*The Application of Photogrammetry to Land Use Planning**

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EVERY form of planning must be preceded by the collection of information relating to those factors which exercise an influence on the project. This is necessary to enable the planning engineer to choose the best amongst several alternatives and solutions. This applies to the project as a whole and also to its vasious details.

Such information may be divided into numerous different groups in construction work. One important group covers information relating to the nature and content of the ground (topography, roads, buildings, lakes and watercourses). This may be described as *topographical information*. Another group concerns the value of the land and its subdivision into property holdings and may be referred to as *land economics*. A third group deals with the geotechnical data for the ground, soil, rock etc., and may be termed *geotechnical information*. Several other groups of information may be mentioned, such as the preservation of nature and cultural amenities, radio disturbance risks, etc.; these groups are not treated in the present report.

The topographical, land economic- and geotechnical information had of course begun to be used before the advent of aerial photogrammetry and the study of aerial photographs, being mainly collected by work in the terrain, terrestrial work and supplemented in later years by ocular inspection from the air also. As terrestrial work occupies a relatively long time, it has been necessary—generally speaking—to limit the collection of such information to fairly small areas. This has entailed a certain risk of restricting the planning to a few alternatives amongst which the most satisfactory one may not be included. If the planning engineer in the course of his work wishes to check an alternative solution, partly or wholly in an area where the information required is not available or is incomplete, strong reasons must exist for deciding to seek for such a solution when new time-consuming and costly field investigations first have to be carried out.

Aerial photogrammetry and photo-interpretation have changed the conditions radically. The air-photographs bring the terrain to the table of the planning-engineer or to the instruments of the planning-office, where measurements and mapping can be undertaken with the precision necessary for reaching decisions on each occasion. The adaptability of aerial photogrammetry to the actual requirements has been found to be very great. All over the world photogrammetry is now regarded as one of the main aids in civil engineering and economic planning of constructions (roads, railroads, waterpower plants, tunnels, power transmission lines, as well as cities etc.).

From time to time the value of the photogrammetric system is compared with the traditional terrestrial methods for collecting information solely on the basis of the costs involved. *Thi is a radical mistake however.* The important point is to compare the reduction in costs which may be several times greater which can be achieved in construction work and in the running costs when an alternative that comes closer to the ideal solution is chosen.

Naturally it is necessary to estimate, in each actual case, the gain that may be achieved by more careful planning by photogrammetric methods. If the eventual gain is then found to be low compared with the possible extra costs involved by the use of photogrammetric methods, the latter should obviously be abandoned.

PHOTOGRAMMETRIC INFORMATION

Three main groups of information to be obtained with the aid of photogrammetric methods were mentioned in the introduction,

* This is a report on some tests carried out by the Swedish State Power Board by Mr. Fredrik Ahlborg, Mr. Holger Eidebo and Dr. Per Olof Fagerholm; the section dealing with electronic computation is by Mr. Bertil Rudfeldt and Mrs. Bodil Andersen. The illustrations have also been published in the Swedish technical journal *Teknisk Tidskrift.*

FIG. 1. Assembly of star templates for obtaining a system of control points for mapping on a skeleton map in accordance with the mechanical radial triangulation method.

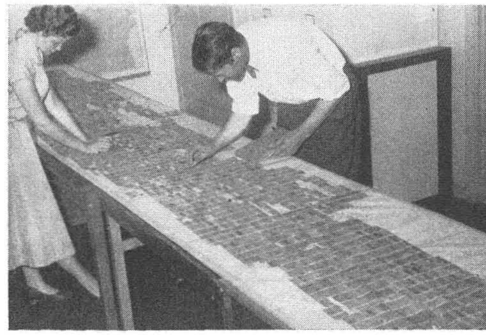

FIG. 2. Completed reference map covered with a network of colored rectangles, indicating the cost for the construction of a 380 KV power transmission line.

namely topography, land economics and geotechnical information.

The *topographical information* may be advantageously obtained step-by-step in the planning by using various photogrammetric methods and sometimes also by taking air-photographs to more than one scale. With a relatively limited expenditure of time and money it is then possible to concentrate progressively on the alternative likely to be the best. This is very important when several alternatives (with the same probability to be the best!) exist in the early stages of the planning work. In this way the use of the most accurate and also most expensive photogrammetric methods can be limited to very small areas in comparison with the areas presented at the outset.

A limiting factor for photogrammetric mapping is naturally found in the ground vegetation (trees, bushes and grass). This drawback can be reduced by choosing a suitable time of year for the air photography. Futhermore natural forests, especially pine-forests, are not usually as dense when seen from above as when viewed from the ground. It must also be observed that even terrestrial survey methods have their limitations. Irregularities in the ground contours and the terrain details may often be difficult to define even by these latter methods.

The use of the air photographs for obtaining information on *land economics* deals amongst other things with property survey, but when correctly employed, the photographs can also provide information about the actual situation, the agricultural conditions, the productivity of the soil and the quality of the growing forest. The accuracy of the results naturally varies but comprehensive investigations have yielded fairly accurate figures. Regarding photo-interpretation for forestry purposes the Board for Forest Photogrammetry in Sweden has carried out somewhat extensive investigations.

The *ground conditions* (geotechnical information) which are to be interpreted from the air photographs relate largely to rock and soil geology as well as to hydrology. An indirect approach is frequently made in this interpretation, contrary to the system followed in terrestrial investigations of the ground conditions. The excellent general view obtained by a stereoscopic viewing of the photographs enables the experienced interpreter to distinguish the geological sequence which has created the area. He then enters into greater detail but reaches his conclusions concerning the ground conditions with the help of the vegetation types, the special nature of the terrain etc. He thus passes from the general to the particular which is entirely contrary to the procedure in the classical terrestrial methods. Naturally, errors may occur and questions remain unanswered, but this is also sometimes the case in terrestrial investigations. It should likewise be observed that the photo-interpretation should be checked in the terrain when possible, and especially those results which are of great importance. These field investigations can, however, be satisfactorily planned in advance and restricted to certain important points or problematical points. During a development phase and with personnel which is not fully trained and experienced, terrestrial studies of "test areas," e.g. selected at random, are of great value. By means of photo-interpreta-

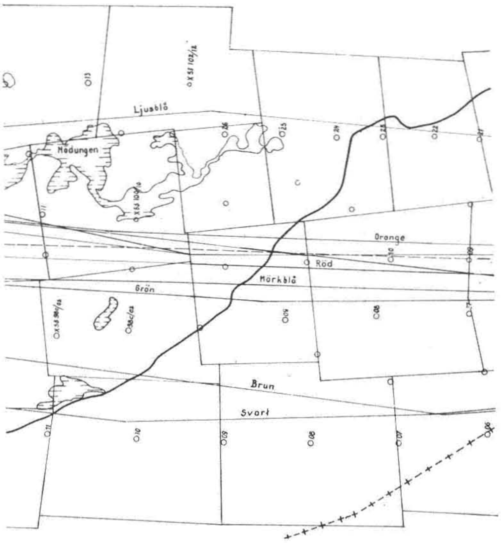

FIG. 3. Part of a completed reference map showing the division of the air photographs and different alternatives for staking. The divergence between the alternatives in this section is about 10 km. (see Table 1).

tion combined with terrestrial reconnaissance, the very expensive boring and seismic profile-recording can be limited to the most important points and planned in the most effective way.

This discussion concerning the use of the photogrammetric methods when planning large constructions has been kept at a general level. It has not been found necessary to cite examples or give details, since the main purpose of this introduction has been to show that photogrammetric methods, owing to their widely varying possibilities, are well-suited to very different types of jobs. This is very typical for construction planning. In the following pages one such job will be described, in which entirely novel principles have been applied.

PHOTOGRAMMETRIC PLANNING OF HIGH-VOLTAGE TRANSMISSION LINES

Sweden is a country of considerable length with most of the hydroelectric plants located in the north and with the industrial centers in the south. The transportation of the electrical energy has made it necessary to build, and to continue to build, long high-tension transmission lines. Usually the voltage is 380 kV. The building cost for such a line at the present time is roughly U. S. $25,000 per kilometer. The cost for energy losses and maintenance, when capitalized, amounts to about $45,000. If the length of the line is extended by one kilometer this will consequently entail an extra cost of roughly $70,000. These costs are rough values and naturally vary in accordance with numerous factors.

Hitherto the planning of the transmission lines has been performed with the help of available maps, and the collection of data has been carried out by field reconnaissance etc. The results obtained have been discussed with the property owners and with various authorities, etc. The comparison of one alternative with another has usually been very difficult. During the last few years a test has been performed by the Swedish State Power Board in order to develop a photogrammetric method (including photo-interpretation) which permits the comparison of several alternative lines within a fairly wide strip.

The test was divided into two parts, one dealing with the problem of finding the most economically favorable route for the line, the other being an attempt to employ photogrammetric profiling in place of terrestrial profiling to secure sufficient data for the location of the transmission towers and the calculation of their height. For the first part of the test a 100 kilometer section of a new transmission line project was chosen.

THE RECTANGLE METHOD

To enable an estimate of the factors which influence the choice of the line route to be made at a reasonable cost, the photogrammetric work had to be systematized. The entire test-area 10×100 kilometers was subdivided into rectangles 1,000 meters long in the main direction of the transmission line and 300 meters wide. The number of such rectangles was 3,200. These rectangles, which were marked on every second photograph in the existing series of air photographs to the scale of 1:20,000, were studied stereoscopically by a geologist, a forestry expert and a construction engineer. Special simplified cost-factors for transmission towers, roads, transports and forests were used. These figures were recorded for each rectangle and summarized. Since no reliable large- or medium-scale maps of the area existed, these rectangles were converted to a skeleton map which was specially prepared by simple radial triangulation, to roughly the same scale as the photographs. It must be clearly pointed out that the requirements for the accuracy of this map can be set very low. Its main purpose is to provide a basis for the graphical demonstration of the above-mentioned cost figures.

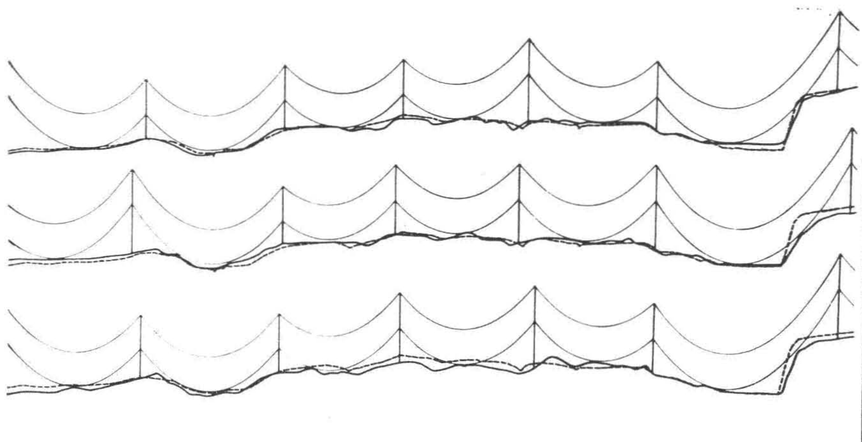

FIG. 4. Profile set up in accordance with - - - - - terrestrial, and ———— photogrammetric methods, showing the location of the towers on the photogrammetric profiles. Top: Stereoscopic presentation from a map 1:10,000; center 1:25,000; bottom 1:40,000.

It was soon found that the most favorable working sequence consisted in first allowing the geologist to mark the soil-geological- and hydrological conditions on the map in colored ink, as several of the other factors, such as transportation, roads etc. are dependent on the soil geology.

As mentioned above, the cost figures were then estimated for special cost groups, that is to say the cost for transmission towers, for road building, for transport along the line and for the purchase or lease of the land. The positions and dimensions of the towers in this phase are only estimated roughly and separately for each rectangle, in order to determine the general costs for each rectangle. If the line were built through such a rectangle it is very unlikely that the towers would be placed as estimated in the separate analysis of each rectangle. Later on, when comparing the cost for the towers along certain alternative lines with the results obtained from the normal tower planning method, it was found that the mean variation in the costs was only 3.9% and max. 7%, thus showing that it is quite possible to determine the costs for the towers by a stereoscopic examination.

For transporting the heavy material to the tower sites it is necessary to build roads along the line. These roads are constructed in the simplest form for tractor traffic. The road-costs depend on the topography and ground. Usually the factors affecting these road-building costs can be studied satisfactorily from the photographs.

The costs for transport along the line have been calculated in a similar manner and include the costs for the transportation of material and personnel from existing roads. The last-mentioned form of transport is naturally dependent on the general position of the rectangle in question.

The photogrammetric methods for the analysis of forest areas are fairly well developed. These methods usually deal with wider areas, however, and not so much with long narrow strips. The factors determined by stereoscopic interpretation are the average height and classes of trees, and also their quality, age and volume per hectare. When checking the photogrammetric results in the terrain it was found that the estimated stereoscopic values were about 20% lower than those obtained in the field, but this was more or less uniform throughout the investigations and therefore exercises a very limited influence on the final result, which was a comparison between different alternatives.

As mentioned above, the resulting costs for the four items—towers, roads, transport and forests—were recorded on the skeleton-map in figures, but they were also grouped in eleven classes with a cost interval of $1,000. A special color was allotted to each class so that it was possible, by studying the skeleton-map, to ascertain where the low and high-cost areas or strips were situated. As the test-area was of a very homogeneous character, consisting of rather flat, rolling forest country of the moraine type, the cost structure did not exhibit any very marked tendencies. For the purpose of investigating various alternatives, a piano-wire was fastened at the predetermined terminal point at one end of the 100 km.-test-section, and guided between pins where possible over low cost rectangles to the

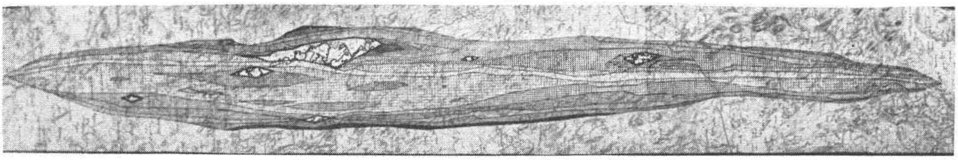

FIG. 5. Results set out under 7 costs classes of the treatment by the BESK data processing machine of the trial area for the selection of an optimum line route; the difference between each costs class is 5,000 crowns.

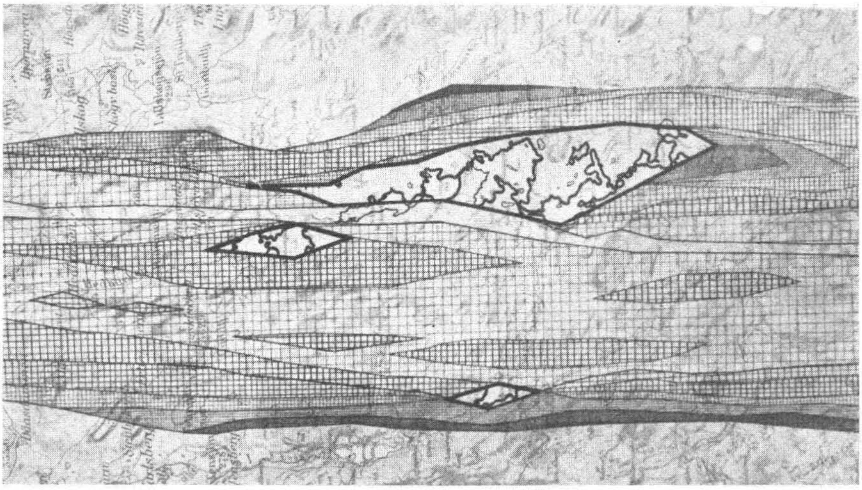

FIG. 6. Detail of the "costs level map."

other end of the test-section. The wire was tightened by a spring. The position of the end of the wire was marked on a scale. By repeating the procedure along various alternatives it was possible to determine the length differences between them at the end-scale. For each alternative the number of rectangles in the various cost-classes were counted and it was thus possible to obtain an approximate figure for the total building costs for each alternative, as well as the length-differences between the alternatives. One kilometer of extra length costs $70,000. Nine different alternatives were investigated in this way, one of which coincided with the line definitely staked out by terrestrial methods in the mean time.

Although this method offers a fairly simple means for checking numerous alternatives, it obviously will not give the optimum solution. There are, of course, an unlimited number of other alternatives, and in an attempt to analyze them, a program was developed by B. Rudfeldt and B. Andersen for processing the data in an electronic computor. This processing was performed in about four hours in the "Besk" electronic computor. The line route chosen by "Besk" did not coincide exactly with any of the previous nine alternatives. This was not expected, nevertheless the "Besk"-solution lay very close to the yellow alternative which was also the cheapest one amongst the nine alternatives investigated. One curious result of the "Besk" choice was that the number of angle towers (special angle towers are needed where the line is broken by a slight angle) was rather great. As a matter of fact 22 such points were first found in the "Besk"-solution, but the result was corrected by hand so that the number was ultimately reduced to nine. This reduced the length of the line slightly but the total cost was somewhat higher, which provides a check on the correct choice made by the "Besk" computor. The various alternatives are set out in Table 1. It can be seen that the costs for operation and maintenance, which are proportional to the length of the line, amount to almost two-thirds of the total costs and that they have a very unfavorable influence on the longer alternatives. Nevertheless, it is found that even relatively small variations in the topography, roads, ground and forest conditions, have such a great influence on the total costs that systematic investigations of extensive areas are justifiable in transmission line planning.

TABLE 1

FINAL STATEMENT OF THE PHOTOGRAMMETRIC INVESTIGATION'S FIRST PART

Alternative	*Length of line (km.)*	*Extension of line in relation to the flight of the crow (km.)*	*No. of angles*	*Costs* Rectangle, valuation (1,000 crs.)	Operating losses (installation+maintenance costs) (1,000 crs.*)	*Total (1,000 crs*	*Difference (1,000 crs.)*
"Besk"	104.9	0.4	22	13,420	23,180	36,600	0
"Besk modified"	104.8	0.3	9	13,445	23,165	36,610	10
Yellow	104.6	0.1	3	13,535	23,120	36,655	55
Orange	104.60	0.1	4	13,620	23,115	36,735	135
Brown	104.9	0.4	2	13,560	23,190	36,750	150
Black	105.1	0.7	3	13,505	23,235	36,740	140
Light blue	104.80	0.3	3	13,600	23,160	36,760	160
Staked+built	104.7	0.2	6	13,645	23,130	36,775	175
Dark blue	104.6	0.1	3	13,670	23,110	36,780	180
Red	104.5	0.0	3	13,690	23,100	36,790	190
Green	104.5	0.1	1	13,760	23,105	36,865	265

Note: 5 Swedish Crowns (crs.) = 1 U. S. $.
* Costs for extension of line and angles included.

In view of the very large number of rectangles to be analyzed (3,200), certain other methods have been studied during the tests. For instance, if the line is first roughly planned according to various alternatives and the costs are then analyzed for these alternatives, all work being done with the aid of photographs, the planning can be carried out much faster. On the other hand, there is a great loss in objectivity and considerable risks that the best alternatives will not be investigated. A combination of the rectangular and line methods has also been tested. The total area is then first divided into larger rectangles e.g. 2×1 km. and each such rectangle can be analyzed fairly quickly. This gives a general conception of the cost-variations over the total area and the lines are then sketched in the low-costs strips. These lines are then investigated according to the line method.

A thorough time-study was carried out during the entire test. The result of this study was, of course, somewhat unfavorable, as the personnel had received no previous training in photogrammetry or photo-interpretation when starting the tests, and the methods had not been definitely worked out in advance. As a rough figure for a complete photogrammetric "rectangle estimate" of the costs, including a definitive proposal for the most favorable line within the width of 10 km., a rough figure of 3 man-days per kilometer may be taken. Even if this figure is on the high side when experienced personnel and fully developed methods are available, the amount of work is rather great. From an economical point of view, however, the method is definitely favorable. The costs may be roughly calculated at about $90 per kilometer of line. These include all costs for extra charges but not the training of personnel nor the costs for a special air photography mission. On the other hand, the costs for copies of existing air negatives are included. Photogrammetric planning of the line is about 25% more expensive than the terrestrial method, but on the other hand, the building costs, which represent the major costs, are considerably reduced.

PROFILE AND PLAN OF LINE BY PHOTOGRAMMETRY

The other part of the test was intended to give a preliminary idea of the advantages and disadvantages in the detailed mapping of the definite line. It was found in these tests that no difficulties are encountered in producing by photogrammetric methods a plan and profile sufficiently accurate for preparing the final construction drawings of the line. In consequence of the very limited width of the strip to be mapped, and the rather high demand for height accuracy however, the costs were higher for the photogrammetric method, than for the terrestrial one. Furthermore, the rather strict laws relating to free height from ground to power line render it difficult to avoid certain mistakes due to the concealing effect of the vegetation.

SUMMARY OF THE RESULTS

The tests have shown that photogrammetric methods (simple photogrammetric map and photo-interpretation) can be used with success for planning long power transmission lines. The tests have shown, generally speaking, that the shortest line is not the cheapest, as other factors exercise a perceptible influence on the costs, such as ground conditions, topography, roads and property costs. Furthermore, it must be observed that in the course of discussions concerning the route for a power transmission line various interests call for the displacement of the line in one direction or another. It is then very expensive to check by traditional methods the extra costs resulting from such variations. With the method described the extra costs can be easily determined, which may be taken into consideration fairly quickly in the discussions. Furthermore, it may be noted that electronic data processing can very suitably be applied for determining the best alternative. On the other hand, the tests also show that the amount of work involved makes it necessary to modify the method if the time is very limited. This is normally the case however, in almost all modern planning of large constructions.

Aerial Color-Film in Military Photo Interpretation*

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I. Introduction and Abstract

IN RECENT years, color-film has been and is being used in sharply increased quantities for non-military purposes. Despite the general popularity, the military services are still using only slightly larger quantities of color-film than they did before the Korean War.

This paper is essentially a review of the factors associated with the use of color-film by the armed forces. It also describes developments which may affect its role in future intelligence-reconnaissance operations.

II. What Is the General Military Viewpoint?

Most military interpreters, photographic specialists, and other reconnaissance planners have attitudes about color-photography that seem to place them in one of three categories:

Enthusiastic about the general military application of aerial color-film;

Feel that it offers very little more than black-and-white-film;

And the largest group of all—those who don't feel strongly either way.

By using aerial color-film sparingly, the armed forces have tended to giving no support to the enthusiastic group.

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Actually, the three-layer emulsion, subtractive type reversal color-film which is in use today has an important although specialized, capability as a military reconnaissance tool. For the purposes of this paper, let us consider that a small, but significant "gain" is feasible because a certain percentage of the targets and images of military interest can best be interpreted on color-photography.

* Presented at the Society's 25th Annual Meeting, Hotel Shoreham, Washington, D. C. March 8 to 11, 1959. This paper is a part of the Panel on the Application of Color Photography in Photo Interpretation.