PRESIDENT SANDERS: Thank you very much, Mr. Kelsh. It has been very interesting to hear the details of your plotter.

While the members of the Committee this morning were worrying because they had not heard from the next speaker, I, fortunately, received a phone call which indicated that he had just arrived after a rather hectic trip from Costa Rica, Panama, and points south.

Our next speaker, Mr. William T. Pryor, has been in highway surveying, mapping and locating work since 1925. One of his outstanding jobs was with respect to the Alaskan Highway where he was engineer in charge of design on the southern six hundred miles. Very recently he has been working as project manager in the location of a section of the Inter-American Highway in Costa Rica and in Panama. It is from that section of the world that he came to us in order to give us the benefit of his experience in the rather extensive use of photogrammetry in highway location work.

I am pleased to present Mr. William T. Pryor.

MR. WILLIAM T. PRYOR: Thank you, Mr. President. Ladies and gentlemen, I assure you that it is indeed an honor and a pleasure to be here this morning and to talk to you on the subject of "Photogrammetry and Highways."

The subject of photogrammetry and highways is broad and includes many things that cannot be described in a brief paper. I will try to analyze the subject briefly and hit the high points, showing some of the uses and benefits of photogrammetry for highways as the highway engineer sees them.

Often highway engineers are thought of simply as men who build highways. Their task is more complex than that. They have the responsibility of locating, designing, constructing, maintaining and improving highways for the use of all types of traffic. Added to this is a multiplicity of conditions which must be met in order that traffic may move over the highways in safety, with comfort and ease at minimum cost in time and money. Some conditions which must be considered are the type of climatic region, seasonal changes, day and night travel, topography and the use of land by nature and man. Nature uses the land for many things which considered together are an indicator of the shape and condition of the topography. Man uses the land for his own purposes and, of course, he has made use-selections depending on the benefits he can get from the topography. In highway engineering, intensity of land use generally governs the selection of terminal points for the highway regardless of whether it is to be a new highway or the improvement of an old one.

Traffic itself in amount and character at the present time and that estimated for the future determines the dimensional limits of the highway. These limits are the roadbed width, number of traffic lanes and whether adjoining or divided, rate of profile grade and sharpness of horizontal curvature. Added to these are the thickness of structural materials, such as subgrade and surfacing, depending upon the type to be used. In order for the highway engineer to design any of these features, he must know specific details that will have a bearing upon the problem.

The next problem is where to place the highway between terminal points. Briefly, it is a matter of fitting the highway to topography and land use, that is, fitting it to its surroundings for the benefit and service of traffic. In addition, possibilities of using existing materials must be determined and the type and amount of materials that must be obtained from other sources ascertained.

It is in fitting the highway to its surroundings between terminal points that full use of photogrammetry by highway engineers is of special benefit. If this is done future highways will be better engineered.

But good highway engineering requires the services of many specialists. No one man can be fully qualified for work in each detail of the complex highway problem.

Heretofore individual highway engineers have developed special skills for some positions such as administrator, chief engineer, highway location engineer, bridge engineer, materials and soils engineer, hydraulic and drainage engineer, highway design engineer, landscape architect, right-of-way engineer, highway construction engineer, engineer of traffic and traffic operations, engineer of highway betterment and reconstruction, research engineer and highway engineer economist. There are others we could mention.

Engineers having special knowledge, training and experience in photogrammetry also have a place in the highway engineering field.

Before a specialist in any one of the types of highway engineering can apply know-how of his particular specialty, which he has obtained by training and experience, he must have information and factual data of proper kind and amount at the right time before he can solve his part of the highway engineering problem.

In addition, to make a complete highway each highway engineer specialist must coordinate his work with that of the others. This cannot be done without full information and factual data at hand. Photogrammetry is a modern tool that may be used to effectively obtain much of the essential information and factual data. This will apply from the first concept of the new highway to the study of some structural failures in an old one.

In explaining how photogrammetry is used in highway engineering, it may be well to consider the stages in development of a highway. These stages can be defined as: selection of terminal points, location and design, construction, maintenance and betterment, condition and inventory surveys and the improvement and reconstruction. Then we can start the cycle all over again when highways become obsolete.

Highway terminal points are usually selected by public officials, administrators, chief engineers and others responsible for important decisions. Theirs is an all-inclusive general problem. They should have complete knowledge of all factors having a bearing on their decision. Here, again, they must have information in the beginning and a complete record afterwards to support their decisions.

Once the terminal points are designated, highway location and design follows, to be accomplished in four successive stages, namely:

1. Reconnaissance of area for selection of feasible alternate routes.
2. Reconnaissance of alternate routes comparing one with another to select the best route for survey.
3. Preliminary location survey and design to determine the place for the highway on the selected route.
4. Location surveys and project (contract) plans; the actual staking of highway alignment, grade lines, cross sections and structures on the ground in readiness for construction.

This latter stage of the highway location would be largely guided entirely by the factual information obtained by the use of aerial photographs and photogrammetry in the three previous stages.

In the past, highway engineers have largely depended upon ground survey methods in obtaining dimensional and interpretive data about the topography and land use between terminal points in each of the stages named above. In difficult and inaccessible areas, a route was often found but it could not be demonstrated to be the best route unless each engineer interested in the location and design went through the same arduous task of acquainting himself with the entire area and route selected—the same as did the locator of that route.

To make his task easier, the highway engineer should rely upon aerial photography and photogrammetry. In doing so he will avoid much arduous ground work. When his task is completed he will have a complete factual record to demonstrate and support every decision made. The uses of aerial photography and photogrammetry fall in two categories:

1. Interpretation of the character and relationship of the topographic features of the earth and land use by nature and man.

2. The measurement of the topographic and land use features in horizontal and vertical directions.

To illustrate an orderly way in which aerial photography and photogrammetry can be applied in highway engineering, four charts have been prepared.

The purpose of Figure 1 is to show the successive stages in the location of a highway in relation to width of coverage and scales. The ordinate of this chart represents ground coverage width in miles and kilometers; the abscissa represents scale of both maps and photographs in representative fraction and in feet to one inch.

The scale requirements for each stage of the highway location are clearly indicated. The wide range in scales is provided for two principal reasons in each stage: (1) width of coverage, (2) amount of detail required on the photographs and maps. For example, scale limits for reconnaissance of area, indicated in the top part of the chart, are 1:63,360 and 1:6,000. Within these limits the highway engineer should select the scale to be used according to his particular highway location problem.

The scale limits may seem to be somewhat arbitrary but when the size of the map that will be produced is analyzed, depending upon the width of coverage, I think it will be realized that there is logic in them. For example, in such areas as Central America and Alaska where terminal points are a hundred or more miles apart, the latitude of direction between terminal points is great. The highway engineer must know everything within a wide area about topography and land use that will have an effect on the location of the highway. Ordinarily you would not deviate from a straight line direction between terminal points more than perhaps one third of the length. Therefore, if you have a highway location that is to be about one hundred miles long, the width of coverage would extend perhaps thirty miles on each side of the generally direct line between terminal points, meaning that you would have a width of about sixty miles to be photographed and mapped. Thus, you might use maps and photographs to scales shown near the upper part of the chart, between the limits of about 1:60,000 and 1:24,000, requiring a map about 5 feet to 12 feet wide, respectively. In some specific areas where ranges of mountains or coastline controls are dominant somewhat narrower coverage than is given in the example would suffice.

If you had a highway to be located between points only ten miles apart, width of coverage might be six or five miles wide and scale of photographs and maps would be perhaps between 1:15,000 and 1:6,000 requiring a map 2 feet to 4 feet wide. Wherever there is a great density of land use, large-scale photographs and maps are needed for interpretation, representation and measurement purposes.

After feasible alternate routes have been found between terminal points still larger-scale photographic and map information is essential for each route. Thus for reconnaissance of alternate routes, scales might range from 1:12,000 to

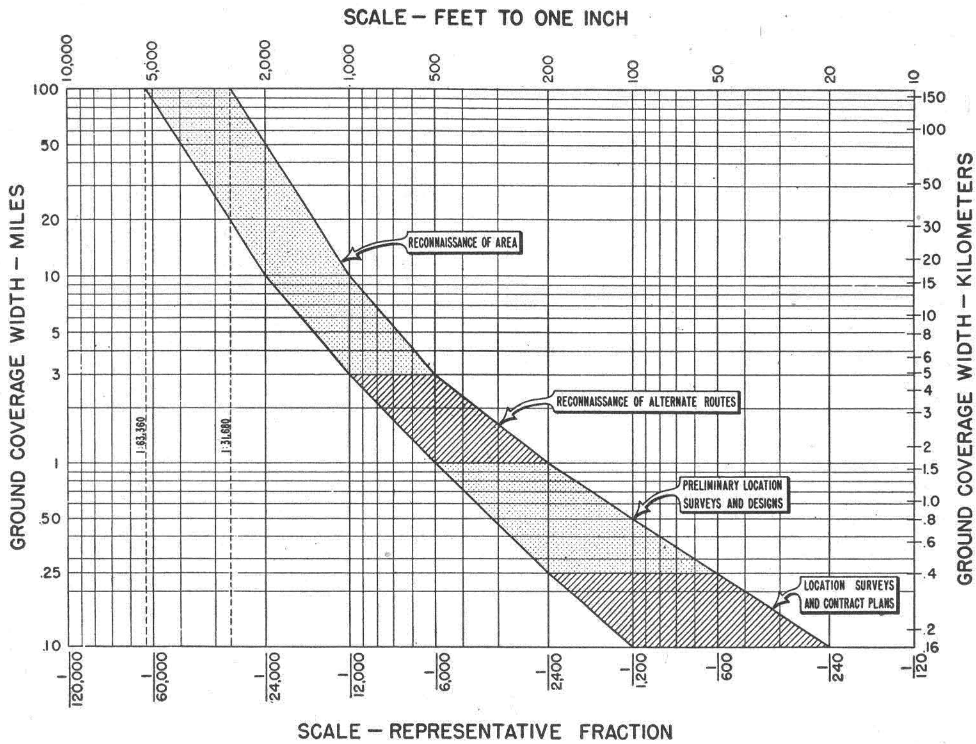

FIG. 1. Stages in the Location of a Highway.

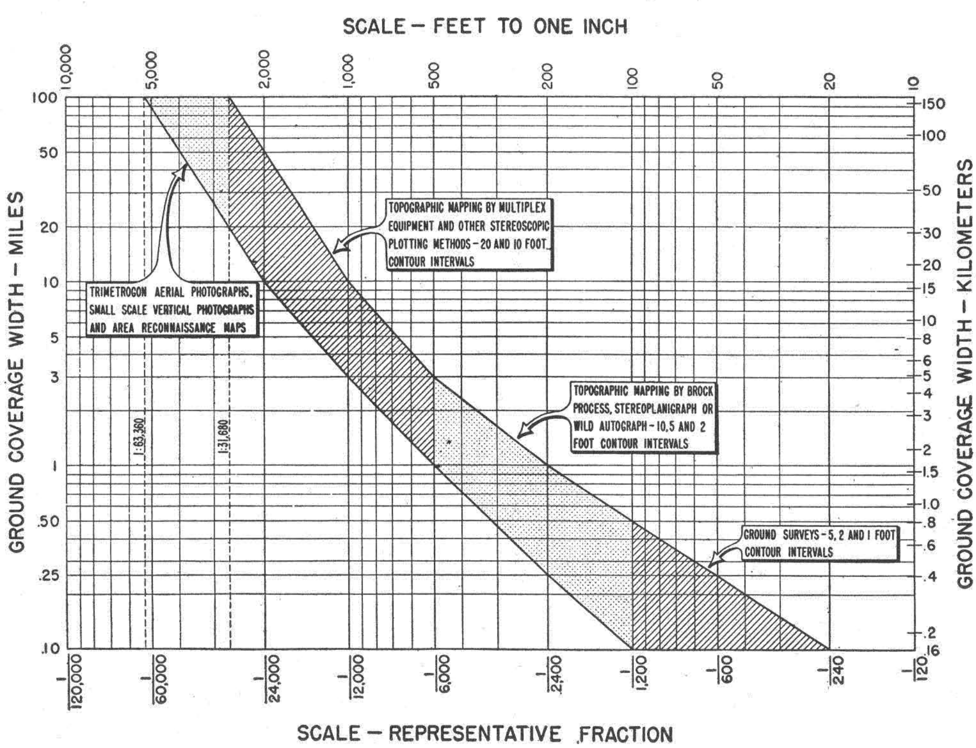

FIG. 2. Selection of Survey Methods.

1:2,400 according to the area width. The area width, on which topographic and land use information are required in this stage, will normally lie between one and three miles. The type of topography combined with the use of land would also have an influence on the width of coverage and scale of map required.

After the highway engineer has compared all feasible routes in detail, he will then select the best route for preliminary survey. The area-width to be considered in the preliminary location survey stage will range between about one-quarter of a mile and one mile. It would be desirable of course to have the highway location problem lie within a narrow area-width of one-quarter of a mile rather than one mile, where this can be done without affecting quality of final results.

The fourth and final stage in highway location is actually staking the highway on the ground, being guided by information obtained and decisions made in each of the three preceding stages.

Figure 2 demonstrates a progressive pattern to be followed in the selection of survey methods to be used. Choice of methods depends upon the scale of information required in each progressive stage. The grid of this chart is the same as Figure 1.

For small scale uses over wide areas, trimetrogon aerial photographs, small-scale vertical photographs and area reconnaissance maps are practicable. Area reconnaissance maps may be obtained from various sources. They may be maps prepared and sold by government and state mapping departments, or, if the country is unmapped, the highway department may have to employ photogrammetric methods to prepare the required maps.

Within the next scale range, between about one-half mile to the inch (1:31,680) and about one-tenth mile to the inch (1:6,000), the required topographic mapping may be done by multiplex equipment and other stereoscopic plotting methods. Here, topographic features may be represented by contours at twenty or ten-foot intervals, depending on the scale of the map. The use of such photogrammetric equipment would be largely for the reconnaissance stages of highway location.

In scales ranging from 1:6,000 to 1:1,200 with contours at ten to two-foot intervals topographic mapping can be accomplished by Brock Process, Stereoplanigraph or Wild Autograph. In addition, a stereoscopic plotter that was recently designed by Mr. Harry T. Kalsh should be added to the chart with the above-named equipment.

Last, of course, there are ground surveys; surveys made in staking the highway and its structures on the ground.

In Figure 3 an outline has been presented to aid highway engineers who are not familiar with the principles of photogrammetry. By using it, highway engineers may visualize procedures and select particular types of photogrammetric equipment and methods of mapping by use of aerial photographs and the photogrammetric equipment that would apply to their special problem. Allowance should be made for differences in availability of equipment, differences in relative accuracy of the equipment, and availability of men to operate that equipment. The actual operations may be carried out by the highway department itself or by contract or otherwise.

At the bottom of the chart, as an abscissa, three stages of the highway location are indicated: reconnaissance of area, reconnaissance of alternate routes, and preliminary location surveys and designs. This was done to relate columns 1 to 21 with the scale scheme devised for Figures 1 and 2. In the ordinate direc-

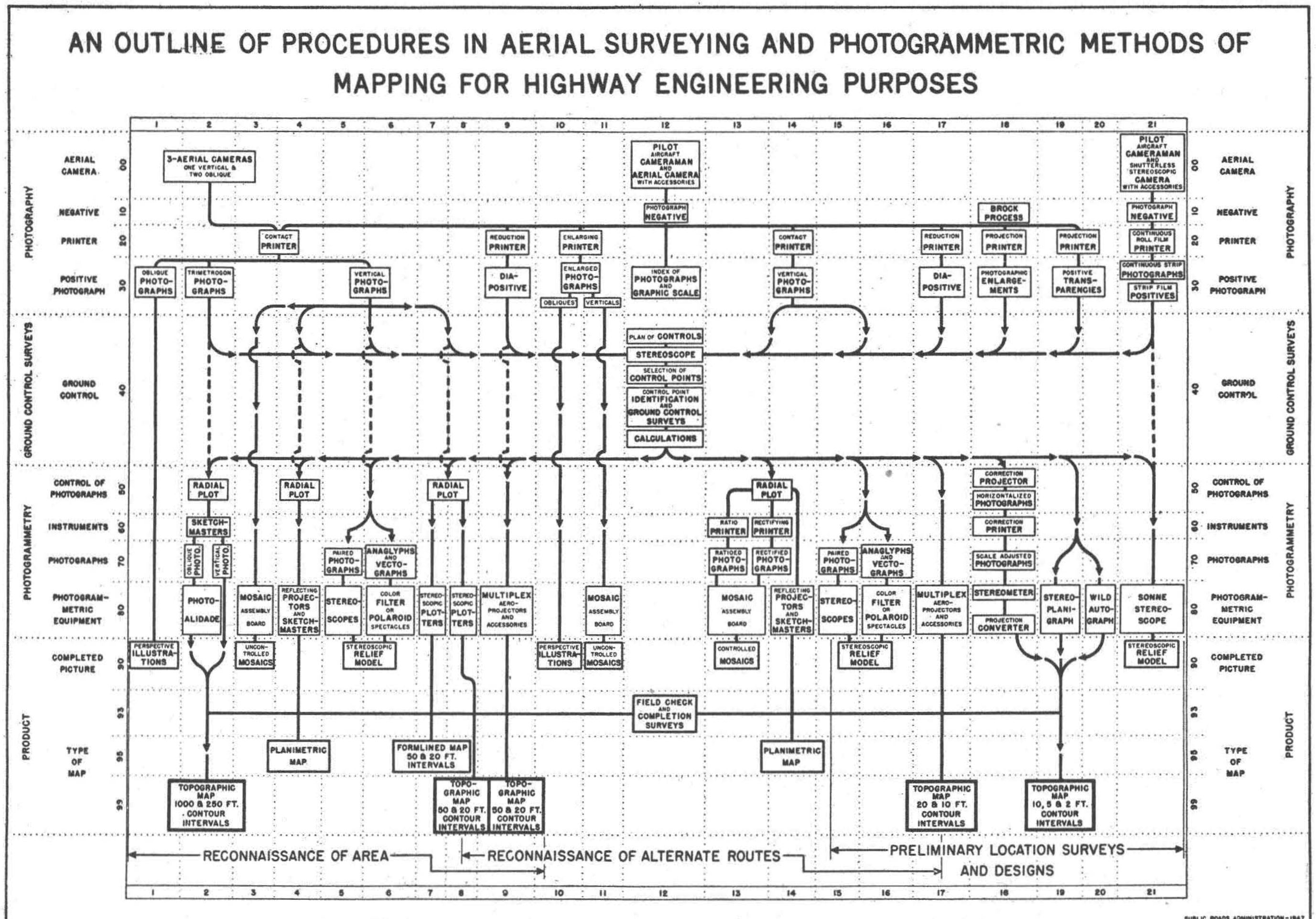
AN OUTLINE OF PROCEDURES IN AERIAL SURVEYING AND PHOTOGRAMMETRIC METHODS OF MAPPING FOR HIGHWAY ENGINEERING PURPOSES
PHOTOGRAPHY
AERIAL CAMERA
NEGATIVE
PRINTER
POSITIVE PHOTOGRAPH
GROUND CONTROL SURVEYS
GROUND CONTROL
PHOTOGRAMMETRY
CONTROL OF PHOTOGRAPHS
INSTRUMENTS
PHOTOGRAPHS
PHOTOGRAMMETRIC EQUIPMENT
COMPLETED PICTURE
PRODUCT
TYPE OF MAP
3-AERIAL CAMERAS ONE VERTICAL & TWO OBLIQUE
PILOT AIRCRAFT CAMERAMAN AND AERIAL CAMERA WITH ACCESSORIES
PHOTOGRAPH NEGATIVE
BROCK PROCESS
CONTACT PRINTER
REDUCTION PRINTER
ENLARGING PRINTER
PROJECTION PRINTER
CONTINUOUS ROLL FILM PRINTER
OBLIQUE PHOTOGRAPHS
TRIMETROGON PHOTOGRAPHS
VERTICAL PHOTOGRAPHS
DIAPOSITIVE
ENLARGED PHOTOGRAPHS
OBLIQUES
VERTICALS
INDEX OF PHOTOGRAPHS AND GRAPHIC SCALE
PHOTOGRAPHIC ENLARGEMENTS
POSITIVE TRANSPARENCIES
CONTINUOUS STRIP PHOTOGRAPHS
STRIP FILM POSITIVES
PLAN OF CONTROLS
STEREOSCOPE
SELECTION OF CONTROL POINTS
CONTROL POINT IDENTIFICATION AND GROUND CONTROL SURVEYS
CALCULATIONS
RADIAL PLOT
SKETCHMASTERS
RATIO PRINTER
RECTIFYING PRINTER
CORRECTION PROJECTOR
HORIZONTALIZED PHOTOGRAPHS
CORRECTION PRINTER
SCALE ADJUSTED PHOTOGRAPHS
OBLIQUE PHOTO
VERTICAL PHOTO
PAIRED PHOTOGRAPHS
ANAGLYPHS AND VECTOGRAPHS
RATIOED PHOTOGRAPHS
RECTIFIED PHOTOGRAPHS
PHOTOALIDADE
MOSAIC ASSEMBLY BOARD
REFLECTING PROJECTORS AND SKETCHMASTERS
STEREOSCOPES
COLOR FILTER OR POLAROID SPECTACLES
STEREOSCOPIC PLOTTERS
MULTIPLEX AERO-PROJECTORS AND ACCESSORIES
STEREOMETER
PROJECTION CONVERTER
STEREOPLANIGRAPH
WILD AUTOGRAPH
SONNE STEREOSCOPE
PERSPECTIVE ILLUSTRATIONS
UNCONTROLLED MOSAICS
STEREOSCOPIC RELIEF MODEL
CONTROLLED MOSAICS
FIELD CHECK AND COMPLETION SURVEYS
PLANIMETRIC MAP
FORMLINED MAP 50 & 20 FT. INTERVALS
TOPOGRAPHIC MAP 1000 & 250 FT. CONTOUR INTERVALS
TOPOGRAPHIC MAP 50 & 20 FT. CONTOUR INTERVALS
TOPOGRAPHIC MAP 20 & 10 FT. CONTOUR INTERVALS
TOPOGRAPHIC MAP 10, 5 & 2 FT. CONTOUR INTERVALS
RECONNAISSANCE OF AREA
RECONNAISSANCE OF ALTERNATE ROUTES
PRELIMINARY LOCATION SURVEYS AND DESIGNS
PUBLIC ROADS ADMINISTRATION-1947

FIG. 3.

tion of this chart, designated as steps 00 to 99, steps are shown from the initial stage of aircraft pilot, cameraman and aerial camera through photography, ground control surveys and photogrammetry to the finished product of picture or map that will be used by the highway engineer. From left to right, it represents a progressive increase in the amount of detail and accuracy in information and factual data that will be obtained by photogrammetric methods for highway engineers' use.

Starting with columns 1 and 2 on the left are oblique photographs and trimetrogon photographs. Obliques are used to illustrate a highway problem and proposed solution in perspective. Trimetrogon photographs can be used for mapping to small scale providing a general pattern of the topography and an idea of where the mountains, the rivers and the central habitations are in an undeveloped or heretofore unmapped country.

Following that is another choice—the preparation and use of uncontrolled mosaics, and radial plot controlled planimetric maps. The planimetric maps may be made by projection methods using such instruments as sketchmasters, reflecting projectors, the radial line plotter or the multiscope.

Then, when the highway engineer needs to know more about topography by seeing its character and shape and the use of land in three dimensions, he should use paired photographs and stereoscopes.

If the task is to illustrate in three dimensions the proposed solution of particular highway engineering problems to officials, the public and administrators, anaglyphs and vectographs may be used. These will require use of the color filter or polaroid spectacles.

When the engineering job requires small-scale large-contour-interval mapping, use stereoscopic plotters such as the stereocomparagraph, the contour finder, the Wernstedt-Mahan stereoscopic plotter, the K:E.K. stereoscopic plotter and other instruments that might be available. The first two instruments named provide form-line maps, column 7; the latter two make a topographic map, column 8. When more accuracy is required, use multiplex equipment, column 9.

Lacking any of the equipment named thus far, the highway engineer may use uncontrolled mosaics, column 11, as map substitutes to obtain a pattern and idea of the shape of the topography and some rough dimensions of it for his use in the reconnaissance stages. Controlled mosaics, column 13, are preferred for the same purpose. Use of mosaics would be supported by stereoscopic study of successively paired photographs, column 15.

An alternative choice for small-scale large-contour-interval mapping required in reconnaissance stages is precise photogrammetric equipment, provided it is available and circumstances make it economical to use such equipment.

In areas of low relief and concentrated use of land, controlled mosaics and planimetric maps of large scale may be used for route studies. Their preparation would be accomplished as indicated in columns 13 and 14, Figure 3.

For the preliminary survey, large-scale small-contour-interval mapping may be accomplished by use of any one of five types of precise photogrammetric equipment. Four of these are shown in columns 17 to 20, namely: Multiplex, Brock Process, Stereoplanigraph and Wild Autograph. The fifth is the Kelsh Stereoscopic Plotter.

Primarily Figure 3 is a reference guide generally describing how a highway engineer would select his photogrammetric equipment according to the product of completed picture or map required. The entire chart shows the progressive procedure and use of equipment from the aerial camera to the picture or map.

A shutterless aerial camera is listed in column 21. This camera may be used to take very large-scale continuous strip photographs of the located highway. Such photographs viewed under the stereoscope provide the means of obtaining a stereoscopic relief model to scales of from 200 to 20 feet to one inch showing everything on the earth's surface along the highway location before the highway is built. Similar photographs taken after the highway has been constructed will show the changes caused by construction. If desired, the highway engineer can have a third continuous-strip photograph taken to show certain kinds of failures

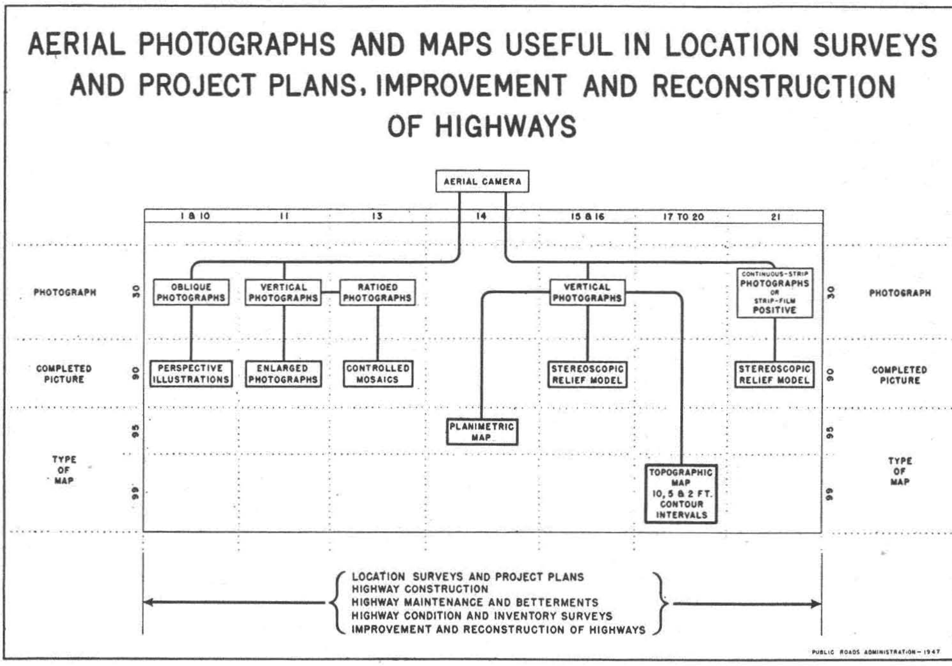

FIG. 4.

after the highway has been used. Where three separate record-photographs have been taken at designated intervals of time they will provide valuable factual information showing all changes that occurred from the beginning. Study of the changes will reveal to the highway engineer where he can improve his engineering or will show where it has been most successful. I believe this suggested practice has great promise.

Figure 4 is a selection of the most typical items from Figure 3 for further use after preliminary location surveys have been completed. Use of the items diagrammed on it will aid the highway engineer in his location surveys and project plans, highway construction, highway maintenance and betterments, highway condition and inventory surveys, and improvement and reconstruction of highways.

I would like to conclude by emphasizing how important it is that engineers use photogrammetry in a coordinated series of stages. Each stage provides the groundwork for the succeeding stage. I believe omission of any link in the chain, which, for the location, begins after selection of terminal points for the new highway and ends with location surveys and the contract plans, may result in the loss of many of the advantages of aerial survey methods.

There are many different procedures to choose from, each of which has particular value according to the specific highway engineering job, and depending on the availability of photogrammetric equipment as well as equipment operators.

I feel that the highway engineer can do well to become better acquainted with the wonderful progress that photogrammetry has made and the great advantages to be gained by using a modern method of obtaining information and factual data essential for the solution of his problems.

PRESIDENT SANDERS: Thank you very much, Mr. Pryor.

I am very pleased to welcome to our meeting as a speaker a representative from the National Geographic Society. We have always felt very close to that Society, although there has not been as much interchange between us as there should be, but perhaps we are correcting that situation when today we have one of their representatives with us, Mr. Newman Bumstead.

Mr. Bumstead has been instrumental in the invention and development of a photocomposing process which makes possible the mass production of hand lettering for a map copy, and he has also been instrumental in many other technological improvements connected with map printing. He is going to talk to us about a new method of map compilation for color printing. I am pleased to present Mr. Bumstead.

MR. NEWMAN BUMSTEAD: Compared to flying and the making of aerial photographs, the drafting of map copy for the lithographer is a pretty drab and unromantic procedure. It is, nonetheless, an important and highly critical link in the complicated chain that connects aerial mapping with the printing press.

Efforts to obtain extreme accuracy in the many phases of photogrammetry, each one of which is a little science in itself, may be largely in vain if the resulting map drawings are not adequately prepared for precision press work.

We in the National Geographic Society's Cartographic Section, with the aid of the Ozalid Division of General Aniline and Film Corporation, have recently developed a map compilation technique that renders more certain the preparation of adequate copy for precision printing. It is also faster and more efficient than the method we formerly employed.

The need for such a technique in the preparation of multi-color maps is easily appreciated when one stops to realize that for each color on the final map there is a separate printing plate. For each of these printing plates there is a separate negative, and for each negative, a separate drawing.

For example, all the place names, railways, parallels, and meridians, which will appear in black on the finished map, are drawn on one piece of paper. Drainage, rivers, shorelines, lakes, etc., to appear in blue are drafted on a second piece. Highways, to be printed in red, are done on a third, and mountains or relief shading, to be printed in brown, are drawn on a fourth piece of paper. Obviously, the relationship of these drawings to each other is extremely critical. Whenever we place a line on any one of them, we must know exactly what relationship it will bear to the lines on all of the other drawings. For instance, when a railroad is being drawn which parallels a river and perhaps runs between the river and highway, it must be placed exactly right with reference to the river and the highway, or on the final map we shall have an obvious misfit, or lack of register.

How then can we be sure that we get this fit between these various types of detail? One procedure that is often used is to prepare a compilation drawing entirely on one piece of paper, regardless of the color in which the various types of detail will appear on the finished map. The photo-engraver, or lithographer, makes a number of negatives of this, and by tedious painting out and negative