DIGITAL CHART CARTOGRAPHY: ERROR AND QUALITY CONTROL

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ABSTRACT:

This paper puts forward a novel concept of tetrahedron model of chart cartography error analysis and quality control which is necessary for introducing user to the former triangle model of error analysis and quality control, i.e. Reality-Producer-Chart-User. For the human being, high quality does not necessarily represent high accuracy, but represent a concept that what is fit for use. Classical cartography error theory coming from physics and mathematics will no longer meet the requirement of users, so the new concept deriving from communication and cognition sciences will compensate for the research. New model should adopt thought science which is from humanities. In tetrahedron model, producer refers to people who provide data, who manipulate data and who check data. User is considered as a quality controlling factor which has equal status with producer. Data quality control has changed from "Check-Driving" to "User-Driving". The words for quality assessment change from error or uncertainty to practicability or applicability. Reality here refers to ocean and coastal zone. From a new viewpoint, the chart has been redefined as chart set. And characters of chart differing from terrain map and the specific quality assessment indexes have been discussed. Some innovative ideas of the research work were as follows: 1) Establishing a new tetrahedron model of quality control. The relationship between error and quality assessment was analyzed and practicability was adopted to assess the quality of chart product. 2) Defining the chart set. After changing from paper chart to electronic chart or digital chart, chart product become a set of digitizing collecting, storing and renewing data. 3) Building up the user assessment system of the chart product, which would perform real-time chart quality control.

1. ACTUALITY OF CHART CARTOGRAPHY ERROR THEORY

The series of steps of chart cartography, e.g. chart editing and designing, and generalizing (including selection, simplification, combination and replacement) will inevitably influence chart quality. How we estimate the degree of those operations? Is the final chart product fit for use? How is the dependability or reliability of the product? All the questions require scientific assessment of chart quality.

The error research of digital chart data has for a long time adopted error and uncertainty theory of spatial data. Because these are part of spatial data, and have many commonness. Now the important norm when evaluate the chart data quality is the error or accuracy of spatial data of chart. The description of error or accuracy is provided by the producer. However, the specific chart cartography process and special user of chart are not deeply discussed. And the reliability and practicability of a chart could not be provided to the user. These lead to re-examine the quality assessment system and more reasonable and efficient quality control model should be built up. Based on the actuality of error theory, a new quality assessment model was established. Then we re-defined the chart set in the digitized society. Finally we built up a user assessment system to perform a real-time quality control.

1.1 Error theory

Error, accuracy, uncertainty, quality, the four words are all about the assessment of geographic spatial data, and each has its own emphasis. The essential of error, accuracy, uncertainty, quality is all about the spatial data application system. Study on the error, accuracy, uncertainty, quality theory is carried out at home and abroad. For example, Li Deren, Liu Dajie, Chen Jicheng, Shi Wenzhong and Michael Goodchild, Giles Foody, Gerard Heuvelink, D. Griffith all study on spatial data error and establish the error analysis system, including the error source, error discrimination and measurement method, error propagation model, error administration and some minimizing methods to errors that influencing spatial data quality (Li D., 2002; Liu D., 1999; Cheng J., 2004; Shi W., 2005; Goodchild M., 1989). Traditional mathematical statistics methods are the base to the error analysis theory system. But the classic mathematical statistics theory must be revised and reinforced according to spatial data manipulating characters. A lot of progress has achieved since 1990s, for example, GIS spatial elements uncertainty model establishing methods (Heuvelink), error propagation model of spatial data processing and analysis(Liu,1999), remotely sensed image error and its impact and its error index establishment (Foody, ;Arnoff, 1985). But there are also many areas that need to be researched, for

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example, the correlation between uncertainty study and spatial data quality control has little compactness. In fact the study of uncertainty focuses on only quality assessment but not on the quality control. So the uncertainty theory and practice should be emphasized on the practice of geographic information system, i.e. the quality control of GIS producing practice.

As M.F. Goodchild said in the keynote presentation in the symposium of Accuracy 2008, "…We need to ask a series of questions, beginning with what should spatial accuracy assessment mean in a world in which everyone is a potential user of geospatial data?" This is a very different perspective from the traditional one of the past 14 years, when it was possible to believe that the results of spatial accuracy assessment were of concern only to small elite of geospatial professionals (Goodchild M., 2008).

1.2 Chart cartography error theory

Chart spatial data has accuracy problems in every procedure from original acquiring, digitizing, generalization and examination. Error or uncertainty is adopted to describe the data quality. Accuracy assessment and error propagation model establishment toward a digital chart production are more complicated than normal survey adjustment and accuracy estimation. For the one thing data source of charting spreads various types of data from different area and different collecting methods. For another, different from survey data which have rigid geometric relationship and are easy to follow their error propagation process, but operations in chart cartography are more complicated. Aside from spatial information, there are attribute information in the operation objects. So the error propagation model of these operation objects is hard to build up. Take positional information for example, considering different scales, different years and different projections of a point position, the error propagation of the position is difficult to follow.

Although the automatic charting producing provides fast and efficient pattern, the quality reliability assessment is not provided. And literatures about digital charting and application have few articles related to error propagation of geographical spatial data, and the quality of input data and output data have no estimation. Though an integrated chart spatial data error analysis theory has not yet been established, there are many articles about the confronted problems and solving methods about theory establishment(Zeng, 2004; Sun, 2004; Li, 2007). These dispersive achievements are important to establish an integrated charting error analysis theory.

2. NEW TETRAHEDRON MODEL OF QUALITY CONTROL

2.1 Triangle model

The quality assessment of chart cartography is defined in a triangle model, i.e. Reality-producer-Chart, a closed loop, see Figure 1.

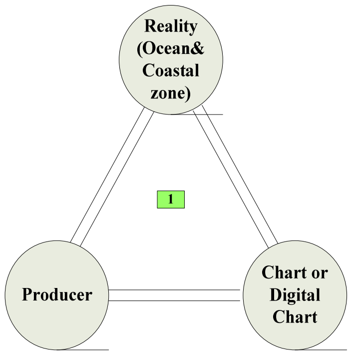

Figure 1 Triangle Model of Quality Control

There are broad meanings of producer, referring to those who provide data, who manipulate data and who check data. Data in different phases will be consider as different product (later will be discussed in the third part of chart set). These people will control the data of different phases subsequently and the contents of error analysis are as the following four part.

1) Error analysis of cartography data preparing

(a) Chart cartography raw material (e.g. sounding data) error analysis and accuracy index;

(b) Chart cartography historical data (e.g. scanning terrain map) error analysis and accuracy index;

2) Error propaganda and accumulate in chart designing and editing

(a) Error analysis in chart sheet designing and mathematics base deciding, the emphasis is laid on to the accuracy of ground control points and cartographic grid.

(b) Error analysis in chart contents selecting and geographic elements expressing, emphasis is laid on to the accuracy of the drawing of various elements and the reasonability of these relations.

(c) Error analysis in cartographic data processing, there are correcting from new material, old material transferring, adjoining the land and sea area, and data copying.

3) Error and uncertainty analysis in cartographic generalization

(a) Integrated analysis of the randomicity of location of spatial data and their and the fuzzy character of attribute data.

(b) Quality assessment of automatic generalization including generalizing process model, generalizing arithmetic and the rationality, maturity of rules, the degree of intelligentizing and the other assessment models.

4) Error propaganda and accumulate in other chart producing

Quality management of plate distribution, publishing, etc.

Figure2 give a concrete process of quality control.

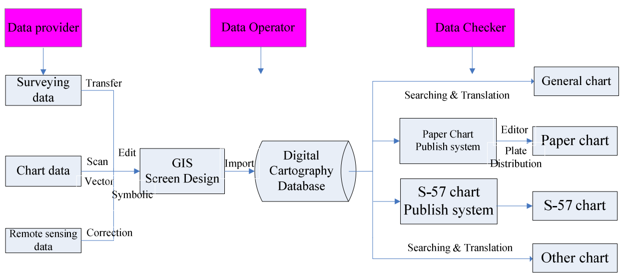

Figure 2 People in digital chart quality correct process

2.2 Tetrahedron model

From the above analysis of digital chart quality control process, the concept model is based on a triangle plane relationship. As the user should be one of the elements of quality control, the former triangle model should be developed to tetrahedron model including six edges or six key relations concerning quality, thus a new quality control concept model based on tetrahedron could be set up, see Figure 3.

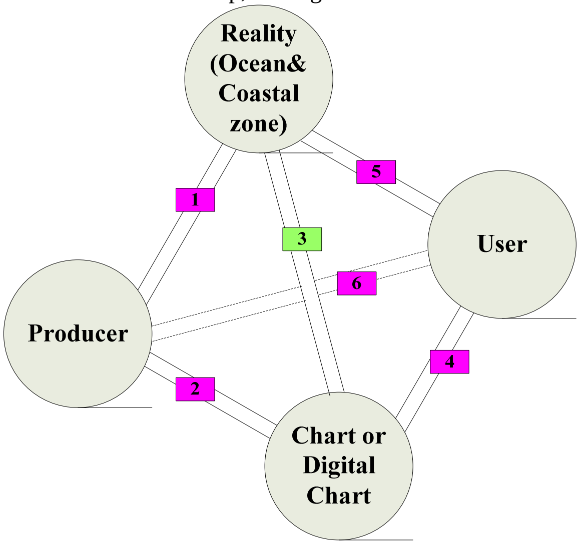

Figure 3 Tetrahedron Model of Quality Control

Here one point must be made clear that quality is determined by the buyer or the seller. In the “Client is God” society, the answer is quite clear. There are few productions like chart, merging arts and sciences together, the quality assessment of chart will not only refer to location, attribute accuracy, logic consistence and time precision, but refer to more important elements about the convenience, simplicity and fastness of chart use. “People-oriented” is an all around standard in this digitizing information era (GAO, 2004).

What the triangle model missed is just the user. For one side, the spatial cognition, visualizing thought when reading a chart, the feeling about virtual space of the user should be considered as influence elements of chart cartography quality, for the other side, the degree of simplicity and fastness should also be regarded as indexes of quality assessment. The former standard of high quality refers to high accuracy. But the viewpoint of equalling high quality with truth of reality has inherent contradiction in concept (Andrew U.F, 2008). And the ontological analysis reveals the necessity to separate the ontology (reality) proper from the epistemology (data). The ordinary language approach clearly identifies the two conflicting interpretations of “data quality”: the viewpoint of the producer and the contrasting viewpoint of the consumer (Timpf et al, 1996). In order to make an overall quality assessment, user should be considered in the process of use. So the data quality does not only refer to accuracy but also refer to practicability or applicability. We aim to make an integrated and scientific error analysis and quality assessment as to set up a tetrahedron model of quality control.

2.3 Integrated Error theory based on Tetrahedron

Traditional error theory focused on the first three relationships. There are abundant research works in RS, GIS spatial data error analysis (Liu, 1999; Cheng, 2004; Ge, 2006). But the 4th, 5th and 6th relationships are lack of attention. The error and quality analysis with only three relationships are partial and local. Only taking consideration of all the six relationships can we wholly master the error accumulation and propagation theory.

In fact, the missing of three edges is the missing of “user”. Error accumulation consists of not only the first three relations: e.g., the survey error in Reality-Producer relationship, and the scanning and digitizing error in Producer-Chart relationship, and the geometric rectification error in Reality-Chart relationship. These three kinds of errors are the main analysis objects of chart cartographic error theory. After introducing tetrahedron model, the user spatial cognition, the visualizing thinking of readers and the error influence effects of virtual spatial cognition should be taken into consideration. People factors that influence the error accumulation system including two aspects: one is that the subjective factors of man can influence the producing process and then lead to error accumulation, the other is that the degree of convenience and simplification of reading for ordinary people can be made an index of chart quality assessment.

The ultimate purpose of error analysis is to establish mathematics statistics equations and models in order to acquire high quality. Take a new perspective of the six edges of the tetrahedron, the error analysis is no longer traditional rigid, linear or static. The 4th, 5th and 6th relationships are related to thinking science, cognitive science and non-linear science, thus, should adopt different research patterns. The characteristic of this study is to integrate the six edges into a comprehensive error theory. The theory framework and conceptual model of each relation are showed in Table 1.

Table 1 Cartography tetrahedron uncertainty conception model

ITEM	Representation	People action	Error describing	Uncertainty theory
1 P-R	Producer-Reality	Cognition	Distance, angle distortion	Probability theory
2 P-C	Producer-Chart	Design	Scanning error, Topology, logic identify	Mathematical statistics
3 R-C	Reality-Chart	Ontology	Error matrix	Ontology
4 U-C	User-Chart	Reading	Fuzzy logic	Fuzzy theory
5 U-R	User-Reality	Practise	Psychophysical action	Psychology theory
6 U-P	User-Producer	Exchange	Communications	Information Science

3. DIGITAL CHART QUALITY ASSESSMENT ELEMENT

Digital chart is produced when chart integrated to computer science. In the new information era, charts are known as marine charts, hydrographical charts, or admiralty charts. They differ somewhat from bathymetric charts which are virtually topographic maps of the ocean floor. But digital charts are still objective reflection of the ocean and coastal zone, and are not necessarily the reflection of paper charts. Digital charts still solve the three contradictions because of scale, map loading and plane limits, i.e. the contradiction of ellipsoid and plane, the finite and infinite, the ordered and disordered. The movement and balance of the contradictions decide the scientific characters of chart.

The same as terrain map, charts have strict mathematics base, simple and efficient symbol system and scientific cartographic generalization. Charts have vivid characters of their own that form the specific style and tradition. The foremost characters exist in their cartographic purpose and their expressive objects. The objects of chart cartography are ocean and coastal zone. The most difference between ocean and land is the covered water. In different parts of ocean and sea, there are different depth, different temperature, salinity, density and transparency. There are also dynamic phenomena due to astronomy, weather and crustal movement, the ever-lasting movement of sea water, the vertical movement of tide, the parallel movement of tide current, ocean current and sometimes tsunami, wave and vortex. When we perform hydrographical survey, we hardly use optics instruments, we often use acoustics instruments. So the instruments, survey methods, the output production, error and accuracy are very different from land terrain surveying. The main product of land surveying are graph materials, while hydrographical surveying produces notes paper, notes tape and text data. So the cartographic process of chart and that of terrain map is of great difference. For example, multi-scanning sonar produced a depth black sheet by scanning the sea bed. In the style sheet, the arrangement of depths is determined by the surveying methods, i.e., four neighbour depth points form a rhombus, the direction of long diagonal line of the rhombus is parallel to the shoreline, and the direction of short diagonal line of the rhombus is vertical to the shoreline. So the differences of surveying methods lead to differences of generalization methods.

Besides these, the difference is bigger still in the content and expression of chart. It should therefore be useful to examine briefly the special features of charts.

1) Projection

Mercator is the most used projection because straight lines on the map are lines of constant azimuth on the ocean. It is convenient for navigation.

2) Scale

Coastal charts are generally in the l: 50 000 to l: 300 000 scale range, while port charts are at larger scales. Such charts are rarely in series and scale is determined by the area covered and the chosen paper size.

3) Datum

The datum for sounding reduction is not mean sea level, but some special lowest normal low water that is fit for navigation.

4) Sheets

Sheets are divided along the seashore, or along the navigation course. Adjoining sheets often have large area of overlap which will be convenient to navigate.

5) Serial number

In order to adapt to the adjoined sheets, charts have definite serial number system.

6) Detail

The detail shown on a chart is carefully selected so that everything useful to the mariner is shown and no more. The topography of the coastline is fully shown but inland only prominent objects visible from the sea, e.g. hills, radio masts, high buildings, chimneys, etc.

On or below water level are shown: (a) aids to navigation: lights, buoys, and beacons; (b) dangers: rocks, wrecks, and cables (c) currents and tidal streams: direction and velocity; (d) nature of the bottom: sand, mud, rock, etc. (e) routes and limits; (f) soundings and approximate isobaths. Information useful to mariners which is not suitable for printing on charts is compiled in book form, such a book being called a 'Pilot' (or Sailing Directions). It gives information about ports and harbours and navigation along coasts, climate, and many other relevant details.

7) Units

Again, because navigation is based on astronomy, the basic unit of distance is one minute of latitude, called a nautical mile. The average value of l852 m is an international nautical mile.

Depths of water are in metres (0.l m in shallow water) for all new work although there are many older charts showing fathoms (= 6 ft). The metre is also replacing the foot for all heights above sea level.

Horizontal scale bars show nautical miles, cables (l cable = 0.l nautical mile), metres, and feet; vertical bars shown feet, metres, and fathoms.

4. DESIGN FOR QUALITY CONTROL SYSTEM AND DISCUSSION

4.1 Understanding of quality

The charts or more specific nautical charts, have different elements concerning about quality assessment from terrain map. These elements, though objective, are still selective factors that influence the purpose of user. Chart quality descriptions represent the viewpoint of the chart producer and are not very helpful for the potential chart user to decide if it is “fit for use”.

So before the quality assessment process, some work should be performed to decide what the quality really means. Purely from a management point of view on the concept of quality, a well-known American quality management expert, Dr. Juran J.M holds the point of view that has been widely recognized: it believed that product quality is applicability of the product, that is, the product can be in what degree met the user needs.

This definition has two meanings, namely, "the user’s requirements" and "satisfaction." People use the product, they make certain requirements and these requirements of the products are often affected by the time, the location, the objects, and social environment and market competition factors. Changes in these factors make people put forward different requirements of the same product quality. Thus, the quality is not a fixed concept, it is dynamic, changing and developing over time, place and users and with the development of society and technology, the definition of quality will be constantly updated and enriched.

The requirements of the product from users are reflected in the product performance, economic characteristics, service characteristics, environmental characteristics and psychological characteristics and so on. Therefore, the quality is a comprehensive concept. It does not require the technical characteristics of the higher the better, but the pursuit the best combination of performance, cost, quantity, namely, the so-called most applicability or practicability.

4.2 Advantages when concerning user

Study of practicability and reliability of chart cartography product has not attracted attention from the documentations. A complete error analysis theoretical system of spatial data of chart has not yet formed more concentrated focus on the study of location uncertainty, attribute uncertainty and so on. But for spatial data products of chart, errors, accuracy of the production process given are not enough to guide the user to practice. So the real user satisfaction survey is a proof of chart of acceptable quality. The user satisfaction is equivalent with the product reliability and suitability.

Learn from the marketing strategy of most commodities, user session will be taken into account. The assessment of practicability has very important and far-reaching significance:

1) Improve chart product competitiveness. To provide appropriate evaluation indicators is becoming a necessary condition of entering the international market. If chart does not provide reliable indicators, it is difficult to survive in the increasingly competitive society.

2) Improve the theory of chart cartography error and quality control. For the special area of cartographic charts and special users, uncertainty and reliability are closely related. Reliability studies can contribute to the research of uncertainty and further refinement.

3) From quality evaluation based on user feedback information, establish the corresponding mapping model, then the problem

can be found in order to chart correction, easy to carry out quality control.
4) Reduce the risks of failure; minimize the occurrence of quality control problems. This can improve the reliability of chart products, but also can reduce the man labour of data maintenance, then to reduce production costs.

5. CONCLUSIONS

As the world's rapid economic development and industrial competitiveness have sharpened, and the seller's market began to change to the buyer's market. Man has been growing attention to quality. The well-known American Quality Management scientist Dr. Juran predicted that the 21st century will be the century of quality. Quality will be the most effective and peaceful weapon to occupy the market and will become a powerful driving force of social development.
For the quality assessment of digital charts cartography, a tetrahedron quality control model was established, but still need further exploration, and there are a range of issues required lots of experiments and calculations, further study should be gradually explored and resolved:
1) Spatial data error and uncertainty theory is getting more sophisticated, but that only applies to the general GIS and remote sensing data, the special nature of chart data are still not involved, it is necessary to extend the theoretical model of error and quality control and change from the former study of error and uncertainty to user-led evaluation of the suitability.
2) As the chart cartographic data with GIS spatial data in general have both similarities and particularities. Some statistical data need to take into account such as surveys on the navigators, engineers of marine resource investigation or other specific chart users.
3) Man is the most critical part of charts suitability evaluation, but the study of people is the most difficult part at present. This requires multi-disciplinary research, such as cognitive psychology, behavioural science, reliability engineering, management and engineering disciplines.

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