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COMPARISON OF ECONOMY OF TERRESTRIAL METHODS WITH PHOTOGRAMMETRIC METHODS

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SUMMARY

It is assumed that we use photogrammetry for a task in the field of surveying. But we refrain from a comprehensive comparison of purely terrestrial methods with photogrammetric methods. We solely deal with the determination of control points and the complementary terrestrial work. The economy of both these tasks depends to a large extent on the picture scale. For this reason we first investigate, how the picture scale is influenced by accuracy, interpretation, plotting instrument and map size.

The cost of a terrestrial determination of control points is compared with the cost of an aerotriangulation. The ratio of the expenses for the determination of a control point and the expenses for the plotting of a model in aerotriangulation is decisive for the choice of the procedure to be used. From the given formulae we can easily conclude, in which cases a strip or block triangulation is more favorable than the terrestrial determination of control points.

The extent of complementary terrestrial work varies considerably and frequently depends on local conditions. In this paper the task is only indicated in short. In particular it is recommended to publish more frequently reliable data obtained in practical work.

1. INTRODUCTION

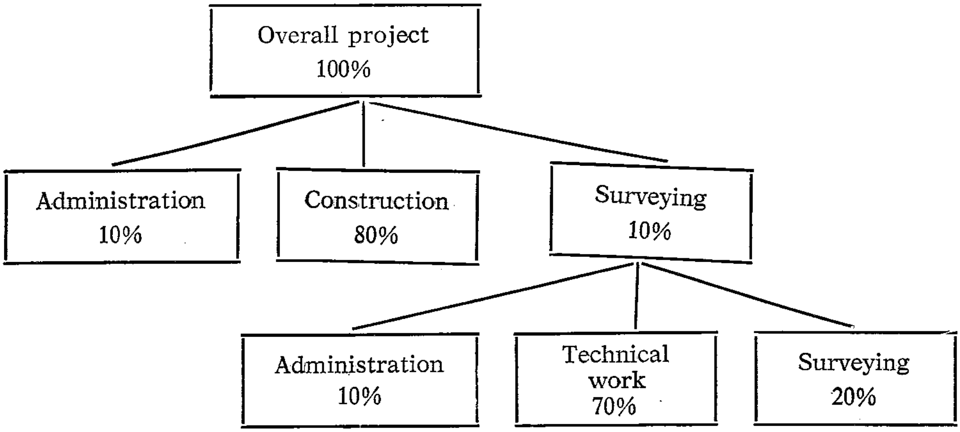
The task of dealing with economical problems is always somewhat difficult because those persons who are thoroughly familiar with this subject only seldom speak about it, whereas the others who speak about it, are in most cases less familiar with the subject. A private company hardly reveals the secret of its calculation, and the calculations of authorities are often to be treated with caution because there one does not always calculate « correctly ». Some years ago, for instance, I had a visitor from such an authority who complained about the high price for a photogrammetric plotting. He was of the opinion that it would be much cheaper to do the work himself because then he would only have to pay for the photographic flight. But he overlooked completely, that someone had to pay for the plotting instruments which he intended to use, and that his operators, too, had to be paid from some budget.

I admit that the topic in its present form has caused me some difficulties. The sub-titles of the French version, however, gave me some clues. They deal with the taking and plotting of air photographs for photogrammetrically produced map series at different scales and with the advantages and disadvantages of aerotriangulation.

Irrespective of the map series covering an entire country, the production of which is frequently considered a cultural task, in most cases the survey is only part of a major project, such as the construction of a higway or a house, the execution of a rural remembrement, or the like. Here only approximately 10% of the entire work belong to the field of surveying.

If we subdivide these 10%, we find that the largest portion thereof is absorbed by planning work, consultations with the persons concerned and the like, and that the portion of the surveying work proper will hardly amount to 20%.

Fig. 1



Here is a practical example: The budget of the City of Frankfurt for underground structures, i.e. road and bridge construction, hydraulic engineering, sewerage, etc. amounts to approximately 60 million DM, whereas the budget of the Municipal Survey Office only amounts to 3 million DM.

2. TASKS

We have to incorporate photogrammetry either into the 20% of the surveying work proper or into the 2% of the entire project. There photogrammetry does not lead a life of its own, but affects other fields of activity, but till now this effect has been very insignificant. What is the reason for this? In most cases one expects that the new measuring method yields the same results as the old one. One has, for instance, prescribed certain tolerances which are only applicable to one certain procedure. But now the new procedure is also judged by these tolerances. Even minor organizational changes are considered cumbersome because one is too lazy to abandon traditional usage. If we, for instance, assume that stereoscopic plotting instruments would already be a hundred years old, and that someone would today invent the measuring rod or the measuring tape, then the existing regulations would have to be amended like this: « After one has now succeeded in measuring short distances with sufficient accuracy with a measuring rod or a measuring tape, there are no objections against the use of these instruments for distances up to 50 meters ».

But photogrammetry has found valuable assistants, if used at the right place. I am thinking of electronic computers, the utility of which no surveying office can deny in the long run, and the results of which it must recognize in the end. It is rather amusing to hear that some surveyors in leading position have objected for many years against photogrammetrically determined coordinates in the national sulvey system under the prete, that these coordinates are unfit for a revision, and that nowadays these same surveyors unhesitatingly make use of these same coordinates furnished by the computer, and that they even praise this method emphatically.

Which are now our most important tasks?

— Above all I mention the measurement of coordinates, where it is unimportant whether they are used for cadastral purpose, for land reallotment or for profile measurements with construction projects. Consequently we have to consider all three dimensions.
— The results of a topographic survey are maps or plans. This field of work, however, is hardly touched by electronic computers. To these topographic maps of the national survey must be added all maps for construction projects, town planning and the like. Apart from the complete representation of planimetry, the representation of elevations is of particular importance. For the time being I do not want to discuss the meaning of « complete ».
— With rectification it is somewhat different. But we should not forget that there topography also plays a certain role. He who furnishes wide-angle photographs for mosaics 1 : 25 000 and who demands planimetric errors of 1 - 2 mm, at elevation differences of 500 - 1000 m, asks us that we at least try to annul the « laws of nature ». This does not apply to the production of orthophotos and drop lines.

If we wanted to treat our topic on the economy of surveying procedures thoroughly, we would have to deal with all these three tasks and to determine cost and time required for both the conventional terrestrial method and the photogrammetric method. Furthermore we would have to distinguish — in accordance with the requirements in practice — between a new surveying project and the maintenance of an existing one. Especially this latter task will cause the leading surveyors considerable troubles in the years to come. We would have to ask for instance: How much money was so far required for surveying involved in a land reallotment, and how much money can we save by making use of photogrammetry? How much money is required for the survey of a topographic map 1 : 25 000 or 1 : 5 000 with planetable or tacheometer, and how much money is required for the same survey when applying photogrammetric procedures? What does the resurvey of a city cost when we use the polar method, and how much does the same survey cost with the aid of orthophotos?

We may obtain the answer to these questions by asking different companies to submit us offers for each method and each task. But will not every firm — depending on its capacity — come to different results? And who will nowadays give a reliable answer to the question: How much does a tacheometric survey of 100 km² cost at the scale of 1 : 5 000?

We do not want to complicate our task any further and assume that we are using photogrammetric procedures. In most cases we refrain from comparing them with purely terrestrial methods and restrict ourselves to the work in the border regions of terrestrial survey and photogrammetry, namely:

— the determination of control points and
— the terrestrial complementary work.

The economy of these two tasks depends to a far extent on the picture scale. But the requirements seem to contradict themselves, as the determination of control points calls for small picture scales, wherease the terrestrial supplementary work necessitates large scales. We have to do justice to both tasks.

3. THE PICTURE SCALE

3.1 *The influence of accuracy.*

The accuracy of a plotting not only depends on the picture scale, but also on the plotting instrument, the air-survey camera, and the operator. There are two different types of plotting instruments: The analogous instruments and the comparators. Comparators are only used for the measurement of coordinates. As to the survey cameras, the film size and the relative aperture of the lens ϑ play an important role. We distinguish at least between the two sizes of 18 x 18 cm^2 and 23 x 23 cm^2, and between normal-angle, wide-angle, and super-wide-angle photographs. But nowadays we know that the accuracy not only depends on the instruments used but also, to a high degree, on the operator. For this reason we should include him into our considerations. I am of the opinion that we have already reached the limit of measurability. Therefore, new instruments should improve the precision of setting. According to the test « Reichenbach » of the OEEPE, the mean error obtained from double measurements made with analogous instruments amounts to approximately 3,5 μ (converted into the scale of the photograph). One center had measured the two runs by two different operators. Here the mean measuring error amounted to 10 μ! It should be mentioned, however, that in one case the magnification in the instrument amounted in the average to 2,5, and in the other case only to 1,8. If we compare the final coordinates with those determined by terrestrial means, then the difference in the accuracy of both measurements disappears. If we compare the results of the measurements obtained in analogous instruments with those obtained in comparators, we find that the situation is similar. Here we also have to take account of the difference in the scale of the model. Some years ago we have been confronted with a similar problem, when the first theodolites with an optical micrometer appeared on the market. The error of reading did not correspond to the error of sighting.

3.1.1. *Planimetric error*

Let us assume that the mean coordinate error of a signalized point pertaining to a single model plotting with four or five control points is $m_o' = 12\ \mu$ (converted into the scale of the photograph); a value which has also been used by *Ackermann* [1] at the symposium in Prague. With comparator measurements the mean error is smaller. The opinions on the errors of coordinates for non-signalized points are still somewhat divergent. The OEEPE found an error of 0,25 m in nature for « easily identifiable points » and an error of 0,50 m for « badly identifiable points ». The picture scales varied between 1 : 4 700 and 1 : 10 000. Due to the fact that the measuring error is relatively small, the identification error in the large scales is relatively larger than in the small scales. This is partly in contradiction to the results published at the symposium in Prague. According to those results the mean error would be approximately 35 μ on the picture (compare e.g. [2] and [3]). Furthermore we assume the required plotting accuracy to be $m_o'' = 0{,}2$ mm. From this we conclude the following:

— If we take the result obtained by the OEEPE for non-signalized points, then even the accuracy for « easily identifiable points » is not sufficient for a plotting 1 : 1 000. If we combine « easily and badly identifiable points » the largest permissible plotting scale would be approximately 1 : 2 000.

— But if we take the results from the various reports published in Prague, then

$$m_b = 6\ m_k \tag{1}$$

(m_b = number of picture scale, m_k = number of map scale); i.e. a picture scale of 1 : 6 000 is sufficient for a plotting of 1 : 1 000. If we take the same accuracy as a basis for the plotting of topographic lines, then the same law also applies to a topographic plotting, i.e. the planimetry of a map 1 : 5 000 could be drawn from photographs 1 : 30 000. For the « German Basic Map 1 : 5 000 », however, the mean planimetric error of a point to be re-established incontestably can amount to ± 3 m (see [4]). According to this, even a picture scale of 1 : 60 000 would be sufficient.

— If with a coordinate measurement with signalized points a mean error of m_o is to be obtained, the required picture scale number is

$$m_b = \frac{m_o}{m_o'} \qquad (2)$$

If e.g. m_o = 6 cm — an accuracy which frequently is not even obtained with trigonometric points — then m_b = 5 000. For special projects, such as railroad surveys, a higher accuracy, above all a higher relative accuracy, may be required.

— If signalized points are only to be plotted, then even

$$m_b = 16\ m_k \qquad (3)$$

If again there is no reason for another scale, a map 1 : 1 000 could be made from photographs 1 : 15 000.

3.1.2 *Altimetric error*

Let us assume that the mean error of the horizontal parallax of a signalized point is constant, namely m_{px} = 12 μ (converted into the scale of the photograph). This value has not yet been confirmed by practical investigations for all picture scales and for all camera types. In case of super-wide-angle photographs *Jerie* (5) assumes for m_{px} avolue which is approximatel 20% higher.

Now

$$m_{px} = m_h' \cdot \vartheta \qquad (4)$$

In normal-angle photographs the base ratio ϑ is approximately 0,3, in wide-angle photographs it is 0,6, and in super-wide-angle photographs ϑ = 1,0. This proves that the altimetric error depends on the type of camera, i.e. m_h' will become 40 μ, 20 μ, and 12 μ respectively. From equation (4) also results, that with the same size of the image the altimetric error is proportional to the focal length f. For the size of 23 x 23 cm^2

$$m_h' = 0{,}13 \cdot 10^{-3} \cdot f \qquad (5)$$

For non signalized points we assume m_{px} = 18 μ. (The values obtained by *Pichlik* and *Skládal* [2] for roof corners are in the average of the same order of magnitude). The corresponding value for the drawing of contour lines is not yet known exactly. We shall discuss that hereinafter.

Now, how accurate are the heights shown on a topographic map? It seems almost hopeless to find the right answer to this question. *Koppe* and *Hammer* empirically found, that the altimetric errors of the contour lines increase proportionally to the slope of the terrain and set:

$$m_h = a + b \cdot \tan \alpha \qquad (6)$$

In looking through the corresponding literature I found that the dependency of the altimetric error m_h on the slope α is rather questionable. But this is not the only difficulty. If we group the coefficients a and b according to equation (6) for the different scales and try to find thereof a mean value as function of the map scale, then we find that this is nearly impossible. According to *Imhof* [6] e.g. the mean altimetric error of the Topographic Map 1 : 25 000 of Germany would only exceed the mean error of the German Basic Map 1 : 5 000 by 0,1 m, and the mean altimetric error of the map 1 : 20 000 of France would even be smaller! If we assume a mean slope of the terrain and convert the altimetric errors, then we can guess a law which approximately reads:

$$m_h = c_t \cdot \sqrt{m_k} \tag{7}$$

For tan α = 0,1 we obtain c_t = 0,012, and for tan α = 0,2 we find c_t = 0,016, m_h is obtained in meters. From this we conclude:

- If for profiles a mean altimetric error of a single point of m_h = 0,10 m is required — it would be senseless to go below this limit — a flight altitude of at least 400 m would be necessary for the size of 18 x 18 m², and an altitude of 500 m would be required for the size of 23 x 23 m². However, these altitudes are almost impracticable.
- The mean altimetric error of a single point of the German Basic Map 1 : 5 000 shall amount to m_h = 0,3 m. For this reason the flight altitude can be three times as high as mentioned above. For f = 21 cm in the first case m_b would be 6000, and for f = 15 cm in the second case m_b would be 10 000.
- With signalized points with the same altimetric error m_h, the flight altitudes can be increased by 50%. This applies to the scale number as well. For profiles, however, the use of a normal-angle camera would not yet be practical, due to the large picture scale (1 : 3 000).
- From the equations (4) and (7) we obtain the well-known formula of *v. Gruber* (see [7]):

$$m_b = c \sqrt{m_k} \tag{8}$$

  v. Gruber obtained this formula empirically. His c-values amounted to between 100 and 130. In more recent literature we find c-values lying between 160 and 240. From these values we obtain for contour lines m_{px} = 30 µ, a value which is also used by *Kasper* and *Blaschke* (see [8]).
- In general the magnification ratios v = m_b : m_k are considerably smaller with altimetric measurements than with planimetric measurements. For this reason the requirements as to the accuracy in elevation are decisive for the planning of the flight.

Finally it shall be mentioned that both altimetric and planimetric errors occur, i.e. that the altimetric errors influence the planimetric accuracy and vice versa. The error formulae of England are established according to these findings. But here I do not want to discuss this matter in detail.

3.2 *The influence of interpretation*

We suppose that the photographs show the more details, the larger the picture scale is. Unfortunately the investigations on this subject are by far not as numerous as those on accuracy. I was not able to compile all the available data in order to try to find a general law. But probably the available material would not suffice at any rate because it is not homogenous enough and therefore hardly fit for comparisons.

Here are a few examples to outline the task:

— At the symposium in Prague we have learned that in a topographic plotting of an old city at 1 : 1 000 scale from photographs 1 : 3 500 approximately 50% of the required points were missing.

— *Kersting* [9] reports on results of coordinate measurements obtained in land reallotment. Here we have to do with signalized points. The picture scale was 1 : 8 400. As long as the points were still marked by gypsum circles of 0,30 cm in diameter, approximately 15% of the points were missing. This was mainly due to atmospheric influences. After the points were marked by plates, only 4-8% of the points were missing. It has been found that the fear of an eventual displacement of such signals was groundless. In order to reduce these losses further, we nowadays use a larger picture scale.

— Good data have been furnished by the « Renfrew » test of Commission IV of the SIP [10]. *Blachut* differentiates between:
A) Small objects (buildings, bridges)
B) Linear details (roads, railroads, rivers)
C) Large superface details (forests, lakes).
The test shows that with a topographic plotting in 1 : 25 000 scale from photographs in 1 : 50 000 scale the « small objects » are only seized on the average by 55%, whereas the « linear details » are seized by 76% and the « large superface details » even by up to 96%. By investing more time these percentages can be increased. The test does not disclose whether this can be facilitated by using a larger picture scale, nor is it known whether all objects necessary for a 100% « completeness » are actually required in practice.

— Commission C of the OEEPE reported on the test « Reichenbach », that in a picture scale of 1 : 8 000 approximately 95% of the signals 25 x 25 cm^2 were easily identifiable, whereas only 80% were identifiable in 1 : 12 000 scale. On the other hand approximately 2.5% of all points were missing at a scale of 1 : 8 000 and 6% at the scale of 1 : 12 000. This difference, however, may partially be attributed to the fact that the photographs 1 : 8 000 covered more open field area than the photos 1 : 12 000 (see [11]).

It would be desirable, that the publications do not contain so many data on the accuracy, but would rather focus on the actual difficulties, in particular as to interpretation. Here we need better and more reliable information.

3.3 *The influence of instruments*

Each instrument has a range of movement which is precisely fixed. Therefore our flight disposition must be chosen in such a manner, that a plotting can be easily performed later on. Some instruments have spoiled us because they concede us a great clearance. The more we are surprised with other instruments, when their range of movement suddenly is at an end. The measurement of coordinates hardly causes difficulties because we can convert the model coordinates into practically any scale and any system whatever.

The situation is different with map plotting. If the motion of the floating mark is transferred by spindles to a coordinatograph, then we obtain by means of the intercalated gears a relatively great freedom of movement (as e.g. with the C8, A7, and A8). The transfer from the photograph or from the model to the map is possible, as long as the dimension of the drawing table is sufficient and as the control points are located on the map sheet. If the operating rang of an instrument does not suffice, then the plotting must lateron be enlarged or reduced by photographic means. With other instruments, such as B8, Stereotop, Multiplex, etc., the magnification ratio of picture scale and map scale is limited.

This applies in particular to all instruments with an optical projection. In the rectifier SEG V of the Zeiss Company we can only enlarge up to 6 : 1. The situation is similar with the Orthoprojector; its range of magnification extending from 2.5 to 4.0 at a focal length of f = 15 cm. Greater differences in elevation will reduce this range even more.

3.4 *The influence of map size*

With coordinate measurements we again do not have any difficulties, as the coordinates can be grouped at choice. But I should like to point out with all emphasis, that in all other cases the map size influences the picture scale decisively when we think of economy. It is amazing to see how often picture scales are only considered with respect to accuracy, but without respect to the map to be produced lateron.

The problem we have to solve is in fact easily set. We should see to it that a *whole* number of models covers one map sheet, or vice versa that one model covers a *whole* number of map sheets. If the map size is prescribed and if we have chosen a certain photographic format then there is always a most favourable picture scale. In many cases we should choose that picture scale which is the most favourable for a map sheet, even when we would have to take into account a small loss in accuracy. If we want to avoid this, we should decide to change the map size! The sheet sizes of the usual maps are in the proportion of 1 : 1 or $\sqrt{2}$: 1. The size of a model, however, is nearly always 2 : 1. Therefore it is also always possible to cover the area of a quadratic map sheet by 2 models. Fractions of the corresponding scale number furnish favourable picture scales. If the size of the map sheet is in the proportion of $\sqrt{2}$: 1 or approximately 1,5 : 1, then 2 maps can be covered by 3 models or 3 maps by 2 models. From this we can again derive the most favourable picture scales. The wild flying at random should be forbidden in the case of aerial survey. Before taking the photographs we should ask ourselves: « What type of map do we need » and not « What type of maps can we make of the aerial photographs? ».

According to the already mentioned « Handbuch für die topographische Aufnahme der Deutschen Grundkarte » (Handbook for the Topographic Survey of the German Basic Map), a picture scale of 1 : 15 000 is for instance sufficient for a map 1 : 5 000. With a photographic format of 23 x 23 cm^2 and a map size of 40 x 40 cm^2, however, in my opinion a scale of 1 : 10 000 up to 1 : 12 000 would be more favourable.

4. DETERMINATION OF CONTROL POINTS

4.1 *Number of control points*

In general the number of control points depends on picture scale, size of photographs, ratio of overlap, and on the size and configuration of the area covered (see [12] and [13]). In most cases we use 4 control points for each model. Once in a while a fifth point in the center is desidered or even required. Such a point only serves the relative orientation. After we have chosen a certain camera and assumed the usual ratios of overlap for the planning of the flight, then the number of control points — apart from an extra factor on account of the shape of area — only depends on the picture scale. With equation (8) we find that the number of control points per unit area is approximately inversely proportional to the map scale.

If

$$F' = (m_b \cdot 1)^2 (1 - p_x)(1 - p_y) = c' \cdot m_k \cdot 1^2 \qquad (9)$$

is the usable area of the stereogram and F the entire area, then the number of models:

$$n_M = \frac{F}{F'} \qquad (10)$$

If we have n_x models in longitudinal direction and n_y strips, then the number of models:

$$n_M = n_x \cdot n_y \qquad (11)$$

and the number of control points required with an ideal model position, i.e. that the control points of adjacent strips are identical:

$$n_E = (n_x + 1)(n_y + 1) \qquad (12)$$

In practice the number of control points is often already greater due to the configuration of the area covered. In these cases it is advisable to extent the area F.

4.2 *Terrestrial determination of control points*

Even though we dispose nowadays of modern distance meters, the principle of the terrestrial determination of control points has only slightly changed. If there is no trigonometric net available or if the density of the available net is insufficient, then we either have to establish a new net or to increase the density of the existing one. For this purpose the Tellurometer is well suited. We determine distances up to 40 km with an accuracy of 10 - 15 cm. The difficulties of distance measurement are due to the fact that we do not know the meteorological conditions with sufficient accuracy. We increase the density of the wide-meshed net by means of traverses or small chains of triangulation. In comparison with the subtense bar such instruments as the Geodimeter VI have a longer range (between 200 m and 4000 m). It must be admitted, however, that the instrumental equipment is greater than in former times and also increases the costs. But in comparison with the total costs the expenditures for instruments still are relatively small. The technique of point determination must be adapted to the new instruments. It is advantageous to measure as many distances as possible at one station. Thus it should be easy to compensate the higher instrumental costs by a saving of time.

The elevations are either levelled or transferred trigonometrically. I do not worry too much about refraction. We should keep in mind that with a relatively large picture scale of 1 : 5 000 an altimetric accuracy of 20 μ already corresponds to an altimetric error in the stereoscopic measurement of 10 cm in nature!

The expenditure for geodetic measurements fluctuates, as it depends on the distance between the given fixed points, the picture scale, i.e. on the distance of the control points, on the configuration of the area, on the season of the year in which the measurements are made, and on the vegetation. It is understood that measurements in wooded areas require more time than in open fields. The costs of determining one control point are indicated by *Ackermann* as follows:

$$k_t = 60 \,\$ \tag{13}$$

(see [1]). This value is in good conformity with our experiences (see also [9]).

4.3 *Strip triangulation*

It is the purpose of each aerotriangulation to reduce the costs of the terrestrial determination of control points. Let us assume we combine n_x' models to one strip, and we have in the first and in the last stereogram 4 control points each which have been determined by terrestrial means. Then the number n_{Str} of the necessary control points is obtained approximately from the following equation:

$$n_{Str} : n_E = \lambda_1 \approx \frac{3}{n_x'} \tag{14}$$

In order to compensate for the missing control points the models must be plotted either as normal strip triangulation with bridging successive photographs in an analogous instrument or as a measurement of single models. In this latter case comparators can also be used. For a quadratic area we obtain from the equations (11) and (12):

$$n_M : n_E = \lambda_0 \approx 1 - \frac{2{,}3}{\sqrt{n_E}} \tag{15}$$

4.4 *Block triangulation*

The unfavourable propagation of errors in strips is almost completely eliminated in block triangulation. Already some years ago *G. Förstner* [14] has demonstrated by means of a small example that with interpolated points the ellipses of error are rather regular. The extensive new investigations made by *Ackermann* in the International Training Center at Delft have shown that these findings are also applicable to large blocks [15] [16]. If we consider the problem of compensation statically, the result does not surprise us. Naturally the margin of the block has to be provided with control points. Thus the experiences formerly made by Hansa Luftbild in Berlin with the slotted-templet method are also confirmed theoretically [17].

Let us assume that the initial and the terminal stereograms contain two control points each which can normally be used for two adjacent strips, and that in addition one control point each is located in the marginal strips at an interval of 2 base lengths, i.e. the interval of the control points around the block corresponds to the width of the strip. Then we obtain the number of the required control points n_{B1} from the equation:

$$n_{B1} : n_E = \lambda_2 \approx \frac{2{,}8}{\sqrt{n_E}} \tag{16}$$

The ratio $n_M : n_E$ corresponds to that of strip triangulation.

4.5 *Cost of the determination of control points*

First of all we have to come to an understanding as to the cost of measuring one model. The time required for measuring one model in the analogous instruments differ considerably. The same still applies also nowadays to comparator measurements. For the sake of simplicity I employ the value found by *Ackermann* [1]. According to him the cost of measuring one model by means of aerotriangulation amounts to:

$$k_p = 15\ \$ \tag{17}$$

i.e.

$$L_o = k_p : k_t = 1 : 4 \tag{18}$$

Now we can easily compute the overall costs K_E, K_{Str} and K_{Bl} of the three methods of control point determination. From this we obtain the ratios of cost:

$$L_1 = K_{Str} : K_E = \lambda_1 + \lambda_0 \cdot L_o \approx \frac{3}{nx} - \frac{0{,}6}{\sqrt{n_E}} + 0{,}25 \tag{19}$$

$$L_2 = K_{Bl} : K_E = \lambda_2 + \lambda_0 \cdot L_o \approx \frac{2{,}2}{\sqrt{n_E}} + 0{,}25 \tag{20}$$

As is apparent from equations (19) and (20) the lower limit for L_1 and L_2 is L_0 . For $n_E = 100$ we obtain $L_2 = 0{,}27$, i.e. nearly L_0. Consequently the ratio L_0 is much more decisive. The ratio L_1 is greater and thus more unfavourable than L_2 . As, in addition, strip triangulation has a worse propagation of errors, we should aim at changing over to block adjustment, wherever practicable. Block adjustment is not only more accurate, but also less expensive. Of course strip triangulation will still be applied in special cases, e.g. with road construction projects. In this case, however, we can easily observe a regular distribution of control points within the strips. Only in the case of $L_1 < 1$ strip triangulation is more favourable than the terrestrial determination of control points. In our example this applies to $n_x' > 4$. If we change the assumed position of control points, then this value for n_x' in also changed. In the equations (19) and (20) we could easily also take into consideration the time required for orientation in the later plotting of the models and furthermore — according to the loss in accuracy — different picture scales between aerotriangulation and single model plotting..

5. TERRESTRIAL COMPLEMENTARY WORK

No photogrammetric plotting is perfect. It requires complementary work. With coordinate measurements we can easily indicate the percentage of missing points, but with a topographic plotting this is more difficult. Here the complementary work is subdivided into the complementary survey proper and into the subsequent elaboration and preparation of the plotted map. The extent of this complementary work varies considerably and often depends on local conditions. Therefore I do not want to treat this problem in detail, but only restrict myself to a few remarks.

The number of missing points is considerably smaller with signalized points than with non-signalized points. *Kersting* [9] has published some results which he obtained from extensive work in land reallotment. According to him the local complementary surveys require 8% of the total time or 12% of the total costs. The publication does not specify the percentages to be attributed to the measurement of coordinates and to the topographic details. Whether we perform field checking *before* or *after* plotting is probably a question of expediency and habit.

The « Renfrew » experiment also furnishes valuable results. Naturally it is much easier to reduce the number of missing points from 50% to 40% than e.g. from 20% to 10%. If only 50% of the « small objects » were seized, the plotting procedure lasted on the average 21 hours, but when 70% were seized, at least 35 hours were required (see [10] and [18]).

A photogrammetric plotting is not yet a final map. It lacks e.g. the entire lettering. According to *Kersting* even the completion of the maps for reallotment purposes requires almost 25% of the total time or 12% of the total cost.

In conclusion I should like to cite the different opinions on two almost identical, photogrammetric plottings. The first judgment reads as follows: « The observed planimetric uncertainty of points determined by photogrammetric means exceeds the limit of errors given by the drawing accuracy for the planimetric representation of a cadastral plan 1 : 1 000. For this reason the photogrammetric plotting 1 : 1 000 does not satisfy the accuracy requirements of a graphical representation in this scale... Apart from the accuracy requirements which the photogrammetric survey is unable to meet, the photogrammetric plotting cannot be compared unhesitatingly with the drawn plan resulting from the new-survey by terrestrial means. The photogrammetric plot calls for a number of complementary operations before it can be considered a complete, directly reproducible map. These operations will probably require a considerable amount of time and money ».

And in the other case we read: « The accuracy of photogrammetric plots has been investigated once by comparing a number of points with available, terrestrially determined coordinate values, and once by comparing the photogrammetric plot with the transparent basic copy in a scale of 1 : 500 and prepared on a terrestrial basis. The comparison of the points with the available coordinates indicated no important deviations, whereas the superposition of the basic copy prepared on a terrestrial basis onto the photogrammetric plotting revealed certain peculiarities: The course of the rail axes, as well as the light poles, buildings with eaves, and other signalized constructional points such as milestones, boundary stones, etc. are in accordance to scale in both plans as regards both accuracy and representation... Besides, the photomap offers — due to its complete representation of planimetry — an absolute guarantee for the conformity with local conditions, whereas the plan prepared on a terrestrial basis derives part of these data from the cadastral register which does not or must not necessarily show this absolute conformity with local conditions ».

These summerizing remarks which I only cited in excerpts confirm the different opinions existing on photogrammetric plotting. We should recognize both these judgments. The question will always be what the map user wants and to what extent he succeds in parting with ancient methods, or whether or not he is susceptible to modern methods.

6. CONCLUSION

I am well aware that I have been very imperfect in treating the given topic, but the more I studied the problems, the deeper I get lost in them. But if I have succeeded in approaching at least a couple of problems and in stimulating you to give some further thoughts to these questions, then I think my report has served its purpose.