# SPATIAL DATA QUALITY

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## WHAT IS DATA QUALITY?

Data quality is an important factor in the process of effectively and accurately conveying information. The term data quality can be misleading, giving rise to ambiguity by interpretation. The *US Spatial Data Transfer Standard* defines "quality" as:

> "Quality is an essential or distinguishing characteristic necessary for cartographic data to be fit for use."

Data quality can vary from person to person, organization to organization, or from application to application. It becomes the responsibility of the user to decide if a data set is sufficient to meet given quality requirements, and the standard may differ by application or use. Data quality may be appropriate for one project but not necessarily suitable for another.

The US Spatial Data Transfer Standard lists five components of a data set which provide the information necessary to assess data suitability for use.

- Data lineage
- Positional accuracy
- Attribute accuracy
- Logical consistency
- Completeness

**Data lineage:** describes the source of the derived data, derivation methods, and all transformations employed in producing the final data. It must also include the specific control points used.

**Positional accuracy:** compares spatial data to an independent and more accurate source. This should include the positional accuracy of geodetic control points and the accuracy of data after all transformations.

**Attribute accuracy:** may include deductive estimates or may be based on independent samples from polygon overlay. Should differentiate between original and derived attributes.

**Logical consistency:** determines the faithfulness of data structures embedded in a transfer file. It should verify the topological and network coverage.

**Completeness:** A data set is complete with regards to aspects such as minimum area employed in polygon construction, gaps in either the data element set or attribute values, etc. Completeness also refers to the aspects of the data set that characterize it as a whole and not as a specific or individual element.

## ERRORS IN GIS - HOW THEY AFFECT DATA QUALITY

Errors may creep in at any stage of data acquisition and transformation. It is therefore imperative to control the errors at each and every transition from observation to the presentation stage and to see to it that the quality is maintained.

Inaccuracy due to errors may be encountered during primary (data collected directly by aerial and terrestrial surveying and satellite imagery) or secondary methods of collection (data is collected indirectly from charts, maps, graphs, etc.) of data.

Errors encountered in **primary methods** of data collection may be classified as

- Personal errors
- Instrumental errors
- Environmental errors

Errors encountered in **secondary methods** of data collection may be classified as

- Errors in plotting control
- Compilation error
- Error in drawing
- Error in map generalization
- Error in map reproduction
- Deformation of the material
- Error introduced due to the use of the wrong scale
- Uncertainty in the definition of a feature
- Error due to feature exaggeration
- Error in digitizing or scanning

Additionally, all the errors encountered in primary methods are also encountered in secondary methods.

Due to the errors that creep in to the data at each and every stage of data acquisition or transformation, inaccuracy (deviation from the true value) increases and leads to the deterioration of data quality. Though errors are an inherent part of the data in GIS, care should be taken at each and ever step, so as to minimize the data error and keep the data quality of the highest order.

## GENERAL SPATIAL DATA INFORMATION

According to [Ries 1993] **spatial information** can be divided into three primary architectures**: data, function, and organization**. Data architecture describes the activity performed between two types of data. Organization architecture describes objects used as input to, or created by, a function. Functional architecture describes the mission, policies, and rules, which determine and shape the former two. By exploring each of these architectures, one can develop a framework to establish spatial design requirements.

Spatial **data** can be displayed in different ways: point, line, polygon, surface, volume, and pixel. Each of these display mechanisms has three components: location, shape, and topology. These components help define the scope of the design requirements for each Location Control Management level. Along with data, its properties are equally important. Data properties describe the quality, or condition of the spatial data.

Traditional definitions for GIS incorporate several **function**s that encompass the spatial feature's life cycle. Retrieval, integration, analysis, and display/report implement this life cycle approach.

**Organization** provides the key support to any data and functional design needed for data integration.

## FACTORS AFFECTING DATA QUALITY

1) Currency
    a) Are data up to date?
    b) Time series

2) Completeness
    a) Feature or Entity completeness
        i) Data completeness
        ii) Model completeness
    b) Attribute completeness
        i) Value completeness

3) Consistency
   a) Map scale
   b) Standard descriptions
   c) Relevance

4) Accessibility
   a) Format
   b) Copyright
   c) Cost

5) Accuracy and precision
   a) Lineage – when collected, by whom, how?
   b) Density of observations
   c) Positional accuracy
   d) Attribute accuracy – qualitative and quantitative
   e) Temporal accuracy

6) Sources of errors in data
   a) Data entry or output faults
   b) Choice of original data model
   c) Natural variation and uncertainty in boundary location and topology - temporal error
   d) Observer bias
   e) Processing
      i) Numerical errors in the computer
      ii) Limitations of computer representations of numbers

7) Sources of errors in derived data and in the results of modelling and analysis
   a) Problems associated with map overlay
   b) Classification and generalization problems
   c) Choice of analysis model
   d) Misuse of logic
   e) Error propagation
   f) Method used for interpolation
   g) Lack of consistency in different analysis of the same data.

## Completeness

According to the *Spatial Data Transfer Standard*, "Completeness must describe the relationship between the objects represented and the abstract universe of all such objects" (SDTS 1997). The selection criteria, definitions, and all the objects collectively describe completeness. The abstract universe and its relationship with the database must be precisely described. The abstract universe can be defined in terms of a desired degree of abstraction and generalization, i.e. a concrete description or specification for a database (Data Quality Parameters, H Veregin).

Completeness can be defined in terms of commission or omission of error, and divided into two broad types: Feature (or Entity) completeness and Attribute completeness. Feature completeness can be further divided into data and model completeness and can be defined over space, time, or theme.

Data completeness acts as a check on data quality. It is defined as the measurable error or offset observed between the database and the specification. If the database contains all the objects with their specifications, the data set is considered complete. Model completeness is referred to as the agreement between the database and the abstract universe required for a particular database application. Because this varies from application to application it is an aspect of ‘fitness for use.’

Attribute completeness is the degree to which all relevant attributes of a feature have been encoded. Value completeness is the degree to which all the values of attributes are present.

## Consistency

Consistency refers to the harmonious uniformity or agreement among parts of a database. It is the lack of apparent contradiction in the data. For geospatial data the term is especially used to specify conformance with certain topological rules (Kainz 1995). Before consumers use any database it is important to insure that it has spatial uniformity in itself, such that the points should meet their actual existence points, lines intersect at nodes, and polygon are exactly bounded by lines.

Consistency problems arise in spatial data when we have to overlay maps, or when trying to combine the data of two or more maps into one. The chances of losing a certain degree of consistency also increase when we try to combine data from two different maps of different map scale.

Inconsistency also arises due to the poorly defined process of GIS. The entire process - from the conceptual stage, to the collection of data, to the analysis, to the actual manipulation and interpretation of data - needs to be standardized and a detailed description is required. The human factors and the limitations of instruments used to achieve these transformations result in a certain degree of inconsistency.

Care should be taken to avoid spatial inconsistency. This can usually be identified through redundancies in spatial attributes. For example, an entity might have the attribute ‘California’ as a state, and ‘Washington’ as a County. Non-redundancy implies that there is independence between two attributes such that meaningful consistency does not exist.

Consistency should also be maintained with regards to the temporary nature of data, i.e., a place or a location is shown on two different maps in different places.

## Accuracy and Precision

Accuracy is the first consideration when data is analyzed and evaluated. Questions such as acceptable error limit range, or to what extent the data be considered to be accurate, are also addressed. Accuracy, precision, and error all have varying degrees of meaning, each with its own significance.

**Error** is the difference between the true and estimated values.

**Accuracy**, in terms of error, is the extent to which an estimated value approaches the true value. It is generally given by a true value +/- some error.
E.g. 23.5 +/- .05

**Precision** is the dispersion of data from the actual data. It is estimated in terms of standard deviation of the observations over the mean. It also refers to the ability to display numbers to a certain number of decimal digits. E.g., the given data is correct unto 3 decimal points – accuracy is +/- 0.001

Maintaining data accuracy and eliminating error are essential prerequisites to providing sound information for a variety of uses. Error appears at any stage: conceptual (perception), in the field, (false data acquisition via theodolite limitations, GPS Satellites, etc.), and in attribute measurement (due to variation in the environment, observer bias, poor handling and manipulating of data, misinterpretation of acquired data, etc.).

Error is inherent and inevitable in GIS data. A GIS dealing with different layers of data collected from multiple sources, scales, dates, and map projections will have its complex error propagated even further. The challenge lies in maintaining the required accuracy and precision.

The word data accuracy is a broad term divided into lineage, positional accuracy, thematic accuracy, and temporal accuracy.

The following factors should considered for accuracy and precision of any spatial data:

- **Lineage – when is it collected, by whom, and how?**
  Lineage in terms of GIS refers to the history of the data, i.e., the description of the source material from which the data was derived and the methods of derivation, including all transformations involved in producing the final data. It is important to know the lineage of the data because most of the errors are the result of errors in the field. To verify previous results it is imperative to establish a set of control points while collecting or describing data. These need to be documented in sufficient detail to allow recovery. Also, the entire path of transformation should be described completely, so as to avoid confusion and round-off (or approximation) error in later stages.

- **Density of observations**
  In order to have a sufficient proof of spatial data accuracy, a number of observations should be taken by a different numbers of persons in order to collect accurate data that is relatively free from errors. While analyzing this data, observations should be meeting to a point where they nearly coincide.

- **Positional accuracy**
  Positional accuracy is defined in terms of the accuracy of geodetic control points, and the accuracy of the data after all transformations, i.e., a set of permanent control points used to achieve sufficient accuracy. Positional accuracy must be determined by comparing the spatial data to an independent source of higher accuracy. The test for positional accuracy must be conducted in accordance of the prevalent rules of ASPRS or NCDCDS.

  **Position and Accuracy** [Ries 1993]
  Position and accuracy determine the way in which the geographic database can ultimately be used. They represent statements of reliability, confidence, and risk, and can be determined by analytical results. Spatial analysis requires consistent precision and accuracy within each geographic layer, because the current statistical sampling method assumes normality.

  **Position and Accuracy** [Chong et al. 1993]
  Positional accuracy can be expressed as two components – absolute positional accuracy, and relative positional accuracy. Absolute positional accuracy addresses how closely all positions on a map or data layer match, corresponding to positions of features represented on the ground in a desired map projection system. Relative positional accuracy of a map considers how closely all the positions on a map or data layer represent their corresponding geometrical relationships on the ground.

- **Attribute accuracy – qualitative and quantitative**
  Attribute or thematic accuracy is defined as the accuracy of the attributes of its data. If rice fields are marked as wheat fields on a map, the result is a thematic or attribute error. Attribute or thematic attribute tests can be made either by deductive estimates or by independent samples from a polygon overlay. Quantitative data can be resolved by the precision of the measurement device. Quantitative attribute accuracy is lacking when a region with average rainfall of 100 inches is plotted with an instrument that measures with 0.1 inch precision and makes a mistake by 0.1 inch. For qualitative or categorical data, resolution is determined in terms of fineness of categorical definition. A pine tree region marked with conifer trees is an example of qualitative attribute error.

- **Temporal Accuracy**
  Temporal accuracy is defined as that part of the data's error that arises due to the temporary nature of the data. It is affected by the interaction between the duration of the recording interval and the rate of change in the event (Data Quality Parameters, H Veregin). The border of a country may not be the same 50 years ago that is today, had it not given independence to or merged with another country. Temporal accuracy is very important for collecting data and until now has been ignored in data collection and data testing phases.

The **entity-attribute-value model** can determine accuracy of a database of a real world phenomenon (Data Quality Parameters, H Veregin). In this model real world phenomenon and attributes are the relevant properties of the objects, and the values are the relative values of quantitative or qualitative measurements. Error is defined as the discrepancy between the actual and the true attribute values of the entity. This model can define spatial, temporal and thematic data.

Data within a GIS is typically treated as having deterministic values, ignoring spatial, temporal, geometric, and thematic uncertainties. Accuracy should be perceived as an added dimension in an integrated environment rather than as a simple attribute of data or metadata. This signals a move towards 'objective GIS', where biases caused by unaccounted uncertainties in data are avoided and the subjectivity of data accuracies is removed.

## Locational Accuracy

[Ries 1993] reports that the Wisconsin Department of Transportation Division of Highways, initiated a project on location control management for strategic information and business planning. Location Control Management geographic area encompasses data and functions regarding shape and absolute topology of spatial features. They found that locational control could be obtained from three subject areas: geodetic, geographical, and linear.

The geodetic area defines and manages the locational surface. The earth's geoid, latitude-longitude, datums, monuments, coordinate systems, and projections are examples of geodetic entities.

The *geographic area* defines and manages the "where" of parts, or areas of the surface defined by the geodetic level. Examples of geographic entities are linear features such as roads, rivers, and rail; and include municipal, parcel, hydrographic, wetland, and soil boundaries.

The *linear area* defines and manages the "where" along geographic parts. Linear entities include routes, mileposts, reference points, photo log miles and street addresses.

The *geodetic area* controls the geographic, which in turn controls the linear. Each level has its own internal management and utility, where transformations between internal location schemes are addressed. To pass between two levels, a transformation would be made from one location area to the other. Each level can be managed and used independently of the others, but a location can also be transformed to exploit the management and utility of another level.

## Sources of Error in Data Collection

Error in data is inherent and cannot be avoided. In order to minimize error, information about the origin and the properties of errors should be analyzed. By the end of the analysis process the original error (which is easy to identify and eliminate at the first step) has become linear and more complex, and is nearly impossible to remove. Bad data should, thus, be identified early.

The following are some of the sources where error can originate.

1. Measurement errors
   Small errors in instrument calibration, biased instruments, variation in instruments due to external factors such as sun, wind, etc.
2. Data Acquisition error
   Field error – Due to the inaccuracy of the surveyor team.
   Lab error – Misinterpretation of data from the map (because of proper map overlay) or inconsistency results in data acquired in labs.
3. Error due to selection of the data model
4. Attribute error

Inability to distinguish characteristics of one part of data from another. Incorrectly interpreting data.

5. Natural variation

   Error due to the temporary nature of data (because of variables beyond human control) that can affect data (such as the sun, wind, etc.).

6. Manipulation of data

   This data requires much higher accuracy than the computer can provide; errors develop while changing the data format and during data exchange.

7. Numerical Processing

   Error induced during the entry of raw digital field observation data due to redundant data. Error injected into the data while subjecting the redundant data to least square analysis resulting in a coordinate file with all non-numerical (attribute) information.

## Sources of Errors in Derived Data and in the Results of Modeling and Analysis

Errors can develop in numerous ways, and at any stage in GIS data, particularly during data analysis and modeling.

Care should especially be taken when overlaying maps having different characteristics. Due to the generalization of map attributes, accuracy is easily lost. While analyzing data (and due to certain types of ambiguous data) it is difficult to determine which classification category data falls into. Since no models are perfect, and since choosing the analysis model is at the discretion of the analyzer, the error rate rises if the appropriate model is not selected.

Error can also develop if interpolation is chosen to arrive at an approximate accuracy. Infinitely sharp boundaries need to be plotted to identify true boundaries. But because this is nearly impossible values are interpolated and boundaries are rounded off. The result can be a serious error when the scale of the map is large. (The figure on page 235 of *Principles of GIS* illustrates this.) Analysis reports of the same material in different labs are found to vary widely, with up to 11% soil sample errors recorded.

## ATTRIBUTE INFORMATION

The distance and angles of points are not enough information to define a point. Because of this, attribute information should also be collected with the locational data on the site. This attribute information should include items like the following.

- Point feature code: a symbol should appear at the surveyed point. Feature code table should also contain feature code name, type of symbol, size of symbol, and color.
- Lines or chains: The line should have the feature code, which is user definable by the type of line (dotted, full, etc.), its thickness and its color.
- Ground or non-ground points: these are above ground points which should be shown differently than ground points, e.g., the overhang part of the roof should not be shown as part of the ground.
- Stationing and offset position: care should be taken to define the stationing and the left/right offset to increase the accuracy of the fixed point.
- Point name and description: name, description and elevation should be provided for each point.
- Layer or zone: split layers according to zones or layers to avoid gathering voluminous amounts of different data attributes.

## INFORMATION FOR METADATA

Metadata is valuable because it provides users with specific information about the lineage of a data set that can be used with full knowledge of its source, quality, and contents. Adequate data is required for the appropriate, responsible, and defensible use of any geographic data set. Metadata, which is data about data, helps us do this.

## DATA INTEGRATION AND ANALYSIS

Integration of data often involves combining multiple geographic layers for analytical purposes. The resulting absolute topology provides the necessary information to perform spatial analysis functions.

## DYNAMIC SEGMENTATION

Dynamic segmentation is a two-step process performed on a spatial data set comprised of linear features. A route system is first created by associating adjacent line segments into one or more groups that have a definite linear sequence. Descriptive information is then associated with the route system by referencing distances from the starting point of each route. For example, a stream route system is created by grouping stream segments into routes that represent the main stream, tributaries, and headwaters. Spawning habitat areas are then mapped by their locations along the routes.

The advantage of using dynamic segmentation is that small areas along a line feature can be referenced without actually breaking the line into pieces.  Linear distances, such as river miles, can also be calculated directly from the routes and their associated attributes.

## Annotated Bibliography

This section contains an Annotated Bibliography of papers related to the area of spatial and locational data quality. Presented below are details of these various papers including: the title of the paper, journal article, or book chapter; the name of the author(s); a categorization of what the source document is; a complete citation for the item; and a brief summary description of the item.

## Quick Reference Table for Annotated Bibliography

| | | |
|---|---|---|
| | [Amrhein & Schut 1990] | Data Quality Standards and Geographic Information Systems |
| | [Backe 1996] | Formal Spatial Data Standards – What are They and who Does Them. |
| * | [Beard & Buttenfield 1999] | Detecting and Evaluating Errors by Geographical Methods |
| | [Bissex et al. 1990] | Quality Assurance for Geographic Information Systems |
| * | [Burrough & McDonnell 1998] | Errors and Quality Control |
| * | [Chong et al. 1993] | A Field Check Sampling Procedure to Evaluate the Positional Accuracy of Digital Landbases. |
| * | [Chrisman 1995] | Living With Error in Geographic Data: Truth and Responsibility |
| | [Dobson 1993] | Commentary: A Conceptual Framework for Integrating Remote Sensing, GIS and Geography |
| | [Donohoo 1990] | Cartographic Quality Control: No longer Optional for Today's GIS Programs |
| * | [Elmes & Cai. 1994] | Structural Reasoning for Spatial Database Accuracy Assessment |
| | [Fegeas 1992] | An Overview of FIPS 173, the Spatial Data Transfer Standard |
| * | [Fisher 1999] | Models of Uncertainty in Spatial Data |
| | [Garza & Foresman 1991] | Embedding Quality into Countrywide Data Conversion |
| | [Godden 1996] | Quality Control for GIS Conversion Projects |
| | [Grady 1990] | The Lineage of Data in Land and Geographic Information Systems (LIS/GIS) |
| | [Greve et al. 1993] | Investigating US Geological Survey Needs for the Management of Temporal GIS Data |
| | [Heuvelink 1999] | Propagation of Error in Spatial Modelling with GIS |

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|---|---|---|
| | [Hintz et al. 1996] | Trends in next Generation Electronic Survey Data Collection |
| * | [Hunter 1999] | New Tools for Handling Spatial Data Quality: Moving from Academic Concepts to Practical Reality |
| * | [Hunter & Williamson 1990] | The Need for a Better Understanding of Spatial Databases |
| | [Kuehlthau 1990] | Data Structures for Data Integration |
| | [Lundin 1989] | Data Quality Reporting Methods for Digital Geographical Products at Statistics Canada |
| * | [Mark et al. 1993] | Data Requirements for Route Guidance |
| * | [Matson et al. 1996] | Development of Mapping Grade Global Positioning System Data |
| * | [Newcomb et al. 1993] | Data Requirements for Route Guidance |
| | [Ng & Shi 1993] | Integration of Qualitative and Quantitative Information for Spatial Query. |
| * | [Ngan 1995] | Digital Quality Control for Manual Digitizing Operations |
| | [Ostman 1996] | Quality Systems for Spatial Data |
| | [Paradis & Beard 1994] | Visualization of Spatial Data Quality for the Decision-Maker: A Data Quality Filter |
| * | [Peng & Dueker 1993] | Error and Accuracy in Spatial Data Allocation |
| * | [Ries 1993] | Design Requirements for Location as a Foundation for Transportation Information Systems |
| * | [Stefandis & Agouris 1996] | Integrated Photogeographic Databases |
| * | [Thapa & Bossler 1992] | Accuracy of Spatial Data Used in Geographic Information Systems |
| * | [Veregin 1999] | Data Quality Parameters |
| | [Wellar 1972] | Standardization: Issues and -----------? |
| | [Wong & Wu 1996] | Spatial Metadata and GIS for Decision Support |
| | [Worboys 1998] | Computation with Imprecise Geospatial Data |
| * | [Wu & Buttenfield 1994] | Spatial Data Quality and its Evaluation |
| * | [Zhao 1997] | Temporal GIS – Potentials and Challenges |

**Title:** Uncertainty in Geographic Data and GIS-Based Analyses
**Author:**
**Category:** Web Page (http://www.ncgia.ucsb.edu/other/ucgis/research_priorities/paper9.html )
**Complete Citation:**

"Uncertainty in Geographic Data and GIS-Based Analyses," research paper of UC Santa Barbara.

**Description:**

This page contains an article about "Uncertainty in Geographic Data and GIS-Based Analyses," which states how uncertainty propagates through data analyses based on GIS. It further argues strategies for identifying, quantifying, tracking, reducing and reporting uncertainty in geographic data and GIS-based analyses. A standardized means by which uncertainty can be addressed in daily applications in GIS is also proposed.

**Title:** Data Quality Standards and Geographic Information Systems
**Author:** Amrhein, C. G. and Schut, P.
**Category:** Conference Proceedings
**Complete Citation:**

Amrhein, C. G. and Schut, P., "Data Quality Standards and Geographic Information Systems," Proceedings of National Conference 'GIS for the 1990's', Canadian Institute of Surveying and Mapping, pp. 918-930, March 5-8, 1990.

**Description:**

This paper discusses the range of errors that can accompany any data sets, and comprehensive statements of data quality that are needed by users.

**Reference:** [Amrhein & Schut 1990]

**Title:** Formal Spatial Data Standards – What are they and who does them
**Author:** Backe, K.
**Category:** Conference Proceedings
**Complete Citation:**

Backe, K., "Formal Spatial Data Standards – What are They and who Does Them." Proceedings of ASPRS/ACSM, Volume 1, *Remote Sensing and Photogrammetr*y, Baltimore, Maryland, pp. 111, April 22-25, 1996.

**Description:**

A standard is defined by the international Standards Organization (ISO) to be an agreement containing technical specifications. Spatial data standards are agreements that precisely specify how real world things are captured; represented and encoded as digital spatial data;

how this data is described for use; how it is processed and how this data is exchanged.

Spatial data consumers and producers need standards for spatial data to avoid the cost associated with duplicative data collection and exploitation s/w development. Hundreds of standards now exist for spatial data because until recently, there have been no formally recognized spatial data standards bodies. Producers and consumers developed their own standards to satisfy their application or community's requirements.

The availability of computers and software will expand exponentially the already growing appetite for spatial data. The good news is that a spatial data standards infrastructure has emerged in recent years in anticipation of a number of professional societies, states and regional organizations. This process promotes more robust standards that support a number of communities and applications.

**Reference:** [Backe 1996]

**Title:** Detecting and Evaluating Errors by Geographical Methods

**Author:** Beard, M. K. and Buttenfield, B. P.

**Category:** Book Chapter

**Complete Citation:**

Beard, M. K. and Buttenfield, B. P., "Geographic Information Systems – Principles and Technical Issues – Volume 1 – Detecting and Evaluating Errors by Geographical Methods," John Wiley & Sons, Chapter 15, pp. 219-233, 1999.

**Description:**

This chapter covers detecting and evaluating errors by graphical methods. It states that since errors are inherent in spatial databases, the process of observing, measuring, interpreting, classifying and analyzing data gives rise to systematic and random errors. Casual users of GIS are unaware of these errors. The author outlines a rationale for the use of graphical methods, highlights several historical and recent examples, develops a framework linking error analysis and graphical methods, and points to research challenges for the future and the potential for new techniques arising from technical innovations.

**Reference:** [Beard & Buttenfield 1999]

**Title:** Quality Assurance for Geographic Information Systems

**Author:** Bissex, D., Franks, C. and Heitkamp A.

**Category:** Conference Proceedings

**Complete Citation:**

Bissex, D., Franks, C. and Heitkamp A., "Quality Assurance for Geographic Information Systems," Proceedings of the Urban and Regional Information Systems Association Conference, Volume 2, 1990.

**Description:**

This paper reports how a U.S. Environmental Protection Agency project team instituted QA/QC standards for the development of GIS products while studying the impact of waste facilities on the Environment of New England. A complete QA/QC plan was developed and broken out into essential components that address many issues ranging from system documentation, to use this paper as a reference when developing GIS QA/QC guidelines.

**Reference:** [Bissex et. al. 1990]

**Title:** Errors and Quality Control

**Author:** Burrough, P. A. and McDonnell, R. A.

**Category:** Book Chapter

**Complete Citation:**

Burrough, P. A. and McDonnell, R. A., "Principles of Geographic Information Systems - Errors and Quality Control," Oxford University Press, Chapter 9, pp. 220-240, 1998.

**Description:**

One chapter of the book concentrates on the errors that occur in a spatial data and the effects it may have on spatial data analysis and modeling. These errors are blunders and gaffs but they are intrinsic parts of data and computational models. Sources of errors in spatial data, the factors affecting the reliability of spatial data, and various methods for estimating errors for quality control purposes are also presented.

**Reference:** [Burrough & McDonnell 1998]

**Title:** A Field Check Sampling Procedure to Evaluate the Positional Accuracy of Digital Landbases

**Author:** Chong, A. K.

**Category:** Conference Proceedings

**Complete Citation:**

Chong, A. K., "A Field Check Sampling Procedure to Evaluate the Positional Accuracy of Digital Landbases," Proceedings of ASPRS/ACSM, Volume 2, Annual Convention & Exposition of Technical Papers, Seattle, Washington, pp. 1, April 7-10, 1997.

**Description:**

Different ways a traditional cartographic land base can be taken are discussed in this paper. It also reports the continuing popularity of electronic sensors and photographic systems because they offer superior image resolution and predictable systematic errors. It sheds light on the fact that when two or more types of imagery are used for a land base image, a significant variation in the positional accuracy can occur. To overcome this, a method is described which would help in determining the checkpoints by using error propagation theory. The locations of these checkpoints are randomly generated to obtain a non-biased evaluation of the overall image land base.

**Reference:** [Chong et al. 1993]

**Title:** Living With Error in Geographic Data: Truth and Responsibility

**Author:** Chrisman, N.

**Category:** Conference Proceedings

**Complete Citation:**

Chrisman, N., "Living With Error in Geographic Data: Truth and Responsibility," Annual Symposium on Geographic Information Systems in Natural Resources Management, Vancouver, British Columbia, Canada, pp. 12-17, March 27-30, 1995.

**Description:**

This paper states that error in GIS cannot be avoided, but we can try to minimize it within allowable limits. Chrisman explains that the user must take responsibility for judging the components of data quality in terms of their fitness for a particular use. He explains that the measurement process in GIS involves choices between attribute and spatial components. He illustrates this using a very good parable in which the data is easily misinterpreted.

**Reference:** [Chrisman 1995]

**Title:** Commentary: A Conceptual Framework for Integrating Remote Sensing, GIS and Geography

**Author:** Dobson, J. E.

**Category:** Journal Paper

**Complete Citation:**

Dobson, J. E., "Commentary: A Conceptual Framework for Integrating Remote Sensing, GIS and Geography," *Photogrammetric Engineering and Remote Sensing*, Vol. 59, No. 10, pp. 1491, October 1993.

**Description:**

The authors discuss the integration GIS, remote sensing and geography data, and talk about the technical issues that arise when such an event it is carried out. The paper describes the elements that are affected due to the integration, and includes factors such as the cultural aspect, temporal change, and spatial interaction.

**Reference:** [Dobson 1993]

**Title:** Cartographic Quality Control: No longer Optional for Today's GIS Programs

**Author:** Donohoo, M. S.

**Category:** Conference Proceedings

**Complete Citation:**

Donohoo, M. S., "Cartographic Quality Control: No Longer Optional for Today's GIS Programs," Proceedings of AM/FM Conference XIII, pp. 78 – 87, April 1990.

**Description:**

This report emphasizes that cartographic quality control cannot be considered an option in the creation of a GIS. A highly skilled cartographic editor should be assigned whose sole responsibility is executing a strategic plan to ensure that accuracy, completeness, consistency and aesthetics are monitored continuously throughout GIS development. Successful quality control programs encompass editing aerial photography; gathering quality control materials, editing compiled information, checking aesthetics, ensuring that map sheets match, editing contours, reviewing corrected data, generating client review plots, and reviewing and submitting the final GIS products.

Tools for quality control includes check plots, photographic enlargements, existing source documents, score sheets, data layer validation programs, and quality control process. More and more municipalities, utility companies, and other organizations only select GIS contractors with proven quality control programs.

**Reference:** [Donohoo 1990]

**Title:** Structural Reasoning for Spatial Database Accuracy Assessment

**Author:** Elmes, G. and Cai, G.

**Category:** Conference Proceedings

**Complete Citation:**

Elmes, G. and Cai, G., "Structural Reasoning for Spatial Database Accuracy Assessment," International Symposium on Spatial Accuracy of Natural Resource Databases, pp. 141, May 16-20, 1994.

**Description:**

Estimation of uncertainty is a product of GIS information according to these authors. A three-phase error handling process is proposed, compromised of error structure learning, priority scheduling, and detailed modeling. Pair-wise comparison of error generating paths is used here to determine priorities for detailed modeling.

**Reference:** [Elmes & Cai 1994]

**Title:** An Overview of FIPS 173, the Spatial Data Transfer Standard

**Author:** Fegeas, R.; Cascio, J.; and Lazar, R.

**Category:** Conference Proceedings

**Complete Citation:**

Fegeas, R.; Cascio, J.; and Lazar, R., “An Overview of FIPS 173, the Spatial Data Transfer Standard," Proceedings of National Conference 'Challenge for the 1990’s,' Canadian Institute of Surveying and Mapping, pp. 381 – 390, Feb 27-Mar 3, 1992.

**Description:**

Following nine years of development, the Spatial Data Transfer Standard (STDS) was approved on July 29,1992 as FIPS Publication 173. The SDTS consists of three parts. Part one is concerned with logical specifications required for spatial data transfer and has three main components: a conceptual model of spatial data, data quality report specifications, and detailed logical transfer format specifications for SDTS data sets. Part two provides a model for the definition of real world spatial features, attributes, and attributes values, and includes a standard but working and expandable list with definitions. Part three specifies the byte-level format implementation of the logical specifications in SDTS Part 1 using ISO/ANSI 8211 (FIPS 123), a general data exchange standard.

**Reference:** [Fegeas et. al. 1992]

**Title:** Models of Uncertainty in Spatial Data

**Author:** Fisher, P. F.

**Category:** Book Chapter

**Complete Citation:**

Fisher, P. F., “Geographic Information Systems – Principles and Technical Issues," Vol. 1, "Models of Uncertainty in Spatial Data," John Wiley & Sons, Chapter 13, pp. 191-205, 1999.

**Description:**

This chapter talks primarily about uncertainty in the spatial data in terms of accuracy. It documents error, vagueness and ambiguity to define uncertainty. The author endeavors to make the picture clear by giving illustrations of different classes in which errors may arise. It tries to show ways to control uncertainty and to distinguish between vagueness and errors. It concludes that spatial data inherently contains uncertainty, and that data must be used carefully to minimize it.

**Reference:** [Fisher 1999]

**Title:** Embedding Quality into Countrywide Data Conversion

**Author:** Garza, R. J. and Foresman, T.

**Category:** Conference Proceedings

**Complete Citation:**

Garza, R. J. and Foresman, T., “Embedding Quality into Countrywide Data Conversion," GIS/LIS Conference Proceedings, pp. 130, 1991.

**Description:**

A standard development methodology of quality planning and implementation for a local government GIS network is introduced here. The basis for this methodology is Dr. W. Edwards Deming’s philosophy for the improvement of quality, productivity, and competitive position. Deming’s components of quality control are described as they relate to the conversion of the Clark County parcel layer. The Clark County QA value system is illustrated as a tool for the improvement and future enhancement of the parcel layer. This metadata component also serves to promote awareness of reliability issues and varying quality for layers which are not of homogenous origin.

**Reference:** [Garza & Foresman 1991]

**Title:** Quality Control for GIS Conversion Projects

**Author:** Godden, R.

**Category:** Conference Proceedings

**Complete Citation:**

Godden, R., “Quality Control for GIS Conversion Projects," Proceedings of ASPRS/ACSM, Volume 1*, Remote Sensing and Photogrammetry*, Baltimore, Maryland, pp. 674, April 22-25, 1996.

**Description:**

A high quality, reliable and comprehensive database is important for any successful implementation of GIS technology. A great deal of effort and expertise is required to create superior, large-scale databases. To achieve that, most companies look to the GIS mapping and conversion industry for assistance. Without an organized conversion management/quality control program, the end user runs significant risk of failure.

The purpose of this paper is to identify the main points of a successful GIS project for end users. The key elements:

- Design: The importance of the physical database design, including characteristics, relationship to applications, and establishment of item definitions.
- Specification: For detailed specification one should require accuracy standards for spatial and attribute data as well as for the conversion process. One should also consider obtaining a Procedures Manual.
- Schedule: How to develop a realistic project schedule based upon the rate at which deliverables can be produced and reviewed. Hard copy and digital techniques should be used.
- Resources: A thorough QC program requires significant personnel, time, and equipment resources.
- Pilot Projects: Designing and managing a successful Pilot. The purpose includes goals, selecting the best area, assessing results, and finalizing the Procedures Manual.
- Production: Monitoring quality throughout the production phase requires consistency, documentation, tracking deliverables and source materials, and well understood acceptance/rejection criteria.

This work addresses those persons responsible for planning and overseeing the data conversion process.

**Reference:** [Godden 1996]

**Title:** The Lineage of Data in Land and Geographic Information Systems (LIS/GIS)

**Author:** Grady, R.

**Category:** Journal Paper

**Complete Citation:**

Grady, R., “The Lineage of Data in Land and Geographic Information Systems (LIS/GIS)," *Journal of the Urban and Regional Information Systems Association,* Vol. 2, Fall 1990.

**Description:**

The importance of recording and tracking information about sources and processing steps for GIS data is emphasized as a part of a data quality report. The author cites traditional problems with accurate recording and reporting of lineage information, and makes arguments (both technical and institutional) for developing better standards and procedures for managing lineage information. The article deals with some practical considerations in establishing better data and temporal aspects of this issue.

**Reference:** [Grady 1990]

**Title:** Investigating US Geological Survey Needs for the Management of Temporal GIS Data

**Author:** Greve, C. W., Kelmelis, J. A., Gegeas, R., Guptill, S. C. and Mouat, N.

**Category:** Journal Paper

**Complete Citation:**

Greve et al Greve, C. W., Kelmelis, J. A., Gegeas, R., Guptill, S. C. and Mouat, N., “Investigating US Geological Survey Needs for the Management of Temporal GIS Data," *Photogrammetric Engineering and Remote Sensing*, Vol. 59, No. 10, pp. 1503, October 1993.

**Description:**

This paper emphasizes the need to manage temporal information in the National Digital Cartographic Database. It suggests obtaining updates to the digital database on a feature basis, rather than implementing the traditional method of revising the entire map sheet. It talks about the importance of the time tag that needs to be recorded along with the feature. It also discusses the different times - logical or event time, physical or base time. Finally it provides a preliminary assessment of US geological survey needs for temporal GIS data.

**Reference:** [Greve et. al. 1993]

**Title:** Propagation of Error in Spatial Modelling with GIS

**Author:** Heuvelink, G. B. M.

**Category:** Book Chapter

**Complete Citation:**

Heuvelink, G. B. M., “Geographic Information Systems – Principles and Technical Issues," Vol. 1, "Propagation of Error in Spatial Modelling with GIS," John Wiley & Sons, Chapter 14, pp. 207-217, 1999.

**Description:**

This chapter describes the development, application and implementation of error propagation techniques for quantitative spatial data. It discusses the different stages where errors can develop including: the level of data acquisition from the field through classification, generalization and interpretation. It also reviews different techniques (Taylor series approximation, Monte Carlo Simulation etc.) to explain the propagation of error in different phases.

**Reference:** [Heuvelink 1999]

**Title:** Trends in Next Generation Electronic Survey Data Collection

**Author:** Hintz, R., Roy, K. and Wahl J.

**Category:** Conference Proceedings

**Complete Citation:**

Hintz, R., Roy, K. and Wahl J., “Trends in Next Generation Electronic Survey Data Collection ," Proceedings of ASPRS/ACSM, Volume 1, "Remote Sensing and Photogrammetry," Baltimore, Maryland, pp. 155, April 22-25, 1996.

**Description:**

This paper discusses past and present generations of data. It goes on to describe the value of computer software in data collection through numerical analysis and attribute information such as location of ground points, stationing and offset positioning, and point features. The paper ends with its example of an ideal data collector.

**Reference:** [Hintz et. al. 1996]

**Title:** New Tools for Handling Spatial Data Quality: Moving from Academic Concepts to Practical Reality

**Author:** Hunter, G. J.

**Category:** Journal Paper

**Complete Citation:**

Hunter, G. J., “New Tools for Handling Spatial Data Quality: Moving from Academic Concepts to Practical Reality," *URISA Journal*, Vol. 11, No. 2, pp. 25-34, Summer 1999.

**Description:**

The author reports the availability of tools developed by himself and his colleagues for implementation by users of spatial data. Examples include:

- A tracking of feature coordinate edits and their reporting in visual data quality statements.
- Testing and reporting the positional accuracy of linear features of unknown lineage.
- Simulating uncertainty in products derived from Digital Elevation Models.
- Incorporating uncertainty modeling in vector, point, line, and polygon files.
- Reporting data quality information at different levels of database structure.

**Reference:** [Hunter 1999]

**Title:** The Need for a Better Understanding of Spatial Databases

**Author:** Hunter and Williamson

**Category:** Conference Proceedings

**Complete Citation:**

Hunter and Williamson, “The need for a Better Understanding of Spatial Databases," URISA proceedings, Annual conference of the

Urban Regional Information Systems Association pp. 121-128, August 12-16, 1990.

**Description:**

This paper discusses the meaning of words like “quality” and “accuracy” in the field of GIS, and states the implications of the spatial data transfer standard in terms of lineage, positional accuracy, attribute accuracy, consistency, and completeness. The paper ends with examples justifying the importance of data quality standards in GIS.

**Reference:** [Hunter & Williamson 1990]

**Title:** Data Structures for Data Integration

**Author:** Kuehlthau, S. W. and Herring, J. R.

**Category:** Conference Proceedings

**Complete Citation:**

Kuehlthau, S. W. and Herring, J. R., “Data Structures for Data Integration," Proceedings of National Conference ‘GIS for the 1990’s’, Canadian Institute of Surveying and Mapping, pp. 73-86, Mar 5-8, 1990.

**Description:**

This paper describes the data structures required to integrate various types, accuracies, and scales of data in order to maintain internal consistency and consistency between data types.

**Reference:** [Kuehlthau 1990]

**Title:** Data Quality Reporting Methods for Digital Geographical Products at Statistics Canada

**Author:** Lundin, B., Yan, J., and Parker, J-P.

**Category:** Conference Proceedings

**Complete Citation:**

Lundin, B., Yan, J., and Parker, J-P., “Data Quality Reporting Methods for Digital Geographical Products at Statistics Canada," Proceedings of National Conference ‘GIS for the 1990’s’, Canadian Institute of Surveying and Mapping, pp. 236-251, Feb 27 - Mar 3, 1989.

**Description:**

A positional accuracy standard, called the Circular Map Accuracy Standard, and the U.S. NCDS have been adopted.

**Reference:** [Lundin et. al. 1989]

**Title:** Development of Mapping Grade Global Positioning System Data Collection System and Documentation Standards in North Carolina
**Author:** Matson, K., Thompson, G., Shaffer, K., Campbell, R. and Clapp, L.
**Category:** Conference Proceedings
**Complete Citation:**
Matson, K., Thompson, G., Shaffer, K., Campbell, R. and Clapp, L., "Development of Mapping Grade Global Positioning System Data Collection System and Documentation Standards in North Carolina" Proceedings of ASPRS/ACSM, Volume 1*, Remote Sensing and Photogrammetry*, Baltimore, Maryland, pp. 122, April22-25, 1996.
**Description:**
This report stresses the importance of GPS technology in pinpointing a location on earth. It points out that if GPS is to be used effectively to collect data for a wide number of users, standards are important for data collection, post-processing, and documentation. It also discusses the GPS Data Collection and Documentation Standards that North Carolina has developed to increase its data collection accuracy which, in turn, contributes valuable information to the multi-user North Carolina Corporate Geographic Database.
**Reference:** [Matson et. al. 1996]

**Title:** Data Requirements for Route Guidance
**Author:** Newcomb, M., Medan, J. and Smartt, B.
**Category:** Conference Proceedings
**Complete Citation:**
Newcomb, M., Medan, J. and Smartt, B., "Data Requirements for Route Guidance," GIS-T '93 Geographic Information Systems for Transportation Symposium, Albuquerque, New Mexico, pp.209, March 29-31, 1993.
**Description:**
The importance of route guidance for creating a system that can intelligently route traffic is discussed in this paper. The paper shows that the shortest route produced by computer software is not always the most efficient path to a database containing all the necessary attributes. The paper goes on to identify the data requirements for route guidance and describes their effects upon routing algorithms. It focuses on the components of an accurate road network and tries to make the reliable route guidance a reality.
**Reference:** [Newcomb et. al. 1993]

**Title:** Integration of Qualitative and Quantitative Information for Spatial Query

**Author:** Ng, C. and Shi, W.
**Category:** Conference Proceedings
**Complete Citation:**

Ng, C. and Shi, W., “Integration of Qualitative and Quantitative Information for Spatial Query," Proceedings of ASPRS/ACSM, Volume 2, Annual Convention and Exposition of Technical Papers, Seattle, Washington, pp. 135, April 7-10, 1993.

**Description:**

This paper tries to integrate both qualitative and quantitative spatial data to build a bridge between natural language query and geographic spactial reasoning. The authors argue that employing integration will result in the development of a more effective and realistic decision support tool for GIS. Proximity, the qualitative and quantitative nature of spatial data, the existence of multi-context nature, and travel time are also discussed.

**Reference:** [Ng & Shi 1993]

**Title:** Digital Quality Control for Manual Digitizing Operations
**Author:** Ngan, S.
**Category:** Conference Proceedings
**Complete Citation:**

Ngan, S., “Digital Quality Control for Manual Digitizing Operations," Proceedings of Ninth Annual Symposium on Geographic Information Systems, Vancouver, British Columbia, Canada, pp. 739, March 27-30, 1995.

**Description:**

This paper attempts to address the issues of digital cartographic data accuracy, and explores the implementation of a data input system for the control of errors that may be introduced by the manual capture of utility data. It states that current manual efforts are slow and error prone, particularly in the areas of positional and attribute inaccuracy, logical inconsistency and incompleteness. The paper shows the database catalog system which can be proved as an effective mechanism for the control of errors in manual digitizing operations.

**Reference:** [Ngan 1995]

**Title:** Quality Systems for Spatial Data
**Author:** Ostman, A.
**Category:** Conference Proceedings
**Complete Citation:**

Ostman, A., “Quality Systems for Spatial Data," Proceedings of the Second Joint European Conference & Exhibition, Part Vol. 1, pp. 268-276, March 27-29, 1996.

**Description:**

The quality of the product may be defined as its “fitness for use." A “product” may be a set of data, a method, or a combination of both. One goal for a quality system for spatial data is to provide the tools an end user requires to evaluate the reliability of the achieved result. Several data quality standardization proposals have been made during the last few years. The goal is to define easy-to-understand and implement quality components, common for many different types of spatial databases.

Due to the generality of the approaches, the quality descriptors proposed here only provide simple answers to simple questions. For complex questions where several different data sets are used in complex analysis other approaches have to be made. Quality systems on distributed and harmonized uncertainties are also proposed. It is assumed that a major portion of uncertainties can be expressed as probabilities. To address this, Monte Carlo simulators are proposed as a foundation when error propagation studies are needed. Other general quality services may also be required in the future.

**Reference:** [Ostman 1996]

**Title:** Visualization of Spatial Data Quality for the Decision-Maker: A Data Quality Filter

**Author:** Paradis J., and Beard, K.

**Category:** Journal Paper

**Complete Citation:**

Paradis J., and Beard, K., “Visualization of Spatial Data Quality for the Decision-Maker: A Data Quality Filter," *URISA Journal,* Vol. 6, No. 2, pp. 25-34, March 1994.

**Description:**

This paper defines a data-quality filter that efficiently organizes and communicates data quality with the decision-maker. The filter relates the data quality information directly to the visualization of data, providing an implicit yet precise portrayal of the data’s fitness to use. To apply the filter the user defines a set of quality requirements with respect to accuracy, resolution, consistency, and lineage.

**Reference:** [Paradis & Beard 1994]

**Title:** Error and Accuracy in Spatial Data Allocation
**Author:** Peng, Z. and Dueker, K.
**Category:** Conference Proceedings
**Complete Citation:**
Peng, Z. and Dueker, K., "Error and Accuracy in Spatial Data Allocation" GIS/LIS Proceedings, Minneapolis Convention pp. 592-603, November 2-4, 1993.
**Description:**
This paper describes spatial data allocation in GIS and its application in spatial data integration. It also describes various methods of spatial data allocation compares the errors associated with different spatial data allocation methods. Finally, it discusses factors affecting errors, and develops an index of population density distribution, which is an important factor affecting accuracy.
**Reference:** [Peng & Dueker 1993]

**Title:** Design Requirements for Location as a Foundation for Transportation Information Systems
**Author:** Ries, T
**Category:** Conference Proceedings
**Complete Citation:**
Ries, T., "Design Requirements for Location as a Foundation for Transportation Information Systems," GIS-T '93 Geographic Information Systems for Transportation Symposium, Albuquerque, New Mexico, pp.48, March 29-31, 1993.
**Description:**
The Wisconsin Department of Transportation (WiDOT) Division of Highways, conducted an analysis of an information strategy plan called Location Control Management (LCM). It concluded that location can be divided into three categories: geodetic, geographical and linear. The paper describes the design requirements and proposed WiDOT solutions for the LCM linear level. It suggests that the GIS-T community should consider these requirements when developing the GIS-T standards.
**Reference:** [Ries 1993]

**Title:** Integrated Photogeographic Databases
**Author:** Stefandis, A. and Agouris, P.
**Category:** Conference Proceedings
**Complete Citation:**
Stefandis, A. and Agouris, P., "Integrated Photogeographic Databases," Proceedings of ASPRS/ACSM, Volume 1, Remote

Sensing and Photogrammetry, Baltimore, Maryland, pp. 32, April 22-25, 1996.

**Description:**

This paper addresses the role of digital photogrammetry within the current trends towards integrated Photogeographic databases, consisting of photos and maps in digital format combined with relevant information in raster or vector format. State-of-the art digital photogrammetric research issues are discussed and focus on automatic orientations, aerotraingulation, and man-made object extraction are presented. Current forms of research activities in terms of accuracy, efficiency, and productivity are also covered.

**Reference:** [Stefandis & Agouris 1996]

**Title:** Accuracy of Spatial Data Used in Geographic Information Systems

**Author:** Thapa, K. and Bossler, J.

**Category:** Journal paper

**Complete Citation:**

Thapa, K. and Bossler, J., "Accuracy of spatial data Used in Geographic Information Systems," *Photogrammetric Engineering and Remote Sensing*, American Society for Photogrammetry and Remote Sensing, Vol. 58, No. 6, pp. 835-841, June 1992.

**Description:**

The authors first discuss different types of phases of GIS which consist of collection, management, display and analysis of spatial data. They also comment that data quality and accuracy are different for different applications, then talk about different types of errors encountered in the "primary and secondary" methods of data collection. Different standards and specifications used in the primary methods of data collection are also explained. Finally, a comparison between primary and secondary methods of data collection is made.

**Reference:** [Thapa & Bossler 1992]

**Title:** Data Quality Parameters

**Author:** Veregin, H.

**Category:** Book Chapter

**Complete Citation:**

Veregin, H., "Geographic Information Systems – Principles and Technical Issues," Vol. 1, "Data Quality Parameters," John Wiley & Sons, Chapter 12, pp. 177-189, 1999.

**Description:**

The chapter starts with answering questions such as "What is data quality? What are its components? And, how do you define its components? It also discusses the components of data – accuracy, precision, consistency, and completeness. The treatment of quality components in data standards and the implications of cartographic bias in geospatial data models are briefly addressed. It ends with a discussion of the ways in which institutional values are embedded in geospatial databases and the ways that data quality documentation can help to articulate these values.

**Reference:** [Veregin 1999]

**Title:** Standardization: Issues and -----------?

**Author:** Wellar, B.

**Category:** Conference Proceedings

**Complete Citation:**

Wellar, B., "Standardization: Issues and -----------?" Proceedings of the Urban and Regional Information Systems Association Conference, pp. 429-444, 1972.

**Description:**

This paper discusses important philosophical and practical tenets of standardization within the context of statistical data generated and used by government organizations. The authors present some arguments illustrating why data standards are important and how they can increase efficiency in the administration of government programs. Institutional obstacles working against the adoption of data standards are also discussed. Standard issues are presented within the context of five phases of system development: specification, acquisition, storage-retrieval-manipulation, dissemination, and applications.

**Reference:** [Wellar 1972]

**Title:** Spatial Metadata and GIS for Decision Support

**Author:** Wong, D. W. S. and Wu, C. V.

**Category:** Conference Proceedings

**Complete Citation:**

Wong, D. W. S. and Wu, C. V., "Spatial Metadata and GIS for Decision Support," Proceedings of the Twenty-ninth Hawaii International Conference on System Sciences (HICSS – 29), Vol. 3, pp. 557-566, March 1996.

**Description:**

This paper argues that current GIS spatial data quality standards are not adequate to document the spatial variation in the data quality of spatial data over a geographical area, which can be regarded as spatial metadata. Spatial metadata should be derived and reported to help users of spatial data make intelligent spatial decisions or policy formulations. This paper proposes that GIS develop logical tools to assess certain types of error in spatial databases because it is widely used to gather, manipulate, analyze, and display spatial data. A framework is proposed to derive several types of data quality information using GIS. These types of quality information include positional accuracy, completeness, attribute accuracy, and to some extent logical consistency. It emphasizes that not all types of spatial data can be derived from GIS.

**Reference:** [Wong & Wu 1996]

**Title:** Computation with Imprecise Geospatial Data

**Author:** Worboys, M.

**Category:** Journal Paper

**Complete Citation:**

Worboys, M., "Computation with Imprecise Geospatial Data," *Computers, Environment and Urban Systems*, pp. 85-106, March 1998.

**Description:**

Imprecision in spatial data arises from a granularity or resolution at which observations of phenomena are made, and from the limitations imposed by computational representations, processing and presentational media. Precision is an important component of spatial data quality and a key to appropriate integration of collections of data sets. Previous work of the author provides a theoretical foundation for imprecision of spatial data resulting from finite granularities, and gives the beginnings of an approach to reasoning with such data using methods similar to rough set theory. This paper further develops the theory and extends the work to a model that includes both spatial and semantic components. Notions such as observation, schema, the frame of discernment, and vagueness are examined and formalized.

**Reference:** [Worboys 1998]

**Title:** Spatial Data Quality and its Evaluation

**Author:** Wu, C. V. and Buttenfield, B.

**Category:** Journal Paper

**Complete Citation:**

Wu, C. V. and Buttenfield, B., "Spatial Data Quality and its Evaluation," Vol. 18, pp. 153-165, 1994.

**Description:**

This paper reviews recent concepts of data quality assessment and presents a model for data quality evaluation. It argues that data quality may be acquired in a static manner by quantitative or qualitative testing, or in an operational state by tracking down what processing steps have been taken. Data quality evaluation information is done on the user decision regarding data's fitness for use. It breaks down the data evaluation process into four steps, with each step given specific tasks.

**Reference:** [Wu & Buttenfield 1994]

**Title:** Temporal GIS – Potentials and Challenges

**Author:** Zhao, F.

**Category:** Conference Proceedings

**Complete Citation:**

Zhao, F., "Temporal GIS – Potentials and Challenges," Proceedings of GIS-T, Greensboro, NC, pp. 155, 1997.

**Description:**

This paper discusses the applications and challenges of temporal GIS. It says that GIS analyses must be performed taking into consideration the fixed time point. Longitudinal analysis takes time and cannot be easily accomplished. If GIS takes the spatial and the temporary nature of data into consideration, it will greatly expand current GIS applications and allow new information to be obtained or derived.

**Reference:** [Zhao 1997]