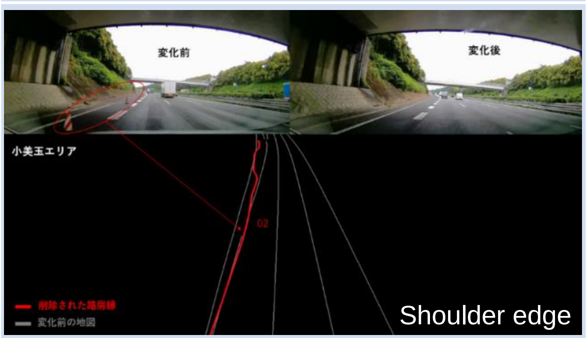
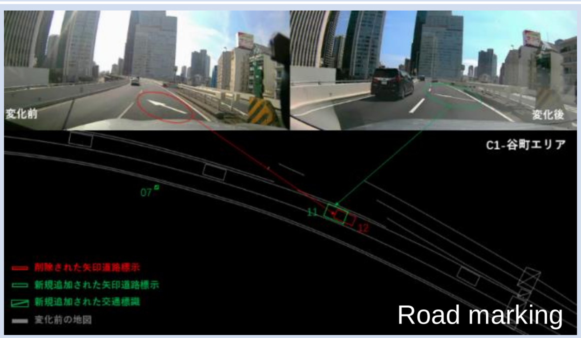
Planimetric feature	Content of changes	True Positive True value: Change Technology: Change	False Positive True value: No change Technology: Change	False Negative True value: Change Technology: No change	Precision Precision= TP/(TP+FP)	Recall Recall= TP/(TP+FN)
Shoulder edge	Addition	2	0	0	100%	100%
	Removal	3	2	0	60%	100%
Road sign	Addition	8	1	0	89%	100%
	Removal	19	5	0	79%	100%
Road marking (Arrow)	Addition	0	1	0	0%	0%
	Removal	0	1	0	0%	0%

Precision: Percentage of data detected as indicating a change that was actually a change
Recall: Percentage of actual changes that are detected as changes

1) Deliberation of device specification requirements ((i) FOTs implementation/evaluation)

- There were 10 false positives, in which the road change point extraction technology judged that there was a change but the map updater judged that there was not. The reasons for the map updater judging that there was no change were confirmed, and the results are shown below.
- With the exception of one case that did not meet acquisition standards, the rest of the cases were determined to be oversights by the map updater. It was confirmed that using road change point extraction technology could more accurately extract road changes.

Table Results of confirmation of reasons for false positives

Item	Situation 1	Situation 2	Situation 3
Reason	Sign did not meet DMP acquisition standards	Not detected by the map updater	
		Overlooked during visual confirmation	Map updater was unable to determine through visual observation if there were changes
Quantity	1 locations	7 locations	2 locations
Appearance (excerpt)			

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1) Deliberation of device specification requirements ((i) FOTs implementation/evaluation)

- Based on the results in the preceding pages, it was determined that road change points could be extracted without problems by using devices with functionality equivalent to that of the devices (TransLog) used in (selected for) the test.
- In order to confirm the availability of products that meet the specifications in the table below, determined based on the test results, etc., a study of device specifications was performed, as indicated below, of the drive records, etc., in the list published by the Cabinet Office of devices that support Michibiki (the quasi-zenith satellite system) (list current as of December 2020)
  - Of the manufacturers of drive recorders in the list of devices that support Michibiki, the study examined the products for which device specifications could be confirmed (13 products from 6 companies)
  - The study also examined products for industrial use vehicles using information published separately (7 products from 5 companies)

* Some manufacturers are included in both categories

Table Device specification requirements based on results of the FOTs (draft)

Required		Recommended specifications	Reference: TransLog (DN-CDR)
Device	Function		
GNSS	Coordinate value	(Open sky) 5 m or less (Urban) 20 m or less	Point positioning
	Speed	2Hz	2Hz
IMU	Angular velocity, acceleration	100Hz*	100Hz
Odometer	Movement distance	50Hz*	1Hz
Camera	Angle of view	Horizontal 118 to 135 deg	Horizontal 118 deg
	Resolution	HD (1280x720)	HD (1280x720)
	Frame rate	22Hz	22Hz

* One of these two requirements must be met

1) Deliberation of device specification requirements ((i) FOTs implementation/evaluation)

- The study of products that met the requirements was unable to determine based on published information alone if GNSS, Odometer, and IMU devices met requirements, so confirmation had to be performed using actual devices. The study did confirm, however, a relatively high level of availability for products with cameras that met camera requirements.
  - 17 of the 20 products met camera specification requirements.
  - Some specification information had not been published for 15 of the 20 products (GNSS, IMU, etc.), so ultimately it was not possible to determine if they met recommended specifications. However, because these specifications were typical specifications, many products are believed to meet these specifications.

Table No. of products meeting device specification requirements

Required		Recommended specifications (requirements)	Recommended specifications		
Device	Function		No. of products meeting specifications	No. of products not meeting specifications	No. of products with unknown specification conformance
GNSS	Coordinate value	(Open sky) 5 m or less (Urban) 20 m or less	-	-	-
	Speed	2Hz	3	5	12
IMU	Angular velocity, acceleration	100Hz*	2	3	15
Odometer	Movement distance	50Hz*	0	13	7
Camera	Angle of view	Horizontal 118 to 135 deg	9	10	1
	Resolution	HD (1280x720)	17	2	1
	Frame rate	22fps	19	1	0

* One of these two requirements must be met

1) Deliberation of device specification requirements ((i) FOTs implementation/evaluation)

- Even if images are collected in accordance with stipulated product specifications, it may not be possible to confirm conditions in distant lanes, which could result in data gaps when modeling is carried out.
- To prevent this, in addition to collecting image data, data must be acquired from industrial use vehicles using procedures that avoid situations in which conditions in distant lanes cannot be identified. We have therefore organized a draft of the operation requirements for collecting all necessary image data, as shown below.
  - In the future, based on the requirements below, we will need to coordinate with business operators that use expressways and confirm the extent to which they can collaborate in this process. Based on this confirmation and coordination, we will need to identify to what degree this can be carried out in this project. Image data is already being stored in some drive recorders, so we will need to deliberate regarding efficient ways of sharing data with business operators.

Table Operation requirements for preventing reductions in quality of modeled results (draft)

Category	Requirement	Contents	Details
Collection	Driving method	Target route	All routes, including tunnel and bridge areas (excluding routes on which accidents have occurred)
		Lanes to be driven	All lanes or center lanes only (the second lane for three lane routes, the second and third lanes for four lane routes)
		No. of drives	Two lane roads: Two or more drives per lane or six or more drives on one of the two lanes Three lane roads: Two or more drives per lane or six or more drives on the second lane Four lane roads: Two or more drives per lane or six or more drives on either odd or even numbered lanes
		Collection frequency	Twice or more per week (to ensure that a sufficient number of drives is performed for the extraction of change points over the course of a month even when driving is only performed on one of the lanes of a two lane road)
		Driving speed	Not specified (obey speed limits)
	Imaging environment	Weather	Clear and cloudy days are best. Imaging cannot be performed during rain or snow.
		Weekdays/weekends/holidays, time of day	Ideally during the day while the sun is up and during times when there is little traffic volume
		Road surface conditions	Ideally in road surface conditions between dry and damp. Imaging cannot be performed when road surfaces are wet, there is fallen or compacted snow, the road surface is icing, or there is frozen slush. * Reference: https://ihighway.jp/pcsite/top/load/static/snowinfo/index.html
		Other	Imaging cannot be performed when there are traffic jams
Other	Vehicle	Vehicle use	Used to observe road conditions
		Vehicle size	Passenger vehicle

2) Deliberation of characteristic point requirements ((ii) when the road change point extraction technologies examined in (i) are used)

- The methods indicated on the preceding pages would be effective for specific roads (such as expressways).
- However, considering deployment in the future (general roads/Global), there is also a need to deliberate regarding methods for gathering data from a large number of sources, such as cameras in ordinary vehicles.
- To reduce the data communications overhead involved and ensure anonymity, characteristic points must be extracted using edge processing before accumulating processed data.
- Based on the results of the FOTs, we performed a theoretical study of the requirements for the characteristic points to be collected (content of required information, frequency of information collection (collection intervals), and accuracy).

Table Requirements for characteristic points envisioned for future operation

Name	Item, collected contents, etc.		Collection frequency
Planimetric feature data	Carriageway line	• Locations (centers) of carriageway edges, carriageway center lines, lane lines, etc. • Attributes (line type, line color, line width, multi-line information, etc.)	High frequency (Ref.: 0.1s)
	Physical structure	• Locations of border lines, etc., delineated by physical structures such as continuous series of curbs, walls, guardrails, poles, etc.	
	Road sign	• Locations of centers of road sign faces • Attributes (normal vectors, sizes (width and height of bounding rectangles of road sign faces), types, auxiliary sign information, etc.)	
	Traffic light	• Locations of centers of traffic light faces • Attributes (normal vectors, sizes (width and height of bounding rectangles of traffic light faces), types)	
	Road marking	• Locations of stop lines, pedestrian crossings, road markings such as arrows and zebra crossing zones, etc. (center of bounding box, bottom left edge of bounding box, bottom right edge) • Attributes (depth from bottom center of bounding box, type (stop line, pedestrian crossing, arrow road marking, direction of arrow, etc.))	
	Reliability information	• Information regarding factors that could reduce accuracy when acquiring data (road grade, acquisition within tunnels, etc.)	
Location, speed, and time data	Own vehicle location	• Location information calculated based on GNSS data • Location information calculated from vehicle trajectory inferred based on image data (including pitch, roll, and yaw attitude information)	High frequency (Ref.: 0.1s)
	Speed	• Vehicle speed	
	Time	• Time information from each device (GNSS, camera)* * Time is not synchronized, so vehicle position information (two types) are used to perform positioning and determine time differences	
Other	Camera mount position	• Drive recorder mount position (origin point used to calculate relative location coordinates of planimetric feature data)	Low frequency (Ref.: 1h)

* The above collected data is envisioned as being sufficiently accurate to determine lanes (sub-meter level accuracy). Planimetric feature location coordinates are calculated based on relative location with respect to the vehicle's own location (absolute value specified in terms of longitude and latitude).

3.1 Road change point extraction technology using image data

2) Deliberation of characteristic point requirements (direction to be used in standardization)

- It is vital that characteristic points be standardized in order to comprehensively and efficiently extract road change point from information provided by numerous vehicles.
- Data was gathered through a review of the literature, such as "Existing standards for collecting data involved in map updates", and interviews with experts. This data was then organized. The two following standards apply to change information involved in the updating of high-precision three-dimensional(3D) maps.
  - Sensor Interface Specification/SENSORIS
  - Vehicle information shared concept specifications/JASPAR vehicle information sharing working group

  * ISO20078 applies to information used in failure diagnosis
- We analyzed differences between JASPAR and the information on the preceding page
  - This is because SENSORIS must be adjusted to fit the systems used in Japan, such as road signs, road markings, etc.
  - The range of information shared between vehicles and the cloud for which standardization is considered necessary varies depending on individual companies' conditions and architecture. It is also not feasible to identify and standardize all shared data.
- Feedback will be provided to JASPAR based on the analysis results of this study.

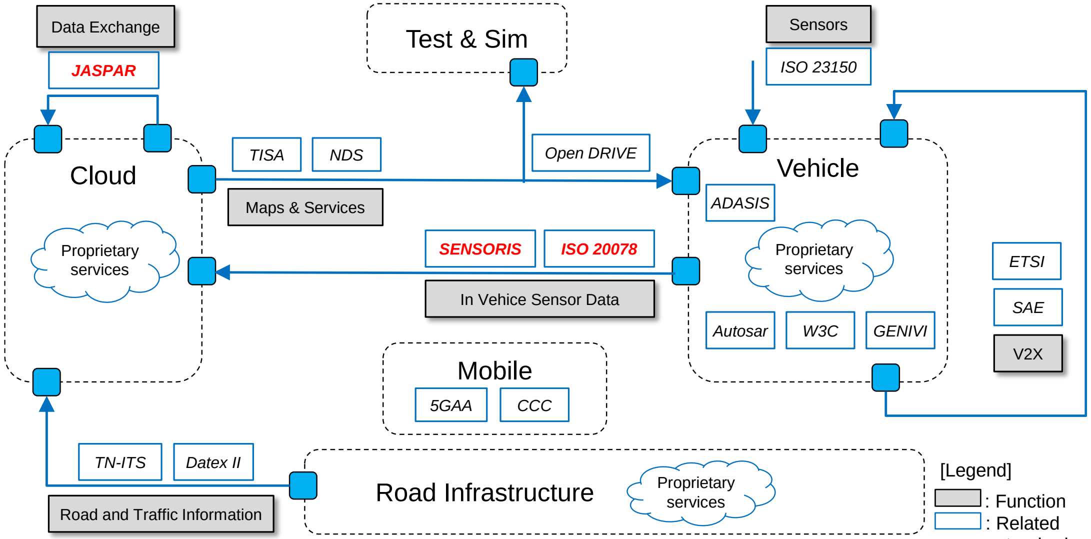

Fig. Methods of passing vehicle data and related standards

Source: Modified version of figure that appears in 2018 SIP-adus Workshop OADF presentation materials

Table Characteristic point requirements and analysis of differences from JASPAR

Name	Item, collected contents	Existence of information item	Lacking attributes	Other
Planimetric feature data	Carriageway line	Yes	• Carriageway marking types cannot be indicated • Multi-line information cannot be indicated	–
	Physical structure	Yes	• Guardrails and poles can be indicated as types of protective barriers • Curbs, walls, and other physical structures cannot be indicated.	• Carriageway widths can be indicated, so the locations of physical structures such as curbs, walls, etc., can be inferred
	Road sign	Yes	• (No lacking attributes)	–
	Traffic light	Yes	• (No lacking attributes)	–
	Road marking	Yes	• Cannot indicate multiple items of location information, such as centers, bottom left edges, and bottom right edges of bounding boxes	–
	Reliability information	None	–	• Accuracy can be indicated within JASPAR (on a five-point scale decided on by users)

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DYNAMIC MAP PLATFORM

3.2 Road change point extraction technology using vehicle probe data

Application scope hypothesis verification and information organization

- We defined the application scope along two axes: the size of the change to be extracted (large or small) and the location of the road where extraction is performed (urban or suburban). We then performed a comprehensive evaluation of the suitability of each sector using the evaluation parameters of operation-related properties, vehicle driving environment, and vehicle probe data acquisition and analysis conditions.

- Defining application scopes

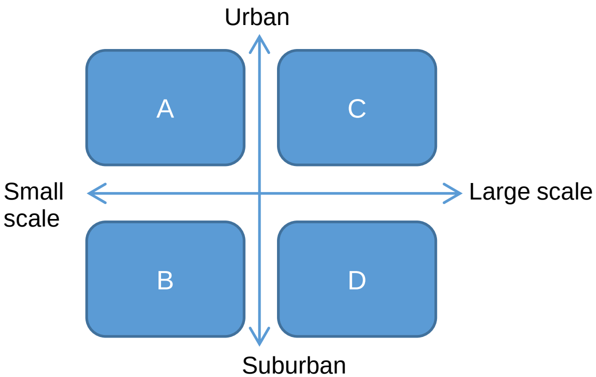

Fig. Evaluation axes

* Urban expressways and expressways connecting Tokyo, Nagoya, and Osaka were defined as “urban” areas, while all other areas were defined as “suburban” areas.

Table Results of evaluation of the suitability of the areas in the figure at left to extracting change points using vehicle probe data

Issue perspective	Small-scale change		Large-scale change	
	A Urban	B Suburban	C Urban	D Suburban
Operation-related issues	○:High potential * Planimetric feature density is high and changes are frequent, creating the potential for changes to go undetected	△: Medium potential * Planimetric feature density and change frequency are relatively low, but it is necessary to confirm that there have been no changes	△: Medium potential * Planimetric feature density and change frequency are relatively low, but it is necessary to confirm that there have been no changes	Medium potential * Planimetric feature density and change frequency are relatively low, but it is necessary to confirm that there have been no changes
Quality issues (Vehicle driving environment)	X: Not suitable The measurement environment is relatively poor	X: Not suitable The measurement environment is relatively good but there are few changes that can be determined through measurement	△: Partially suitable The measurement environment is relatively poor	○:Suitable The measurement environment is relatively good Changes can be detected without seasonal/weather influences
Quality issues (Vehicle probe data acquisition and analysis)	△: Partially suitable The level of data comprehensiveness is high, but data is easily affected by noise	○:Suitable The level of data comprehensiveness is low, but data is not easily affected by noise	△: Partially suitable The level of data comprehensiveness is high, but data is easily affected by noise	○:Suitable The level of data comprehensiveness is low, but data is not easily affected by noise. The level of data comprehensiveness can be adjusted through the timing of data collection.
Overall evaluation	X: Not suitable The measurement environment presents disadvantages and there are complex road structures, so noise countermeasures are necessary. Although operational expectations are high, for small-scale changes, the likelihood of detection is low even when conditions are good, so the use of these technologies is not suitable in this sector	△: Partially suitable Good measurement environments can be maintained, and road structures are relatively simple, which keeps data relatively free of noise. From an operational vantage, there are some expectations for this sector, but the likelihood of detecting small-scale changes is low even when conditions are good, so the suitability of this sector is limited.	△: Partially suitable The measurement environment presents disadvantages and there are complex road structures, so noise countermeasures are necessary. From an operational vantage, there are some expectations for this sector, but there are concerns about cost effectiveness after implementing countermeasures.	○:Suitable Good measurement environments can be maintained, and road structures are relatively simple, which keeps data relatively free of noise. From an operational vantage, there are some expectations for this sector, and the level of suitability is highest for this sector.

- ➢ The high reliance on measurement environments makes suburban areas highly suitable. Within these areas, large-scale changes had the highest level of suitability.
- ➢ One issue that will require future consideration is the expansion of the scale to which these technologies are applied, such as assessing which areas have highly conducive conditions, even if these only apply to parts of those areas, because change frequencies are low and application scopes are limited.

4. Results and future measures

4. Results and future measures

- **Practical implementation**
  - We confirmed that road change point extraction technologies could be implemented to extract road changes with a greater level of accuracy.
  - We confirmed that commercially available drive recorders could be used, without the need for specialized devices.
  - We organized the operation requirements for collecting all necessary image data, without omission, for use in actual operation.
  - We plan to coordinate business-related factors, such as how costs will be borne, and practically implement the extraction of change points using image data starting in fiscal year 2022.
    - However, the degree to which vehicle probe data can be applied to extract change points in high-precision 3D maps is limited, so we will move forward with the extraction of change points using image data instead.
- **Future initiatives (future issues)**
  - In preparation for the maintenance phase, which will begin after high-precision 3D maps are prepared for general roads, we will (1) keep a close eye on the movements of other parties (in other countries) while approaching concerned parties through standardization activities, etc., (2) build a scheme for extracting characteristic points on the vehicle side and uploading them, and (3) deliberate regarding methods for creating and operating a system for analyzing and integrating data (characteristic points) sent by vehicles and using this data to detect change points.

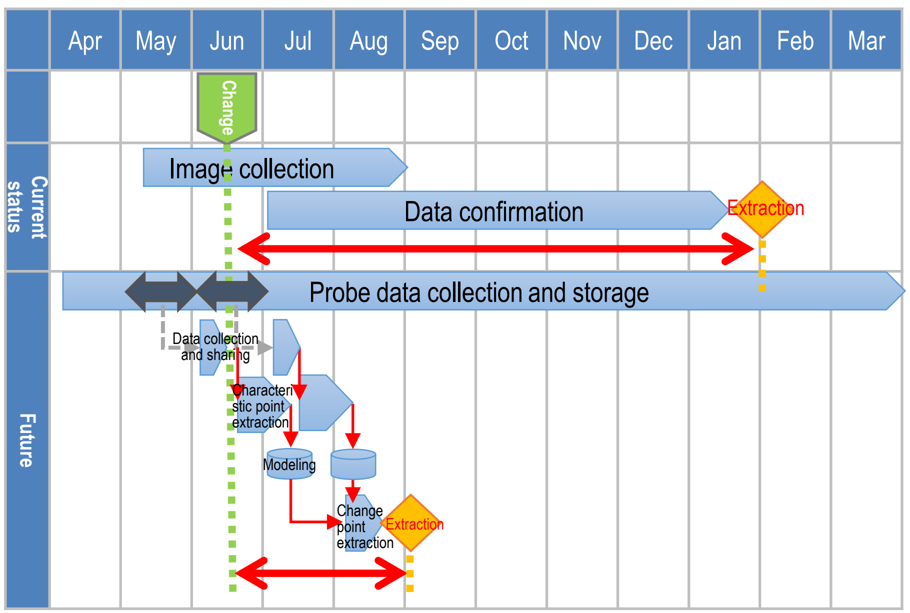

Fig. Pipelined operational processes and lead times

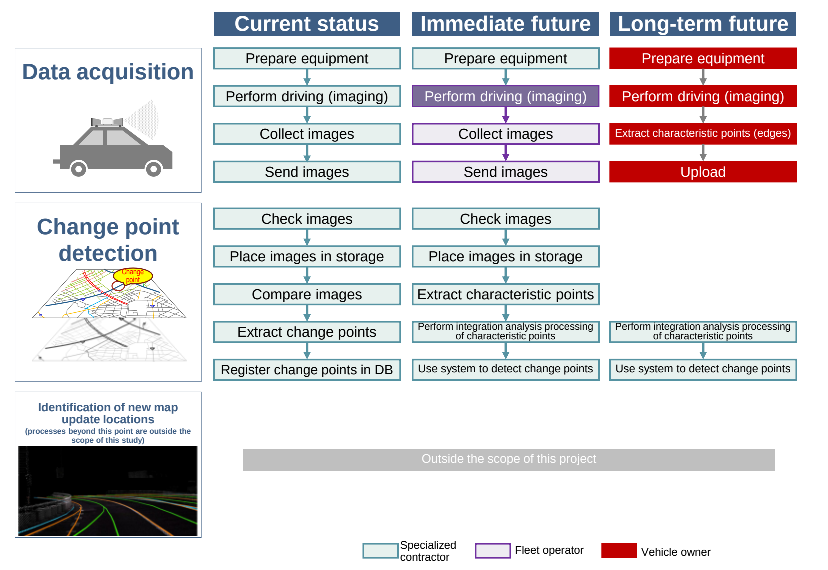

Fig. Envisioned work processes and cost reduction potential

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Appendix

Contents of measures implemented in FY2020

DYNAMIC MAP PLATFORM

Background and objectives

- Updating high-precision 3D maps imposes substantial costs and lead times
- Detection of change points is the most upstream process of all update processes, and is the most important process
- Updating maps requires diverse change data. Existing administrator data alone is insufficient.
- Different ways of detecting changes are currently being explored. One of those ways is the use of probe data.

- **In addition to using administrator data, it is also essential to develop technologies for identifying road changes based on probe data**
- **We aim to use the results of this verification work to reduce costs and lead times, to deploy systems globally, and to extend systems to general roads.**

	Change data necessary for updating high-precision maps	Detection possible?
Related to road structure changes	New road construction	○
	Road extension	○
	Cruising line shape changes	○
	Increase/decrease in number of lanes	○
	Lane widening	○
	Interchange construction, decommissioning, relocation	○
	Service Area/Parking Area construction, decommissioning, relocation	○
	Junction construction, decommissioning, relocation	○
	Toll booth construction, decommissioning, relocation	○
	Divergence/merging position changes	○
Not related to road structure changes	Increase/decrease in number of lanes	△
	Lane widening	△
	Divergence/merging position changes	△
	Physical structure construction, decommissioning, relocation	×
	Zebra crossing zone creation, removal, changes	×
	Carriageway marking solid line/dashed line/color changes	×
	Emergency parking area creation, removal, changes	×
	Carriageway marking repainting	×
	Road sign installation, removal, changes	×
	Road marking creation, removal, changes	×
	Traffic light installation, removal, changes	×

Change data to be identified in this verification project

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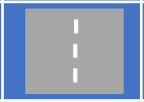
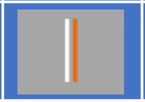
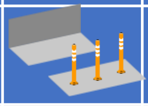
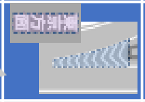
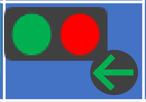
Changes in roads and current issues with change extraction

	Change information	Planimetric features in high-precision 3D maps							Ease of acquisition of information necessary for change extraction (as of current time)
		Lane center line 	Carriageway line 	Multiple carriageway line 	Shoulder edge 	Road marking 	Road sign 	Traffic light 	
Related to road structure changes	New road construction	○	○	○	○	○	○	○	No issues
	Road extension	○	○	○	○	○	○	○	
	Cruising line shape changes	○	○	○	○				
	Increase/decrease in number of lanes	○	○	○	○	○			
	Lane widening	○	○	○	○				
	Interchange construction, decommissioning, relocation	○	○	○	○	○	○		
	Service Area/Parking Area construction, decommissioning, relocation	○	○	○	○	○	○		
	Junction construction, decommissioning, relocation	○	○	○	○	○	○		
	Toll booth construction, decommissioning, relocation	○	○	○	○	○	○	○	
	Divergence/merging position changes	○	○	○	○	○			
Not related to road structure changes	Increase/decrease in number of lanes	○	○	○					Issues
	Lane widening	○	○	○					
	Divergence/merging position changes	○	○	○		○			
	Physical structure construction, decommissioning, relocation				○				Issues
	Zebra crossing zone creation, removal, changes					○			
	Carriageway marking solid line/dashed line/color changes		○	○					
	Emergency parking area creation, removal, changes		○			○	○		
	Carriageway marking repainting		○	○					
	Road sign installation, removal, changes						○		
	Road marking creation, removal, changes					○			
	Traffic light installation, removal, changes							○	

Extract changes that did not involve road structure changes from probe information (vehicle probe data* and image data*)

* This research and development project uses the term "vehicle probe data" to refer to vehicle probe data such as driving trajectories, driving operation histories, etc., and the term “image data" to refer to road environment data sensed by sensors, cameras, etc.

Study procedure (process)

- The study process used in this research and development project is shown below. The portions outlined in red were implemented in FY2020 (this fiscal year).
- A study was performed of road change point extraction technologies used to identify changes in the planimetric features indicated on the previous page using vehicle probe data and image data, and of mechanisms predicated on the rapid application of those technologies.

1. Road change point extraction technology using vehicle probe data

- **1.1 Selection of data to be used for road change point extraction**
  - Theoretical study → FS implementation → Coordination with OEMs
- **1.2 Study of technologies for extracting map change points by overlapping vehicle probe data**
  - Technology investigation and deployment (FOTs) → Establishment of technologies for extracting map change points based on vehicle probe data

2. Road change point extraction technology using drive recorders

- **2.1 Selection of image data to be used**
  - Data acquisition → FS implementation
- **2.2 Establishment of technologies for extracting road change points using image data, etc.**
  - Organization of technologies (FOTs) → FOT preparations

3. Road change point extraction technologies predicated on rapid application of said technologies

- **3.1 Deliberation of device specification requirements**
  - Theoretical study → Implementation of FOTs (FOTs)
- **3.2 Deliberation of characteristic point requirements**

4. Future measures for achieving target results

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Road change point extraction technology using image data

1) Deliberation of device specification requirements (theoretical study/requirement, etc. study/device selection)

- To address issues caused by device capabilities, device specification requirements needed to be defined based on the features of road change point extraction technologies.
- Based on the results of the previous year's study, the location accuracy of the results of road change point extraction had a significant impact, so the FOT used the TransLog drive recorder, which is able to acquire GNSS, IMU, and Odometer values.
- To extract changes that were not related to road structure changes (the items in yellow on page 17), this FOT envisioned the use of image data provided by industrial use vehicles, and the FOT was carried out accordingly.

Table Road change point extraction technology requirements and functions needed to meet requirements/TransLog specifications used in FOTs

Road change point extraction technology requirement			**Device needed to meet requirement**	**Function needed to meet requirement**	**TransLog (DN-CDR)**
Must be able to identify planimetric features from image data	Planimetric feature must be visible in image		Camera	Angle of view	Horizontal 118 deg
	Resolution must be sufficient to identify planimetric feature		Camera	Resolution	HD (1280x720)
Must be possible to perform modeling accurately from image data	Must be possible to determine driving trajectory	Must be possible to obtain absolute location	GNSS	Coordinate value	Point positioning
		Must be possible to obtain relative location (must be possible to obtain displacement data)	GNSS	Speed	2Hz
			IMU	Angular velocity, acceleration	100Hz
			Odometer	Movement distance	1Hz
			Camera	Angle of view, resolution, framerate	22Hz

Road change point extraction technology using image data

1) Deliberation of device specification requirements (FOT implementation/driving plan formulation and image acquisition)

- Driving plan (target routes, investigation dates, contents of planned changes to routes) and the results that map updaters* visually compared the image data from before and after changes (without using road change point extraction technology) after collecting image data in accordance with driving plans are shown below.
- In accordance with DMP-defined change standards, personnel performed visual confirmation. Changes were confirmed primarily for shoulder edges and road signs, but personnel were not able to visually confirm changes to road markings.

* This test was carried out by DMP.

Table Driving plans and results

No.	Driving plan*						Image data acquisition results	
	Target road		Distance	Pre-change investigation date	Post-change investigation date	Selection method and contents of planned changes	Results of visual confirmation by map updater	
							Shoulder edge	Road sign
1	Joban Expressway/Kita-Kanto Expressway Tomobe Junction area	Tomobe Interchange - Iwama Interchange	2 km	2020. 5.14	2020. 5.22	Selected based on published information (details regarding location of planned change unknown) Hypothesis: the change was due to temporary construction work (change to shoulder edge)	Two removals	Two removals
2	Joshin-Etsu Expressway Fujioka Junction area	Fujioka Interchange - Takasaki Tamamura Smart Interchange	1.1 km	2020. 5.15	2020. 6.3	Selected based on published information (details regarding location of planned change unknown) Hypothesis: the change was due to temporary construction work (change to shoulder edge)	One addition	Two additions, one removal
3	Metropolitan Expressway C1	Tanimachi Takaracho	Tanimachi: 1 km Takaracho: 0.25 km	2019. 10.1	2020. 6.18	Selected based on consultation with road administrator Changes planned due to addition/removal of road markings (arrows)	None	Tanimachi: Three additions, four removals Takaracho: One addition, four removals
4	Joban Expressway Chiyoda Ishioka Interchange area	Ishioka (Ishioka → Omitama) Omitama (Omitama → Ishioka)	Ishioka: 1.4 km Omitama: 2.5 km	2020. 7.17	2020. 7.21	Selected based on consultation with road administrator Changes planned due to addition/removal of shoulder edges (virtual), addition/removal of road signs	Ishioka: One addition Omitama: One removal	Ishioka: Two additions, seven removals Omitama: One removal

* Due to COVID-19, etc., the scope of this study was restricted to the Tokyo area, and investigation dates and driving routes were decided based on published information and consultation with related parties.

Road change point extraction technology using image data

1) Deliberation of device specification requirements (FOTs implementation/change point extraction)

- The collected image data indicated on the previous page was used to identify change points by applying road change point extraction technologies. In this research and development project, change points were identified using the process shown below.
    - ① After the image data was collected, characteristic points were extracted (anonymization was performed, planimetric features were identified, and location information, etc., was assigned to identified planimetric features). Modeling was performed based on the extracted results (data was generated for use in comparison).
    - ② Newly modeled data and previously modeled data were compared and change points were identified based on the change definitions shown on the following page.
    - ③ The locations of changes to planimetric features on roads were identified. A format was created for reflecting identified results on a high-precision 3D map (a unique format was used for this task).

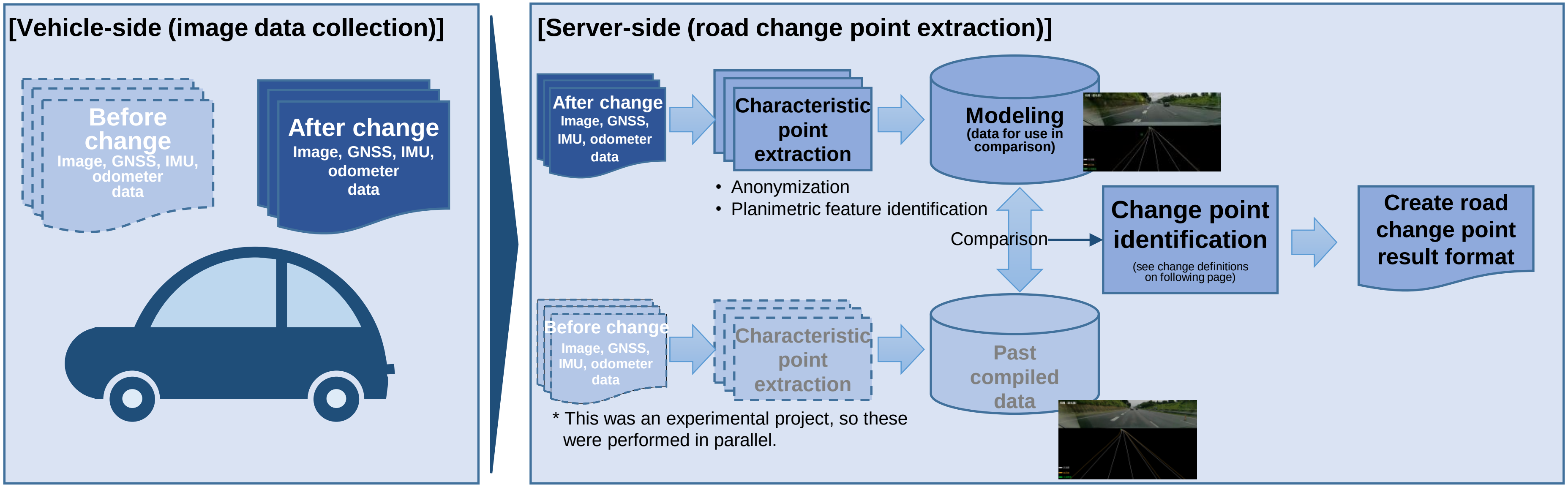

Fig. Conceptual image of process used by road change point extraction technology

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[Ref.] Definitions of changes

- Modeled data created from characteristic point extraction results (data for use in comparison) was used to define the following change conditions for identifying change points.
- Standards have been detailed for determining if individual planimetric features have been added or removed, taking into consideration the standards defined by DMP when updating high-precision 3D maps and the mechanisms used by road change point extraction technologies.

Fig. Definitions of changes

No.	Planimetric feature	Contents of standard for determining that there has been a change (if none of the following conditions are met for a planimetric feature, it is deemed to be unchanged)
1	Carriageway line	• There is continuous section* of carriageway marking in the approach direction extending 10 meters or more that does not match the carriageway marking before the change * Different color and/or type (solid line/dashed line) before and after change * After the change, there is no carriageway marking within 0.5 meters*1 horizontally from the location of the carriageway marking before the change
2	Shoulder edge	• There is continuous section* of shoulder edge in the approach direction extending 10 meters or more that does not match the shoulder edge before the change * After the change, there is no shoulder edge within 0.5 meters*1 horizontally from the location of the shoulder edge before the change
3	Road sign	• After the change, there is no road sign within 1 meter*1 of the center point of the location of the road sign before the change • The shape (circle, triangle, rectangle, diamond) differs before and after the change • The difference in normal vectors of the road sign differ by 30 degrees or more before and after the change • The surface area of the sign portion of the road sign differs by more than 80% before and after the change Note) Changes in contents (speed limits, etc.) cannot be determined due to technical reasons and are not included within the scope. Note) Rectangular signs with sign portion areas measuring 35 cm x 35 cm or less and circular signs with sign portion areas measuring less than 58 cm in diameter cannot be determined due to technical reasons and are not included within the scope.
4	Road marking (Arrow)	• After the change, there is no road marking within 1 meter*1 of the location of the road marking before the change • The shape of the arrow differs before and after the change • The area of the bounding rectangle differs by more than 70% before and after the change
5	Road marking (delta zone)	• After the change, there is no delta zone peak within 0.5 meters of the peak of the delta zone before the change in the approach direction or 90 degrees to the approach direction

*1 Locations (figures) decided on based on discussions with OEMs

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Road change point extraction technology using vehicle probe data

1) Organization of theoretical study approach

- Based on the results through the end of last year, we verified hypotheses regarding the usability of vehicle probe data from the following vantages.
  - We defined hypotheses regarding application scopes.
  - We performed theoretical verification of these hypotheses from quality and operation perspectives, and ultimately organized information regarding the conditions under which it would be promising to perform road change point extraction based on vehicle probe data.

Defining hypotheses regarding application scopes	Vehicle driving environment conditions	Vehicle probe data acquisition and analysis conditions	Organization of practical implementation schemes and identification of necessary system elements	Evaluation of applicability to hypotheses
Based on the results through the end of last year, we **defined hypothetical conditions under which change identification based on vehicle probe data could be applied**, along the axes of the accuracy of the map change points to be extracted and the road conditions within the extraction scope.	We organized the vehicle driving environment conditions that affect map change point extraction and verified our hypotheses in terms of **quality factors caused by the environment**.	We organized the conditions related to the acquisition of vehicle probe data such as location information and the conditions related to analysis methods that affect map change point extraction, and verified our hypotheses in terms of **quality factors caused by analysis**.	Assuming technical feasibility, **we organized information regarding the overall scheme to be used in the practical implementation of map change point extraction, the roles of individual players, and the systems necessary to achieve this**, and verified our hypotheses from an operational standpoint.	Based on our quality and operation verification results, we evaluated our initial hypotheses to **organize information regarding the application scope of map change point extraction based on vehicle probe data.**。

Road change point extraction technology using vehicle probe data

2) Defining hypotheses regarding application scopes (definition using an effectiveness evaluation matrix)

- Through FS verification and verification using OEM data, we redefined vehicle probe data, the change extraction scope, and vehicle probe data items that are expected to be effective for change extraction.
  - Large and medium-sized changes could produce major differences in latitude and longitude (vehicle location information) and turn signal operation
  - For other items with continuous values, changes in actual data could be small, so they were marked with a "△".
  - Small-scale changes would produce little change in latitude and longitude values, so changes would need to be detected based on minor value changes.

Change information		Size of change	Acquisition time (◆: mandatory)	Acceleration pedal stroke	Brake pedal stroke	Turn signal	Steering wheel turn angle	Headlight on/off state	Shift lever position	Hazard lights	Windshield wipers	Latitude and longitude (◆: mandatory)	Direction of movement	Vehicle speed	Acceleration	Angular velocity (turn direction)	Geomagnetism (vehicle direction)	Engine rpm (running/stopped)
Not related to road structure changes	Increase/decrease in number of lanes	Large	○	○ Traffic jam alleviation	○ Traffic jam alleviation	○	△					○	□	○ Traffic jam alleviation	△	△	△	△
	Lane widening	Large	○	○ Traffic jam alleviation	○ Traffic jam alleviation	○	△					○	□	○ Traffic jam alleviation	△	△	△	△
	Divergence/merging position changes	Medium	○	△	△	○	△					○	□	△	△	△	△	△
	Physical structure construction, decommissioning, relocation	Small	○	△	△	△	△					△	□	△	△	△	△	
	Zebra crossing zone creation, removal, changes	Medium	○	△	△	○	△					○	□	△	△	△	△	△
	Carriageway marking solid line/dashed line/color changes	Small	○	△	△	△	△					△	□			△	△	
	Emergency parking area creation, removal, changes	Small	○						△ Stopped state	△ Emergency situations		△	□	△ Stopped state				△ Stopped state
	Carriageway marking repainting	Small	○	△	△	△	△					△	□			△	△	
	Road sign installation, removal, changes	Small	○	△	△							△	□					
	Road marking creation, removal, changes	Small	○	△	△							△	□					
	Traffic light installation, removal, changes	Small	○	△	△							△	□					△

Legend
○:Items expected to cause major changes
△: Items for which detection could be possible (changes, if any, would be expected to be small or infrequent)
□: Items which could be used in processing

Size of change
Large: Change with major impact on lane center line (or over large area)
Medium: Changes with impact on lane center line
Small: Changes with no impact on lane center line

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3) Operation-related hypothesis verification and organization (organization of practical implementation schemes and identification of necessary system elements)

- Based on these tests and studies, we created a pipelined conceptual image of the operation process, shown below.