FINAL REPORT OF W.G. IV/4: STANDARDS FOR PHOTOGRAMMETRIC PROCEDURES

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ABSTRACT:

This report outlines the guidelines developed by the W.G. on the establishment and verification of data quality standards. The approach followed was to first identify the main production lines used in the photogrammetric collection of digital GIS data and then to review all possible influencing factors involved. On the basis of these influencing factors and error sources, data quality standards are drawn up, which include the elements of data history, positional accuracy, data base completeness, logical consistency, data security and data decay rate.

1. BACKGROUND

Based on resolution IV/5 adopted at the 1988 ISPRS Kyoto Congress, that guidance be drawn up in drafting specifications for the photogrammetric and remote sensing tools and techniques used for the production of data for GIS's, W.G. IV/4 was set up, with the terms of reference to concentrate on:

a) Specifications for photogrammetric point determination, with quality control.
b) Organising courses and producing lecture materials and tutorial papers for the spread of knowledge in this field.

2. MODIFICATION OF SCOPE OF W.G. PROGRAMME

In the discussion of these Terms of Reference within the W.G., the following points were raised:

- since we are concerned with the collection of digital data for a GIS, it is more appropriate to speak about **standards** rather than **specifications**.
This distinction is particularly relevant when dealing with data quality, where the traditional map specifications deal with the establishment of the data quality requirements to be satisfied in a final product, such as a map. The digital data quality standards, on the other hand, deal with the establishment and verification of the data quality actually obtained in the data collection process, and it is up to the users assessing such data to evaluate its suitability for their particular application in mind i.e. with **standards**, the interest lies in establishing a **true quality label** of the data, whilst with specifications one is interested in setting up **numerical thresholds that will allow one to achieve a pre-determined quality.**

- Since the term **photogrammetric point determination** is commonly used to describe aerial triangulation, which is rather limited in its scope, it was felt more appropriate to extend the terms of reference to developing standards for **photogrammetrically collected data** i.e. also cover the photogrammetric digital data collection for GIS's, etc.

- In order to be practical, the W.G. must set itself a target that can be realised in the time available, up to the Washington Congress.

The W.G. therefore decided to concentrate on **data quality standards** and not to deal with **data classification standards** and **data exchange standards.** Unlike the other two, data quality standards are application independent and are thereby suited to a discussion on an international level. Furthermore, data quality is by itself an important topic, even if its treatment only leads to a reduction in the confusion in the statistical terminology used.

- In developing standards, the W.G. would concentrate on producing **guidelines** on the establishment and verification of data quality standards. Hereby the intention is to assist agencies faced with this task and not to try to develop a universal standard.
Considerable work has and is being done in this field of data standards throughout the world and this has led to publications such as the Canadian CCSM National Standards for the Exchange of Digital Topographic Data, USGS Digital Cartographic Data Standards and the UK National Standards for the Transfer of Digital Data. This work is not going to be re-shuffled here just for the sake of trying to achieve universal uniformity, which is also unnecessary. What is necessary, however, particularly if data is to be exchanged amongst different data bases, is that the different agencies involved correctly interpret each other's standards i.e. that even if the agencies use different terms and definitions, there is at least clarity as to what is implied.

- With regard to the second item in the terms of reference, concerning spread of knowledge in this field of data quality standards, it was felt that this could best be achieved by producing the required **guidelines** and then testing these at ISPRS Workshops, arranged in cooperation with other W.G.'s also having **spread of knowledge** in their terms of reference.

As a result, the W.G. finally got underway with the revised terms of reference to concentrate on:
a) Standards of photogrammetrically collected data, whereby the results are presented as guidelines to be used in their establishment and verification.
b) Presenting these guidelines at ISPRS Workshops to be organised in cooperation with other ISPRS Working Groups.

3. GUIDELINES ON THE ESTABLISHMENT AND VERIFICATION OF DATA QUALITY STANDARDS

Most of the attention in this paper will be directed towards setting up standards for the two main elements of the data quality standards, POSITIONAL ACCURACY and ATTRIBUTE ACCURACY. These standards will be looked into for three main production lines; point determination, photogrammetric data collection and digitising existing maps. Hereby, the error sources will be evaluated after each of the successive production phases of data collection, data storage and processing and finally, data presentation.

The discussion in the paper then turns to the other elements within data quality standards such as DATA HISTORY, LOGICAL CONSISTENCY, DATA SECURITY and DATA DECAY, where the main question will be whether some of these elements could not be more usefully incorporated into the accuracy elements.

3.1 Positional accuracy standards

In this presentation, the accuracy is expressed as a standard deviation in metres on the ground, but of course can be readily transformed to any other system in use.

Absolute accuracy measures are given, but these imply error in relation to nearby control points and not a distant origin of the coordinate system, simply because they are based on the equivalence of relative and absolute accuracy in an aerial triangulation with a high density of control.

Finally, these guideline standards only cover planimetric accuracy. Full standards have been produced and can be made available, on request.

3.1.1 Point determination applications
The main applications of aerial triangulations are:
- the determination of minor control for digital and analogue mapping
- the densification of geodetic control networks
- numerical and graphical cadastral surveys

In order to satisfy the widely varying accuracy requirements (point determinations ranging from a few centimetres to decimetres or even metres on the ground), different types of aerial triangulation are available, such as HIGH PRECISION, PRECISION, STANDARD, etc.

Phase I: data collection
This initial phase of data collection covers the whole aerial triangulation process. The input errors include the errors in ground control (measuring equipment and method used), the effect of the ground control requirements on the total process (density and distribution of control, number of control points in each location, the signalisation of control), errors in the aerial photography (type of camera, photo scale, film deformation, lens distortion), errors in the preparation phase (point transfer errors, if signalised tie points are not used) and the effect of the A.T. requirements on the process (instrument to be used; method, bundle or IMT; use of single or multiple tie points; use of increased lateral overlap to obtain double rows of lateral tie points; etc.)

The measuring errors are confined to pointing errors if the bundle method is used and to relative orientation plus pointing errors for the IMT method.

The accuracy standards of aerial triangulation are readily established and verified, simply because they form an integral part of the A.T. results. **The golden rule in establishing A.T. accuracy standards is therefore to resort to your own A.T. figures.**

However, in order to have some figures for discussion and comparison purposes with other accuracy standards, examples of figures obtainable in High Precision AT's and Precision AT's are accuracies of respectively 5μm and 10μm at photo scale.

Hereby it must be borne in mind that the **high precision A.T.** involves bundle adjustment, signalised control and tie points, perimeter plan control at two to three model intervals, correction for systematic image errors and possibly also systematic errors in the measuring instrument used. Also, the less stringent requirements for a **precision A.T.** still involve bundle or IMT adjustment, perimeter plan control at three to four model intervals, signalised control points, multiple tie points in each location and, if possible, double rows of lateral tie points.

On the basis of these examples, a table can be drawn up for the accuracy of the photogrammetric point determination phase.

(units m)

Type of AT Photo scale	High Precision AT	Precision AT
1:50,000	0.25	0.50
1:30,000	0.15	0.30
1:10,000	0.05	0.10
1: 5,000	0.03	0.05
1: 2,500	0.01	0.03

Table 1: Photogrammetric point determination

Phase II: data storage and processing

Since no further processing takes place with regard to the aerial triangulation and no rounding off errors, etc. will take place with storage, the accuracy standard after storage and processing will be the same as that shown in table 1, after data collection.

Phase III: data presentation

A graphical plot is quite often required as an additional product in a numerical cadastral survey. As the standard accuracy of this plotting error is 0.15 mm at map scale, there is a considerable loss in accuracy of the graphical as compared to the original digital data. This can be verified in the table below, showing the accuracy of the graphical plot of photogrammetric point data.

(units m)

photo scale \ map scale	1:10,000	1:5,000	1:2,500	1:1,000	1:500
1:50,000	1.58	0.90	0.63	0.52	0.51
1:30,000	1.53	0.81	0.48	0.34	0.31
1:10,000	1.50	0.76	0.39	0.18	0.13
1: 5,000	1.50	0.75	0.38	0.16	0.09
1: 2,500	1.50	0.75	0.38	0.15	0.08
1:50,000	1.52	0.79	0.45	0.29	0.26
1:30,000	1.51	0.76	0.40	0.21	0.17
1:10,000	1.50	0.75	0.38	0.16	0.09
1: 5,000	1.50	0.75	0.38	0.15	0.08
1: 2,500	1.50	0.75	0.38	0.15	0.08

Table 2: Graphical plot of photogrammetric point data (Precision AT ; High Precision AT)

3.1.2 Photogrammetric digital data collection

Photogrammetric digital data collection is equivalent to digital mapping, whereby the resulting digital data is either stored in one or several data bases for further processing within a GIS or is used to produce or up-date graphical maps.

Phase I: data collection

This initial phase of data collection covers the whole mapping process. The input errors include the errors in ground control and aerial photography (as outlined in 3.1.1), in addition to the aerial triangulation errors: point transfer errors; system errors depending upon the number and distribution of tie points and measuring errors which vary with the type of point (signalised or pricked) and further depend on image quality, object quality, the measuring instrument, the base-height ratio and observer acuity.

The measuring errors include errors in the relative and absolute orientations; measuring errors, which vary depending on whether the measuring mode is static or dynamic and, in the latter case, the measuring speed; the image quality; the base-height ratio; the object quality, including parameters such as terrain slope, vegetation coverage, etc.; the instrument errors; the operator acuity; etc. A separate component of the measuring error is the identification error, which varies with the definition of the feature being measured i.e. corner of a house or boundary of a forest. Identification errors also arise if the definition of the feature to be picked up is not clear enough e.g. if it is not clear whether the boundary of a canal is to be taken as the top of the bank or the water line, etc.

The accuracy standards for the digital mapping phase are not difficult but are time-consuming to establish and verify.

Looking to the components involved,
- the A.T. accuracy is obtained from the A.T. results
- the measuring accuracy is obtainable from repeated model measurements, such as occur in checking operations. The coordinate differences used should only refer to well-defined points i.e. those without an identification error

- the identification accuracy for different features and different feature definitions is obtainable from repeated model measurements at these features.

It is, of course, a tremendous task to build up this data base for the identification accuracy of different features, particularly since this accuracy varies with feature definition (i.e. centre of road or edge of road) and with the photo scale used. This task will unquestionably become part of the checking operations.

In order to have figures for discussion and comparison purposes, the following realistic assumptions are made, using figures obtained in practice:
- A.T. accuracy: σ = 10 μm at photo scale, for a precise A.T., which is sufficiently accurate for all mapping purposes
- measuring accuracy: σ = 15 μm at photo scale

- identification accuracy:
control point	0 cm
wall	5 cm
hedge, ditch	10 cm
canal bank	20 cm
river bank	50 cm

From these figures, the following table can be drawn up for the accuracy of photogrammetric digital data collection.

(units m)

Photo scale \ Identif. error	0 cm	5 cm	10 cm	20 cm	50 cm
1:50,000	1.00	1.00	1.00	1.02	1.12
1:30,000	0.60	0.60	0.61	0.63	0.78
1:10,000	0.20	0.21	0.22	0.28	0.54
1: 5,000	0.10	0.11	0.14	0.22	0.51
1: 2,500	0.05	0.07	0.11	0.21	0.50

Table 3: Photogrammetric digital data collection

Note: The first column in the above table gives the intrinsic accuracy of the digital data base i.e. the accuracy excluding a possible identification error.

Phase II: data storage and processing

Since no further processing takes place until the data are eventually incorporated into a GIS, the accuracy of the photogrammetric data after initial storage and processing will be the same as that shown in figure 3, after data collection.

Phase III: data presentation

A graphical plot is a quite normal requirement to be produced from photogrammetric digital data. With a standard plotting accuracy of 0.15 μm at map scale, tables can be drawn up showing the accuracy of the graphical plot of photogrammetric digital data collection. Note, however, that different tables are needed for the different values of the identification error. The table given below refers to intrinsic data i.e. with no identification error.

map scale / photo scale	1:10,000	1:5,000	1:2,500	1:1,000	1:500
1:30,000	1.62	0.96	0.71	0.62	0.60
1:20,000	1.55	0.85	0.55	0.43	0.41
1:10,000	1.51	0.78	0.42	0.25	0.21
1: 5,000	1.50	0.76	0.39	0.18	0.12
1: 2,500	1.50	0.75	0.39	0.16	0.09

Table 4: Graphical plot of photogrammetric digital data (with no identification error)

3.1.3 Digitising existing maps

Digitising existing maps is an attractive alternative to photogrammetric digital data collection in order to set up a digital data base. In the feasibility study, however, careful consideration must be given to the following two issues:
- the age of the maps and the rate of development of the area concerned, which determine the number of changes and hence the revision effort required. In this context, changes also imply changes in the map content requirements, since the original maps were produced
- in view of the loss of accuracy through the digitising process, one will in general want to digitise at a larger map scale than has to be finally plotted and this, of course, reduces the economic attractiveness.

Phase I: data collection

This initial data collection phase covers the whole digitising process. The input errors are the positional errors in the map original. In evaluating these, account will have to be taken of the original production method and parameters used such as photo scale, control distribution in the A.T., etc. etc.; the original accuracy specifications (which imply a standard deviation of 0.3 mm at map scale with the standard specifications of "90% within 0.5 mm", but only applicable to well-defined features); the identification errors to be added to all other non well-defined feature classes and finally the generalisation errors introduced in the form of feature displacements, during the cartographic phase.

The measuring errors in the digitising process vary with the digitising method used: point digitising and the sampling density in relation to the complexity of the feature; stream digitising and the digitising speed, again in relation to the nature of the feature; automated scanning in the raster mode and the subsequent raster to vector conversion; automated scanning in the vector mode; the precision of the digitiser or scanner; the map quality (thickness of lines, errors in the original, etc.) and the operator acuity.

Assuming an accuracy in the map original of 0.3 mm (excluding identification and generalisation errors) and a digitising accuracy of 0.15 mm, the digitised data will have an accuracy of 0.35 mm at map scale. This is illustrated for different map scales in table 5.

map scale	σ
1:50,000	17.50
1:25,000	8.75
1:10,000	3.50
1: 5,000	1.75
1: 2,500	0.88
1: 1,000	0.35

Table 5: Digitised map data (excl. identification and generalisation errors)

Phase II: data storage and presentation

Since no further processing takes place until this data is incorporated into a GIS, the accuracy of the digitised map data after initial storage and processing will be in the same as that after data collection, shown in table 5.

Phase III: data presentation

A graphical plot is quite a normal requirement to be produced from digitised map data. The accuracy of this graphical plot is determined from the accuracy of the digitised map data and the plotting accuracy, which can be taken to be 0.15 mm at plotting scale. Note, however, that different tables are needed for the different values of the identification and generalisation error. The table given below refers to the intrinsic data accuracy i.e. accuracy excluding identification and generalisation error.

(units m)

digitising scale / plotting scale	1:50,000	1:25,000	1:10,000	1: 5,000	1: 2,500	1: 1,000
1:50,000	19.04	-	-	-	-	-
1:25,000	11.52	9.52	-	-	-	-
1:10,000	8.28	5.13	3.81	-	-	-
1: 5,000	7.70	4.14	2.30	1.90	-	-
1: 2,500	7.55	3.85	1.74	1.15	0.95	-
1: 1,000	7.51	3.77	1.54	0.82	0.51	0.38

Table 6: Graphical plot of digitised map data (excl. identification and generalisation errors)

3.2 Attribute accuracy standards

Attribute accuracy expresses the correctness and completeness of the digital data stored in a data base and is built-up from an evaluation of the following different characteristics defining the quality of the digital data:
- data classification: have errors been made in not going to a sufficant degree of detail in data collection i.e. streams not further classified as perennial, intermittent, dry; was the feature definition clear enough so that the correct boundary has been picked up i.e. not clear if boundary of a highway area to be taken from cadastral boundaries as depicted by the fences or the limits of the hardened highway surface; has account been taken of temporal changes in the classification system e.g. roads department changes its road classification

system; have temporal changes occurred in spite of a correct classification during the field verification phase i.e. type of crop changed from maize to potatoes and finally have there been any errors in the field verification phase itself.

- data completeness, though decisions taken on the extent of the data base content: this aspect of completeness, indicating the extent to which features on the ground are actually included in the data base, is related to the problem of generalisation in the traditional mapping environment. Here, in order to keep the maps readable, fewer and fewer features can be represented as the scales decrease and therefore they are simply not picked up. This type of reasoning does, however, not apply to data bases and so, in terms of assigning a quality label for this type of completeness, the content requirements of different data bases will have to be quantified in relation to the maximum completeness. E.g. assume that a 1:50,000 map series has been found to have an average generalisation percentage of 30%. If now these 1:50,000 maps are digitised to create a data base, the quality indicator for the completeness of the digitised data based only on data base content will be 70%.

Data with a security classification also fall into this category, but the effect on the completeness percentages will depend on whether:
a) the security label prevent general access to these elements, whereby the data is de facto entirely removed from the data base. If this concerns 5% of the features in an area, the data completeness percentage become 95% due to security restrictions.
b) the above solution has the disadvantage of yielding gaps when a graphical plot is produced. To overcome this, some agencies retain the feature (in simplified form in open areas) and give it a general classification such as **government building** or **government area-restricted**. With regard to the simplified form of the security object in open areas, this will generally only include the boundaries of the complex, plus the location of through roads, if the complex has more than one entrance.
Besides eliminating gaps, this alternative also increases the data completeness percentage.
Some authors advocate that data security be treated as a separate item in attribute accuracy standards, but the majority of W.G. members were in favour of retaining it as an integral element within data completeness, as affected by decisions on the data base content.

- data completeness, expressing the degree to which features which should have been included in the data base, have actually been picked up. The data completeness depends on factors such as the quality of the field verification phase i.e. have all missing features been picked up; the temporal validity of the data i.e. the extent to which all changes have been recognised and new features have been picked up; the lack of

accessibility to the data due to security restrictions and finally, missing and thereby incomplete data due to the fact that the input data has been generalised. This will occur, for example, when the individual buildings have been generalised by the built-up area symbol on a medium scale map and this map is subsequently digitised.

In these guidelines, attribute accuracy will be expressed as a percentage of the correctness and completeness of the attribute, in relation to the true situation. There are three of these quality indicators for attribute accuracy: data classification, data completeness related to data base content and data completeness related to errors in data collection. This implies that the final figure for attribute accuracy is the product of the three figures obtained for the indicators e.g. with figures of 85% for data classification, 90% for completeness (content) and 80% for completeness (errors), the attribute accuracy figure will be 0.61 or 61%.

Besides determining the attribute accuracy for each data item class, summaries will also be produced of groups of items falling within different accuracy classes, in order to provide useful indicators for map revision needs.

Attribute accuracy is only readily verifiable in the field during the field completion or field verification phase. An exception to this is the figure for data completeness related to data base content, which must come from the organisation's statistical records.

3.4 Data history

The data history describes the standards themselves and summarises the methods used in data collection and data quality verification. It is probably the most important element in the data quality standards, simply because it allows users accessing the data to correctly interpret the implications of the quality measures used.

3.5 Logical consistency

Logical consistency is a general term for fidelity in representing features in a data structure. It thus does not belong to the data collection parameters described in these standards and will not be treated further here.

3.6 Data security

Instead of taking this as a separate item, data security has, in these standards, been included as a component of the quality indicator **data completeness, in relation to data base content,** described in paragraph 3.2.

3.7 Data decay

The decay rate of data has been mentioned in paragraph 3.2 as being an important factor, affecting the quality of both data classification and data completeness. Nevertheless, **decay rate is** probably not important enough to be included as a separate item defining quality within the

attribute accuracy standards. An added
complication is that any classification system
used to define decay rate, will be highly
subjective.

A possible exception in this regard would be to
attach a label **high decay rate** to those attribute
items which can change within 6 months, but almost
certainly will change within a year. Examples of
these are the physical changes in shacks in slum
areas; classification changes in type of crop
grown on arable land; classification changes in
the space use of buildings in city centres, etc.
Such warnings, presented by these labels, could be
very useful for planning purposes.

4. CONCLUDING REMARKS

Quite some effort is involved in setting up
standards for data quality, but it has to be done
and when done properly, can lead to numerous
hidden advantages to management, such as:

- users will have more faith in map data, since
  there is now little room for interpretation
  errors, which have lead to considerable
  financial losses in the past. A part of this
  greater faith arises from the fact that users
  are now able to evaluate for themselves whether
  the quality is sufficient for the decisions they
  have to take

- mapping managers can use a lot of the quality
  indicators for planning purposes. Examples of
  these are:
* the use of the summaries produced of the groups
    of features falling within different accuracy

    classes as indicators for map revision needs
  * if data items have a **high decay rate**, do not
    incorporate these into the national topo data
    base but transfer them specialised user data
    bases, where for example agriculturalists
    interested in predicting maize yield, will
    only be too happy to record all land use
    changes involving maize
  * see which conclusions can be derived from the
    accuracy tables of your organisation. For
    example, if the maps produced from the
    photogrammetric digital data collection have
    to satisfy the plotting accuracy requirement
    of being within 0.2 mm at map scale, table 4
    shows that the maximum enlargement that can be
    used from photo to map is 6.6x.
    Similarly, if the maps produced from
    digitising existing maps also have to satisfy
    the 0.2 mm accuracy requirement, then table 6
    shows that the original maps will have to be
    at a 2.7 x larger scale.