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*Economic Factors in the Integrated Photogrammetric System of the U. S. Geological Survey**†

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THE United States Geological Survey is now in the process of affecting important changes in its mapmaking procedures. These integrated changes affect all the major aspects of the topographic mapping operation: aerial photography, photogrammetric instruments, plotting techniques, field operations, cartographic finishing, and reproduction processes. It is the purpose of this paper to review the economic background of this transformation and to discuss, in simple terms, advantages of the new system from the economic point of view.

To begin with, a brief outline of the principal changes in instrumentation needs to be stated, so that the transformation can be viewed in proper perspective. Prior to instituting the new system, the Geological Survey operated some 350 Multiplex plotting units, utilizing some 800 Multiplex projectors, including those used in bridging. In addition, 69 Kelsh plotter units and 9 heavy plotter units were in operation. Under the new system, the Multiplex projectors are being replaced by ER-55 projectors, to be used principally with twin low-oblique photography. Also, Twinplex plotters are being installed for aerotriangulation of twin low-oblique photography. Because of increased efficiency resulting from the new techniques and instrumentation, the planned replacement rate is 2 units of ER-55 equipment for 3 units of Multiplex equipment;

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that is, 100 ER-55 units are expected to produce as much mapping as 150 Multiplex units. Operation of the Kelsh plotters and heavy plotters will be continued in a supporting role. (The technical characteristics of the new instruments are discussed by R. K. Bean in a separate paper.)

For the purposes of this paper, it is convenient to group mapmaking operations into two broad categories: (1) operations that contribute to the production of a completed original manuscript map, and (2) operations that are required to transform the product from a completed manuscript to printed multi-colored copies.

Manuscript Production

In the production of a Geological Survey map manuscript by photogrammetric methods, there are two major phases that offer an opportunity to effect significant savings. These are supplemental fourth-order control obtained by ground surveys, and stereocompilation. If the number of supplemental control points to be obtained in the field, for controlling aerotriangulation or individual model setups, can be reduced by a substantial amount, important savings can logically be expected. Likewise, if the rate of stereocompilation can be increased appreciably, further savings of a considerable amount are to be expected.

Reducing Requirements for Ground-Survey Control

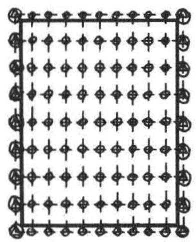
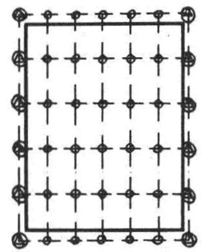
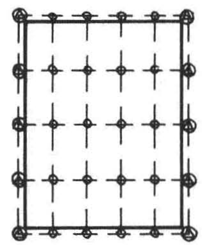
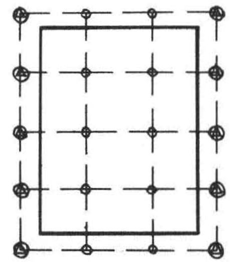
In the new Geological Survey system, a reduction in the number of supplemental vertical control points to be obtained by ground survey is achieved by applying the well-known approaches of increasing the area of the terrain covered in one model, and increasing the use of vertical aerotriangulation. The crucial question in applying these approaches is whether it can be done while maintaining the required accuracy standards. In the new Geological Survey system this is accomplished by using twin low-oblique photography and suitable equipment (ER-55 projectors and Twinplex plotters) for exploiting it.

Other means of increasing the model area have been given due consideration. The objective cannot be attained merely by increasing the flight height of conventional vertical photography, because of the *C*-factor limitations of conventional plotting equipment and because of the loss of planimetric detail in high-altitude photography. An answer could lie in the use of an ultra-wide-angle camera lens, provided that it is of precision quality, and is incorporated in an integrated photogrammetric system, including cameras, plotters and related equipment. A practicable ultra-wide-angle camera would provide a means of exploiting the convergent-photography technique further, to obtain still larger model coverage.

A key instrument in the Geological Survey system is the ER-55 plotter. Even when used with conventional vertical photography, this instrument permits a relatively high *C*-factor, approaching that of the so-called "heavy plotters." At the same time, it has the same convenience for aerotriangulation with vertical photography as the Multiplex, at about the same cost for equipment. When used with convergent low-oblique photography, the *C*-factor of the ER-55 equipment is increased still more so that it can be regarded as having the same *C*-factor as the heavy plotters used with vertical photography. Furthermore, the Twinplex plotter fitted with ER-55 projectors has a vital potential for accurate vertical aerotriangulation.

Figure 1 shows, for four different photogrammetric mapping systems, the theoretical layout of models and control for compiling a map of a 15-minute quadrangle area with 20-foot contours. The four systems included are: Multiplex

THEORETICAL LAYOUT OF MODELS AND CONTROL FOR 20-FOOT CONTOURS ON A 15-MINUTE QUADRANGLE
(Assumed dimensions of a 15-minute quadrangle: 72,000 x 91,000 ft.; flight direction E-W)

	Multiplex Vert. Photog.	ER-55 Vert. Photog.	Heavy Plotter Vert. Photog.	ER-55 Converg. Photog.
C-factor	600	1000	1200	1200
Flight Height	12,000' (3,660m.)	20,000' (6,100m.)	24,000' (7,330m.)	24,000' (7,330m.)
Base-Height Ratio	.63	.63	.63	1.23
Width-Height Ratio	1.00	1.00	1.00	1.10
Sketch of Layout ⊕ = H-V pts. req'd o = V pts. req'd Note: H-V = Horizontal and vertical V = Vertical				
Model area	3.3 sq. mi. (8.5 sq. km.)	9.0 sq. mi. (23.4 sq. km.)	13.1 sq. mi. (33.9 sq. km.)	28.0 sq. mi. (72.8 sq. km.)
Models per strip	10	6	5	2.5
Number of strips	8	5	4	3.5
Models per quad.	80	30	20	10
H-V pts. req'd.	18	12	10	10
V pts. req'd.	81	30	20*	10*
Remarks	In all cases, the control points indicated show the minimum requirement; this applies only when model layout is as shown. The actual requirement may be more, depending on layout of models.			

*Required only if vertical bridging is not used.

plotter with vertical photography, ER-55 plotter with vertical photography, heavy plotter with vertical photography, and ER-55 plotter with convergent photography. Keeping in mind that values shown are relative rather than absolute, there will first be compared the layouts for the ER-55-with-convergent-photography system and the heavy-plotter-with-vertical-photography system, as the latter is usually regarded as the most economical of the conventional systems with respect to supplemental control requirements.

It can be seen from the figure that the area of an ER-55-with-convergent-photography model is more than twice that of a heavy-plotter-with-vertical-photography model although both are planned to yield the same accuracy of results. It takes only 2.5 ER-55-with-convergent-photography models to span the 15-minute quadrangle, compared to 5 heavy-plotter-with-vertical-photography models. The prospect of performing vertical bridging successfully is, of course, much better for a 3-model (or shorter) bridge than for a 5-model bridge. A strong feature of a 3-model bridge is that there is only one uncontrolled model between two controlled models, as is readily apparent on the diagram.

Only 10 models are required for coverage of the quadrangle by the ER-55-with-convergent-photography system, compared to 20 for the heavy-plotter-with-vertical-photography system. Each system requires 10 *H-V* (horizontal and vertical) control points. If vertical bridging is used, none of the *V*-points shown on the diagram are required. If the *V*-points must be obtained in the field, 20 are required for the heavy-plotter-with-vertical-photography system, compared with 10 for the ER-55-with-convergent-photography system.

Differences of the same nature, but successively greater in degree, are apparent when the ER-55-with-convergent-photography system is compared with the other systems shown on the diagram.

CAPITAL OUTLAY

It would be a fair question to ask why the use of heavy plotters with convergent photography is not included in the foregoing analysis. There is every reason to conclude that convergent photography used in a heavy plotter capable of accommodating it would result in a system as efficient, operationally, as the ER-55-with-convergent-photography system, and possibly more so. But from the economic standpoint, the question of capital outlay must be considered. To replace present Multiplex by ER-55 equipment will cost the Geological Survey less than $3,000 per unit, including a prorated cost for Twinplex aerotriangulation equipment, diapositive printers and other accessories. This low unit cost applies because the existing Multiplex table frames, slate table tops, supporting frames, tracing tables and auxiliary equipment are utilized with the ER-55 projectors. In essence, the ER-55 projectors replace the Multiplex projectors on existing Multiplex units. In addition to the factor of low unit cost, it is important to remember that fewer units are required, in a ratio of 2 to 3, as already mentioned, for the same amount of production.

On the other hand, heavy plotters would cost on the order of $25,000 to $60,000 per unit. Consider what the capital outlay would be for installing heavy plotters as the work-horse instrument as compared to the capital outlay for ER-55 plotters. In an organization like the Geological Survey, which operates hundreds of plotting units, this difference in capital outlay would run into millions of dollars. We know of no operation anywhere, in which heavy plotters are concentrated in great numbers for the execution of a really extensive mapping program. This does not mean that the heavy plotters do not have an important place in photogrammetric operations. The Geological Survey has nine such instruments, which are used mostly for executing special assignments. But, for massive mapping operations, the ER-55 plotter is a practical and economical solution as a "bread-and-butter" instrument.

STEREOTEMPLETS

In addition to the savings in control costs resulting from the use of the convergent ER-55 system, the introduction of the stereotemplet system (as opposed to conventional slotted templets) for horizontal aerotriangulation achieves further economies by permitting greater flexibility in the placement of horizontal control points obtained in the field. Even if the number of points required remains the same, the increased freedom in positioning the points leads to economies. The accuracy of pass-point positions obtained by this system has been found to be essentially equal to that obtained by instrumental stereotriangulation.

SAVINGS IN STEREOCOMPILATION

The increase in area covered by each convergent ER-55 model means that there are fewer models and less time spent in setting up and joining detail from model to model. The improved quality of the model permits an acceleration of the compilation process as there is greater certainty regarding the identification of detail and less need to refer to contact prints. The more favorable ray intersections in the convergent model leads to better repeatability of elevation readings and more accurate plotting of contours.

The use of a variable-ratio pantograph greatly facilitates preparation of the original compilation at or near the publication scale for the map, even though the model may be several times larger, thus speeding up the compilation procedure.

SCRIBING TECHNIQUES

In an important move towards economy in Geological Survey practice, the operation of drafting the original compilation of map detail on paper with pen and ink is being superseded by the technique of scribing the detail on a transparent plastic material coated with a special semi-opaque paint. The scribing technique consists of delineating the lines and symbols representing map detail with sharp tools that cut out the paint along the path of the scribing tool. This leaves a pattern of transparent map detail, the base remaining opaque except where it has been scribed. Copies of the scribed map are readily made by contact printing from this scribed base to a photographically sensitized surface.

Scribing permits great flexibility of operations and lends itself to all sorts of conveniences and economies. Smooth, uniform copy is readily achieved with simple tools. Corrections are easily made by painting over the incorrect detail and scribing the correct detail. Edges are quickly transferred from one sheet to the other by contact printing. Notes can be made anywhere on the sheets without the need to remove them before copying.

The original compilation can be compiled and scribed on two separate sheets, one for planimetry and one for contours.This permits convenient preparation of two-color copies, printed on a scribing base, for use in field completion surveys. Necessary changes, scribed directly on the field copies, are readily transferred to the scribed originals. The largest single element of economy, however, arises from the fact that the original contour compilation sheet can, under favorable conditions, be preserved as reproduction copy.

Map Finishing

While scribing techniques have contributed in an important way to economy in producing the original manuscript, they have contributed in an even greater degree to the economy of cartographic finishing and reproduction; it may well be said that these operations have been virtually revolutionized by the scribing technique.

In the new method for preparing color-separates for reproduction, several guide copies are made by contact printing on a scribing base from the original scribed planimetric compilation. For each of the several color-separation elements, a guide copy is scribed appropriately so that separate plates are produced for culture, drainage, woodland, and "red roads." These scribed separate plates, together with the original scribed contour compilation (if suitable), are then used as reproduction copy. If the original contour compilation is not of suitable quality for reproduction, a guide copy is prepared from the original and the contours are re-scribed.

This procedure eliminates the slower and more costly, pen-and-ink drafting and at the same times gives a better quality of copy. Costly and time-consuming photographic steps are eliminated. Revision and correction processes are simplified. Efficiency and quality are continually improved by an increasing application of mechanical aids to scribing. There is no doubt that the savings are very substantial; the Geological Survey is therefore adopting scribing techniques for map finishing as rapidly as orderly change permits.

Conclusion

The integrated photogrammetric and map-finishing system now being installed by the Geological Survey is already saving money in the principal phases of topographic mapmaking. As an indication of the trend, savings of about 30% have already been recorded in the supplemental control phase, on those projects where convergent photography has been available. In one regional office, a saving of one-third of the color-separation labor costs has been realized by the application of scribing techniques. As the system gains momentum, an increasing degree of economy is anticipated.

NEWS NOTE

Relief Map of Wisconsin

A new relief map of Wisconsin has been published by Aero Service Corporation. The 44 by 36 inch map shows the Badger State in realistic third dimension and is printed in 9 colors on heavy Vinylite plastic. It is vacuum formed to show Wisconsin's hills, valleys, and drainage patterns in detailed relief. The surface of the map has been plastic coated. It can be marked freely with soap crayon or china marking pencil; it is easily cleaned. The map weighs only two pounds. It is self-framed in durable Vinylite. The scale of the relief map is 1 inch equals 10 miles. The vertical exaggeration is 20 to 1.

The map includes all of Wisconsin and extends south to the northern half of Chicago, west to Minneapolis and St. Paul and on the north and east it includes all the Keweenaw Peninsula, and the western half of the Northern Michigan Peninsula beyond Munising and Escanaba, Michigan. There is detailed coverage of Wisconsin's famous northern lakes area. Over 500 lakes and rivers are named, all State forests and parks, most State and all U. S. highways, major airports, and military and naval bases.

More than 2,000 cities and towns are shown. Different type sizes and symbols distinguish six population categories, and a special symbol marks county seats. All counties are named.

For more information, write to P. J. Murphy, P. O. Box 123, Union Grove, Wisconsin, or Robert Sohngen, Aero Service Corp., Philadelphia 20, Pa.