

High-precision Autonomous Driving Map Quality Inspection Indicator System and Evaluation Method

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With the rapid development of autonomous driving technology, the demand for high-quality maps has significantly increased. The accuracy and reliability of high-precision maps are crucial for the safety of autonomous vehicles. In this research, we aim to investigate the current state of quality inspection for high-precision autonomous driving maps, analyze the elements of the maps, establish a comprehensive quality inspection indicator system, and propose evaluation methods. To validate the quality inspection, research data from a Beijing high-level autonomous driving demonstration zone was used. The results showed that the form of traffic signals, characteristics of traffic information, and other related information are prone to errors and should be given attention during quality inspection. The quality inspection indicators and evaluation methods meet the practical application needs of high-precision autonomous driving maps, sufficiently guiding the map quality control and inspection. The high-precision autonomous driving map quality inspection indicator system and evaluation method can effectively ensure the data quality of autonomous driving maps.

1. Introduction

At the current stage, intelligent technologies represented by AI will become important engines for developing new production capabilities. Intelligent connected vehicles are a typical application of new-generation AI and an important carrier for building a new traffic system integrating the “vehicle–road–cloud”.⁽¹⁾ High-precision autonomous driving maps effectively establish close ties between drivers, vehicles, road environments, semantic environments, and social environments, promoting the gradual evolution of autonomous driving technology from level L0 to L5.⁽²⁾

High-precision autonomous driving maps are characterized by high precision (high map data accuracy), high richness (diverse map data types), and frequent map updates,⁽³⁾ and are mostly

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used in positioning, planning, and perception modules.⁽⁴⁾ The maps, utilizing in-vehicle high-precision positioning equipment and onboard sensors, complement each other to provide safety assurance for autonomous driving. Therefore, the quality of high-precision autonomous driving map data results is crucial.

High-precision maps differ from traditional navigation electronic maps in terms of data production, result presentation, and application scope, and have higher requirements for element content, accuracy, and evaluation methods. Current standards such as “Specifications for quality inspection and acceptance of surveying and mapping products”,⁽⁵⁾ “Specifications for inspection and acceptance of quality of digital surveying and mapping achievements”,⁽⁶⁾ and “Specifications for navigable map data test”⁽⁷⁾ can be referenced to evaluate the quality of traditional basic geographic information and navigation electronic maps. However, their quality elements are not fully applicable to high-precision autonomous driving maps.⁽⁸⁾ Moreover, the technical requirements for high-precision maps are not unified among various map vendors or car companies, and it is difficult to objectively evaluate high-precision map results. The “Specification for automatic driving map data”⁽⁹⁾ and “Quality specification for automatic driving map”⁽¹⁰⁾ issued by Beijing are local standards, and there is yet no nationally unified standard or industry standard. In this study, we investigated the quality inspection technology, tools, and problems; analyzed the data content and key components; developed a comprehensive quality inspection indicator system for high-precision autonomous driving maps; and proposed evaluation methods and indicators. The test data from a Beijing high-level autonomous driving demonstration zone was verified to ensure that the quality inspection index system and evaluation methods proposed in this article are scientifically valid and effective.

2. Data, Materials, and Methods

2.1 Data preparation

In the process of traditional high-precision map collection and crowdsourced data collection, sensors such as Light Detection and Ranging, high-definition cameras, and millimeter-wave radars are used to obtain geoinformation data such as point clouds and images, which are the main sources of high-precision map data.⁽¹¹⁾ We took data of 20 km of the highway and urban road from a Beijing high-level autonomous driving demonstration zone as examples to verify the scientific value and effectiveness of the indicator system and evaluation methods. An example of sample data is shown in Fig. 1.

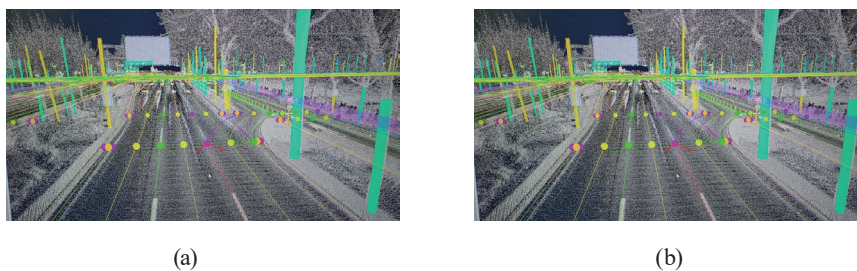


Fig. 1. (Color online) Sample data: (a) urban road and (b) highway.

2.2 High-precision autonomous driving map elements

High-precision autonomous driving maps include static map layers, dynamic data layers, real-time data layers, and user model layers. The static map layer is the focus of mapping⁽¹²⁾ and is the foundation of high-precision autonomous driving maps, which is the subject of quality inspection in this paper. High-precision autonomous driving maps include roads, lanes, and traffic facilities. “Specification for automatic driving map data”⁽⁹⁾ was subdivided into five layer groups: road traffic signs, road traffic markings, road-level traffic networks, lane-level traffic networks, and other traffic facilities. The layer groups and element content of high-precision maps are summarized in Table 1.

Table 1
High-precision autonomous driving map layer groups and element content.

Layer group	Element content	Element attributes	Geometric type
Road traffic signs	Road traffic signs	Identification code, type, shape, use type, background color, text border color, orientation, and identification code of road reference line.	3D polygon
Road traffic markings	Linear traffic markings	Identification code, type, color, and length.	3D line
	Flat traffic signs	Identification code, type, texture, color, pattern, arrow type, and semantic information.	3D polygon
Road-level traffic network	Road network	Identification code, location, directional, status, classification, morphology, special road structure, speed limits, lane count, spatial level, start identification code and end identification code.	3D line
	Road nodes	Identification code, intersection node identification within an intersection, spatial level, road identification code, intersection identification code	3D point
	Road intersections	Identification code, road identification code, and node identification code.	3D point
	Road surface	Identification code, road identification code, and road surface type.	3D polygon
Lane-level traffic network	Lane centerline	Identification code, lane number, status, direction, turn arrow, lane type, lane location, speed limits, vehicle restrictions, restriction time, left line identification code, right line identification code, start identification code, end identification code, road identification code, intersection identification code.	3D line
	Lane nodes	Identification code, lane identification code, and node type.	3D point
	Shape points	Identification code, curvature, heading, longitudinal slope, lane number, shape point sequence number.	3D point
Other traffic facilities	Traffic signals	Identification code, mounted object, direction, signal light type, arrangement, affected lanes, and affected roads.	3D polygon
	Intelligent roadside facilities	Identification code, equipment type, road identification code, and lane identification code.	3D point, 3D line, 3D polygon
	Traffic safety facilities	Identification code, facility type, facility color, semantic information, road identification code, and lane identification code.	3D point, 3D line, 3D polygon

2.3 Quality inspection process

We studied the high-precision map quality inspection indicator system and evaluation method for the above layer groups. By referencing “Specifications for quality inspection and acceptance of surveying and mapping products”,⁽⁵⁾ the process follows a “two-level inspection and one-level acceptance” method for full-process quality control, including process inspection, final inspection, and acceptance inspection. Each stage should be independent, sequential, and not omitted, replaced, or reversed. Process inspection requires full inspection. Final inspection requires full internal inspection, and external inspection items can be sample-checked. Acceptance inspection can also be sample-checked.

The overall quality inspection process for high-precision autonomous driving maps is divided into general inspection and detailed inspection. After receiving the results, a general inspection of the overall data results is conducted first. If the general inspection is qualified, a detailed inspection is carried out. According to the quality inspection contract requirements, technical design, and other demand conditions, the inspection batch, unit result, quality inspection indicators, and quality evaluation process are divided and the inspection report is finally given. The inspection process is shown in Fig. 2.

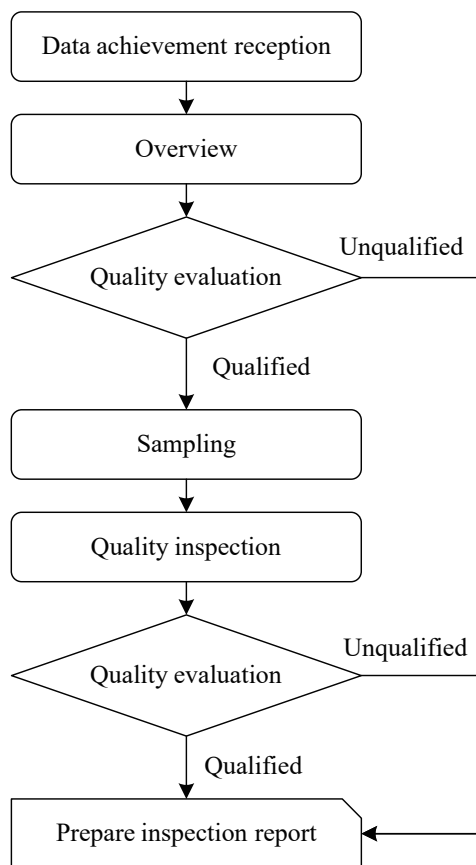


Fig. 2. Quality inspection process flowchart.

2.3.1 General inspection content and methods

During the general inspection, the overall high-precision autonomous driving maps are checked, including mainly layer group completeness and spatiotemporal datum, to ensure compliance with the quality inspection commands.

(1) Layer group completeness

High-precision autonomous driving maps should include five layer groups: road traffic signs, road traffic markings, road traffic network, lane traffic network, and other traffic facilities. According to the collection range and element characteristics, the maps should ensure the completeness of the layer groups without omissions.

(2) Spatiotemporal datum

We checked whether the coordinate system and elevation system used in the results are correct. “Autonomous Driving Map Data Standards” requires that the spatiotemporal datum for high-precision maps should use the China Geodetic Coordinate System 2000 and the National Elevation Datum 1985, and the time datum should use the Coordinated Universal Time (UTC) or the Beijing Standard Time (BST).

2.3.2 Detailed inspection content and methods

When the general inspection is qualified, further detailed checks should be conducted, including checks of position accuracy, geometric topology, and attribute information. The content and methods for checking are as follows.

(1) Positional accuracy check

Positional accuracy mainly checks the absolute position accuracy and relative position accuracy. “Specification for automatic driving map data”⁽⁹⁾ requires that the absolute positional accuracy of autonomous driving map data should be better than 1 m, and the relative positional accuracy should be better than 0.5 m.

Positional accuracy checks mainly include the internal reference data comparison method or the external field feature point measurement method. The reference data comparison method calculates the difference between the inspected data and the reference data for positional accuracy checks. The field feature point measurement method yields the difference between the inspected data and the field measurement data through same-accuracy or high-accuracy detection for positional accuracy checks.

a) Absolute accuracy

The absolute error is calculated according to Eq. (1).

$$\Delta_i = \sqrt{(X_{mi} - X_{ti})^2 + (Y_{mi} - Y_{ti})^2 + (Z_{mi} - Z_{ti})^2} \quad (1)$$

Here, Δ_i is the absolute error of the i -th inspection point, X_{ti} , Y_{ti} , and Z_{ti} are the horizontal coordinate, vertical coordinate, and elevation of the i -th inspection point measured value, and X_{mi} , Y_{mi} , and Z_{mi} are the horizontal coordinate, vertical coordinate, and elevation of the i -th inspection point map value, respectively.

b) Relative accuracy

The number of point pairs is calculated according to Eq. (2).

$$l = C_n^2 = n(n-1)/2 \quad (2)$$

Here, n is the number of inspection points, and l is the number of point pairs.

The distance difference of point pairs is calculated according to Eqs. (3)–(5).

$$d_t = \sqrt{(X_{tj} - X_{tk})^2 + (Y_{tj} - Y_{tk})^2 + (Z_{tj} - Z_{tk})^2} \quad (3)$$

$$d_m = \sqrt{(X_{mj} - X_{mk})^2 + (Y_{mj} - Y_{mk})^2 + (Z_{mj} - Z_{mk})^2} \quad (4)$$

$$\Delta_i = |d_t - d_m| \quad (i = 1, 2, \dots, l) \quad (5)$$

Here, k and j are the two points forming a point pair, and $k = 1, 2, \dots, l-1; j = k+1, k+2, \dots, l$.

d_t is the measured distance of the point pair, and d_m is the map distance of the point pair.

c) Mean error

When high-accuracy detection is used, the mean error is calculated using Eq. (6). When same-accuracy detection is used, the mean error is calculated using Eq. (7).

$$M = \pm \sqrt{\frac{\sum_{i=1}^n \Delta_i^2}{n}} \quad (6)$$

$$M = \pm \sqrt{\frac{\sum_{i=1}^n \Delta_i^2}{2n}} \quad (7)$$

Here, M is the mean error, n is the total number of detection points or edges, and Δ_i is absolute error or relative error.

(2) Element sampling inspection

The current sampling technical standards are relatively complete. “Sampling procedures for inspection by attributes - Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection”⁽¹³⁾ is the main sampling inspection method for count-class products. The sampling rules of batch and sample sizes in “Specifications for quality inspection and acceptance of surveying and mapping products”⁽⁵⁾ can be used in this study. After receiving high-precision maps, the inspection batches should be determined according to the count quantity, and then the unit results should be divided by geographic area or map sheet.

The sample extraction requirements are as follows.

- a) The sample should preferably be extracted by the simple random sampling method or the stratified proportional random sampling method on the basis of the operation subject, process or production period, layer group, operation method, and so forth.
- b) The samples of the inspection batch should be evenly distributed.
- c) Areas containing three or more levels of roads should be sampled separately.

3. Construction and Analysis of Indicator System

3.1 Principles for constructing the indicator system and selecting indicators

High-precision autonomous driving maps have numerous elements and fine features. When establishing a quality inspection indicator system, the following principles must be followed. (1) It must objectively reflect the quality status of the high-precision map. (2) It should provide the most minimal and clear indicators on the basis of the characteristics of the high-precision map elements, making quality inspection convenient and easy to implement.

When selecting quality inspection indicators for high-precision maps, the following principles should be followed. (1) Scientific value: The indicators and the indicator system must objectively reflect the characteristics of high-precision autonomous driving maps. (2) Comprehensiveness: The indicators should comprehensively reflect the temporal, spatial, and attribute information characteristics of the various elements of high-precision autonomous driving maps. (3) Independence: The indicators should be independent of each other, without overlapping meanings, and each should function independently.⁽¹⁴⁾ (4) Operability: Indicators should have clear meanings and standardized and simple evaluation methods, making them easy to operate and implement.

3.2 Construction of indicator system

By reviewing relevant literature on high-precision map data production, geographic information data evaluation, and related national and industry technical standards and specifications, we have summarized 12 quality inspection and evaluation indicators for high-precision autonomous driving maps. They are comprehensively divided into five primary indicators. On the basis of the principles for selecting indicators, 2–4 secondary indicators corresponding to each primary indicator were determined. The two-level indicator system and its description are shown in Fig. 3.

3.3 Analysis of indicator system

3.3.1 Data integrity indicators

Data integrity includes two situations: omission and redundancy. On the basis of the element content in Table 1, we checked whether there are any omissions in the high-precision autonomous

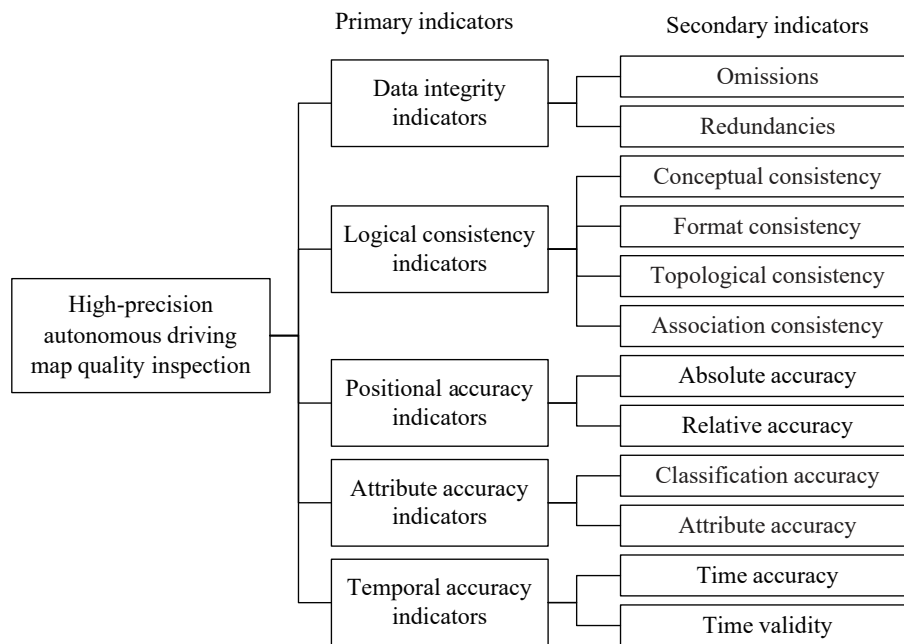


Fig. 3. Hierarchical structure of quality inspection indicators.

driving maps. By field verification or comparison with point cloud data, 2D road vectors, or image data, we checked whether map elements are redundant, duplicated, or “created out of nothing”.

3.3.2 Logical consistency indicators

(1) Conceptual consistency

We checked whether elements overlap, whether similar elements are merged, and whether interacting elements or continuous similar elements are not incorrectly segmented into multiple parts.

(2) Format consistency

We checked whether the data format is 3D vector format and whether the attribute structure meets the data type format requirements for various elements in Table 1.

(3) Topological consistency

We checked the connection relationships and relative positions of roads and lanes. For multilevel roads such as interchanges, we checked the accuracy of spatial hierarchies.

(4) Association consistency

As a link code among roads, lanes, traffic signs, and traffic facilities, we checked the uniqueness of the identification code and the association relationships among 3D point, line, and polygon elements in roads and lanes to ensure that they match the actual situation.

3.3.3 Positional accuracy indicators

We checked the absolute positional accuracy by absolute accuracy inspection methods, i.e., the proximity of element coordinates to measured values. We checked the relative positional accuracy by relative accuracy inspection methods, i.e., the proximity of relative positions among elements to measured values.

3.3.4 Attribute accuracy indicators

(1) Classification accuracy

On the basis of the layer group and element content in Table 1, we checked whether the classification of high-precision map elements is correct.

(2) Attribute accuracy

On the basis of the element attributes in Table 1, we checked whether the value domains of element attribute contents are correct.

3.3.5 Temporal accuracy indicators

For lane restriction times, we checked whether the times are valid and whether the time values match the actual values.

3.4 Indicator inspection items and weight analysis

On the basis of the high-precision map quality inspection indicator system, we used a percentage system to score quality. First, on the basis of the importance of the layer group in the overall autonomous driving map, we determined the quality score of various elements, then, allocated weights to inspection indicators on the basis of their importance to quality evaluation. Simultaneously, we determined inspection items on the basis of the content of the indicators, providing a basis for subsequent quality evaluation. High-precision autonomous driving map quality inspection items and weights are shown in Table 2.

3.5 Analysis of severity of inspection item errors

On the basis of the impact on autonomous driving safety, the error types of quality inspection indicators are categorized into three types: extremely serious errors, serious errors, and general errors.

- 1) Extremely serious errors refer to errors that have a fatal impact on the safe operation of autonomous driving. The corresponding indicator items mainly include data format errors, classification errors, accuracy exceeding limits, and omission of prohibited information.
- 2) Serious errors refer to errors that have a significant impact on autonomous driving. The corresponding indicator items mainly include redundant prohibited information and incorrect types of nonprohibited information.

3) General errors refer to errors that have a minor impact on autonomous driving. The corresponding indicator items mainly include errors in form, type, material, color, and other information.

Table 2
High-precision autonomous driving map quality inspection items and weights.

Layer group	Quality score	Inspection indicator	Indicator weight	Inspection item
Road traffic signs	20	Data integrity	0.20	Are road traffic signs missing or redundant?
		Logical consistency	0.20	1. Are there incorrect overlaps between signs or between signs and other elements?
				2. Do the data format and attribute structure comply with the regulations?
				3. Is the identification code unique?
Positional accuracy	0.30	Does it satisfy absolute accuracy ≤ 1 m and relative accuracy ≤ 0.5 m?		
Road traffic markings	25	Attribute accuracy	0.30	1. Are the type, shape, color, and direction of signs correct? 2. Do the sign images match the actual situation?
		Data integrity	0.20	Are road traffic markings missing or redundant?
		Logical consistency	0.20	1. Are road traffic markings incorrectly overlapping with road facilities?
				2. Do the data format and attribute structure comply with the regulations?
3. Is the identification code unique?				
Positional accuracy	0.30	Does it satisfy absolute accuracy ≤ 1 m and relative accuracy ≤ 0.5 m?		
Road traffic network	10	Attribute accuracy	0.30	1. Are the types of markings correct?
				2. Are the dashed and solid lines, and color types of linear markings correct?
				3. Are the arrows, textures, colors, patterns, and semantic information of area markings correct?
		Data integrity	0.20	Are road segments, road areas, and intersections missing or redundant?
Logical consistency	0.25	1. Do the data format and attribute structure comply with the regulations?		
		2. Is the identification code unique?		
		3. Are the relationships among road nodes, intersections, and road areas and other elements correct?		
Positional accuracy	0.20	Does it satisfy absolute accuracy ≤ 1 m and relative accuracy ≤ 0.5 m?		
Attribute accuracy	0.25	1. Are the classifications of road reference lines, road nodes, intersections, and road areas correct?		
		2. Are the status, grade, shape, direction, and special structure of roads correct?		
Temporal accuracy	0.10	3. Do the maximum and minimum speed limits match the actual situation?		
		4. Does the number of lanes match the actual situation or the lane network expression?		
				Are the restriction times valid and in line with actual regulations?

Table 2
(Continued) High-precision autonomous driving map quality inspection items and weights.

Layer group	Quality score	Inspection indicator	Indicator weight	Inspection item
Lane traffic network	30	Data integrity	0.20	Are the relationships among lane centerlines, lane groups, intersections, and lane nodes missing or redundant?
		Logical consistency	0.25	1. Is the lane traffic direction correct? 2. Is the lane centerline or intersection lane centerline correct? 3. Do the data format and attribute structure comply with the regulations? 4. Is the identification code unique? 5. Are the relationships among lane nodes, lane centerlines, road reference lines, and lane groups correct?
		Positional accuracy	0.20	Does it satisfy absolute accuracy ≤ 1 m and relative accuracy ≤ 0.5 m?
		Attribute accuracy	0.25	1. Are the classifications of lane centerlines, lane nodes, and lane shape points correct? 2. Are the lane status, type, and turn arrows correct? 3. Do the lane width, curvature, heading, and slope deviation exceed limits? 4. Do the maximum and minimum speed limits match the actual situation? 5. Are the lane numbers and vehicle restriction conditions missing?
		Temporal accuracy	0.10	Are the restriction times valid and in line with actual regulations?
Other traffic facilities	15	Data completeness	0.20	Are the other road traffic facilities missing or redundant?
		Logical consistency	0.20	1. Are there any invalid overlaps between traffic facilities? 2. Are linear (or areal) facilities of the same nature and connected segments ineffectively divided into multiple parts (or blocks)? 3. Do the data format and attribute structure comply with the regulations? 4. Is the identification code unique? 5. Is the association between traffic facilities and the corresponding lane centerline or road reference line correct?
		Positional accuracy	0.30	Does it satisfy absolute accuracy ≤ 1 m and relative accuracy ≤ 0.5 m?
		Attribute precision	0.30	1. Are traffic signals, intelligent roadside equipment, and other road traffic safety facilities misclassified? 2. Are the types, orientation angles, colors, and semantic information of traffic facilities correct?

4. Evaluation Methods and Applications

4.1 Evaluation methods

High-quality autonomous driving maps are essential for ensuring the safety of autonomous driving. For the quality inspection of high-precision autonomous driving maps, a sampling inspection method is used to determine the quality evaluation methods for layers, unit results, samples, and inspection batches. A demerit system is adopted on the basis of the severity of errors to obtain high-precision map quality inspection and evaluation results.

4.1.1 Layer group quality scoring

The number of errors in the inspection indicators is counted on the basis of the types of error in the inspection items. The error rate of general errors in the layer group quality elements is calculated according to Eq. (8). One severe error is counted as five general errors.

$$r_{ij} = n_{ij} / N_i \times 100\% \quad (8)$$

Here, r_{ij} is the error rate of the general error of the j -th primary indicator of the i -th layer group in the sample, n_{ij} is the number of general errors of the j -th primary indicator of the i -th layer group in the sample, and N_i is the total number of elements of the i -th layer group in the sample.

The quality score of the layer group is calculated by the weighted average method according to Eq. (9).

$$S_i = s_i \sum_{j=1}^m p_{ij} (1 - r_{ij}) \quad (9)$$

Here, S_i is the quality score of the i -th layer group, V_i is the quality value of the i -th layer group, W_{ij} is the weight of the j -th primary indicator of the i -th layer group, r_{ij} is the error rate of the general error of the j -th primary indicator of the i -th layer group, and m is the number of primary indicators of the i -th layer group (if the layer group includes time accuracy, the value is 5; if it does not, the value is 4).

4.1.2 Unit result quality evaluation

The quality score of a unit result is the sum of the quality scores of each layer group, calculated according to Eq. (10).

$$S = \sum_{i=1}^5 S_i \quad (10)$$

Here, S is the quality score of the unit result, and S_i is the quality score of the i -th layer group in the unit result.

The quality grade of unit results is evaluated as either qualified or unqualified.

- a) If a unit result has one extremely severe error, its quality grade is unqualified.
- b) If the quality score of all layer groups in the unit result exceeds 90% of the quality value of the layer group, and the unit result quality score exceeds 95 points, the quality grade is qualified; otherwise, it is unqualified.

4.1.3 Sample quality evaluation

If all unit results in the sample are qualified, the sample quality grade is evaluated as qualified; otherwise, it is unqualified.

4.1.4 Inspection batch quality evaluation

If both the general inspection and detailed inspection of the inspection batch are qualified, the inspection batch is deemed qualified; otherwise, it is unqualified.

4.2 Method application

The construction of the Beijing high-level autonomous driving demonstration zone started in 2020 and iterated to the 3.0 stage, expanding to 600 square kilometers in June 2024, involving the three districts of Daxing, Tongzhou, and Shunyi. In this study, we used the high-precision autonomous driving map results of 20 km of expressway and urban roads in the demonstration zone as the quality inspection subjects to verify the entire quality inspection process. The inspected qualified data can better meet the needs of autonomous driving. Table 3 shows the data quality scores of the unit result.

Table 3
Experimental data unit result quality evaluation.

Layer group	Primary indicator	Element count	Extremely severe errors	Severe errors	General errors	Quality scores
Road traffic signs	Data completeness	377	0	0	0	19.97
	Logical consistency		0	0	1	
	Positional accuracy		0	0	0	
	Attribute precision		0	0	1	
Road traffic markings	Data completeness	3326	0	0	2	24.99
	Logical consistency		0	0	5	
	Positional accuracy		0	0	0	
	Attribute precision		0	0	1	
Road traffic network	Data completeness	869	0	0	0	9.99
	Logical consistency		0	0	1	
	Positional accuracy		0	0	0	
	Attribute precision		0	0	3	
	Time accuracy		0	0	0	
Lane traffic network	Data completeness	2645	0	0	0	29.97
	Logical consistency		0	0	4	
	Positional accuracy		0	0	0	
	Attribute precision		0	0	7	
	Time accuracy		0	0	0	
Other road traffic facilities	Data completeness	1031	0	0	1	14.97
	Logical consistency		0	0	2	
	Positional accuracy		0	0	0	
	Attribute precision		0	1	1	
Unit result score			99.88			

The test data includes five layer groups, totaling 8248 elements. After quality inspection, no extremely serious errors were found in the test data, but there was one serious error, and the rest were all general errors. The unit achievement quality score was 99.88 points, and the results were deemed qualified.

The analysis revealed that the serious error was an incorrect orientation angle of a traffic signal in the traffic facilities, which has a significant impact on autonomous driving. Additionally, during the production of high-precision autonomous driving map data, considerable attention must be paid to the attribute accuracy and logical consistency of the lane traffic network and the logical consistency of road traffic markings, to avoid general errors.

5. Summary and Recommendations

In this study, we used high-precision map data from a Beijing high-level autonomous driving demonstration zone to verify the entire process of high-precision autonomous driving map quality inspection and acceptance. Upon verification, prohibited traffic information was found to have a significant impact on autonomous driving, and there were fewer issues in the quality inspection process. However, the form of traffic signals and the characteristics of traffic information were more prone to errors than the other information and should be given attention during the quality inspection process. The results showed that the quality inspection and acceptance process in this study is simple and easy to operate and well applied to autonomous driving. The quality inspection indicators and evaluation methods are in line with the practical applications of high-precision maps, effectively guiding the establishment of a high-precision autonomous driving map data quality control system and the conduct of quality inspection activities, thereby improving the quality of autonomous driving map data.

With the development of high-precision map collection and updating methods, high-precision maps are increasingly characterized by multisource heterogeneity, large update volumes, and high update frequencies. Therefore, using AI and other technologies to control high-precision map quality is particularly important. Zhou and Peng⁽¹⁵⁾ developed a map element inspection system capable of automatically checking, correcting, and reporting errors, and quickly calculating map quality rates. Hu *et al.*⁽¹⁶⁾ used deep learning technology to extract key elements of high-precision maps based on new foundational mapping results. Huang *et al.*⁽¹⁷⁾ discussed the review requirements for high-precision maps, providing suggestions for the safe and compliant application of high-precision maps.

In the future, the use of crowd-sourced update methods for the collection and production of high-precision autonomous driving map data will become increasingly widespread. Therefore, ensuring the quality of high-precision maps is particularly important. The quality inspection indicator system and evaluation method developed in this study can support the establishment of better standards for the quality inspection of autonomous driving maps. It can also be validated and tested in more high-precision map application pilots. Quality inspection of high-precision autonomous driving maps can promote the high-quality development of high-precision maps, which can also provide a commercial pathway for new quality productivity, such as high-precision maps, integrated vehicle-road-cloud systems, and autonomous driving.

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References

- 1 K. Q. Li: *Rob. Ind.* **6** (2020) 28. <https://doi.org/10.19609/j.cnki.cn10-1324/tp.2020.06.005>
- 2 Q. Y. Du, L. L. Kuang, F. Ren, J. T. Liu, C. Feng, Z. N. Chen, B. C. Zhang, K. Zheng, and Z. C. Li: *J. Geo-inf. Sci.* **26** (2024) 15. <https://doi.org/10.12082/dgxkx.2024.240054>
- 3 T. Yin, H. Huang, C. Guo, J. Zhan, and W. M. Meng: *China Stand.* **04** (2021) 33 .
- 4 B. J. Li, Y. Guo, J. Zhou, Y. C. Tang, Q. H. Dong, and Z. J. Li: *Geomatics Inf. Sci. Wuhan Univ.* **49** (2024) 491. <https://doi.org/10.13203/j.whugis20230287>
- 5 GB/T 24356-2023, Specifications for quality inspection and acceptance of surveying and mapping products.
- 6 GB/T 18316-2008, Specifications for inspection and acceptance of quality of digital surveying and mapping achievements.
- 7 CH/T 1019-2010, Specifications for navigable map data test.
- 8 X. D. Wang, Y. M. Xu, J. Huang, L. B. Zhang, and Y. H. Cai: *Geospatial Inf.* **22** (2024) 93. <https://doi.org/10.3969/j.issn.1672-4623.2024.05.020>
- 9 DB11/T 2041-2022, Specification for automatic driving map data.
- 10 DB11/T 2166-2023, Quality specification for automatic driving map.
- 11 Y. X. Liu, M. Dong, B. G. Yang, Q. J. Li, and C. D. Chen: *Beijing Surv. Mapp.* **38** (2024) 189. <https://doi.org/10.19580/j.cnki.1007-3000.2024.02.013>.
- 12 J. N. Liu, J. Zhan, C. Guo, Y. Li, H. B. Wu, and H. Huang: *Acta Geod. Geophys. Sin.* **48** (2019) 939.
- 13 GB/T 2828.1-2012, Sampling procedures for inspection by attributes - Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection.
- 14 D. C. Zhang, Z. M. Wang, Y. J. Li, H. Fan, and Y. Y. Liu: *J. Environ. Eng. Technol.* **14** (2024) 289.
- 15 X. J. Zhou and Y. K. Peng: *Geospatial Inf.* **21** (2023) 5.
- 16 M. Hu, W. Zhong, W. Q. Mao, and Y. Ding: *Geospatial Inf.* **S1** (2024) 266. <https://doi.org/10.13474/j.cnki.11-2246.2024.S153>.
- 17 G. Huang, X. J. Shi, C. H. Li, and B. Li: *Geomatics Spatial Inf. Technol.* **47** (2024) 1.

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