SPATIAL DATA QUALITY: FROM METADATA TO QUALITY INDICATORS AND CONTEXTUAL END-USER MANUAL

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Abstract

The context within which geospatial data are used has changed significantly during the past ten years. Users have now easier access to geospatial data but typically have less knowledge in the geographical information domain, so have limited knowledge of the risk related to the use of geospatial data. This sometimes leads to faulty decision-making that may have significant consequences. In order to reduce these risks, geospatial data producers provide metadata to help users to assess the fitness for use of the data they are using within the context of their application. However, experience shows that these metadata have several limitations and do not reach their information goal for this new group of non-expert users. In addition, geospatial data are becoming a mass product that has to follow legal requirements related to this class of products. Metadata, as currently defined, do not reach these obligations, especially concerning the requirements for easily understood information about product specifications and potential risks of misuse. This paper describe an approach that aims to reduce these risks of misuse by comparing data producers specifications and data users needs and providing indicators describing data quality to users. The system, named Multidimensional User Manual (MUM), allows the management of geospatial data quality and the communication of the quality information using indicators that can be analysed at different levels of detail.

Keywords : Geospatial data Quality Indicators, GIS Risk, interactive User-Manual, Spatial OLAP, Law.

1. INTRODUCTION

The development of information and communication technologies such as the Internet has significantly modified the context within which geospatial datasets are used. We now face an increase of geospatial datasets being exchanged between people or organisations. Geospatial data can now be easily downloaded on the Internet (e.g. Geospatial data catalogues). It is also possible to download free GIS software that is easy to use for non-expert users (Agumya and Hunter, 1997, Elshaw Thrall and Thrall, 1999, Goodchild, 1995). In addition, many organisations are building new data infrastructures such as Data Warehouses in order to regroup their different data in a common system and share them at different levels of the organisation, facilitating then information diffusion. Decision processes based on geospatial data are also increasing (Hunter, 1999). Geospatial datasets are now used in a wide range of applications such as public health, geology, forestry, transportation, urban planning, etc. (Longley et al., 1999). They are also used today by people at different levels of the organisation (i.e. operational, tactic and strategic levels) whereas it used to be used mainly by experts in geographical information (Longley et al., 1999). Consequently there are new categories of GIS users who are experts in their field of application but not in the geographic information domain.

Such a situation leads to a higher risk of misuse of the GIS data, potentially leading to faulty decision-making that may have significant legal, social and economical impacts. Many cases of Geospatial data misuse are mentioned in the literature and the media, causing an increasing number of legal contentious (e.g. (Beard, 1989, Goodchild and Kemp, 1990, Monmonier, 1994, Curry, 1998)). Most of Geospatial data users do no understand the main geographical information concepts and many of them are not aware of the uncertainty that digital data may contain (Morrison, 1995). They then often integrate several datasets having similar appearance without being aware of the potential risks that may arise from these combinations (Curry, 1998).

The objective of this paper is to present the Multidimensional User Manual (MUM) project that aims at providing to the users of geographical information an automatic contextual manual that helps them evaluate the risk involved when using one or several geospatial datasets for a given region. We thus aim at reducing the number of potential cases of geospatial data misuse.

We will first discuss about some problems arising from data quality terminology and its impact on systems dealing with data quality. We will continue with a discussion about limitations of present metadata in term of communication between data producers and users. We will then see how well these metadata are compliant to legal requirements, using Quebec province legislation as an example. We will then focus on different aspects of geospatial data quality management and communication by describing the general architecture of the MUM in order to identify the different modules of the system. We will present a way to manage geospatial data quality in a multidimensional database and introduce the concept of quality indicators defined from a user perspective. Finally, data quality visualisation issues will be briefly described in the context of the MUM.

2. COMMUNICATIONNAL AND LEGAL LIMITATIONS OF PRESENT METADATA

2.1 Spatial Data Quality issues

Data quality is a very active domain in geographic information research and has a growing interest because of the increase of data exchange (Goodchild, 1995, Veregin, 1999). There is now considerable agreement on the definition of quality in the literature, quality being defined as “fitness for use” (Veregin, 1999). Quality is defined by ISO 8402 as the “totality of characteristics of a product that bear on its ability to satisfy stated or implied needs”. This means that to define quality you need both the information on the data being used and on the users needs (e.g. intended use). Although the “fitness of use” definition is frequently referred to, it is surprisingly rare that user needs are actually taken into account. There has only been a relatively small amount of research on measurement of fitness of use (Bédard and Vallière, 1995, Agumya and Hunter, 1997, De Bruin et al., 2001), but there is a strong need for systems that can implement data quality as fitness for use.

However, there is an ambiguity in the definition in the term "quality". It is noticeable that data producers often define a product of quality as being consistent with specifications (ex: difference between a database and the nominal ground) while data users define it as meeting or exceeding their expectations (Kahn and Strong, 1998). It is frequent to see products having a numeric value as quality. However, it does not make sense to allow a unique value on a certain scale of quality for a product, as quality may only be measured within the intended use context that may be different for each users, and even among different for the same user.

Another problem is the difficulty in properly communicating the information about data quality. Although several researchers have explored the best way data quality may be visualised (Beard and Mackaness, 1993, Buttenfield and Beard, 1991, Buttenfield, 1993, Leitner and Buttenfield, 2000), the only way actually used to communicate data quality parameters is using metadata. However, the currently produced metadata still have strong limitations in term of communication media for non-expert users as well as for expert users.

2.2 Present spatial metadata limitations

In order to help users to assess the fitness for use between the data and their needs, data producers often provide metadata describing different aspects of the datasets (Guptill, 1999). Metadata are usually stored in text files using "home-made" formats that may be based on national standards (e.g. FGDC). However, data providers are moving to international standards such as ISO and OpenGIS which include both conceptual and implementation specifications. However, these metadata are still often stored in files that are independent from their related data, then, if data are being modified, changes are not always propagated to their associated metadata. As metadata are static in nature, they are not very useful for dynamic operations when using a GIS. In addition, for reasons of cost, time and complexity, metadata are often related solely to the dataset and rarely to individual objects (or even to geometric primitives). As quality is often heterogeneous within a single dataset, it is important to describe it, at least, at the object level as allowed by the most recent standards and high-quality datasets.

Metadata are also often technical descriptions dedicated to experts or professionals, using a terminology that is hermetic for non-expert users (ex: "Polygon topology was verified with the Arc/Info "BUILD" command" – extract from SMMS for GeoMedia quality metadata sample example). Consequently, geospatial metadata are often unused by the users (Harvey, 1998, Timpf et al., 1996). Thus, quality description is inadequate for most users and does not help them to decide if a potentially useful dataset should be acquired and used (Frank, 1998).

2.3 Spatial Metadata and legal issues

In many countries, applicable legislation allows one or more civil liability regimes with whom the objective is to govern interrelations between citizens and to penalize some reprehensible behaviours, should the occasion arise. There are many similarities between the legal systems in different states, especially those having a legislation originating from the Napoleon code (province of Quebec in Canada, France, Belgium, etc.). The analysis of the juridical context related to the MUM project focuses on the legislation actually applied in the province of Quebec in Canada, especially by rules included in the Quebec Civil code (Q.C.c.). Even if the conclusions may not be *fully* applicable in all countries supporting a similar regime, the data producers' juridical obligations are usually built in these countries on identical concepts.

The two main liability regimes in Quebec are civil *contractual* liability (art. 1458 Q.C.c.) and civil *tort* liability (art. 1457 Q.C.c.). The first one results from a contravention to a *to do* obligation or *not to do* obligation, *temporary* and getting its source in a juridical *act* (contract). The second one results from a violation of a *not to do* obligation, *continuous* and *legal* and getting its source in a juridical *fact* (Baudoin and Deslauriers, 1998, Baudoin and Jobin, 1998). It involves, normally, two parties that are not bound by a convention.

With regard to tort liability, the following constitute a fault for producers or distributors:

- Failure to give warnings and cautions that are clear, complete, and up to date;
- Failure to inform the user adequately about the product risks and dangers;
- Failure to give the means to take precautions against it (directions for use) and on the particularities making it inappropriate to the expected use (ex: road map designed for pedestrian tourism navigation and inappropriate for car navigation).

To these different fault categories, we can also add poor product conception. (Ex: map road designed for car navigation but without considering one-way streets).

Different means of exemption exist for producers and distributors. However, any of these can be admissible with regard to corporeal or moral damages (art. 1474 Q.C.c.). As for material damages, exemption will be effective if absence of security default is demonstrated, that the prejudice origins either from a major force case (event unforeseeable and irresistible, art. 1470 Q.C.c.), or from victim negligent behaviour itself, or finally, from an unknown default considering the science development at the moment of the product commercialisation.

The development of the mass market of consumer goods has greatly influenced the juridical context and had given birth in many places to a distinct liability regime much more severe (more particularly the «*Loi sur la protection du consommateur* (L.P.C.), c. P-40.1 » in Quebec, and the « *Directive 85/374 du Conseil du 25 juillet 1985* relative au rapprochement des dispositions législatives, réglementaires et administratives des États membres en matière de responsabilité du fait des produits défectueux dans certains pays d'Europe ») with which the main goal was to frame the relations between physical and moral persons having "consumer" status and trades people. In Quebec, a consumer is defined as *a physical person, except for a trade people who is procuring a good or a service with a commercial purpose* (art. 1 (e), L.P.Q, free translation). The number of court decisions, related to this type of trade has exploded in the past twenty years. This new liability regime are distinguishing itself from the others notably by the following characteristics:

- Additional obligations about formal procedures;
- Vice precedence presumption, i.e. that product default is presumed to be present at the transaction moment;
- Impossibility to plead ignorance or reasonable diligence or absence of risks knowledge (irrefutable presumption, risk relied to the technological uncertainty is burden to the trade people);
- Increased pressure to take the information disclosure initiative;
- Punitive or exemplary damages in addition to usual compensatory damages (art. 272 L.P.C.);
- Interpretation on consumer's behalf (art.17 L.P.C.).

The information industry (which includes geographic information) is changing in the direction of massively increased information production and circulation, loss of privileged contact between producer and consumer, and increasing number of non-experts users, as discussed above. These factors contribute considerably to the increasing risk of bad decisions, bad interpretations, and failing applications. In this context, if it is as fact that to the same causes follow the same effects, contentious increasing may statistically increase in this direction (Montero, 1998).

A Geographic information producer or distributor sees their liability involved if, firstly, they make a fault in the Quebec civil code sense, secondly, this one cause a certain prejudice and, thirdly, if there is a causal relation between fault and prejudice. It is notably at the level of proof burden and the fault concept that the impact of the "*Loi sur la protection du consommateur*" is much more noticeable. Twenty years ago, a consumer taking proceedings against producer need to prove (which was often complex and outside his field of expertise), a product conception default or of the prejudice author's negligent behaviour. Then the legislator, anxious of consumer protection and contractual balance maintenance, reversed the proof burden and requires now that the producer and distributor themselves prove absence of default, the consumer having only to declare that product or service was containing a *default*.

Liability regime interpretation, with regard to informational product, allow us to assimilate to the fault concept the following situations where producer and/or distributor neglects to put in place technical and organisational mechanisms in a way to prevent damages, to reveal the part of uncertainty included into the data, to formulate indications on the value of provided information, and to control the software performance being used for interface between user and informational product (Montero, 1998). For this last obligation, we can expect that the producer or distributor has to do some compatibility tests between geographic information system available on the market and the database in order to inform the user which one is recommended.

Considering the different liability regime mentioned above and the possibility that they can be brought into operation following the commercialisation of geographical information, database producers must ask themselves if the information furnished in a transaction are consistent with the juridical *obligations* which fall on them. With respect to the previous discussion, it is plausible to believe that the current forms of metadata do not allow the producer to respond *adequately* and *totally* to these requirements especially with regard to producers' and distributors' information obligations. In fact, metadata:

1. Rarely contain warnings and cautions with regard to the expected use, and considering the language used, are hardly admissible in front of a civil court with regard to the requirement of being clear and complete;
2. Do not constitute directions for use, which inform user on the product risks and dangers and the means to take precautions against it, even in some cases, when sufficient information allowing one to infer it is present, the interpretation burden falls on the user (Frank, 1998);
3. Can be hardly considered as a technical and organisational mechanism in a way to prevent damages, especially since they are often incomprehensible to non-experts users. (Ex: Mercator Transverse cartographic projection, reference datum NAD 83, etc.) ;
4. Are much too numerous (particularly when they are associated to each entity) to allow efficient consultation and to infer in which measure the expected application will generate *reliable* results, this situation can be considered as much a management and user-friendliness constraint as a juridical constraint.

The user manual conception, the ultimate goal of the MUM project, will take into consideration these obligations of Quebec legislation described in this section.

3. SPATIAL DATA QUALITY MANAGEMENT AND COMMUNICATION

In order to provide to users information about geospatial data quality in an easily understood format, we need to define database structures that may store this information. We suggest an implementation using (i) a single multidimensional database containing both raw data (metadata and other source of information about data quality) being used before comparing information about data quality and users' needs and (ii) another multidimensional database containing the values of comparisons between the aggregated values and the users needs (indicators values) that will be displayed to the users.

3.1 Multidimensional User Manual General Architecture

In order to solve these different problems, we aim at elaborating a system that evaluates data quality according to the "fitness for use" definition.
The system would compare data specifications as provided by data producers, with the needs, as expressed by users. It would also take into account the level of risk a user is willing to take for his project. In order to be able to compare these descriptions, the system would formalise them into a product ontology and a user ontology. By comparing these two ontologies (describing the properties of objects, relations, etc.), it would be possible to quantify and qualify the proximity between the two (i.e. the overall quality). The information produced by this comparison would highlight some possible risks that may occur when manipulating the data in some context. For example, a dataset may represent houses. According to data producers, houses may be all constructions that have more than 150 m^2 whereas data users may need all constructions of any size. These risks can then be communicated to users using an interface coupled or integrated with the GIS.

3.3 Spatial Data Quality indicators hierarchy

Information about Geospatial data quality has to be provided to data users in order to help them during their decision processes. Cognitive sciences and decision processes theory teach us that humans often base their decisions on indicators. A physician will for instance look at different indicators when treating an illness (ex: pulse, tongue, temperature) before deciding on the medical treatment to apply. Decision support systems also often use indicators in order to provide high-level aggregated values to strategic decision-makers. In this context, indicators may be defined as "a way of seeing the big picture by looking at a small piece of it" (Jackson community Council, 1999). We need then to define indicators that may inform users more efficiently than present metadata descriptions.

The MUM system organises the indicators following a multidimensional hierarchy (see Figure 1) that may be managed using an On-Line Analytical Processing (OLAP) system (Berson and Smith, 1997, Codd, 1993). This category of tools allows users to navigate at different levels of aggregation within a multidimensional database without having an information overload (only a few pieces of information are displayed at each level). Indicators' values may be displayed using different representations depending on the type of value (street light, yes/no, percentage, speed meter, etc.). Figure 1 uses only a street light display for indicators values, the green light meaning that data is fit for the intended use (low risk), the red one meaning that there may be high risks on the associated indicator and the yellow one being somewhere in between. A user may then be aware of the overall data quality by viewing a single indicator "SD Quality" (for Spatial Data Quality). If he wants to have further detail on this indicator he may use the OLAP function "Drill down" in order to display the indicators of which this high level indicator is composed (in this case, Confidence, Data quality and Risk seriousness). He may then wonder why the Data Quality indicator has a red value and drill down again on this indicator to display the next level of detail, etc.

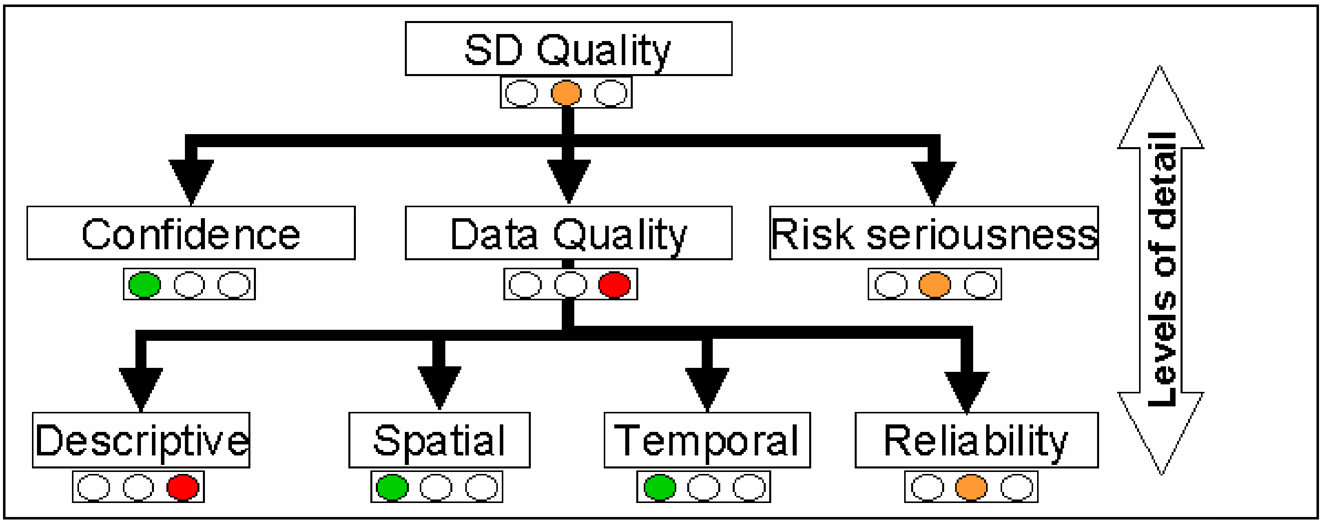

Figure 1. Example of Geospatial Data Quality indicators hierarchy.

3.2 Spatial Data Quality dimensions

Information about Geospatial Data Quality may be organised using different levels of aggregation within the database. In order to manage these data into a multidimensional database, we first need to define the different dimensions the data may follow. Three reference dimensions are used in this structure (geometry, semantic and temporal) in addition of dimensions for each quality indicator. Reference dimensions allow the association of quality values with its level (e.g. Indicator A associated to an instance of the class object lake). Unique combination of reference and quality dimensions allows to have a measure for the quality.

3.2.1 Geometric dimension

Quality metadata may be attached to elements at different levels of detail on the geometric dimension. The levels are:

- Geometric primitives (ex: line segments composing a polygonal lake);
- Complete geometric shape of an object (ex: complete polygon of Lake Placid);
- All geometric shapes of a same object class (ex: all polygons representing lakes);
- Dataset or all geometric shapes of all object classes (ex: topographic map of a region including lakes, rivers, streets and houses).

3.2.2 Semantic dimension

Quality metadata may be attached to elements at different levels of detail on the semantic dimension. The levels are:

- Value (ex: commercial);
- Domain (ex: commercial, industrial, residential);
- Attribute (ex: building type);
- Object Class (ex: building);

- Semantic (ex: semantic of buildings, lakes, rivers and streets).

3.2.3 Temporal dimension

Quality metadata may be attached to elements at different levels of detail on the temporal dimension. These levels may depend on the hierarchy defined by the user, such as:

- Temporal primitives;
- Complete temporality of an attribute (evolution) or an object (existence);
- Complete temporality of an object (evolution thru all attributes + its existence);
- All temporalities of a same object class or of same attribute type of a same object class;
- Dataset or all temporalities of all object classes.

3.2.3 Quality indicator dimension

Quality indicator hierarchy is organised in term of dimensions in the multidimensional database. The different levels are not generic and may change depending on the system conception.

3.4 Information about Quality aggregation

Whereas data producers often documented datasets using a short description at the dataset level, many data producers want now to document their datasets at a more detailed level, such as the entity level. However, a complete documentation of the dataset following, for instance, the ISO standard for geospatial metadata, may require to fill more than 400 fields for each object. Then, the volume of metadata that has to be managed by the system would be much more important than the volume of data. It would be in this case impossible to communicate clearly to users a big picture of the overall quality. There is then a need to provide users an aggregated view of the overall dataset quality. We are suggesting in our approach the use of contextual quality indicators that are an aggregation of several information about quality.

Quantitative data aggregation may be done using some basic formulas such as minimum, maximum or average, or more sophisticated methods, depending on the context (ex: aggregation of horizontal and vertical accuracy to create a “Spatial accuracy” indicator). However, if these methods may work for quantitative data integration, it is not possible to apply them to qualitative data aggregation. These may also be adapted for qualitative data aggregation by other data fusion techniques may be more appropriate; for example, certain logical formalisms may allow, using rules, the definition of more complex aggregation techniques.

3.5 Spatial Data Quality visualisation

Geospatial data quality may be communicated to users in different ways. Quality indicators can be visualized using different representations (see section 4.2) within the GIS interface, such as within a “dashboard” that user may consult when needed. For example, figure 2 presents a Spatial OLAP system that integrates the quality information dashboard. This dashboard includes indicators selected by the user. Indicators’ values change when the user adds or removes data in the application. The yellow light on the bottom right of the screen, should always be visible in the GIS environment, representing an aggregation of all the indicators’ values displayed on the dashboard.

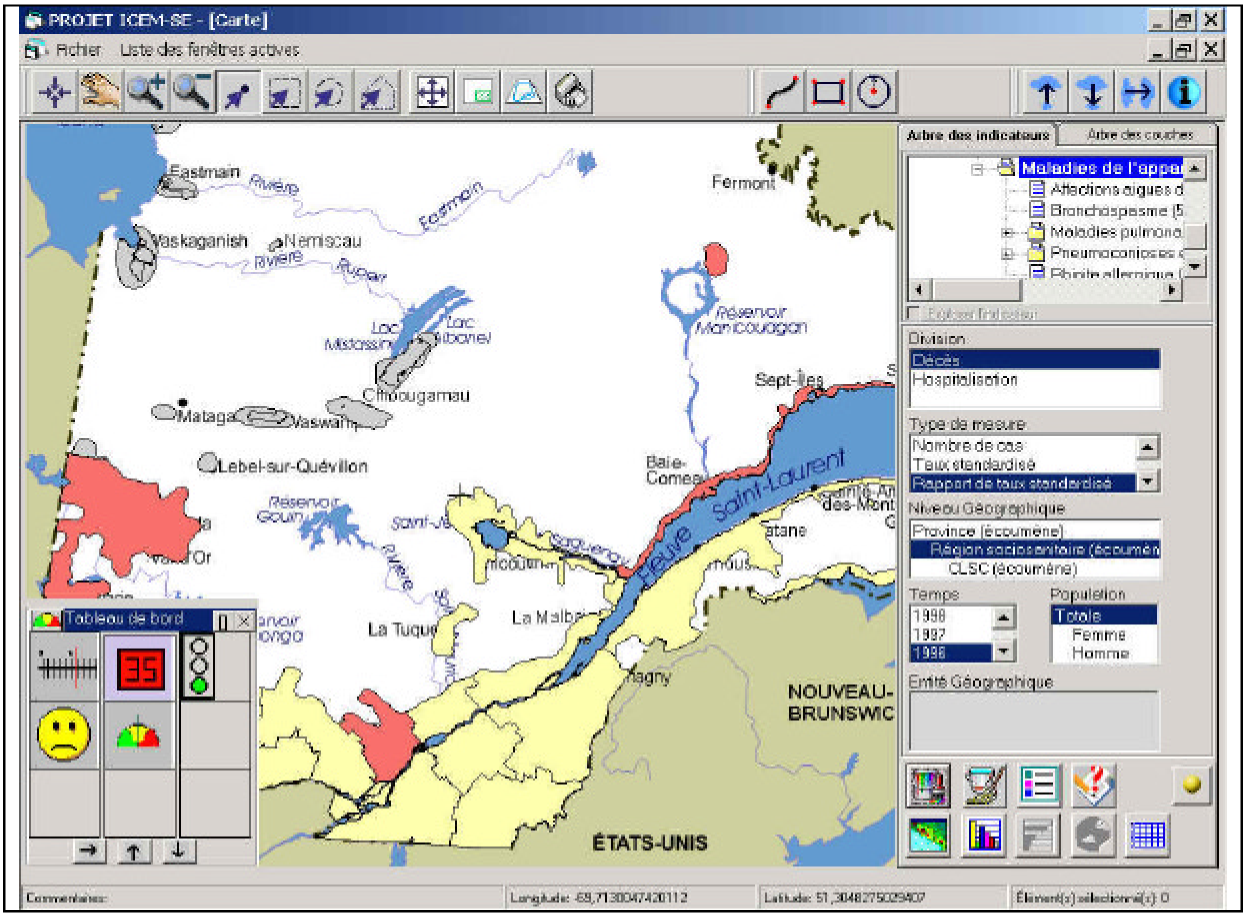

Figure 2. Visualisation of geospatial data quality using a dashboard (bottom left). Each symbol in the dashboard represent an indicator selected by the user.

Another way to represent quality indicators value is to display them directly on maps using Spatial OLAP systems (Rivest et al., 2001). This category of system allows the management and the visualisation of geometric entities at different levels of detail. It may then be possible to directly visualise quality indicators on the associated geometric entities and then to navigate at different levels of aggregation using SOLAP operators (e.g. Drill down). Figure 3 provide an example of Geospatial Data Quality visualisation using a Spatial OLAP system. Users can display quality indicators either with a streetlight representation, or by directly associating the quality indicators to the individual objects, at different levels of detail.

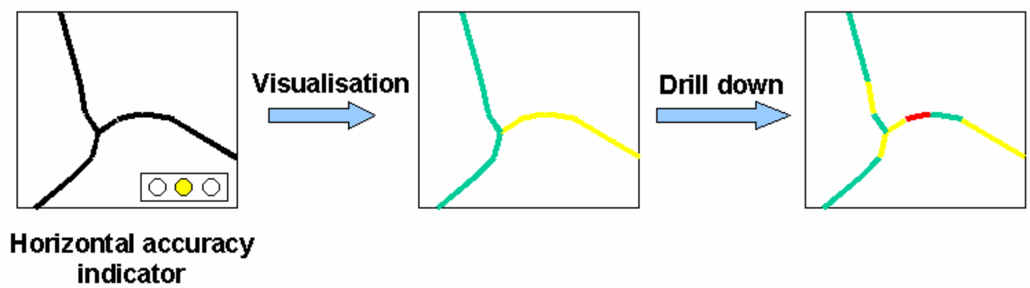

Figure 3. Visualisation of geospatial data quality using indicators and a Spatia l OLAP system.

As quality may vary spatially, indicators values have to be updated dynamically when the user change the area visualised.

4. CONCLUSIONS AND REFERENCES

This paper presented a method that allows the management and the communication of spatial data quality to users in order to reduce the risk of misuse. This system, the Multidimensional User Manual (MUM), would respond both to the problem of poor communication with the end users, and to the legal requirements for data producers seem certain to have to follow. We presented the advantages of communicating data quality using indicators, based on the aggregation of different information about data quality, which would be easier to understand for end-users than present metadata. Metadata are fundamental to this approach, since they represent a large part of the information available describing data quality; however we will need more formally defined metadata, using more quantitative data or enumerated values for instance, in order to be able to automatically produce the quality indicators. We described how the quality information and these indicators could be stored at different levels of detail within a multidimensional database and retrieved using an OLAP system. We briefly introduced the challenges in term of data aggregation that will be necessary for the definition of the indicators' values. We then presented how this information about data quality may be communicated to the end-users, whether they are experts in the geographic information domain or not, using both the indicators display at different levels of detail and a Spatial OLAP visualisation system. Each aspect of this User Manual system will be explored in detail in different research projects.

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