

DIGITAL MAPPING IN NORWAY - EXPERIENCES FROM AN ACCURACY TEST

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ABSTRACT

The paper outlines some experiences gained from a Norwegian investigation on digital mapping in general, but with emphasis on the accuracy aspect. In connection with the production of large-scale maps of the city of Bergen, some parts of the map production were examined. The sources of error in different sub-processes and the final accuracy were estimated in order to make comparisons with the mapping standards and the traditional analogue methods. The use of a smaller image scale than traditionally used in Norway was also interesting, both economically and technically. Four different mapping companies delivered comparable data from a common test area, and the results showed uniform and high accuracy without any significant equipment-dependent differences. No source of error was found to be a "bottleneck" in the production lines, but the identification problems using the smaller image scale were, together with ground control errors, the largest contributors to the overall error. The need for standards for digital mapping was found to be obvious during the investigation.

1. INTRODUCTION

Initially, digital methods were introduced in mapping because of a number of expected benefits. Better accuracy preservation and cost reduction in revision and map drawing were central aspects. Digital data, instead of printed maps, promised a greater flexibility for the users, while automated methods for generalisation and redrawing would simplify derived mapping.

Looking back on the development so far, a number of influences seem to have caused problems. In the early days of digital system development, nobody could have designed a system capable of meeting all of today's needs for digital map data. When combined with the idea of developing methods to match existing manual operations without an integrated design, this has reduced the expansion.

This also resulted in a great number of different systems becoming available, based on different ideas and technology, which is causing much difficulty to would-be users when they choose equipment and a system. Today, it seems to be more a market for the equipment dealers than a matter of supplying the needs in mapping.

At least in Norway, the production rate of digital data seems to have reached a break-through before a common specification on the use of the data was established. A proposal for a data exchange standard has already been made, but still much is undecided. The market of digital mapping in the private sector has "exploded" the last two years, not without consequences for the labour structure in the companies involved. Graphical "artists" have had to turn to compiling and debugging without much time for adaptation if they want to stay in their jobs.

There are many interesting aspects to examine in the area of digital mapping. This paper gives some results and experiences from an investigation of accuracy preservation in the production of large-scale map data. The use of a smaller image scale than traditionally used in Norway, was also an interesting accuracy and cost aspect. With a mapping scale of 1:500, an image scale of 1:3500 is normally used in the production. Here the image scale was 1:5000, being still inside scale limits commonly used elsewhere. Both analogue and analytical stereo instruments were used in the production, and comparison of the final accuracy would be of interest. The reference for the accuracy test was the existing Norwegian mapping standard related to traditional map production. Throughout the whole investigation, the need for an adapted standard specification in digital mapping increased.

2. TEST METHODOLOGY

The basic strategy for the investigation was to search for bottlenecks in the production lines. We asked if some of the subprocesses had particularly high or low accuracy. If so, what could be the reason(s), and was it profitable to correct the system ?

To answer these points, the participating mapping companies delivered data from different stages in the production. Then each of the contributing error sources in the accuracy model was estimated. Reference data for the test was obtained by geodetic field measurements. Since the product delivered to the employer was to be graphic maps, the final plotting of the data was also included in the test. For this reason and due to practical solutions, input data for the final accuracy assessment was collected by digitising the maps. The participation of four leading Norwegian mapping companies made the comparison of the results from a common test area of national interest.

3. DETAILS OF THE INVESTIGATION

3.1 QUALITY OF DATA

Data presented by computers tend to be regarded as precise and reliable, no matter how they appear. The risk of misapplication is then present and definitions of accuracy concepts are required to describe the data quality.

The accuracy of data collection depends on both the method and the source material. Two major types of registration methods are used : plain registration, e.g. digitizing lines on a map, and

registration combined with interpretation, e.g. contouring in a stereo model. Also the source material can be classified into two groups depending on the accuracy. "Exact" material like graphical maps can be digitized without problems of interpretation, while "non-exact" material like stereo models demand experience to interpret them. To clarify different concepts of quality and accuracy, a classification model is presented.

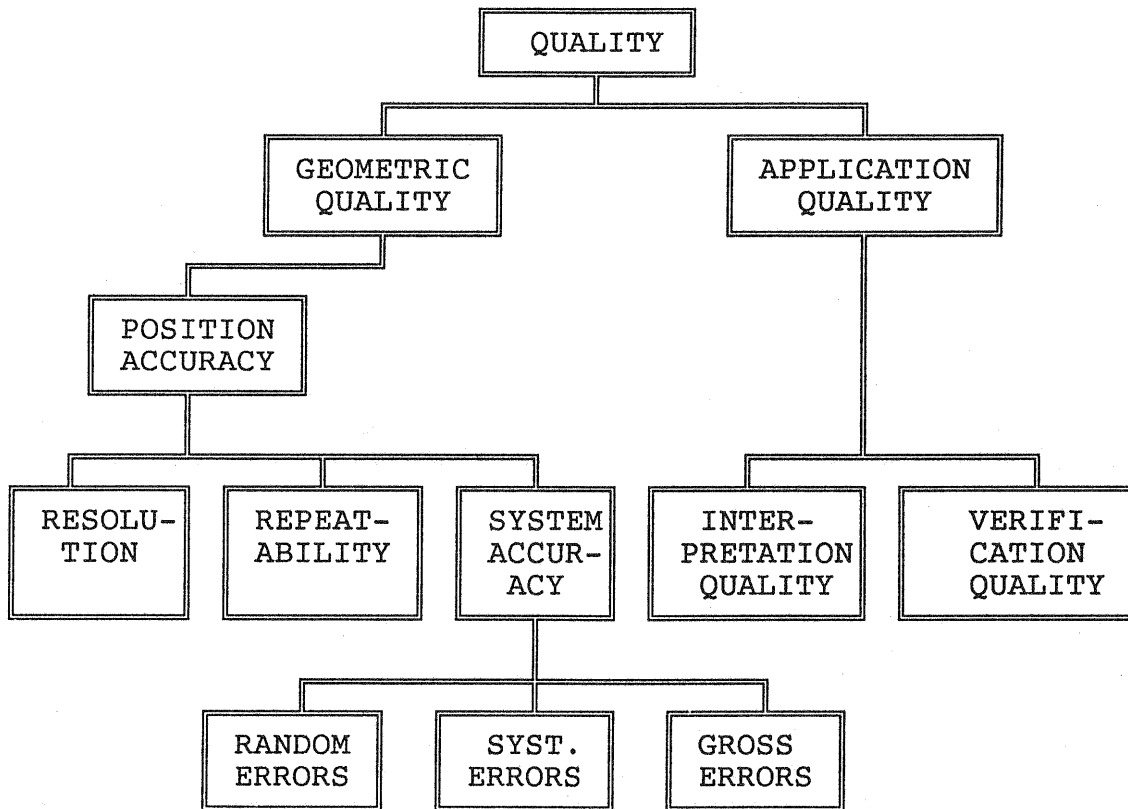


Figure 3.1 Quality of map data.

The resolution of a system indicates the smallest values that can be registered along one axis.

Repeatability gives a measure of the expected accuracy of repeated measurements of the same object, with the same operator and method and within short time intervals.

System accuracy includes errors due to human factors, surroundings and deformations of materials used (e.g. film).

Interpretation quality is the expected quality of the data when the operator needs to use his experience in identifying / interpreting objects. This operation includes two parts: the operator and the source material, and the quality may be improved by reference to the source (here: terrain).

Verification quality can be defined as the reliability of, for instance, a map, and indicates how the map meets the demands for information.

Random errors will in this connection be errors not included in the repeatability. They are described by some probability

function.

Systematic errors can be described by a mathematical model.

Gross errors may be divided into two groups: one group containing the observations falling outside the confidence interval when testing the reliability, the other with the data classified as blunders (wrong numbering, etc.).

In addition to the model above, we have some other associated terms like static and dynamic accuracy.

3.2 NORWEGIAN MAPPING STANDARDS

The present accuracy standard for mapping that formed the basis in our investigation is not adapted to digital methods in mapping. When made, it was reflecting the possible accuracy with the methods of that period. Analogue stereo instruments and manual redrawing were central parts in map production lines. Even though the requirements for accuracy were not quite upgraded, the regulation procedures for testing were followed. The systematic error in the x-direction, a_x is defined by

$$a_x = \frac{\sum \epsilon_x}{n_x}, \quad \text{where } \epsilon_x = x_{\text{map}} - x_{\text{control}}$$

We regard ϵ as a "true" error, when assuming x_{control} is of significantly higher quality than x_{map} . Similar equations are valid for y and height coordinates. For point error we have : $a_p = a_x^2 + a_y^2$. When the map data are divided into groups to estimate systematic errors, the field of data must correspond to at least one map sheet. The mean error is estimated by :

$$m_x = \sqrt{\frac{(\epsilon_x - a_x)^2}{n_x - 1}}, \quad m_p = \sqrt{m_x^2 + m_y^2}$$

The neighbour error : $m_n = \sqrt{\frac{\epsilon^2}{n}}$ where ϵ is the difference

between distance in map data and distance measured by the control. With mapping scale of 1 : 500, the specifications for plan accuracy are:

$$a_p = 0.12 \text{ m} \quad m_p = 0.17 \text{ m} \quad m_n = 0.17 \text{ m}$$

The height accuracy specifications deal both with given height points and contour lines :

$$\begin{array}{ll} \text{Given height points :} & a_h = 0.10 \text{ m} & m_h = 0.12 \text{ m} \\ \text{Contour lines :} & a_{hc} = 0.20 \text{ m} & m_{hc} = 0.17 \text{ m} \end{array}$$

3.3 INVESTIGATION PLAN

An instruction for the evaluation was made in order to fulfill the intention of this investigation. The interesting parts were listed and the estimation approaches defined for each of the tasks.

i) Quality of ground control and aero-triangulation.

The investigation of the ground control should have been done by another institution, but due to shortage of labour, a complete check was not carried out.

ii) Relative and absolute plan accuracy.

A number of points with different distributions were chosen for the estimation of neighbouring errors across short distances, both within models and across model and strip borders. Some points which were easy to define and measure in the terrain were chosen for the absolute accuracy estimation. The repeatability was estimated from double-digitization of smaller areas in some of the models.

iii) Height accuracy data were obtained by measuring height points in the terrain. Corresponding height values in the map data were estimated by interpolation using two different methods.

iv) Completeness / application quality.

Without the capacity for making a complete investigation of the application quality, we merely indicated a method to describe the application by an information index.

v) Instrument accuracy.

The companies using analogue stereo instruments were to perform a certain grid measurement, while companies with analytical instruments were to deliver the latest calibration report of the instrument.

vi) Production design

The participating companies were themselves instructed to make a report on the instrumentation, time consumption and other central parts in the production of the test material. A questionnaire was produced to obtain comparable results.

The field measurements were made by polar methods using a geodetic total station. A total of 873 points were measured.

4. RESULTS

4.1 GROUND CONTROL

Since no investigation of the ground control was made, we could only indicate the error sizes in the control network of the test area. The results from the coordinate computations show errors in both distances and directions between the control points. The largest distance deviation between measured and calculated distance was 0.07 metres. More complete investigations of local control networks elsewhere in Norway show results of similar size.

4.2 PLAN ACCURACY

The results of plan accuracy were obtained by the methods described in 3.2, and the average values from the four different companies are given in table 4.2.1. The systematic errors were estimated from a smaller area than demanded and the present exceedence is not significant.

	Systematic error	Mean error	Numbers of observation
All companies (average value)	0.08	0.11	425
Highest value	0.16	0.14	
Lowest value	0.04	0.10	
Accuracy specification	0.12	0.16	

Table 4.2.1 Absolute plan accuracy.

In the plan accuracy investigation we also separated the data in different object classes :

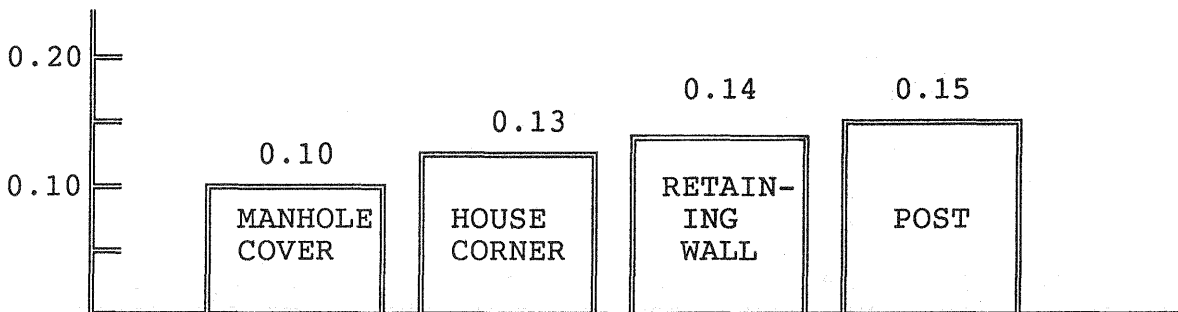


Figure 4.2.2 Absolute plan accuracy for different object types.

To estimate the mean error of short distances within and across model borders, a number of points were digitized in the models and compared with geodetically measured distances or measurements from the neighbour model.

Neighbour mean error within models :	$m_{n1} = 0.09$ metres
Neighbour mean error across model borders :	$m_{n2} = 0.05$ metres

The result show no higher level of mean error across strip/model borders than within models, so there is no obvious "stress" between the models caused by aero-triangulation. One possible reason why the mean neighbour error across borders seems to be smaller than within models is that identification problems are nearly eliminated when measuring the same point for the second time.

The repeatability results indicates how accurately the stereo operator is able to align on details when digitizing. Instrument accuracy and our test digitization accuracy also contribute to the estimated values, but to a lesser degree.

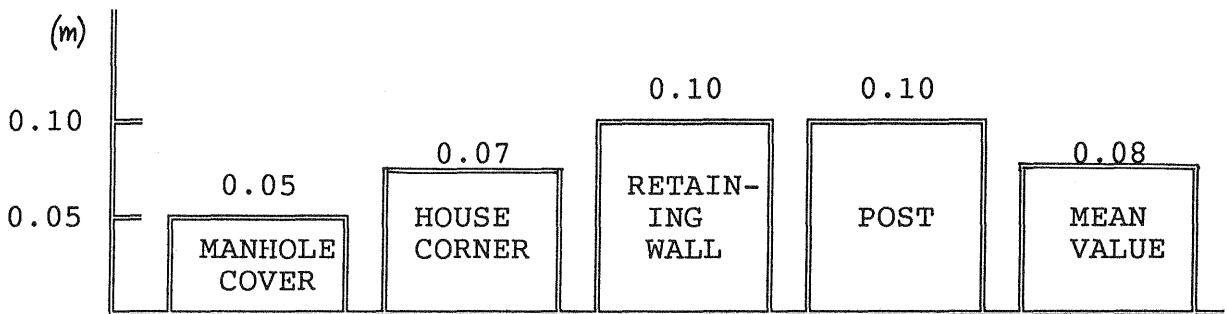


Figure 4.2.3 Repeatability for different object types.

Based on the different results for the accuracy in the sub-processes and the accuracy differences between the object types, an attempt to quantify the error sources for each object type was made. The point mean error (m_p) can be described by the effect of the different error sources :

$$m_p^2 = m_i^2 + m_a^2 + m_c^2 + m_t^2$$

where m_i is instrument error

m_a is "addition" error caused by identification problems among others

m_c is ground control error

m_t is error in our test measurements.

From the definitions we m_i , m_c and m_t to be independent of object type. The results show nearly the same differences between repeatability and absolute accuracy for each of the object types, and confirm the validity of our model.

m_c is set empirically to 0.08 metres and m_t is estimated as 0.03 metres. When assuming a manhole cover to be the most "ideal" object to digitize, and setting m_a to 0.00 metres in that object class, we get the following values of the error sources :

	m_p	m_i	m_a	m_c	m_t
Manhole cover	0.10	0.05	0.00	0.08	0.03
House corner	0.13	0.05	0.08	0.08	0.03
Retaining wall	0.14	0.05	0.10	0.08	0.03
Post	0.15	0.05	0.11	0.08	0.03
All objects	0.13	0.05	0.08	0.08	0.03

Table 4.2.4 Absolute accuracy, error sources.

4.3 HEIGHT ACCURACY

The height investigation does not quite comply with the regulation procedures in the mapping standards since random points, rather than contour lines, were measured in the terrain. Our method represents, however, more the situation of map data application. Two different interpolation methods were tested, both linear interpolation and weighted-average calculations. In this case linear interpolation had the lowest standard deviation value and was chosen for the further estimations. The rugged topography of the test terrain may be one reason for this effect. The results were divided into 8 groups depending on terrain elevation and given in figure 4.3.1.

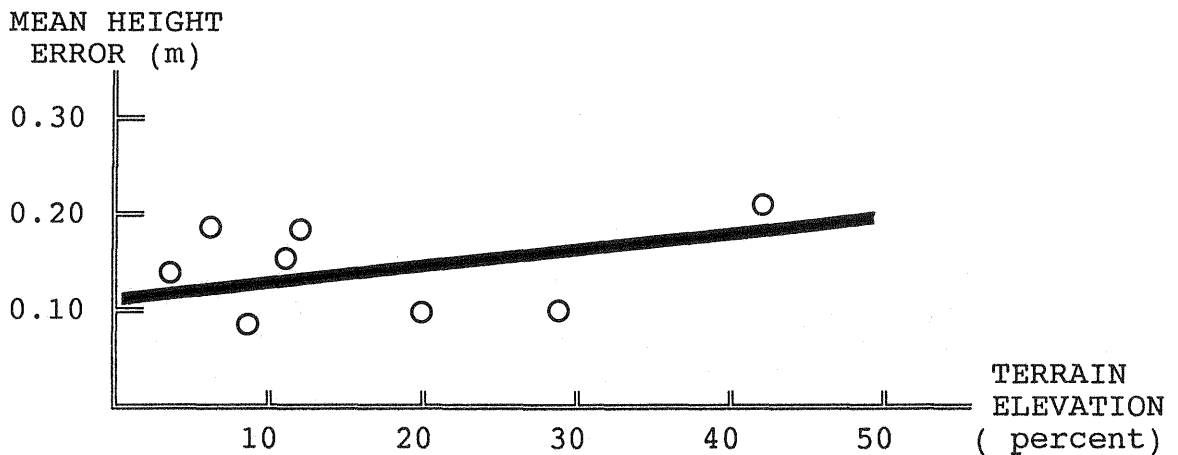


Figure 4.3.1 Mean height error

The mean height error is given by Koppe's formula as :

$$m_H = 0.11 + 0.18t$$

where t is the elevation of the measured point.

4.4 COMPLETENESS / APPLICATION QUALITY

When we use a map or map data information in, for instance, planning, the completeness of the information is often of greater importance than the accuracy specification. Replanning caused by the unsuspected existence of objects found at a late stage is expensive.

The application quality (Q_A) may be given as an information index with different weight models being defined by the user groups.

$$Q_A = \frac{\sum_i [p_i \cdot (1 - p_{i0}) \cdot w_i]}{\sum_i (p_i \cdot w_i)}$$

for all i
object types.

p_i is the probability of existence of object type x_i in the map area, p_{i0} is the probability of omission of object type x_i and w_i is the relative weight of the object type.

4.5 INSTRUMENT ACCURACY

The results are within the area of expected values both regarding analogue and analytical stereo instruments. The calibration reports for the analytical instruments show mean errors round 1.5 microns (0.75 cm with image scale 1:5000), while the grid measurements gave mean errors of 0.0037 per cent of flying height (3 cm in our case).

4.6 PRODUCTION DESIGN

The reports made by the participating companies were the basis for the evaluation of possible differences in the accuracy results. Analyses of the present results show no obvious effects caused by different production lines. It is most interesting to note that the final accuracy seems to be independent of the type of digitizing instrument, which means the instrument accuracy is not the deciding factor in this case.

5. CONCLUSIONS

The accuracy results largely fulfill the standard requirements of today (yesterday?) and indicate the uniform quality of the mapping companies in Norway. In our search for bottlenecks in the production lines, we did not find any process or error source to be totally dominating for the final accuracy. Seen from an economic point of view, the most ideal case is equal sizes of each of the sub-processes and the final accuracy just fulfilling the requirements. Then the planning of the mapping and the utilization of the present resources would be optimal.

Together with ground control error, we found that the errors caused by identification problems are the largest in this set of data. That means that the image scale could not have been any smaller and still keep inside the accuracy requirements. In this production the image scale to map scale relationship was 10:1 and we obtained a von Gruber coefficient, $c = 224$ (from $c = m_B / m_K$, where m_B is the image scale and m_K is the map scale). This result seems to fit well into common assumptions of possible values with today's technology.

It seems to be impossible to improve to much higher accuracy in mapping without a more uniform accuracy in the ground control.

The need for a digital mapping standard is obvious and it can be divided into at least three main groups :

- A standard for the classification of topographic objects.
- A standard for the quality evaluation of digital topographic data.
- A standard for the transfer of digital data.

The quality-evaluation part have to consist accuracy specifications divided into groups concerning object type and application. Also specifications of application quality of map data may take place in this part. Our investigation also put forward the question of height accuracy estimation done by some more applicable methods than today.

6. REFERENCES

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