العنوان:	A Mathematical Model for GIS Quality Control :
المصدر:	المجلة العربية لنظم المعلومات الجغرافية
الناشر:	جامعة الملك سعود - الجمعية الجغرافية السعودية
المؤلف الرئيسي:	Al Garni, Abd Allah M.
المجلد/العدد:	مج3, ع5
محكمة:	نعم
التاريخ الميلادي:	2010
الصفحات:	1 - 28
رقم MD:	747934
نوع المحتوى:	بحوث ومقالات
قواعد المعلومات:	HumanIndex
مواضيع:	نظم المعلومات الجغرافية، الاستشعار عن بعد، المواقع الجغرافية
رابط:	http://search.mandumah.com/Record/747934

© 2021 دار المنظومة. جميع الحقوق محفوظة.
هذه المادة متاحة بناء على الإتفاق الموقع مع أصحاب حقوق النشر، علما أن جميع حقوق النشر محفوظة. يمكنك تحميل أو طباعة هذه المادة للاستخدام الشخصي فقط، ويمنع النسخ أو التحويل أو النشر عبر أي وسيلة (مثل مواقع الانترنت أو البريد الالكتروني) دون تصريح خطي من أصحاب حقوق النشر أو دار المنظومة.

A Mathematical Model for GIS Quality Control

Dr. Abdullah M. Al-Garni

Abstract

Activities in mapping sciences are experiencing vast improvements on almost a daily basis. Today, spatial information is playing important roles in decision-making. In this respect, GIS is a strongly recognized technique, which hosts all traditional mapping information, and improves spatial information effects through strong heterogeneous databases. Accordingly, traditional quality control processes, used to assess spatial mapping data, cannot handle all quality aspects of spatial information hosted in a Geographical Information System (GIS). This means that the traditional standards for positional accuracy, lineage, logical consistency and completeness constitute only partial measures for assessing GIS contents in a fully integrated spatial system.

This paper presents a quantitative mathematical model and strategy to facilitate the quality control (Q.C.) process of a GIS. The model (called the DEMAIS Model) treats geometric and descriptive data of a GIS in precise and global modes. The model has been developed based on least-squares theories and concepts. It was tested and found to be successful. In a research to be published soon, automation facilities that are under development for the model will be presented.

1.0 Basic Concepts and Themes:

In engineering sciences, the traditional process of quality control (Q.C.) is applied to pure numerical, physical or geometrical data. Nowadays, several conceptual and descriptive data sets are associated with numerical, physical and geometric spatial data and consequently affect their quality. However, today the conceptual and descriptive parts of the data set are not subjected to proper quantitative assessment. By neglecting to apply the Q.C. process to conceptual and descriptive data, the GIS will never reflect actual, robust and comprehensive real-world entities. Accordingly, any value engineering processes and assessments conducted on such projects may give misleading quality reports of the spatial databases. In some engineering fields, *Value Engineering (VE)* is defined as *an organized approach to providing the necessary functions at lowest cost*. In this paper, however, VE is described as an organized approach to providing the necessary quality measures for spatial objects in a numerical form.

Different quality assurance operations are applied to mapping and engineering activities. Q.C. operations should represent a measure of the overall quality of products under investigation. Loose and non-quantitative Q.C. methods and models will never reflect the actual quality of the products. In the case of traditional mapping activities, such as ground surveying, Photogrammetry, GPS and map production, very well established Q.C. models and methods are applied to each task.

Recently, GIS has become the instrument for mass production mapping, often by non-specialists in the mapping field. GIS today, therefore, influences decision-making activities. Using GIS, one more dimension is introduced to traditional mapping activities and their Q.C. methods and models. This new dimension is related to spatial databases. The database is now strongly reshaping the methodology and concepts of known Q.C. methods of traditional mapping activities. This means that using GIS as a spatial information system, the Q.C. methods and models should behave and reflect the quality of the full system.

For instance, traditionally a precisely located electric pole, which is well presented in any cartographic product, can be assessed as an acceptable mapping object with a high Q.C. score. On the other hand, the same exactly positioned pole with the same quality as stated above may be rejected by a well-established Q.C. model of a GIS because the electric pole may have many fields in a GIS record. Let one of these fields be designed to hold a property called *TYPE*, which will describe the electric pole. If the input in this field is *telephone_switch*, then the Q.C. of the GIS should reject the object and should give it a very low or null score, the reason being that the value *telephone-switch* is not the correct description for the electric pole.

2.0 Literature Review and Background:

Generally speaking, GIS quality control models and methods have not yet been well established. They are still far behind the expectations of the users. In this study , we will introduce new concepts, strategy and models that may contribute to a robust quality assurance for a GIS in a system or global sense.

It is known that standards for geometric information, such as positional accuracy, are well developed (Montgomery and H. Schuch, 1993). In this sense many researchers have realized the importance of having standards to facilitate the Q.C. processes of assessing GIS data (Brassel et al., 1995). The subject has been treated extensively in several publications (e.g. Johnston, 1999). In Germany, a research on the quality management of the "Authoritative Topographic-Cartographic Information System" (ATKIS) was conducted (Busch, et. al., 2002). Also, it was realized that describing the quality of digital geodata in a geodatabase is essential for applications (Willrich, et. al., 2002).

Spatial databases contain attributes describing spatial objects and known as object records. These attributes may be referred to as thematic data or attribute data. In this view, thematic accuracy is described as the accuracy of the attribute data. Qualitative values assigned to these thematic data are of concern to many researchers (Congalton et al., 1983; Aronoff, 1985; Rosenfield and Fitzpatrick-Lins, 1986; Redman,1992). It is believed that knowledge of the error sources in GIS data help to identify proper Q.C. methods to assess database contents (Aronoff, 1989). Also, measures of errors such as mean error, root mean squared error, standard deviation, inference tests, confidence intervals, validity, logical consistency, physical consistency, referential integrity, positional accuracy, etc. are parts of traditional quality controls known and frequently used in spatial mapping fields (Paul, et. al., 2006).

Layer accuracy in remote sensing studies received good attention from researchers (Aronoff, 1982). Recently, GIS became the host of many different spatial data. Consequently, it has been noticed that a large amount of newly introduced errors have arisen due to integrating a large diversity of data in databases (Goodchild, 1989; Chrisman, 1989; and Openshaw, 1989). In this respect several studies have identified and defined different factors such as lineage, positional accuracy, attribute accuracy, logical consistency and completeness as important factors to be validated in any GIS environment to ensure spatial data quality. (Bolstad, et al.,1992; Caspary and Scheuring, 1993; Stanislawski et al., 1996). Verification of road geodatabase quality has been conducted in a recent study (Gerke, et. al., 2003). In fact, more advanced knowledge-based image interpretation system was introduced to support spatial quality assessment of spatial data (Straub, et. al.,2003). Many other recent researches have contributed to different aspects of geodatabase quality in many different ways (Busch,et. al., 2004; Gerke, et. al., 2005; Busch, et. al., 2006).

However, most of the current studies have not developed precise mathematical models for Q.C. of the attribute information in the database. Erroneous attribute information that affects the overall quality and decisions that are made from the GIS analysis may no longer have any reliability. It is also important to state that although today most of the known Q.C. procedures are conducted manually, there are some efforts to automate the procedures. This is being achieved through developing software to partially handle the Q.C. process (Montgomery, et. al., 1993).

3.0 The Mathematical Model:

The mathematical Q.C. model of a GIS presented in this study is based on the concepts of least-squares adjustment. The model has the purpose of analyzing the two types of information contained in a GIS:

1. Geometric information, which includes
   a. Positional accuracy (β_i)
   b. Node accuracy ($и_i$); and
2. Attribute information, which can include all records or fields in a GIS database (αi)

The two items mentioned above are not always classified as either numerical or descriptive data. They can be numerical (physical geometry), semi-numerical, and/or descriptive data. Therefore, the challenging task in this study is to develop a master Q.C. model that can account for the heterogeneous properties of GIS entities or objects. This means that the model should be mature enough to report a quality assessment of real-world GIS objects that may have the following characteristics:

1. be a physical/geometrical entity such as a road (GIS line),
2. have numerical properties such as positional accuracy at certain nodes or segments,
3. have semi-quantitative nodal data such as *from-to-node*, *left polygon, right polygon*, etc.
4. have fully descriptive properties in the database records such as *road name*.

In a GIS patch (small window), the concept of Q.C. is similar to the well-known international methods conducted for the Q.C. of maps. That is, 90% of tested information should have no errors for the window to pass the Q.C criteria. In other words, with enough check samples, no more than 10% of the checked data should be in error. In some GIS practices, only 5% is acceptable. This figure can also be used in our model which we call it DEMAIS in this research. The difference between the methods of our study and the traditional international criterion is that the conceptual and descriptive part of the data is considered in our method as an important component, whereas it is neglected in the traditional methods. Consequently, in the DEMAIS method the descriptive and conceptual values of the data are involved in the Q.C. operations in a quantitative sense.

For Q.C. purposes in a GIS environment, a few random patches (W_{pi}) are considered and selected from the master window (W_m). These random patches act as samples for conducting the Q.C. process. The selected patches should be well-distributed (randomly distributed) and be representative samples of the type of data to be tested. Each patch shall contain geometric (β), node (и), and attribute (α) data. The geometric data is related to points, lines or polygons. Nodes can be forms of line or polygon structures that contain quantitative and qualitative factors. Finally, attributes represent any field selected from records of the database that the Q.C. process is targeting.

The patches (W_{pi}), as subsets of the master window (W_m), must have the following properties:

i. $W_{Pi} \in W_m$ where both W_{pi} and Wm ≠ Ø

ii. W_{Pi} should be well-distributed and representative of the spatial information under consideration.

In this paper, parametric least-squares concepts are applied to assess heterogeneous data, some of which are not numerical (i.e. they are descriptive). Consequently, an important part of model development concentrates on designing *value engineering* measures to reflect descriptive data quality in quantitative modes. Now, a full least-squares adjustment process should be applied to each patch according to the following parametric model:

$$l_i = f(x) \text{ .... } (1)$$

where ℓ_i represents the observations of objects under-investigation, and $f(x)$ relates the observations with the unknowns. Unknowns here are the actual errors (δ_i), which can be described as the values that do not meet users' standards, or quality expectations of users.

The developed model can work in one of two modes:

1. The global model: This tells, in general, if a patch is passing the Q.C. criteria. That is, it will decide if the mapping content (geometry, nodes, and attributes) of the patch are of acceptable quality or else needs to be rejected.
2. The precise mode: This reports the quality of each object in the patch window.

In order to develop a proper mathematical model based on least-squares principles, the quality measures or criteria for each object and its attributes should be defined or set prior to the Q.C process. Parts of the Q.C. criteria (K_i) are subjective variables with subjective values. We will call them value engineering. That is, a database may contain (as an example) 40 fields. Some of these fields are very critical to some organizations, others are of moderate importance to other organizations, and some may be negligible to others. Based on the subjective quality of these fields (variables), values of different weights may be assigned to each record or object attribute. The only non-subjective values are those of geometric (positional accuracy) characteristics. Their values are known and are based on the allowable standard positional accuracy of the source maps. The acceptable positional accuracy is defined by the international specifications in spatial mapping. Designing the *value engineering* measures for observables is explained later (section 3.1). Figure (1a) and (1b) show the functionality of the model.

Figure (1a): Operations of the Demais Q.C. Model in a general flow chart

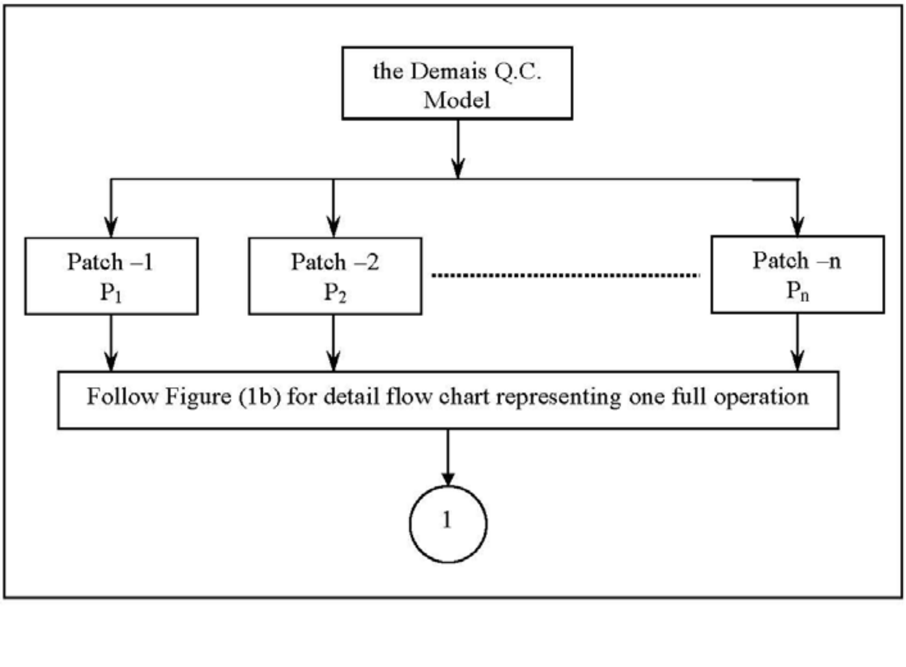
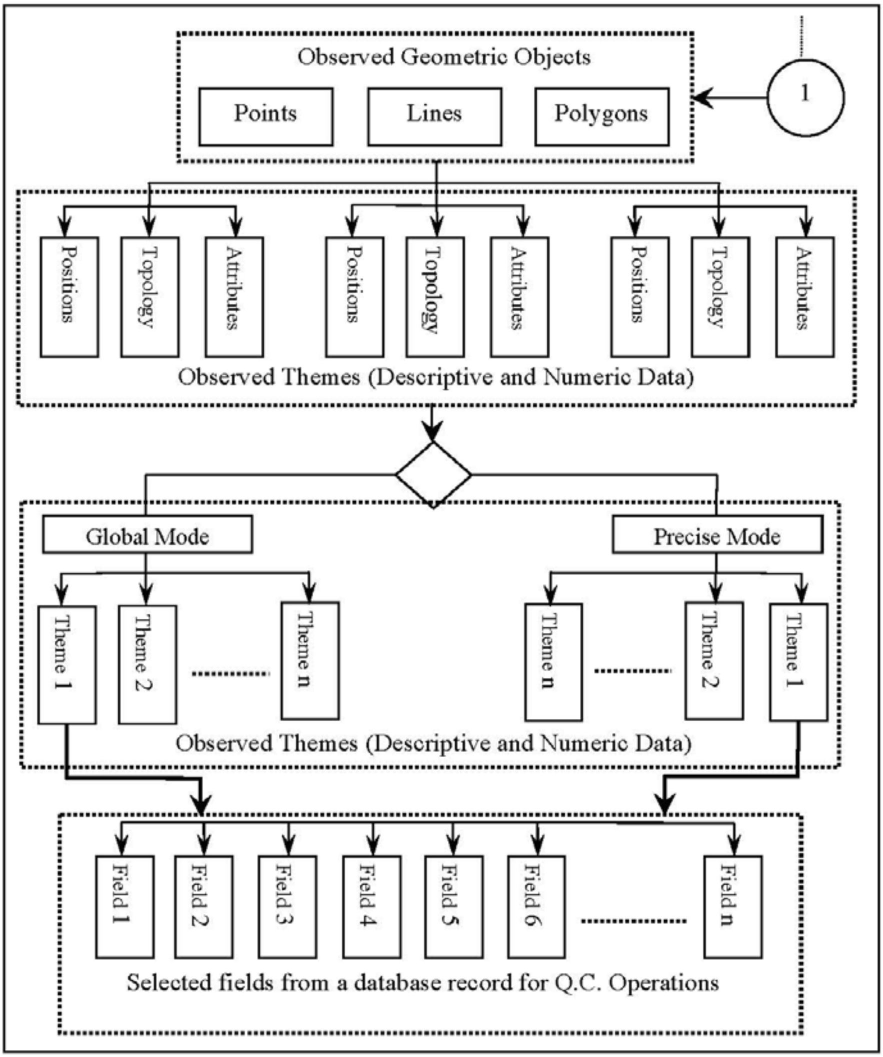


Figure (1b): Operations of Demais Q.C. Model in a Detailed flow chart.



3.1 Methods of Assigning Criteria Values:

A GIS database consists of two types of data. The first is the geometric (graphical) values. These can be assessed based on positional accuracy. For instance, if 1:50,000 base-maps are to be used in a GIS application and the user is accepting a RMSE of ± 15m, then the Q.C. process will consider any value out of the range ±15m as inaccurate, and therefore, unacceptable (rejected).

The second is the topology and attributes (fields) of the database. Since topology and database attributes are sensitive, their assessment should be based on the concept of binary-like criteria. That is, a topology relations and attribute values should be *true*, *false* or *negligible*. For instance, a missing node at an intersection of two roads informs the GIS spatial engine or analyst that there is no road intersection – which is a false decision or analysis. If this analysis (the wrong topology) is not important to the user, then it will be assigned a negligible value. In such a case, negligible features should not affect user Q.C. scoring or assessment.

Similarly, in a field of a GIS database called *City_Name*, either the city name is correct (e.g., Riyadh) or incorrect (e.g., Dammam written incorrectly instead of Riyadh). The same concept is applicable for every attribute in the database (e.g., population, date, time, year, area, distance, roadname, etc, as well as metadata, if considered).

The True/False-like topology and attribute values are used in the DEMAIS model to report the Q.C. of a spatial database. There are different ways of assigning *value* *engineering* measures for *binary-like* data. In this study ±1σ and ±2σ are utilized, where σ is the acceptable standard positional accuracy for the contents of spatial database under investigation. In this case, if the binary-like data (conceptual, descriptive, and/or qualitative data) is true then it should utilize the value ±1σ, otherwise ±2σ is used. In the case of negligible Q.C. for certain spatial features, a default value of ±1σ is assigned.

For the geometric information, the known standard accuracy values of the source map are considered as the reference values, whereas observed accuracy values (ℓ_i) are collected through Q.C. operations. In this way, reference observation values are used to estimate the elements of the unknown vector of the database. The Other observation values called "on-the-spot" values are collected from selected patch windows. The differences between the reference values and the on-the-spot observations values construct the misclosure vector of the database.

3.2 DEMAIS Mathematical Model:

The present model is named "the DEMAIS Model". The mathematical expressions of the DEMAIS model are as follow:

$$l_i = f(x) \quad \text{...} (2)$$

$$V_i = Ax + W_i \quad \text{...} (3)$$

$$\delta_i = N^{-1}U \quad \text{..} (4)$$

where ℓ_i represents the patch containing objects observed during a Q.C. process. Once the functional model (2) is applied for each observation (those under investigation), misclosures W_i are calculated through (3). Normal equations are set up via:

$$(A^T PA)\delta = (A^T PW) \text{ .... } (5)$$

where P is the weight matrix. Defining N = (A^T P A) and U= (A^T P W), the solution vector (δ_i) is obtained as shown in equation (4).

It should be emphasized that the three equations above are constructed of (n x m x ℓ) sources as follows:
n = number of patch windows, m = number of objects, and ℓ = number of approved criteria for evaluation (positional, topology, and attributes).

Since there are no *true* observations (ℓ_i) in the real world, raw observations (ℓ_{io}) are considered as contaminated data with residuals (V_i). The same concept is applicable to the values of the unknown parameters. That is, since there are no *true* observations, then there will be no *true* values for the unknown parameters (x). Hence, computed unknowns contain some errors. Therefore, the following expressions are introduced to modify the ideal parametric methods of least-squares concept:

$$l_i = l_i^o + v_i \text{ .... } (6)$$

$$x_i = x_i^o + \delta_i \text{ .... } (7)$$

Following the same principles, the derivation of the design matrix gives:

$$l_i = f(x) \ldots\ldots (8)$$

$$\overset{o}{l}_i + v_i = \overset{o}{x}_i + \delta_i \ldots\ldots (9)$$

$$v_i = \delta_i + (\overset{o}{x}_i - \overset{o}{l}_i) \ldots\ldots (10)$$

$$= \delta_i + w_i \ldots\ldots (11)$$

or in matrix notation:

$$\begin{bmatrix} v_1 \\ v_2 \\ \\ v_n \end{bmatrix} = \begin{bmatrix} \delta_{11} & \delta_{12} & \ldots\ldots & \delta_{1n} \\ \delta_{21} & \delta_{22} & \ldots\ldots & \delta_{2n} \\ \\ \delta_{n1} & \delta_{n2} & \ldots\ldots & \delta_{nn} \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \\ \\ w_n \end{bmatrix} \ldots\ldots (12)$$

In a compact form, equation (12) is represented as the least-squares principle which states that:

$$\sum v_i^2 = Min. \ldots\ldots (14)$$

$$V^T PV = Min. \ldots\ldots (15)$$

from which the normal equations can be developed (see equation (5)). From that equation the solution vector δ_i is calculated. δ_i shows clearly the Q.C. of all elements evaluated in each window patch.

4.0 Results of the Test:

A sample of testing the model is given in this section. Tables (1-3) represent a magnified anatomy of an internal process conducted using Demais methods. DEMAIS Q.C. mathematical models were applied to a number of GIS databases. The models are accurate and found to be the only available quantitative least-squares method for Q.C. of full

GIS database contents (geometric and attributes). Two samples of the applied tests are shown below. One sample was applied in a global mode and the other in the precision mode. Each sample represents two patches of a master window, as shown in Fig. (2). Figure (2) shows IKONOS image of Part of KSU campus. This image is orthorectified and georegistered to the Saudi National Geodetic Network Datum (NGN ain Al abd) and projected using Universal Transverse Mercator (UTM) projection using Zone 38.The next paragraph explains the process. Vector data are displayed on this image. The vector data includes utilities (electricity, water, telephone, …), roads, buildings and many others. The vector data and its attributes here are the data on which the Q.C. model was applied.

In the global mode, three groups of data were assessed. The groups are positional accuracy, topology data, and attribute data. Each group contains three types of objects – points, lines, and polygons. Three database fields of each object were evaluated. That is, nine unknowns were calculated in each window. Since we are talking about global mode, the nine fields evaluated were grouped to three master unknowns. One represents window global accuracy from the viewpoint of geometrical positions, the other represents topological assessment, and the third one represents window quality from the view point of attributes of the database.

As can be seen, a patch of three features (point, line, and polygon) is subjected to Demais methods for testing a GIS database. Each of the three features must have one record in the database. In this test, each record contains three fields to be tested. The fields contain geometric data (positional accuracy), topological data, (intersections), and descriptive data (names). Even though we used three themes for each record, Demais test can accept unlimited number of themes (fields). Users are the judges to include or exclude fields they care about. An interactive cataloguing metadata interfacing tools were created to allow users to collect *value engineering* measures (scoring or observations) for the tested features. Table (1) shows a compact interactive sample of observations for a patch.

Table (1): Concepts of assigning value engineering to Demais model.

Reliability Items Observed		Observations and type of observed entities						Accepted RMSE
		Points		Lines		Polygons		
		Rounded Values	Actual Values	Rounded Values	Actual Values	Rounded Values	Actual Values	
Positional accuracy	1	5	1	5	1	5	5	±5
	2	5	2	10	12	10	6	±5
Topology function	1	5	5	5	5	10	10	±5
	2	10	10	5	5	10	10	±5
Attribute function	1	10	10	10	10	5	5	±5
	2	10	10	5	5	5	5	±5

On Table (1), rounded values are used in the global mode of the Demais model to report a general assessment of the patch contents. On the other hand, the actual values presented on Table (1) are used in precise mode of the Demais model and can point out precisely the source and the values of errors in the patch contents.

Figure (2): Partial Master and Patch Windows of KSU GIS Campus with IKONOS Image - Tested in This Study: Partial Master [red box] Partial Patches [blue box] .

Table (2) represents a sample of the parametric least-squares method of testing the Demais approach in a global mode. Results of selected four windows are presented in Fig (3-a). On the other side, Table (3) represents sample of the parametric least-squares methods of developing Demais mathematical models to conduct GIS Q.C. operations in precise mode. Results of selected four windows are presented in Fig. (3-b). Finally, Table (4) shows partial results of evaluating a GIS database covering 3km x 3km master window with 1:500 scale base map, in a global mode. In a bar chart form, Fig. (4) shows results of the tested windows.

Table (2): Demais model in a global mode.

	Feature Type	Developed observations			Q.C. Target
Patch-1 in global mode of Demais Model	Area	$l_1^o + v_1 = x_1^o + \delta_1 \Rightarrow$	$5 + v_1 = 5 + \delta_1 \Rightarrow$	$v_1 = \delta_1$	Positional accuracy
	Line	$l_2^o + v_2 = x_1^o + \delta_1 \Rightarrow$	$5 + v_2 = 5 + \delta_1 \Rightarrow$	$v_2 = \delta_1$	
	Point	$l_3^o + v_3 = x_1^o + \delta_1 \Rightarrow$	$5 + v_3 = 5 + \delta_1 \Rightarrow$	$v_3 = \delta_1$	
	Topo-1	$l_4^o + v_4 = x_2^o + \delta_2$	$5 + v_4 = 5 + \delta_2 \Rightarrow$	$v_4 = \delta_2$	Topology accuracy
	Topo-2	$l_5^o + v_5 = x_2^o + \delta_2$	$5 + v_5 = 5 + \delta_2$	$v_5 = \delta_2$	
	Topo-3	$l_6^o + v_6 = x_2^o + \delta_2 \Rightarrow$	$5 + v_6 = 5 + \delta_2 \Rightarrow$	$v_6 = \delta_2$	
	Trribute-1	$l_7^o + v_7 = x_3^o + \delta_3 \Rightarrow$	$5 + v_7 = 5 + \delta_3 \Rightarrow$	$v_7 = \delta_3$	Attribute accuracy
	Trribute-2	$l_8^o + v_8 = x_3^o + \delta_3 \Rightarrow$	$5 + v_8 = 5 + \delta_3 \Rightarrow$	$v_8 = \delta_3$	
	Trribute-3	$l_9^o + v_9 = x_3^o + \delta_3 \Rightarrow$	$5 + v_9 = 5 + \delta_3 \Rightarrow$	$v_9 = \delta_3$	

Table (3): Demais model in a precise model.

Feature	Tested factors		Developed observations		
Points	Positions	P_1	$l_1^o + v_1 = x_1^o + \delta_1 \Rightarrow$	$2 + v_1 = 5 + \delta_1 \Rightarrow$	$v_1 = \delta_1 + 3$
		P_2	$l_2^o + v_2 = x_2^o + \delta_2 \Rightarrow$	$1 + v_2 = 5 + \delta_2 \Rightarrow$	$v_2 = \delta_2 + 4$
	Topology	T_1	$l_3^o + v_3 = x_3^o + \delta_3 \Rightarrow$	$5 + v_3 = 5 + \delta_3 \Rightarrow$	$v_3 = \delta_3$
		T_2	$l_4^o + v_4 = x_4^o + \delta_4 \Rightarrow$	$10 + v_4 = 5 + \delta_4 \Rightarrow$	$v_4 = \delta_4 - 5$
	Attributes	AT_1	$l_5^o + v_5 = x_5^o + \delta_5 \Rightarrow$	$10 + v_5 = 5 + \delta_5 \Rightarrow$	$v_5 = \delta_5 - 5$
		AT_2	$l_6^o + v_6 = x_6^o + \delta_6 \Rightarrow$	$10 + v_6 = 5 + \delta_6 \Rightarrow$	$v_6 = \delta_6 - 5$
Lines	Positions	P_3	$l_7^o + v_7 = x_7^o + \delta_7 \Rightarrow$	$1 + v_7 = 5 + \delta_7 \Rightarrow$	$v_7 = \delta_7 + 4$
		P_4	$l_8^o + v_8 = x_8^o + \delta_8 \Rightarrow$	$12 + v_8 = 5 + \delta_8 \Rightarrow$	$v_8 = \delta_8 - 7$
	Topol	T_3	$l_9^o + v_9 = x_9^o + \delta_9 \Rightarrow$	$5 + v_9 = 5 + \delta_9 \Rightarrow$	$v_9 = \delta_9$

Feature	Tested factors		Developed observations		
		T_4	$l_{10}^{o}+v_{10}=x_{10}^{o}+\delta_{10}\Rightarrow$	$5+v_{10}=5+\delta_{10}\Rightarrow$	$v_{10}=\delta_{10}$
	Attributes	AT_3	$l_{11}^{o}+v_{11}=x_{11}^{o}+\delta_{11}\Rightarrow$	$10+v_{11}=5+\delta_{11}\Rightarrow$	$v_{11}=\delta_{11}-5$
		AT_4	$l_{12}^{o}+v_{12}=x_{12}^{o}+\delta_{12}\Rightarrow$	$5+v_{12}=5+\delta_{12}\Rightarrow$	$v_{12}=\delta_{3}$
Polygons	....	....	....	....	....

Figure (3): Sample of Solution vectors obtained from Demais Model with Least-Squares adjustment.

$$\delta_1=\begin{bmatrix}0.000\\-1.667\\-3.333\end{bmatrix}\quad \delta_2=\begin{bmatrix}3.000\\2.537\\-4.435\end{bmatrix}\quad \delta_3=\begin{bmatrix}-1.152\\4.936\\2.333\end{bmatrix}\quad \delta_4=\begin{bmatrix}2.017\\12.114\\-1.653\end{bmatrix}$$

a) Four patches evaluated in a global mode

$$\delta_1=\begin{bmatrix}10.123\\-4.253\\1.173\\3.726\\-3.953\\2.995\\5.000\\1.983\\2.729\\4.257\\-2.711\\-3.019\end{bmatrix},\ \delta_2=\begin{bmatrix}1.537\\-2.183\\3.123\\-4.123\\2.721\\1.908\\-3.416\\2.029\\1.293\\0.523\\3.128\\-4.027\end{bmatrix},\ \delta_4=\begin{bmatrix}3.071\\-1.125\\4.891\\-3.172\\2.944\\1.016\\2.905\\4.025\\2.087\\3.973\\-8.914\\3.084\end{bmatrix}\quad \delta_4=\begin{bmatrix}-6.131\\2.389\\3.982\\-1.628\\4.145\\2.091\\3.768\\-0.925\\4.926\\-2.194\\2.904\\1.983\end{bmatrix}$$

b) Four patches evaluated in a precise mode

Table (4): Sample of Results Obtained by Demais Q.C. Model in Global Mode.

Evaluation Factors	Patches	Themes				
		T_1	T_2	T_3	T_4	T_5
NoO	Patch Number 1	12	12	12	6	6
δ CEV		3.357	2.438	-3.381	-4.846	-3.695
NoPO		12	12	11	6	6
NoFO		0	0	1	0	0
% of Success		100%	100%	92%	100%	100%
Q.C. DoT		Pass	Pass	Pass	Pass	Pass
CL		98.4%				
Q.C. DoP		Pass				
Remarks	Only 1 Odd observation in T_3 May be Checked – If Needed					
NoO	Patch Number 2	5	5	5	6	9
δ CEV		-1.891	-4.914	4.010	-0.809	1.484
NoPO		5	5	5	6	8
NoFO		0	0	0	0	1
% of Success		100%	100%	100%	100%	89%
Q.C. DoT		Pass	Pass	Pass	Pass	Fail
CL		97.8%				
Q.C. DoP		Pass				
Remarks	Only 1 Odd observation in T_5 May be Checked – If Needed					
NoO	Patch Number 3	9	9	9	8	5
δ CEV		-2.256	0.280	2.329	2.204	-2.207
NoPO		9	9	8	8	5
NoFO		0	0	1	0	0
% of Success		100%	100%	89%	100%	100%
Q.C. DoT		Pass	Pass	Fail	Pass	Pass
CL		97.8%				
Q.C. DoP		Pass				
Remarks	Only 1 Odd observation in T_3 May be Checked – If Needed					

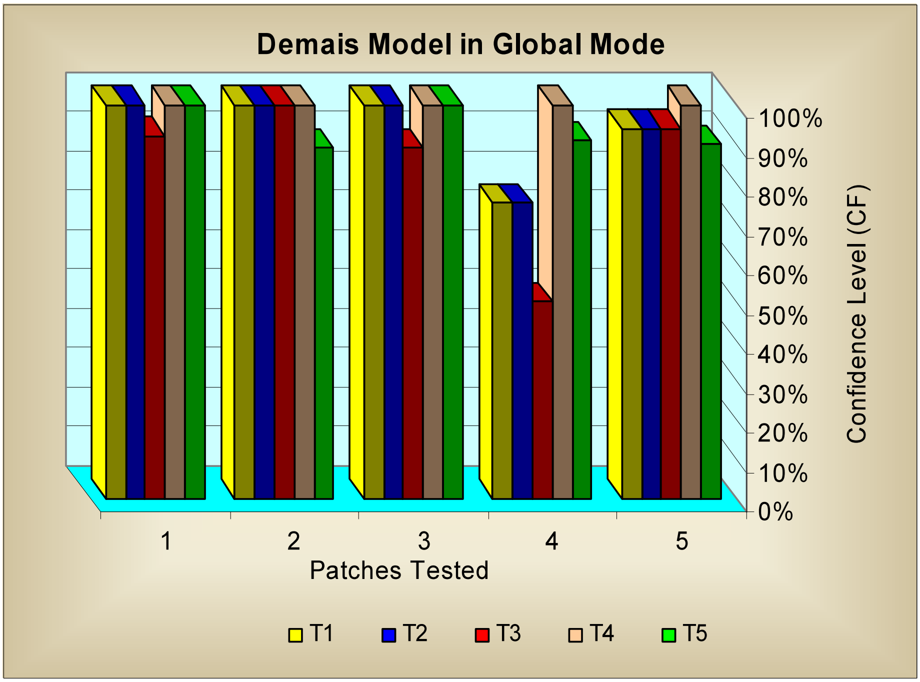
Table (4): Sample of Results Obtained by Demais Q.C. Model in Global Mode…Continues

Evaluation Factors	Patches	Themes				
		T_1	T_2	T_3	T_4	T_5
NoO	Patch Number 4	4	4	4	10	11
δ CEV		-0.271	-4.028	-2.728	1.609	-4.184
NoPO		3	3	2	10	10
NoFO		1	1	2	0	1
% of Success		75%	75%	50%	100%	91%
Q.C. DoT		Fail	Fail	Fail	Pass	Pass
CL		78.2%				
Q.C. DoP		Fail				
Remarks	Must Check T_1, T_2, and T_3 – Serious Errors in Positions					
NoO	Patch Number 5	35	35	35	6	10
δ CEV		-4.904	-1.708	-1.265	-1.125	-1.286
NoPO		33	33	33	6	9
NoFO		2	2	2	0	1
% of Success		94%	94%	94%	100%	90%
Q.C. DoT		Pass	Pass	Pass	Pass	Pass
CL		94.4%				
Q.C. DoP		Pass				
Remarks	This Patch is Superior in Quality					
Over All Decision on the Master Window Based on Tested Patches						
MWCL	98%					
Q.C.MJW	Pass					

Descriptions: **NoO** = No of Observations; **δ CEV** = δ calculated errors vector; **NoPO**= No. of Passed Observations; **NoFO** = No. of Failed Observations; **Q.C.DoT** = Q.C. Decision on Themes; **CL** = Confidence level (Patch Score); **Q.C.DoP**= Q.C. Decision on

Patch; **MWCL** = Master Window Confidence Level; **Q.C.MJW** = Q.C. on overall Major Window. **T_i**=Theme i

Figure (4): Themes' results (T_i) of each patch (P_i) can easily be figured out from this diagram.



5 Conclusion.

A quantitative mathematical model for assessing quality control of geographic information systems called Demais has been developed. Both spatial database aspects (the geometric aspects and the descriptive aspects) of data were treated in this research using the precise and the global modes of Demais model. The well known least squares adjustment techniques were used in conducting the Q.C. processes. The model (Demais model) proved to be successful. The author, therefore, appeals to GIS users to consider utilizing this technique for assessing their respective GIS works.

6.0 References:

Aronoff, S., 1982, **The map accuracy report: a user's view, photogrammetric Engineering and Remote Sensing**, 48: 1309-1312.

Aronoff, S., 1985, **The minimum accuracy value as an index of classification accuracy**. Photogrammetric Engineering and Remote Sensing 51: 99-111.

Aronoff, S., 1989, **Geographic information Systems: A Management Perspective**, WDL Publications, Ottawa, Canada. pp. 141.

Bolstad, P.V., and Smith, J.L., 1992, **Errors in GIS**, Assessing Spatial Data Accuracy, Journal of Forestry, November pp, 21-29.

Brassel K., F. Bucher, E-M. Stephan and A. Vckovski, 1995, **Completeness**, In Guptill S C and Morrison J L (eds) Elements of spatial data quality, Oxford, Elsevier: 81-108.

Busch, A., F. Willrich, 2002, **Quality Management of ATKIS Data**, Proceeding CD of the OEEPE/ISPRS Joint Workshop on Spatial Data Quality Management, Istanbul, Turkey, pp. 30-41.

Busch, A., M.Gerke, D. Grünreich, C. Heipke, C. E. Liedtke, S. Müller, 2004, **Automated Verification of a Topographic Reference Dataset: System Design and Practical Results: IntArchPhRS**, Volume XXXV, Part B2, Istanbul, 2004, pp. 735-740.

Busch, A., M. Gerke, D. Grünreich, P. Helmholz, C.-E. Liedtke, S. Müller, 2006, **Automated verification of a**

topographic dataset using Ikonos imagery, Symposium ISPRS- Commission IV Goa.

Caspary, W. and R. Scheuring, 1993, **Positional Accuracy in Spatial Databases**, Comput, Environ, And Urban Systems, 17:103-110.

Chrisman, N. R., 1989, **Modelling Errors in Overlaid Categorical Maps**, In Accuracy of Spatial Databases, Taylor and Francis, Philadelphia, Penn.,pp. 21-34.

Committee on Cartographic Surveying, Surveying and Mapping Division, 1983, **Map uses**, scales and accuracies for engineering and associated purposes, American Society of Civil Engineers New York: American Society of Civil Engineers.

Committee for Specifications and Standards, Professional Practice Division, 1985, **Accuracy specification for large-scale line maps**, American Society of Photogrammetry Photogrammetric Engineering and Remote Sensing 51: 195-199.

Congalton, R. G, R. G. Oderwald and R. A. Mead 1983, **Assessing Landsat classification accuracy using discrete multivariate analysis statistical techniques**, Photogrammetric Engineering and Remote Sensing 49: 1671-1678.

Dilks, K., et. al., 2000, **Quality Assurance/Quality Control Procedures for ITAM GIS Databases**, Engineer Research and Development Center Champaign IL Construction Engineering Research lab; Final Reprt No. A784283, pp 131.

Gerke M., M. Butenuth, C. Heipke, F. Willrich, 2003, **Graph Supported Automated Verification of Road Databases Using Aerial Imagery**, Proceedings of the 2nd International Symposium on Spatial Data Quality, Hongkong, W. Shi, M. F. Goodchild, P. F. Fisher (Ed.), pp. 421-430.

Gerke, M., 2005, **Automatic Quality Assessment of GIS Road Data Using AerialImagery - A Comparison between Bayesian and Evidential Reasoning: IntArchPhRS**, Band XXXVI 3/W24, Wien, 2005, S. 171-177.

Gerke, M., A. Busch, 2005, **Verification of a Digital Road Database Using Ikonos Imagery**, IntArchPhRS, Volume XXXVI, Part I/W3, ISPRS Hannover Workshop, High-Resolution Earth Imaging for Geospatial Information.

Gerke, M., C.Heipke, 2006, **Quality Assessment of Road Databases in Open Landscape Areas: IntArchPhRS**, Band XXXVI-4, Goa; 115-120.

Ghose, M. K., 2006, Product quality assurance for GIS life-cycle, http: //www. gisdevelopment.net / technology/gis/techgi0042.htm.

Goodchild, M. and S. Gopal, (eds.) 1989, **Modelling errors in objects and fields**, In Accuracy of Spatial Databases, Taylor and Francis, Philadelphia, Penn.,pp. 107-113.

Goodchild, M. F., 1989, **Accuracy of Spatial Databases (M. Goodchild and S. Gopal, Eds.)**, Taylor and Francis, London, pp. 263-276.

Goodchild M. F. 1991, **A Issues of quality and uncertainty In Muller J C (ed) Advances in cartography**, London, Elsevier: 113-139.

Johnston, D. M. , 1999, **Quality Assurance/ Quality Control Procedures for ITAM GIS Databas**es, U.S. Army Construction Engineering Research Lab; P.O. Box 9005, Champaign IL 61826-9005; Under contract no: DACA88-97-D-0004; Delivery Order No. 0009; Perform QA/QC Procedures on Fort Hood, TX ITAM GIS Data Layers.

Montgomery, G. E., and Schuch, H.C., 1993, **GIS Data Conversion Handbook**, GIS World, Inc. and UGC Consulting, Fort Collins, Co. pp. 136-141.

Montgomery, G. E., and H. C. Schuch, 1993, **GIS Data Conversion Handbook**, GIS World, Inc. and UGC Consulting, Fort Collins, CO. pp. 143-146.

McCain, M. and W. Masters, 2006, **Integrating Quality Assurance Into the GIS Project Life Cycle**, http://www.esri.com/news/arcuser/798/qa.html

Openshaw, S., 1989, **Learning to live with errors in spatial databases**, In Accuracy of Spatial Databases, Taylor and Francis, Philadelphia, Penn.,pp. 21-34.

Paul, M., S. K. Ghosh, S. C. De Sarkar and P. S. Acharya,2006, **A Service Oriented Architecture for Enterprise-GIS**, In the Proceedings of 9th Annual International Conference on Geographic Information Science, Technology and Application (Map India 2006), New Delhi, India.

Rosenfield, G. H. and Fitzpatrick-Lins K., 1986, **A coefficient of agreement as a measure of thematic**

classification accuracy, Photogrammetric Engineering and Remote Sensing 52: 223-227.

Stanislawski, L. V., B. A. Dewitt, and R. L. Shrestha. 1996, **Estimating Positional Accuracy of Data Layers Within a GIS Through Error Propagation**, Photogrammetric Engineering & Remote Sensing, 62(4):429-433.

Straub, B. M., M. Gerke, 2003, **Automatic Mapping of Settlement Areas Using a Knowledge-Based Image Interpretation System**, ICVS 2003, Graz, Lecture Notes in Computer Science 2626, Crowley, Piater, Vicze, Paletta (Eds.) pp.355-364.

Veregin, H. and P. Hargitai, 1995, **An evaluation matrix for geographical data quality**, In Guptill S C and Morrison J L (eds) Elements of spatial data quality, Oxford: Elsevier 167-188.

Willrich, F., 2002, **Quality Control and Updating of Road Data by GIS-driven Road Extraction from Imagery**, Proceedings of the Joint International Symposium on 'Geospatial Theory, Processing, and Applications' and ISPRS comm. IV symposium, Ottawa, Canada , 7 p.