RULES AND STANDARDS FOR SPATIAL DATA QUALITY IN GIS ENVIRONMENTS

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ABSTRACT

In the last thirty years the need to associate geographical data to quality specifications has become particularly evident. Digital spatial data of different origins and quality are usually integrated in GIS environments, by determining an indefinite level of global accuracy in such systems. Moreover, the introduction of GIS in the mapping process has produced a completely new type of user different from the traditional map user.

This situation requires the identification of shared requirements for a rational and accurate implementation of such systems. It is necessary to define parameters and data transferring modalities in order to share the same data among different users without losing information: parameters and modalities become essential in the definition of a transfer or exchange standard. With a standard it is possible to maintain open systems and extensible applications, and also to allow public and private agencies to make the use and the production of digital data optimal. The problem is the choice or the definition of international standards that have to acknowledge the needs and the interests of data users, developers and providers.

In this paper the quality approaches in GIS contexts and some of most meaningful standards are examined. This is the starting point to face spatial data quality problems in GIS environments. In fact, since users determine quality according to their multidisciplinary information needs, other factors, such as compliance to specific needs and availability of rules and quality control tools integrated in such systems, etc., must be considered

1. INTRODUCTION

In the last thirty years there have been great changes in the world of cartographic information. The availability of high spatial resolution satellite images and GIS softwares have modified the demand towards greater scale cartography with a improved articulation of thematisms, compared to the past cartographic works. The production of cartography is moving from Geographical Institutes to smaller and specialized productive structures able to follow the constant evolutions of technologies. This has introduced new operators compared to the traditional producers and cartographic users (Guptill et al., 1995).

At the same time, in the GIS environments the demand to produce geographical information of a multidisciplinary nature with elevated quality level remains, because of the evolution of methods and spatial base data acquisition tools.

In GIS environments spatial data frequently have different origins and contain different quality levels, leaving undetermined the global accuracy of such systems. (Caprioli et al., 2001).

All these problems lead to the need of a form of standardization in the way data quality is described, in order to be able to evaluate homogeneously different dataset. This activity has been carried out by various national and international groups aiming at the determination of generally accepted standards (Albrecht, 1999). Nevertheless, the necessity to offer new tools for quality controls and spatial data management remains tied up more to practical applications than to academic contexts (Hunter G. J. ,1999), answering the demands of the final users and aiming at rendering them more accessible or directly available in the very near future in commercial GIS.

2. COMPLEXITY IN GIS DATA CREATION

The main requirement for the data source is that the locations for the variables must be known. Location may be annotated by x, y, and z coordinates of longitude, latitude, and elevation. Any variable that can be located spatially can be fed into a GIS. Many government agencies and private firms produce several attributes and spatial databases that can directly be entered into a GIS. A GIS can also convert existing digital information, which may not yet be in a map form, into forms it can recognise and use. For example, digital satellite images can be analysed to produce a map in the form of a layer of digital information. Likewise, tabular data can be converted into a map-like form, serving as layers for thematic information in a GIS. New data can be created using satellite images, field survey data and GPS survey data (Wahi, 2002).

Moreover, other important issues for creation of GIS data have to be considered:

- Necessity of Analysis. The client will have certain ideas for the development of data. However, in most cases, he may not be fully aware of what is the best that can be done. It is the job of the GIS analyst to assess carefully the requirements of the user and suggest what is best suited for his needs. Such an analysis will help in evolving the needed specifications.
- Cost. With any type of information system, carefully planning prior to the acquisition or the creation of data generally increases the degree of success and efficacy. On the contrary, lack in planning increases the possibility of a mismatch between the system's capabilities and the user needs, becoming just a waste of money. The cost of data development is quite high and the customer should be advised and shown the method through which he can achieve his aim within his estimate.
- Accuracy. Another major issue for the creation of data relates to accuracy, completeness and timeliness. Digitising information to be included in a GIS is not simple and straightforward. As information is included or excluded to fit with the application, the accuracy and completeness of that information can be compromised. In addition the conversion of existing records, without verifying the accuracy of the information with the data subject, can mean that the quality of the newly digitised information is poor as it is out-of-date or incomplete.
- Scaleability Issues. It is important to develop data in order to maintain future expansion always possible. If this is not considered during the creation of data then different kinds of spatial data pertaining to the same area cannot be attached with each other because of the difference in the projection systems and the attribute information.
- Lack of quality and availability of base data. Data quality is essential when a GIS is used to make decisions that, potentially, could adversely impact the data subject. Without an accurate information, any potential operational efficiency or benefit, may be compromised. Many efforts in the creation of data get stuck either because the base data is unavailable or because id very poor in quality.
- Permissions from authorities. This policy on data development needs to be reviewed.
- Standards/Formats. A standard format needs to be developed for spatial data because to convert data from different formats causes the loss of data and their quality gets reduced.
- Symbology. Standard sets of symbols should be developed in order to be used with different kind of applications which use GIS.

3. RECENT INITIATIVES FOR GIS QUALITY STANDARDISATION

Standards provide a common method to acquire, manage, and display information. They are necessary to maintain an open system concept and an extensible application. For any organization it is possible to maximize the use and the application of digital data by using accepted international standards, or widely used proprietary formats (*defacto* standards). The problem is the choice or the definition of international standards that have to acknowledge the needs and the interests of data users, developers and providers.

Standards are usually compiled through normative dispositions proposed by national and/or international technical commissions, with the purpose of supplying the best solution to a vast public. Currently, the difficulties arising from the process of compiling consensually shared norms force the data and geographical systems producers to develop personal formats. In this way, they really become standards de facto (DXF, DGN, various formed GIS, etc.). Such trend has recently lead to recognise that the ability of computer developers and the direct experience of the consumers constitute an essential contribute to face such themes globally.

3.1 Open GIS Consortium, Inc. (OGC)

The OGC is an international membership organization composed by many private companies, government agencies, and academic institutions, committed to the development of geospatial data and geoprocessing standards. The OGC is working to develop the Open Geodata Interoperability Specification (OGIS), described as "...a comprehensive software architecture specification that provides a standard way to represent all kinds of geodata in software and a common set of services to support distributed geoprocessing in heterogeneous environments".

The OGIS promises true interoperability between software applications and data. OGIS aims to achieve the objectives of a universal format while satisfying the needs of data producers and the different data models they employ.

3.2 ISO/TC 211

The ISO *(International Standards Organization)* Technical Committee 211, Geographic Information/Geomatics was established in 1994 to coordinate standards efforts through its 23 member countries. Thirteen countries currently have observer status on the proceedings of TC 211. There are also nine external liaison commitments to such organizations as

CEN/TC 287, the International Cartographers Association (ICA), and the Digital Geographic Information Working Group (a NATO cooperative effort resulting in the DIGEST family of standards).

Five working groups were set up within TC 211 to produce over twenty technical specifications that will become the ISO 15046 family of standards.

The intent of this ISO standard is to develop an abstract model of geospatial data and geoprocessing. Implementation details are left to other organizations such as the Open GIS Consortium. The ISO/TC 211 shares and includes the finalities of the CEN/TC 287 but, while this last is addressed to data, the first aims to the whole process connected to spatial information. This difference is mainly due to the quotas of the market. In fact, the European GIS software producers represent only the 10% of the market. For this reason one of the dominant concepts, the interoperability, that is a priority objective undertaken by the OGIS Consortium, assumes a greater importance in the working program of ISO in comparison with the program of the CEN.

3.3 CEN/TC 287

The European Committee for Standardization (CEN) has formed the Technical Committee 287 to deal with the issue of geospatial standards. The aim of this committee is to develop "... a structured set of standards which specifies a methodology to define, describe, structure, interrogate, update, codify, transform and transfer data and metadata that represent geographic information". In the CEN/TC 287 program the development of a Quality Model (QM) for the Geographic Information rises in order to provide the possibility for producers to describe performances of their own products and for users to identify their own needs in the same terms used by producers, promoting mutual understanding.

3.4 Canadian Geospatial Data Infrastructure (CGDI)

The Inter-Agency Committee on Geomatics (IACG) was set up by the Canadian government to enable collaboration between government and industry for the development of an infrastructure to collect, manage, and broadcast geospatial information over the Internet. This work is the result of the continuing development of the Canadian Geospatial Data Infrastructure. The IACG has set off four projects that embody this mission: Canadian Earth Observation Network (CEONet); GeoExpress; National Atlas of Canada; Mercator Initiative. The latter is focused particularly on developing geospatial information standards.

3.5 National Spatial Data Infrastructure (NSDI)

The National Spatial Data Infrastructure is an initiative of the U.S. government aimed at the development of policies, standards and procedures for a more efficient collection, management and exchange of geospatial data. There is a number of major targets to the NSDI:

- create a basic framework of digital geospatial data to be used as a support for future data collection activities;
- identify quality thematic datasets of critical national importance;
- develop or adopt standards to collect, document, access, and exchange digital geospatial data;
- develop a means to search and query geospatial information.

The Federal Geographic Data Committee (FGDC) is the agency responsible for the evolution of the NSDI. The FGDC is composed of 14 government agencies that produce geospatial information in order "..to make accurate and timely geographic data readily available to support sound decisions over a geographic area, and to do so with minimum duplication of effort and at a reasonable cost. The Standards Working Group of the FGDC promotes and coordinates FGDC standardization activities, aiming at the co-ordination of overlapping standards activities, review and recommend proposals for FGDC standards, and review standards for compliance to policy and procedures.

3.6 Digital Geographic Information Exchange Standards (DIGEST)

The Digital Geographic Information Working Group (DWIWG) represents a NATO effort to develop standard geospatial data exchange formats for military applications. The Digital Geographic Information Exchange Standards (DIGEST) developed through this effort, define rules and coding conventions for the exchange of raster, vector and matrix datasets between the members of the international community. DIGEST uses the Vector Product Format (also called the Vector Relational Format) of the U.S. Department of Defence. VRF contains structures to handle tiled datasets, indexing of variable length data fields, and supports all levels of topology. Thematic data is encoded from a standardized catalogue of features and attributes. A report of spatial and aspatial aspects of data quality is also included.

3.7 Spatial Archiving and Interchange Format (SAIF)

The Canadian General Standards Board, Committee on Geomatics approved the Spatial Archive and Interchange Format (SAIF) as a national standard in 1993. As implied by the name, SAIF was designed, buildinging it on object-oriented programming principles, as an archive and exchange format. This is an open standard that is now receiving acceptance from many agencies and companies across Canada. Users can derive their own data model based upon the abstract objects contained in the SAIF specification applying object-oriented programming principles, such as inheritance and polymorphism. Moreover, the SAIF shares many concepts faced by the OGIS and it is steering into the integration with the DIGEST and the SDTS.

3.8 Spatial Data Transfer Standard (SDTS)

The Spatial Data Transfer Standard (SDTS) has been implemented as the distribution standard for geographic data for all branches of the United States government. It has been designed as an open standard based on object-oriented programming techniques. Currently, the United States Geological Survey is the custodian of this standard.

The SDTS is made up of three parts:

- Logical specifications, consisting in a conceptual spatial data model, a data quality report, and detailed format specifications;
- Model of real-world features, attributes, and attribute values;
- Format implementation of Part 1 specs on byte level using ISO 8211 encoding methods.

One of the main features of the SDTS is that it requires a data quality report. The five portions of this report reveal lineage, positional accuracy, attribute accuracy, logical consistency and completeness. SDTS employs a truth-in-labelling approach to the quality report that places the burden of determining acceptable data quality on producers and receivers of data.

3.9 The Italian experience

For many years now, in many Italian meetings it has been underlined the importance to identify shared and all-embracing requisites for a correct implementation of the geographical information. On the other hand, various Organizations have produced norms connected to the control of the single phases of the GIS processing (for instance base cartography, geology, land use, etc.). At the moment, many companies provide good quality cartographic products in conformity with the requirements of territorial agencies.

If in the past quality guarantees were implicitly ensured by the Geographical Institute, today professionalism and responsibility have to be protected by means of different committees works, that will be transformed in national information directives or norms.

One crucial aspect is the superficiality of cartography tenders. Frequently, the customer does not define data specifications to be insert in maps and the task of identifying information details is left to the experience of the firm, with consequences easy to understand (Bianchin, 2001).

There are significant initiatives aimed at developing methods and instruments needed to face globally such problems. Among these, the "*Handbook and Multimedia Support Tool to Aid the Assessment of Data Quality Issues in GIS Databases"* produced by the Consorzio Venezia Ricerche (CVR) with the Università di Venezia (Giordano et al., 1994) is certainly a work to be pointed out.

4. APPROACHES TO SPATIAL DATA QUALITY

As observed from the various initiatives analysed, the need to associate geographical data to quality specifications is evident. The way of executing quality controls has still not been defined, because the methodologies are being studied.
Quality is a subjective concept, and the meaning of the word strongly depends on the point of view of the single individual.

Some examples of approaching quality are:

- quality consists in following norms specifications (tenders): this is a technical approach, where the product and the production process are the essential elements to assure quality;
- quality is "fitness for use": this is a practical approach directed to the market, where quality is determined by the customer ;
- quality is "excellence": in this approach it is the point of view of the seller to determine the concept of quality;
- quality can be recognized only by experts: this is a point of view connected to some essential services, for example medical assistance or specialist operation.

The theme of the quality of a product or a service has been faced for a long time by the ISO whose philosophy of quality is defined as "*the totality of characteristics of an entity that bears its ability to satisfy stated and implied needs*" (ISO 8402, 1994).

For the ISO, therefore, quality is a result that has to be observed during use. As a consequence there is an approach to the quality that follows the whole production system: the Quality Management System (QMS) consists of an organisation that intervenes in the quality process and on the products.

The following phases have been identified in the evolution of the concept of quality (Koen, 1997):
- craft phase (individual approach and absence of formalized rules);
- final control (approach focussed on the product);
- prevention (approach focussed on the process);
- quality system (it involves the whole organization);
- certification (ISO 9000 norms);
- innovation.

The ISO 9000 reference standards, published in 1987 and revised in 1994, constitute a normative outline for the definition of the QMS. They have a basic concept, that is the constant improvement and the verification of such improvement according to the satisfactory answer of the consumer. The ISO 9000 standards have been thought mainly for industrial products and their application on geographical information remains for some reason an open question (Bianchin, 2001).

An important European initiative related to quality has been the development of a Quality Model for Geographical Information. Such model has been developed by the European Technical Committee on Geographic Information CEN/TC 287 and it will become an European standard. Through the Quality Model the geographical information producers have the possibility to fully describe the performances of their own product.

4.1 Quality Parameters

The American Standard SDTS (Spatial Data Transfer Standard, 1997) has been the first to propose a series of instructions that define and document the GIS data quality, fixing the basic scheme of the data quality report in five parameters: genealogy, positional accuracy, thematic accuracy, logical coherence and completeness (Bianchin, 2001).

Data quality depends fully on the scale, the accuracy, and the extent of the data set, as well as the quality of the other data sets that have to be used. The conventional point of view is that geographical data is “spatial”, so a better definition of geographical data should include the three dimensions of Space, Time and Theme (where-when-what). These three dimensions are the basis for any geographical observation. Data quality also contains several components such as accuracy, precision, consistency and completeness.

The three components of space, time, and theme are covered by the first three Primary Parameters. The last two indicate: on one hand if the data set is complete in terms of the queries that one wants to answer with the help of this data set and on the other if the representation of the data is internally consistent. If every possible accuracy values have to be evaluated the costs of information on accuracy would be too high and thus not affordable.

A closer look at each of the Primary Parameters pertaining to GIS quality follow and their associated sub-parameters are discussed (Ghose, 2002).

4.1.1 Accuracy

Accuracy is the degree to which information on a map or in a digital database matches Actual/ True or Accepted values. The discrepancy between the encoded and the actual value of a particular attribute for a given entity is defined as an “error”. Accuracy is an issue pertaining the quality of data and the number of errors contained in a data set or map. In discussing a GIS database, it is possible to consider horizontal and vertical accuracy according to the geographic position, as well as to attribute, conceptual, and logical accuracy. The level of accuracy required for particular applications varies greatly. Highly accurate data can be very difficult and costly to produce and compile. Accuracy is always a relative measure, since it is always measured according to the specifications.

To judge fitness-for-use, one must judge the data according to the specification, and also consider the limitations of the specification itself.
- *Spatial Accuracy.* Spatial accuracy is the accuracy of the spatial component of the database. The metrics used depend on the dimensionality of the entities under consideration. For points, accuracy is defined in terms of the distance between the encoded location and “actual” location. Error can be defined in various dimensions: x, y, z, horizontal, vertical, total. Metrics of error are extensions of classical statistical measures such as mean error, RMSE or root mean squared error, inference tests, confidence limits, etc. For lines and areas, the situation is more complex. This is because error is a mixture of positional error (error in locating well-defined points along the line) and generalization error (error in the points selected to represent the line). The spatial position of an arbitrary object defined within a GIS data layer has a positional error that can be described by one of the Primary Parameters, Positional Accuracy.
- *Temporal accuracy*. Temporal accuracy is the conformity between the encoded and the “actual” temporal co-ordinates of an entity. Temporal coordinates are often only implicit in geographical data, e.g., a time stamp indicating that the entity was valid at a precise time. Often this is applied to the entire database. More realistically, temporal coordinates are the temporal limits within which the entity is valid. Temporal accuracy is not the same as

"currentness" (or up-to-date ness) which is actually an assessment of how well the database specification meets the needs of a particular application. Temporal Accuracy occurs if the GIS data set has a temporal dimension and thus the spatial information data type results in the form of: x,y,z,t. For the error model it is necessary to investigate this additional coordinate and its dependencies with the other three in order to pay attention to any possible existing correlation.

- *Thematic Accuracy*. Thematic GIS information is generated by collecting and assigning the properties of spatial data to stored objects or areas, that may lead to errors, that can be due to a misclassification error in the first place, or in the second, that originates from the number of different data classes occurring in the same spatial object. In some cases the favouring of one topic can be necessary to make the presentation meaningful, for example the detection of water reservoirs (oasis) in a desert area. Thematic accuracy is the accuracy of the attribute values encoded in a database. The metrics used depend on the measurement scale of the data: Quantitative data (e.g., precipitation) can be treated like a z-coordinate (elevation) and assessed using metrics normally used for vertical error (such as the RMSE). Qualitative data (e.g., land use/land cover) is normally assessed using a cross-tabulation of encoded and "actual" classes at sample of locations. This produces a classification error matrix. Another possibility of presenting thematic accuracy to the user is to attach to each object or even to each pixel an Accuracy of attribute value.

4.1.2 Resolution

Resolution (or precision) refers to the amount of details that can be discerned in space, time or theme. Resolution is always finite because no measurement system is infinitely precise, and because databases are intentionally generalized to reduce detail. Resolution is an aspect of the database specification that determines how useful a given database may be for a particular application. Resolution is linked to accuracy, since the level of resolution affects the database specification against which accuracy is assessed. Two databases with the same overall accuracy level but different levels of resolution do not have the same quality; the database with the lower resolution has less demanding accuracy requirements. For example, thematic accuracy will tend to be higher in general land use/land cover classes like the "urban" one than in specific classes like the "residential" one. Resolution is distinct from the spatial sampling rate, although the two are often confused on with the other. Sampling rate refers to the distance between samples, while resolution refers to the size of the sample units. Spatial resolution of raster data refers to the linear dimension of a cell, whereas for vector data it is the minimum mapping unit size. Temporal resolution is the length of the sampling interval and it affects the minimum duration of an event that is discernible. For example, the shorter the shutter speed of a camera, the higher the temporal resolution (other factors being equal). Thematic resolution refers to the precision of the measurements or to the categories of a particular theme. For categorical data, resolution is the fineness of category definitions (e.g., "urban" vs. "residential" and "commercial"). For quantitative data, thematic resolution is analogous to spatial resolution in the z-dimension (i.e., the degree to which small differences in the quantitative attribute can be discerned).

4.1.3 Consistency

Consistency refers to the absence of apparent contradictions and is tthe measure of the internal validity of a database. Spatial consistency includes topological consistency, or conformance to topological rules, e.g., all one-dimensional objects must intersect at a zero-dimensional object. Temporal consistency is related to temporal topology, e.g., the constraint that only one event can occur at a given location at a given time. Thematic consistency refers to a lack of contradictions in redundant thematic attributes. For example, attribute values for population, area, and population density must agree for all entities. Attribute redundancy is one way in which consistency can be assessed. The absence of inconsistencies does not necessarily imply that the data are accurate. Logical consistency covers on the one hand topological aspects and on the other the validity ranges of values that occur in the data set and that can occur in spatial, thematic, and temporal parameters. For a Measure of topological consistency it is possible to investigate for example the correctness of polygons.

4.1.4 Completeness

Completeness refers to a lack of errors of omission in a database. It is assessed according to the database specification, which defines the desired degree of generalization and abstraction (selective omission). There are two kinds of completeness. "Data completeness" is a measurable error of omission observed between the database and the specification. Even highly generalized databases can be "data complete" if they contain all of the objects described in the specification. A database is "model complete" if its specification is appropriate for a given application. Completeness informs the user about the spatial, thematic, and temporal coverage capabilities of the data according to the predefined purposes. The two Measures Omission and Commission are considered to be sufficient to describe how well a data set fulfils the demands of the user.

5. CONCLUSION

Despite the numerous efforts carried out to standardize geographical information, standards are not always able to guarantee or to improve quality, since they do not consider all the possible applications and can be valued only in specific contexts. The standards content regards the guide lines or the requisites needed to establish the documentation and the last procedures but, without the context, they are not able to define quality. A useful information regarding quality asks for the final use to be known.

If data with different scale are present in a GIS, then the respective different positional accuracies can preclude an accurate analysis. The fulfilment of a standard does not assure the quality and in decisional contexts it does not allow the accessibility to metadata.

Associating standards content to particular conformity values is one way to understand quality. Developed in the manufacturing industry, the use of control to achieve quality leaves users out of the whole process. The knowledge of quality in satisfactory characteristics is a misleading concept because it makes implicit the objectiveness of quality assessment, and it does not include the requirements of the users in the determination of the quality.

Practical purposes ask for a more pragmatic understanding of the concept of quality. This is recognized in the GIS as "fitness to use". This widely accepted expression affirms that spatial data quality is recognized only in terms of its specific use. Isolated metadata do not determine satisfactory geographical information quality. If data for quality valuation are not available, metadata do not satisfy the primary purpose. This is perhaps the most serious defect of standards. They contain the knowledge of the data producer, other information that concern quality determination has to be added by users.

The efforts to standardize metadata content and data quality are taking important steps toward the overcoming of closed metadata. Since these efforts are focused on least requisites, interchange requisites and documentation guide lines their results at present open “small rooms” in order to put metadata sources in a new greater “room”. By following these standards, producers can require metadata availability, but these last will be incomprehensible to geographical information users. Moreover, the metadata achievement is not enough to help quality decisions, if barriers to access remain.

Inside the subject of accessibility, the contentious standards nature is also important. It is the result of discussions and negotiations that expressly or implicitly highlight institutions and dominant disciplines contributions. A look to other disciplines, such as software engineering, can offer impulses for an wider knowledge of geographical information quality. This is necessary with the increasing role of the GIS user and the information producers, not exclusively for the users of data provided by national cartography agencies, etc.

Standards will always be essential, but the intrinsic quality conformity is only a part of geographical information quality. Moreover, procedures of quality evaluation need to include users applications. It is be important to find the way to distinguish different typologies of quality demands by dealing with the market.

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Biography

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