Surveying the Earth to Create the Future

"Cross-ministerial Strategic Innovation Promotion Program (SIP)/Automated Driving System" Study on Examination of Accuracy Improvement and Complementing Methods for Dynamic Maps Using Fundamental Geospatial Data (FGD) Information

Digest Version Report (Proposal)

March 29, 2019

PASCO CORPORATION

Purposes, Problems, and Aims of This Study

[Purposes]

- ✓ Versatile application of Dynamic Maps
- ✓ Creation of a new digital infrastructure industry, etc.

[Problems]

- ✓ Dynamic Maps have lower accuracies in some sections, such as inside a tunnel and under an overpass, where the GNSS reception states are poor.
- ✓ The areas for which Dynamic Maps have been prepared are not seamless nationwide.

[Method of This Study]

- ✓ This study is aimed at examining the accuracy improvement and complementing methods for Dynamic Maps using basic map information, public criteria for positions on electronic maps and data extensively prepared nationwide.

Description of Study

- In this Study, we surveyed white lines, markers, and road shoulder edges that are static information of Dynamic Maps (hereinafter referred to as "road vector data") and point cloud data obtained when Dynamic Maps are prepared, conducted quantitative evaluations on absolute and relative accuracies of them, and examined the items described below.

1. Examining the linking method for road vector data

- We examined an optimal algorithm for linking road vector data to basic map information and created a data processing program for positional alignment between road vector data and basic map information (hereinafter referred to as the "positional alignment program"). In addition, we conducted quantitative evaluation on accuracies of road vector data after linking and examined the criteria for permissible accuracies.
  - ✓ Format conversion of road vector data and creation of a format conversion program
  - ✓ Quantitative evaluation of absolute accuracies of road vector data
  - ✓ Examination of an optimal algorithm for linking road vector data to basic map information
  - ✓ Creation of a program for linking road vector data to basic map information
  - ✓ Creation of linked data for road vector data and setting of optimal parameters
  - ✓ Quantitative evaluation of a linking accuracy of road vector data

2. Examining the method for linking point cloud data to basic map information

- Using as reference the examination process and result in "1. Examining the linking method for road vector data," we examined an algorithm for linking it to basic map information.
  - ✓ Sorting of differences between road vector data and point cloud data
  - ✓ Evaluation of absolute accuracies of point cloud data
  - ✓ Examination of policies for a linking method based on the know-how obtained in the above process
  - ✓ Proposal of an algorithm for linking

Schedule

Description of Study	FY 2018					
	October	November	December	January	February	March
a. Examining the method for linking road vector data to basic map information						
i. Format conversion of road vector data						
ii. Quantitative evaluation of absolute accuracies of road vector data						
iii. Examination of an optimal algorithm for linking road vector data to basic map information						
iv. Creation of a program for linking road vector data to basic map information						
v. Creation of linked data for road vector data and setting of optimal parameters						
vi. Quantitative evaluation of a linking accuracy of road vector data						
b. Examining the method for linking point cloud data to basic map information						
i. Examination of an optimal algorithm for linking point cloud data to basic map information						
Compilation of the report						
Meeting with interested parties (map structurization task force)		★ Nov. 22		★ Jan. 23		Mar. 14 ★

Examining the Linking Method for Road Vector Data

■ Format conversion of road vector data

We developed a program that converts Dynamic Maps (XML) into Shapefile (Figure 1). The program was created as an add-in function that runs in general-purpose GIS software.

◆Operating environment

●Operating environment of ArcGIS 10.6.1

Windows 10 (64-bit), Windows 8.1 (32-bit, 64-bit), Windows 7 (32-bit, 64-bit), Windows Server 2016 (64-bit), Windows Server 2012 R2 (64-bit), Windows Server 2012 (64-bit), Windows Server 2008 R2 (64-bit)

●ArcGIS 10.6.1 ●Microsoft .NET Framework 4.5 以上, C# 2017

◆Conversion targets

●A range of XML data shown in Figure 2

●Output of features included in XML data

001101※1 ：Road edge (Road shoulder edge)	002000※1 ：Traffic signal
011050※1 ：Maximum speed	012030※1 ：Stop line
012040※1 ：Traveling direction	012082※1 ：Buffer zone

Conversion of 85 features included in XML data such as those listed above was confirmed *2.

*1 The numbers represent the feature type codes in Dynamic Maps.

*2 Even unconverted features can be converted as long as they conform to the Automated Driving System Map Data Encoding Specification Proposal (Test Data Encoding Specifications) Ver.1.0.

◆ Image of program operation

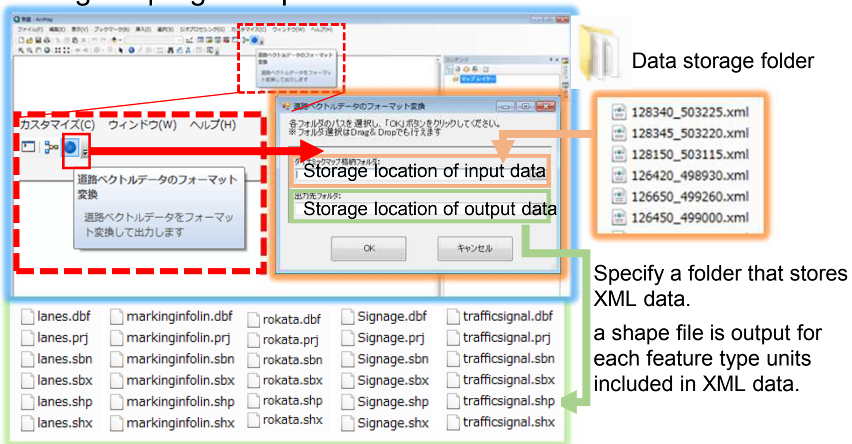

Figure 1 Image of conversion using a format conversion program

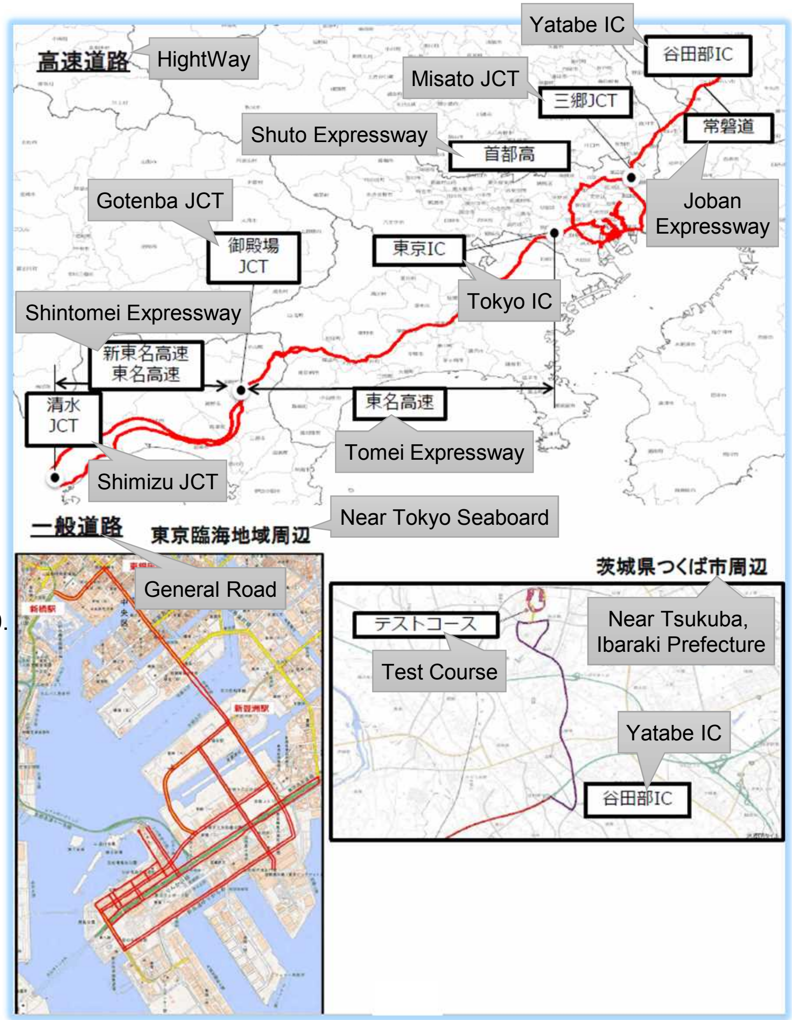

Figure 2 Scope of Dynamic Map (XML) data in use

Source: Excerpt from a Cabinet Office press release (October 14, 2017)

Examining the Linking Method for Road Vector Data

■ Quantitative evaluation of absolute accuracies of road vector data

According to the work flow shown in Figure 3, we conducted quantitative evaluation of absolute accuracies of road vector data.

◆ Classification of characteristic sections

In a scope shown in Figure 1, characteristics of ordinary roads and limited highways are classified and shown in Tables 1 and 2.

Table 1 Characteristic sections of ordinary roads

No.	Characteristic section type	Extension	Number of locations
1	Good overhead visibility	Approx. 38.9 km	154
2	Between buildings	Approx. 4.2 km	12
3	Inside a tunnel	-	-
4	Between buildings	-	-
5	Under an overpass	Approx. 5.5 km	15
	Total	Approx. 48.6 km	181

Table 2 Characteristic sections of limited highways

No.	Characteristic section type	Extension	Number of locations
1	Good overhead visibility	Approx. 363.6 km	470
2	Mountain area	Approx. 10.0 km	16
3	Inside a tunnel	Approx. 35.2 km	38
4	Between buildings	Approx. 6.1 km	15
5	Under an overpass	Approx. 15.3 km	69
	Total	Approx. 430.2 km	608

● Verification of characteristics of ordinary roads

Ordinary roads are expected to have different characteristics than limited highways, such as asymmetric inbound and outbound lanes due to sidewalks and bus stops and many intersections. Therefore, we verified the amounts of the following deviations between road vector data and basic map information.

- ✓ Those resulting from asymmetric inbound and outbound lanes because of existence of sidewalks, bus stops, etc. (Figure 4)
- ✓ Those resulting from many intersections (Figure 5)
- ✓ Those resulting from complex road networks (Figure 6)
- ✓ Influences from planting zones and noise barriers

As a result of verification, no significant amount of deviation was found in any of the above locations. No characteristic unique to ordinary roads was extracted.

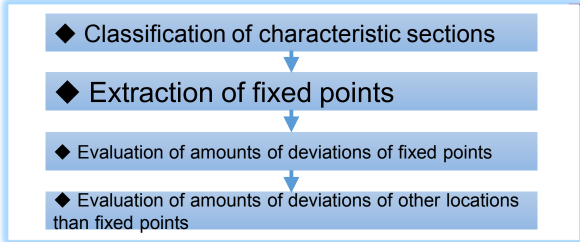

Figure 3 Work flow of quantitative evaluation

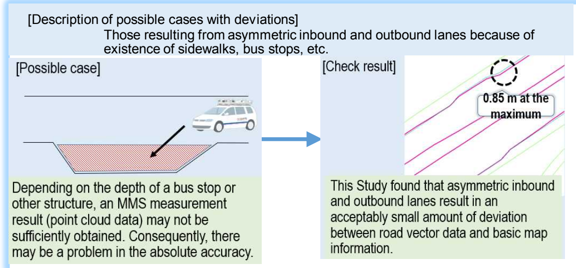

Figure 4 Verification of cases of asymmetric inbound and outbound lanes

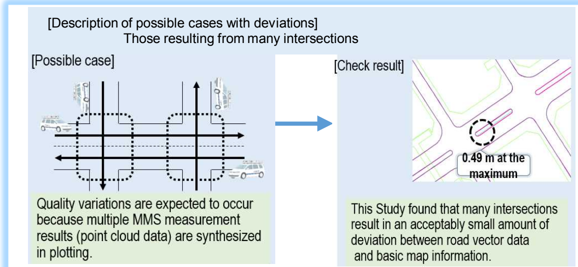

Figure 5 Verification of cases of intersections

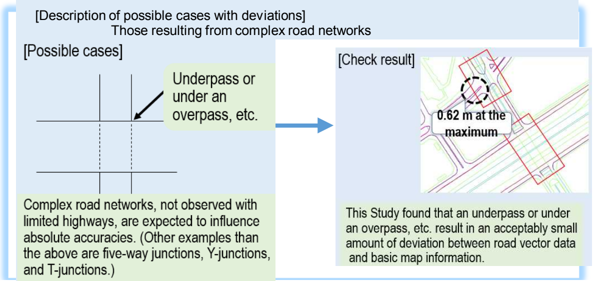

Figure 6 Verification of cases of complex road networks

Examining the Linking Method for Road Vector Data

◆ Extraction of fixed points

Regarding characteristic sections listed in Tables 1 and 2, we studied the points (Figure 7) that can be identified as the same features (such as junctions) in ordinary roads and limited highways. As a result of study, we extracted 230 fixed points. However, few fixed points could be extracted from limited highways because they are free of intersections so that we decided to measure the amounts of deviations shown in Figure 8.

◆ Evaluation of amounts of deviations of fixed points

We studied the amounts of deviations of fixed points shown in Figure 7 and sorted the maximum value, minimum value, average value, and standard deviation of each of the characteristic sections as shown in Tables 3 and 4 (the exclusion requirements are as shown by *1).

Table 3 Amounts of deviations of ordinary roads (fixed points)

Characteristic section	Number of fixed points	Amount of deviation (m)			
		Maximum	Minimum	Average	Standard deviation
Good overhead visibility	128	1.66	0.03	0.41	0.33
Mountain area	-	-	-	-	-
Inside a tunnel	-	-	-	-	-
Between buildings	25	0.54	0.06	0.22	0.13
Under an overpass	4	0.85	0.15	0.35	0.34

Table 4 Amounts of deviations of limited highways (fixed points)

Characteristic section	Number of fixed points	Amount of deviation (m)			
		Maximum	Minimum	Average	Standard deviation
Good overhead visibility	56	2.56	0.07	0.77	0.44
Mountain area	3	2.21	0.25	1.36	0.82
Inside a tunnel	52	1.91	0.01	0.84	0.50
Between buildings	9	1.18	0.08	0.54	0.35
Under an overpass	30	3.72	0.16	1.06	0.81

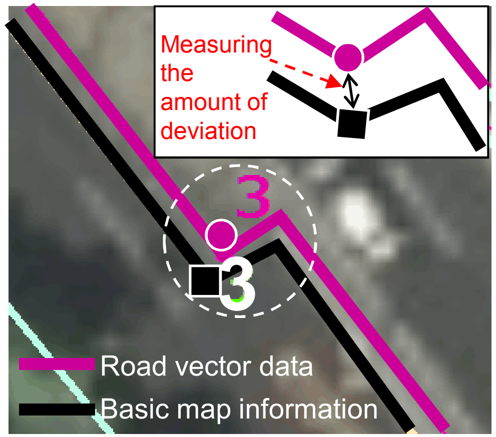

Figure 7 Image of extracting a fixed point
Source: Geographical Survey Institute map (aerial photograph)

◆ Evaluation of amounts of deviations of other locations than fixed points

Regarding the amounts of deviations of other locations than fixed points shown in Figure 8, we measured the amounts of deviations at 10 or more points per 1 km for each of the characteristic sections including fixed points and sorted the maximum value, minimum value, average value, and standard deviation of each of the characteristic sections as shown in Tables 5 and 6 (the exclusion requirements are as shown by *1).

Table 5 Amounts of deviations of ordinary roads (other locations than fixed points)

Characteristic section	Number of fixed points	Amount of deviation (m)			
		Maximum	Minimum	Average	Standard deviation
Good overhead visibility	90	1.74	0.02	0.59	0.41
Mountain area	-	-	-	-	-
Inside a tunnel	-	-	-	-	-
Between buildings	14	0.33	0.00	0.14	0.10
Under an overpass	35	1.81	0.05	0.57	0.41

Table 6 Amounts of deviations of limited highways (other locations than fixed points)

Characteristic section	Number of fixed points	Amount of deviation (m)			
		Maximum	Minimum	Average	Standard deviation
Good overhead visibility	105	2.13	0.10	0.76	0.39
Mountain area	32	1.85	0.08	0.59	0.56
Inside a tunnel	152	9.08	0.02	1.33	1.20
Between buildings	35	1.47	0.19	0.76	0.36
Under an overpass	37	2.34	0.07	0.74	0.51

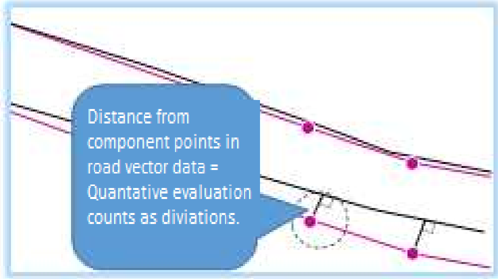

Figure 8 Evaluation of amounts of deviations of other locations than fixed points

*1 The following locations are excluded from the evaluation of amounts of deviations.
- Locations of map information level 25000 in basic map information
- Locations of deviations assumed according to the specifications

Examining the Linking Method for Road Vector Data

■ Examination of an optimal algorithm for linking road vector data to basic map information

Using as reference the algorithm proposed in FY 2017 Linking Report, we organized an optimal algorithm for linking road vector data to basic map information (Figure 9).

◆ Setting of characteristic sections

We classified road vector data to be linked by the characteristics of good overhead visibility, mountain area, inside tunnel, between buildings, and under an overpass and set the sections having these characteristics using the work flow shown in Figure 10.

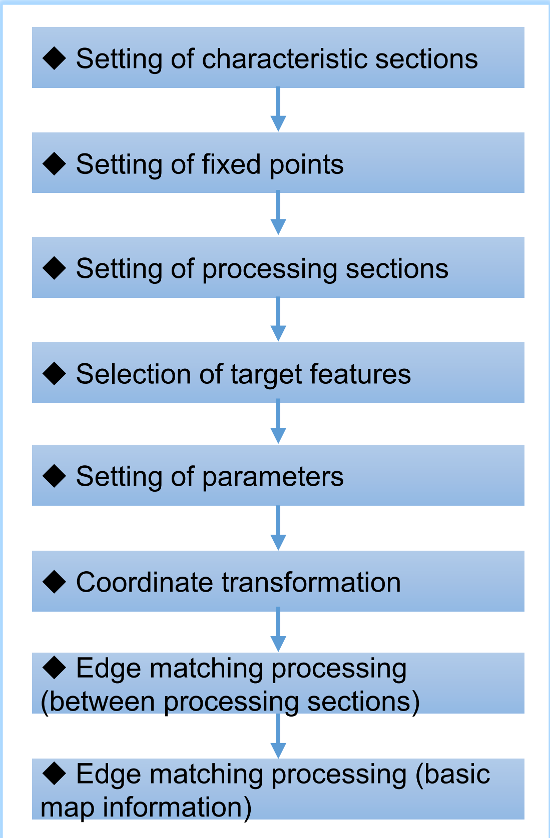

Figure 9 Optimal algorithm

Figure 10 Work flow for setting of characteristic sections

Examining the Linking Method for Road Vector Data

- **Setting of fixed points**
  Extract points that can be identified as the same features (such as junctions) in the road vector data and the basic map information and set them as fixed points (Figure 11).
  Note that road shoulder edges are target features in the road vector data and that road components and road edges are target features in the basic map information.
- **Setting of processing sections**
  To conduct efficient linking processing, divide characteristic sections into groups to configure processing sections (Figure 12).
- **Selection of target features**
  Select target features using the work flow shown in Figure 13 while maintaining absolute accuracies of the road vector data and considering that target features are different between the road vector data and the basic map information. At this time, measure the amounts of deviations using fixed points. In an area where fixed points cannot be obtained, select target features as shown in Figure 14.

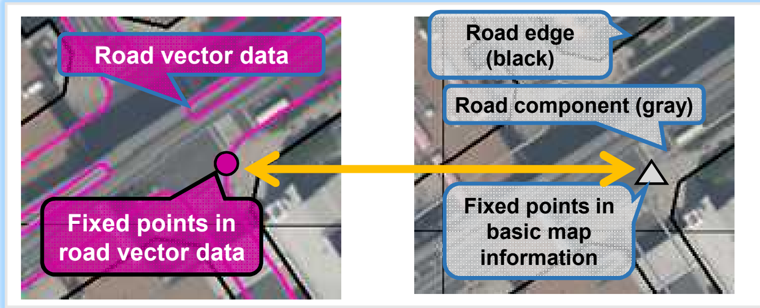

Figure 11 Setting of fixed points

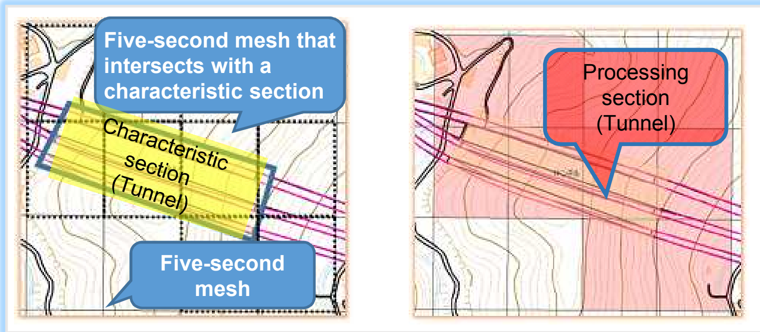

Figure 12 Setting of processing sections

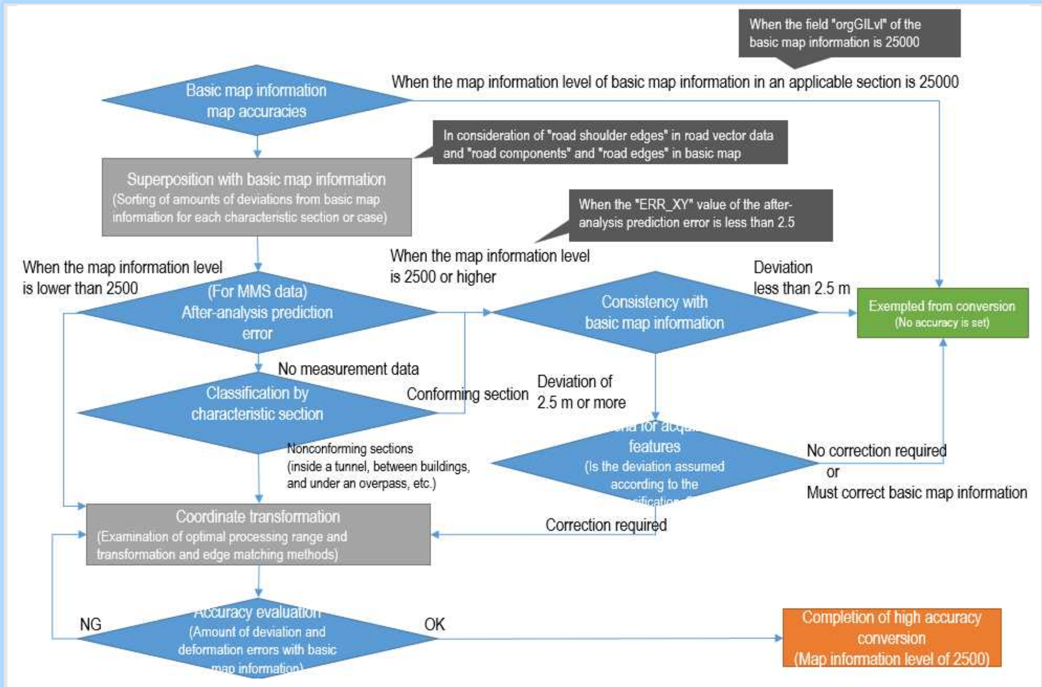

Figure 13 Work flow for selecting target features

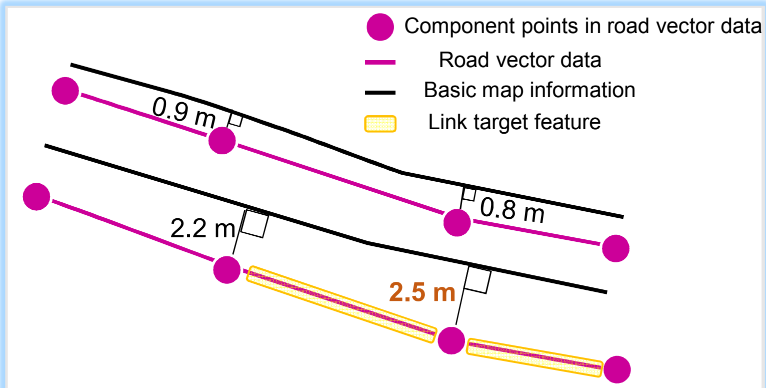

Figure 14 Selection of target features other than fixed points

Examining the Linking Method for Road Vector Data

◆ Setting of parameters

Set the amounts of deviations of fixed points as parameters. As shown in Figure 15, select fixed points to be used as parameters in a distributed way, for example, at four corners of a range of a classification of characteristic sections. Register the selected parameters as the coordinates of fixed points in the basic map information and the road vector data as shown in Figure 16.

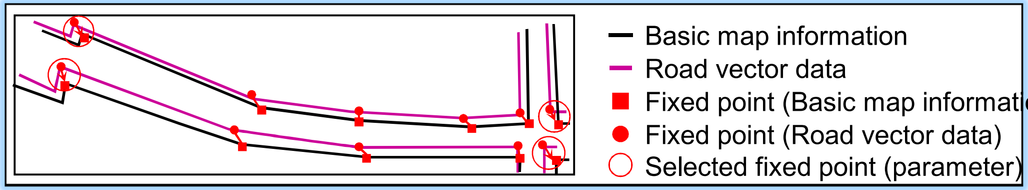

Figure 15 Selection of fixed points as parameters


リンク テーブル

ID	X 座標 (ソース)	Y 座標 (ソース)	X 座標 (ターゲット)	Y 座標 (ターゲット)	残差エラー
1	-31627.613060	-54482.598004	-31630.306373	-54482.698292	0.000001
2	-31687.613060	-54512.598000	-31690.306370	-54512.698290	0.000000
3	-31687.613060	-54442.598004	-31690.306373	-54442.698292	0.000000
4	-31627.613060	-54512.598004	-31630.306373	-54512.698292	0.000001

RMS エラー: 0.000001

Figure 16 Parameter registration screen

◆ Coordinate transformation

The linking method, the target of this Study, refers to achieving positional alignment of the road vector data and the basic map information. The coordinate transformation methods used to achieve positional alignment include Helmert, affine, pseudo affine, and polynomial affine.

We summarized the transformation methods for positional alignment in this Study in Table 7 and examined an optimal transformation method.

Table 7 Coordinate transformation methods for positional alignment

No.	Coordinate transformation method	Characteristics
1	Helmert transformation (Similarity transformation)	While maintaining the shape of a figure under coordinate transformation, this method can adjust the coordinates to a figure for which positional alignment is to be achieved.
2	Affine transformation	While the shape of a figure deformed by moving, rotating, stretching, etc under coordinate transformation, this method can adjust the coordinates to a figure for which positional alignment is to be achieved.
3	Pseudo affine transformation, polynomial transformation	These transformation methods are used for remote sensing image processing in consideration of 3D aerial photographs and correction of image distortions.

Similarity transformation (the shapes of figures do not change after transformation) is not suited for the positional alignment processing of road vector data, having mismatching shapes with basic map information. **Affine transformation is suited for the positional alignment processing of data with mismatching shapes**.
Pseudo affine transformation and polynomial transformation should also be considered for transformation of 3D aerial photographs and images including elevation into planes, that are not targets of this linking processing.

Examining the Linking Method for Road Vector Data

- Edge matching processing (between processing sections)
  As shown in Figure 17 (1), the after-analysis prediction error information is used to match the edge of a linking target feature to the end of a non-link target feature considering that the former has a low positional accuracy. However, features that are both linked are matched at the intermediate point. Register the selected edge matching method to the figure.

- Edge matching processing (Basic map information)
  As shown in Figure 17 (2), the after-analysis prediction error information is used to determine whether edge matching should be conducted on the road vector data or the basic map information in consideration of their positional accuracies. However, if there is little difference between them, features are matched at the intermediate point. No edge matching is conducted if the road vector data has a map information level of 2500 or higher. Register the selected edge matching method to the figure. This way, any position for which no Dynamic Map exists can be complemented with the basic map information.

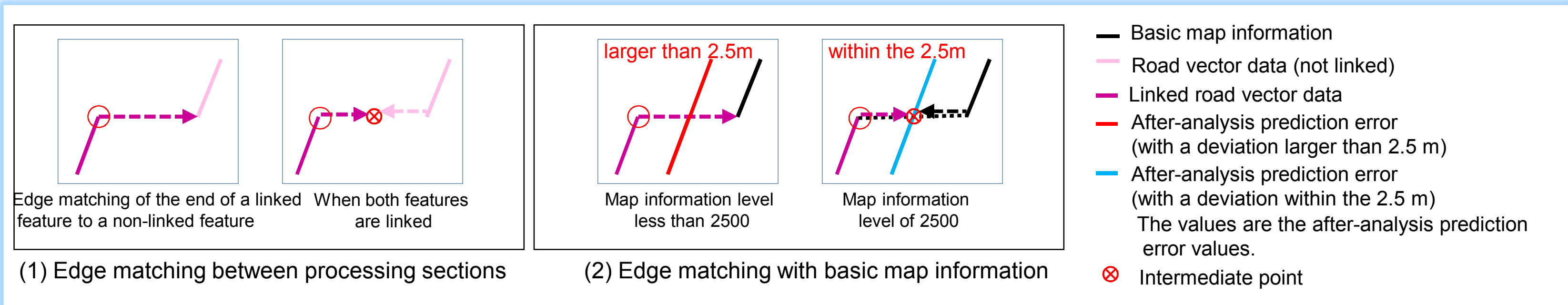

Figure 17 Edge matching processing method

- Creation of a program for linking road vector data to basic map information
  The program was created as an add-in function that runs in general-purpose GIS software in the same way as for the format conversion program for the road vector data.
  - Operating environment ... Same as for the format conversion program of road vector data
  - Image of program operation

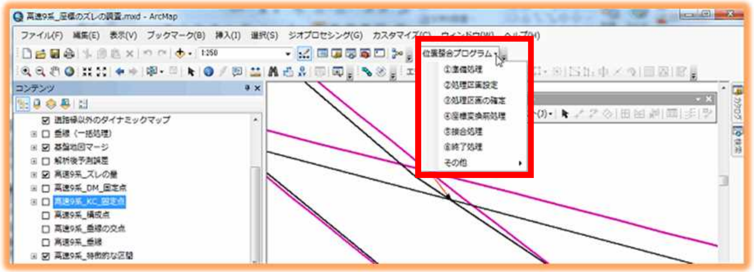

Figure 18 Positional alignment program

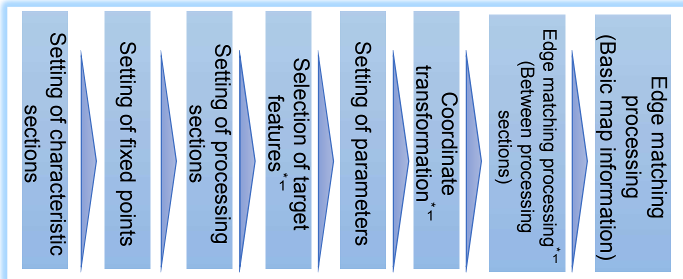

Figure 19 Program-based processing

*1 Function for which labor saving is achieved using an automatic processing program

Examining the Linking Method for Road Vector Data

- Creation of linked data for road vector data and setting of optimal parameters

  According to an optimal algorithm for linking road vector data to basic map information, we created linked data and set optimal parameters. The created data concerns five locations set as shown in Figure 13, "Work flow for selecting target features" and listed in Table 8.

Table 8 Locations for creating linking target data and optimal parameters

No.	Location	Classification of characteristics	Extension (m)	Movement type	Parameters				
					X1,Y1	X2,Y2	X3,Y3	X4,Y4	X5,Y5
1	Near Rainbow Bridge	Good overhead visibility	180	Source	-5,234.2, -40,342.0	-5,302.9, -40,358.6	-5,248.7, -40,344.3	-5,303.5, -40,356.2	—
				Destination	-5,231.7, -40,342.1	-5,302.8, -40,358.8	-5,247.8, -40,344.5	-5,303.1, -40,356.7	—
2	Near New Tsuburano Tunnel	Inside a tunnel	80	Source	-69,918.0, -70,054.4	-69,878.9, -70,087.6	-69,905.3, -70,065.8	-69,856.4, -70,104.7	-69,770.2, -70,116.7
				Destination	-69,918.1, -70,054.5	-69,876.6, -70,090.6	-69,905.2, -70,066.5	-69,855.9, -70,104.3	-69,770.9, -70,118.5
3	Azumayama Tunnel	Inside a tunnel	380	Source	-69,519.8, -70,302.8	-69,572.9, -70,286.9	-69,662.8, -70,257.1	-69,718.1, -70,234.1	—
				Destination	-69,518.5, -70,299.1	-69,570.5, -70,280.4	-69,659.7, -70,248.5	-69,716.1, -70,228.4	—
4	Wadashima Tunnel	Inside a tunnel	1,105	Source	-2,255.1, -100,720.5	-2,178.0, -100,595.9	-2,115.9, -100,488.9	-2,059.5, -100,386.1	-2,004.8, -100,280.1
				Destination	-2,258.1, -100,718.6	-2,181.1, -100,594.0	-2,118.7, -100,487.3	-2,062.0, -100,384.8	-2,006.7, -100,279.2
5	Fujikawa Tunnel	Inside a tunnel	4,500	Source	6,837.9, -92,838.6	6,974.9, -92,805.7	7,096.8, -92,776.6	7,243.2, -92,741.7	7,361.7, -92,713.4
				Destination	6,838.5, -92,841.2	6,975.6, -92,808.7	7,097.6, -92,779.9	7,244.0, -92,745.0	7,362.6, -92,716.8

- Quantitative evaluation of a linking accuracy of road vector data

  Using the road vector data that has been linked, we evaluated the amounts of deviations between the linked road vector data and the basic map information (Table 9).

Table 9 Quantitative evaluation of a linking accuracy of road vector data

No.	Location	Number of points evaluated	Amount of deviation (m)	Remarks
1	Near Rainbow Bridge	1	1.25	Evaluated by the amount of deviation between the fixed points in a figure after linking and the fixed points in the basic map information
2	Near New Tsuburano Tunnel	1	0.24	Evaluated by the amount of deviation between a figure after linking and the basic map information
3	Azumayama Tunnel	4	0.00	Evaluated by the amount of deviation between a figure after linking and the basic map information
4	Wadashima Tunnel	5	0.12	Evaluated by the amount of deviation between a figure after linking and the basic map information
5	Fujikawa Tunnel	7	0.07	Evaluated by the amount of deviation between a figure after linking and the basic map information

Examining the Linking Method for Road Vector Data

- Transformation state of road vector data due to linking

  Figure 20 shows the transformation state before and after linking of locations shown in Tables 8 and 9. Figure 20 shows the crossing of a main road and a junction, etc. extracted as fixed points. The amount of deviation is 2.5 m or less although the component points do not match because the shapes are different in the road vector data and the basic map information.

  On the other hand, the shapes of the tunnel are matching so that there is little deviation.

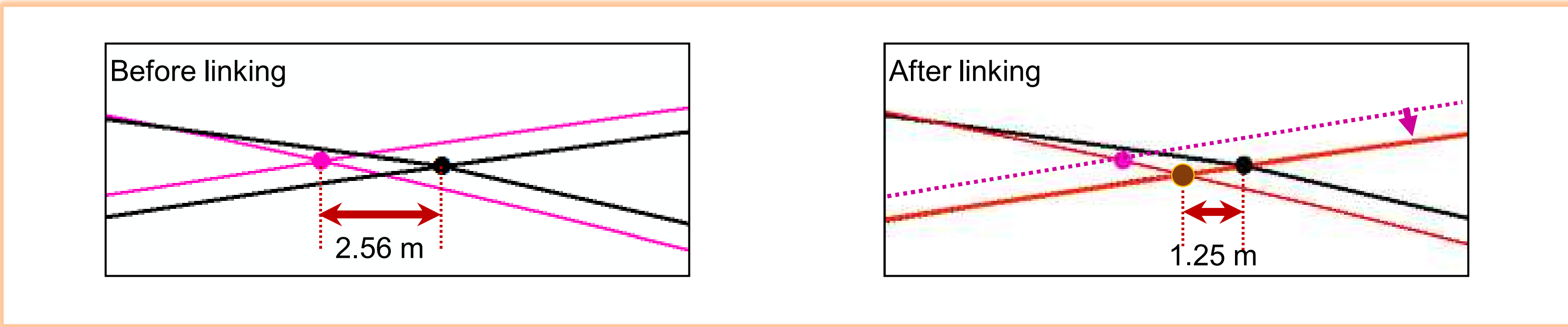

Figure 20 Linking state near the Rainbow Bridge

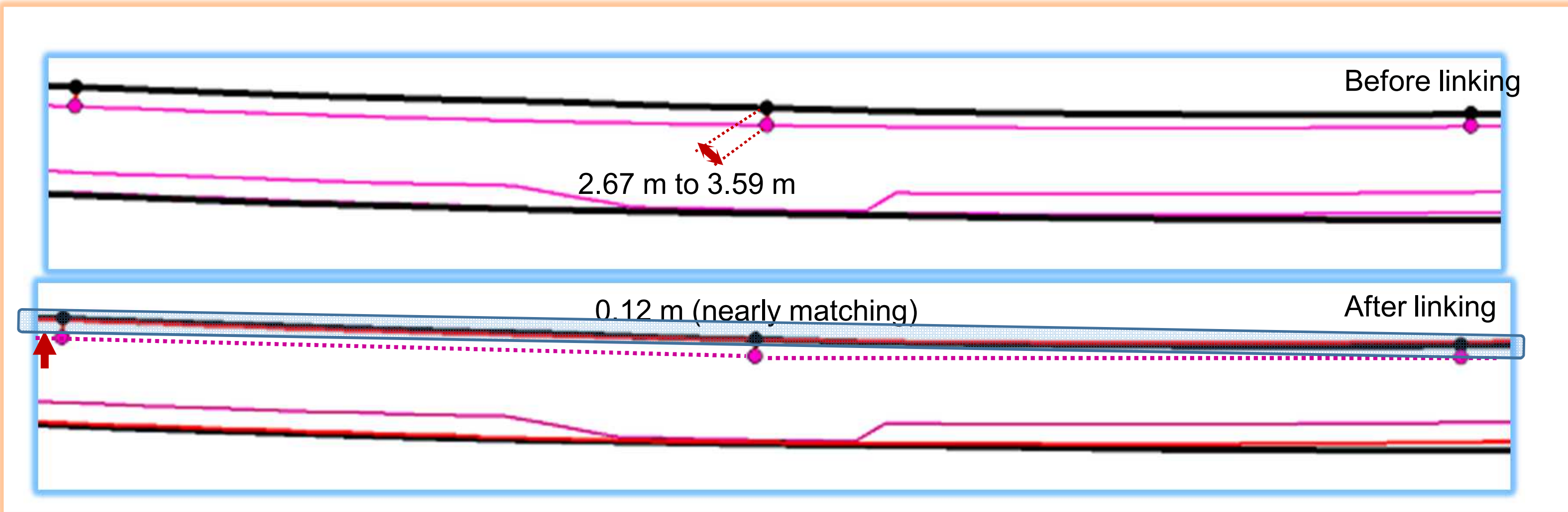

Figure 21 Linking state near the Wadashima Tunnel

Examining the Method for Linking Point Cloud Data to Basic Map Information

■ Sorting of differences between road vector data and point cloud data

As the characteristics of geospatial information, we classified the items such as data formats, forms, and properties into road vector data and point cloud data to summarize the differences between road vector data and point cloud data.

Table 9 Differences between road vector data and point cloud data

	Road vector data	Point cloud data
Data format	XML, Shape	CSV, Las, etc.
Data form	Point, line, and plane	Point
Data volume	Small	Large
Feature classification	Yes (Road shoulder edge, white lines, markers, etc.)	No
Data acquisition method	Plotting using point cloud data	Using MMS measurement
Data positional accuracy	Compliant with point cloud data	Depending on the equipment in use, measurement specifications, surrounding topographic features, and measurement time zone
Data properties	• Data classified by features	• No feature information included in point cloud data • R, G, and B (colors) and Intensity (reflection intensity) in addition to position coordinates

■ Evaluation of absolute accuracies of point cloud data

To evaluate absolute accuracies of 3D point cloud data, we plotted the road shoulder edges and road edges (about 100 m) from 3D point cloud data and compared the positions in each of the road vector data and the basic map information to evaluate absolute accuracies.

Table 10 Evaluation of absolute accuracies of point cloud data

No.	Evaluation location	Amount of deviation of road shoulder edge (m)	Amount of deviation of road edge (m)
1	Near Rainbow Bridge	0.058	0.505
2	Near Yokohama Machida IC	0.053	2.085
3	Ordinary road (vicinity of Odaiba)	0.037	0.608

The road shoulder edges plotted from the point cloud data are matching with the road vector data.
At locations for which road vector data is available, it can be used to provide reference positions for point cloud data.
The road shoulder edges plotted from the plot cloud data and the basic map information are matching within permissible limits of deviations between the basic map information and the road vector data.

Examining the Method for Linking Point Cloud Data to Basic Map Information

- Examination of policies for a linking method based on the know-how obtained in the examination process
  - Road vector data can be used to link 3D point cloud data to basic map information.
  - When road edges are plotted using 3D point cloud data, it can be linked to basic map information.
    - ➢ In consideration of these matters, we examine a method for linking point cloud data to basic map information while using as reference the method for linking road vector data.

- Proposal of an algorithm for linking

Figure 22 shows the method for linking 3D point cloud data to basic map information while using as reference the study result so far and the method for linking road vector data.

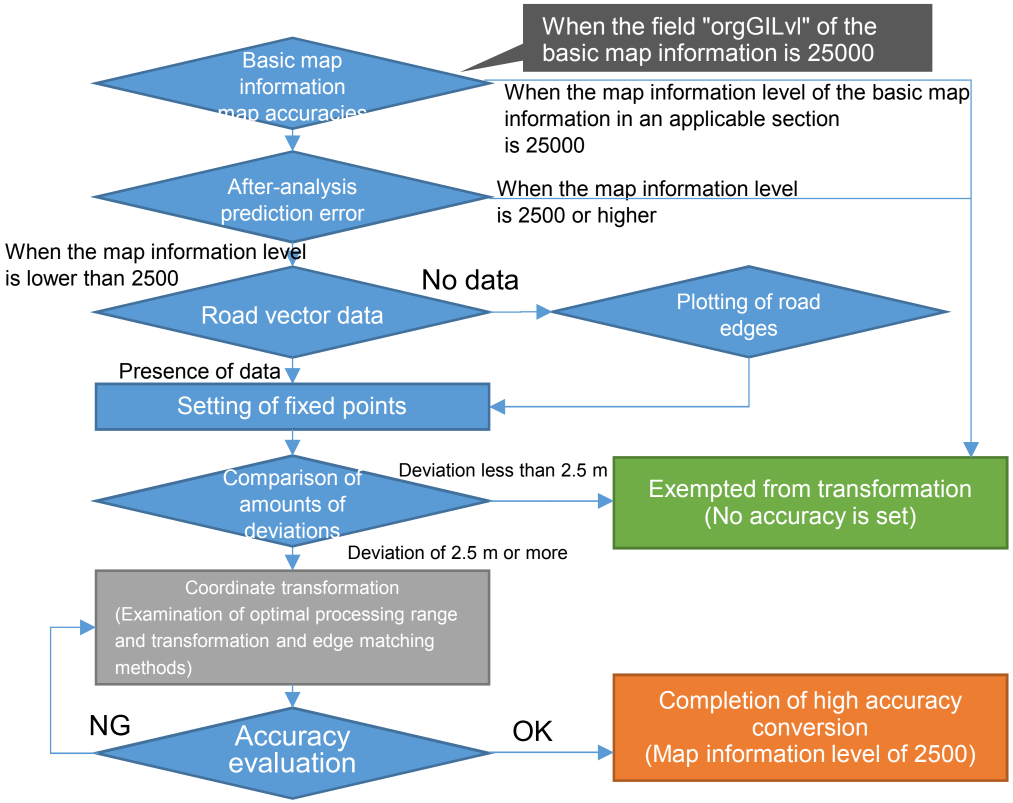

Figure 22 Proposed algorithm

◆Map accuracy of basic map information
Check the map information level of basic map information in an applicable section.
It is exempted from transformation if it is 25000.

◆After-analysis prediction error
It is exempted from transformation if the prediction error in the XY axis direction is less than 2.5 m.

◆Road vector data
The shapes of road edges that can be obtained from 3D point cloud data are used as the criteria. If there is no data of an applicable shape, plot road edges from 3D point cloud data.

◆Setting of fixed points
Set fixed points in the same way as the linking method for road vector data.

◆Comparison of amounts of deviations
Compare amounts of deviations in the same way as the linking method for road vector data.

◆Coordinate transformation
Conduct coordinate transformation in the same way as the linking method for road vector data.

◆Accuracy evaluation
Check the amount of deviation and deformation errors with the basic map information and repeat this step until the amount of deviation becomes less than 2.5 m.