Forest Service Photogrammetric Aids in Expediting Road Location and Design

E. S. MASSIE,
Project Chief, Eastern Photogrammetric Unit,
U. S. Forest Service, Washington, D. C.

ABSTRACT: *Because necessary to administering the National Forests, the U. S. Forest Service needs a very great mileage of roads. Generally these are quite different in standard than the primary highways on the Interstate and State systems but usually are rather similar to the lower standard roads on other systems. Primarily because of topography and timber cover the conditions affecting these Forest roads are difficult and unusual. The paper describes the methods of location and design which the Forest Service has developed and which have proven satisfactory*—EDITOR

THE Forest Service, although interested in Forest Highways in cooperation with States and the U. S. Bureau of Public Roads, has a prime interest in the administration of National Forest lands and in connection with such administration the location and construction of Forest Development Roads.

Aerial photographs and photogrammetry in our opinion are among the items which offer the best possibilities for increasing engineering productivity in road and highway location, design, and construction. Both are specifically mentioned inasmuch as the former is a basic tool from which qualitative and quantitative information can be obtained. Photogrammetry, the latter, is the science which by employing the photographs in modern equipment, provides precise quantitative data. Certain of this information can be tabulated in a form suitable for use in electronic computers. The qualitative data, however, are equally important; it is in this field that the aerial photograph provides information of great value which, while not suitable for electronic computations, increases the efficiency of the road or highway engineer. The Forest Service has been doing work along these lines. It may be of interest to briefly describe the use being made of photogrammetry in connection with its work.

It is essential to point out that the same basic steps of highway location and design are involved whether the work be executed by long accepted ground-methods or by using photogrammetry. There may be variations between agencies using aerial photographs and photogrammetry for road activities. The differences, however, are primarily in techniques and details of procedure in the approach to the problem. Equipment employed may vary also from the simple stereoscope—primarily used to procure qualitative information—to the most precise and expensive stereoscopic plotting equipment—used to procure exact quantitative data.

The Forest Service breaks its work down into the following basic steps:

1. *Reconnaissance.* The area study to determine possible routes.
2. *Verified reconnaissance.* The study of the most feasible route or alternate to assure compatibility of the selected route and road standard. It is used also as the basis for flight-line planning in connection with the procurement of large-scale aerial photographs required for road location and design.
3. *Strip mapping.* The topographic information on which the road design and location is based.

Like others, it is our opinion that reconnaissance should be based on comparatively small-scale data. If at all possible a topographic map constructed from aerial photographs is preferred. The scale of these maps usually varies from 1:24,000 to 1:62,500 with contour intervals of 10, 20, 40 or 80 feet. With the termini of the proposed road known, an area of approximately one-half the width of the length of the proposed road is normally studied to determine possible routes. This is done by using a pair of dividers set to a distance appropriately matching the scale of the map, and by marking the points where the grade of the proposed road crosses the contours. In this manner comparable route distances are procured.

In the event that good topographic maps made from aerial photographs are not available, substitute methods must be employed. Standard field methods for running preliminary lines are avoided because of the time involved and limited route information secured. It is possible to use aerial photographs and the simplest of elevation measuring devices—the parallax bar—to determine approximate grades and routes. Or with a minimum amount of geodetic control, a small-scale reconnaissance area map or individual bands of topography might be prepared. The mosaic is not used by the Forest Service because of excessive differences in elevation in forest lands and exaggerated displacement.

In any event, a study of aerial photographs covering the possible routes provides a means of eliminating some of these for various reasons. Without going on the ground the extent of forest cover is easily noted, rock outcrops bare of vegetation are apparent, and under some conditions costly construction factors may be detected. To illustrate the advantages of this procedure the following is taken from material furnished to one of the National Forests for use in connection with determining the proposed route. In this particular case a topographic map made from aerial photographs was available. The scale of the map was 1:20,000 (1 inch = 1666 feet). The contour interval in part was 40 feet and for the balance 80 feet. The length of the road depending upon location would be from five to seven miles.

Six different possible routes were selected. These routes were labelled in various colors on the map; by corresponding colors these were shown on the aerial photographs from which the map was made. This material was reviewed in the office by a photogrammetrist and also by a soils man. The report of each based on over-all familiarity with the area and on an office study of the material, contained the following:

> "The geology of the area is granitic and the soils are most likely shallow, loose and course-textured. Thorough dissection of the mountains by drainage has, in addition to providing rapid and complete soil drainage, left a strong landform pattern of numerable sharp ridges and V-shaped draws. Instability of the soil mantle and substratum in many of the steeper cuts will likely be a maintenance problem."

In respect to one of the routes the soils report indicates: "station 0 to station 3.5 looks good as it includes a stable bench. Station 3.5 to station 5 is too dark on the photographs to study clearly but the slope is steep and could possibly have some hidden land stability problems. Station 5 to station 27 looks fairly good—slopes are not too steep and landforms appear to be more stable."

The photogrammetric portion of the report for the same route indicates:

> "This route is for the most part, located in a canyon bottom. The lower end of the canyon, however, is too steep for road construction. From station 1 to 7 it was necessary to go around the side hill in order to gain elevation. There are several deep cut drains and sharp ridges in this area and these are so abrupt that rather large cuts and fills would be necessary in order to maintain alignment. The country is characterized by steep (50°–75°) slopes, however, not as severe as the other routes. The route between stations 7 to 20 follows the canyon bottom as nearly as possible. There will be numerous culverts or bridges because of the heavy dissection. In order to maintain alignment, it will be necessary to cut through sharp ridges which will probably be rock. Part of the way, at least the canyon, will be narrow so that side hill construction will be necessary. Cuts and fills in this area will be heavy. The grade is, for the most part, considerably less than the 8%. Stations 20 to 26 are again on the side hill in order to gain elevation to get up the steep side canyon. Conditions would be similar to that of 1 to 7. The upper end of the route is again in the canyon bottom. Total length is about 5 miles."

A similar analysis was made of each of the five possible routes and these analyses furnished to the administrators information on rights of way problems and other factors not evident on maps or photographs, for use in making a determination of the most feasible route. Without the aid of aerial photographs, securing data of this nature would require excessive field time. All of these data, while containing some general quantitative information such as general slope and grades, are primarily qualitative in nature.

After the most feasible route has been selected the material is returned to the photogrammetrist for verified reconnaissance. The Forest Service in most cases has field control necessary for preparing standard topographic maps. Otherwise establishment of ground control along the selected route is required.

Medium-scale photographs are employed in verified reconnaissance. Work is normally performed on a Kelsh plotter. The scale of these reconnaissances will depend upon the scale of the photograph and the focal-length of the taking lens. Normally the verified reconnaissance scale approximates 1 inch equals 800 and the contour interval is not larger than 20 feet. Timber-covered areas are mapped but the extent of dense cover is indicated. Stereoscopic plotting proceeds along the approximate route which was selected from the reconnaissance stage. Careful stereoscopic study of the terrain is made as work progresses. This is done to spot conditions which might adversely affect the route. A band of topography varying in width but normally approximately $\frac{1}{2}$ mile is drawn. Road standards and specifications are kept in mind while this work progresses. The actual route followed may vary somewhat from the selection made as a result of the reconnaissance stage, in order that grades and alignment may be maintained. Qualitative information, not visible on smaller scale material, is obtained during the course of this work. The emphasis shifts during this step, however, from qualitative to quantitative. Dimensional data are required to assure grade, curvature, and width of road being compatible with the topography of the route.

Small, clearly identifiable photographic images in close proximity to the approximate center line of the road are selected during this step. These reference points are shown on the verified reconnaissance and photographs with reference numbers assigned to each. A description of each point is prepared. Distances and bearings between reference points are easily determinable since all work is based on the plane coordinate system and the grid as well as magnetic declination is shown on the map.

These materials are returned to the forest engineer. Ground inspection is recommended at this stage. The engineer "walks out" the proposed line, using the verified reconnaissance, reference points and aerial pictures to keep him on line. He checks actual conditions on the ground, procuring a verification of soils data, type of excavation, amount of tree cover, drainage and local factors affecting final ground location and construction. It is desirable at this time to build ground targets which will appear on aerial photographs to be procured for the purpose of strip mapping. These ground targets serve more than one purpose. They become reference points for the future use of the road engineer and aid the photogrammetrist in his work. They also aid the aerial photographer in centering the flight line over the proposed route.

If the findings of the field examination are that the proposed route is satisfactory, the verified reconnaissance becomes the base used by the photogrammetrist in laying out flight lines for photography to be used in strip mapping. A copy of the verified reconnaissance with flight lines, flight datum and reference points (which are usable as navigational aids) are provided to the aerial photographer.

In forest work, because of extremes in elevation, heavy timber cover, and hazardous flying conditions, strip photographs are procured with an $8\frac{1}{4}$ inch camera on a scale of 1:10,000. A 6 inch lens would result in low hazardous flying conditions, and the covering up of ground areas because of displacement of tall timber. A camera with a 12 inch focal length lens would alleviate these difficulties to a great extent, but because of the lack of precision equipment of this focal length, the $8\frac{1}{4}$ inch lens has been accepted as the best substitute.

Verified reconnaissance has provided information relative to the center-line location within narrow limits. Accordingly, in strip mapping the width of the band of topography to be drawn is decreased to a distance of three or four hundred feet on each side of the route along tangents, and is increased sufficiently at curves to assure that elevational data are secured for an adequate distance on both sides of the center-line of the proposed route. The width of this band of topography is a matter of judgment, for in this step the photogrammetrist is watching the type of country traversed, plotting an approximate center-line, is aware of the approximate grade, is cognizant of the desired width of the road and can estimate the approximate limits of cross-sections. By using this method, procurement of topographic information for an area $\frac{1}{2}$ mile or more in width is wasted effort.

Using a Kelsh plotter for this work usually results in a strip map on a scale of approximately one inch equals 200 feet with five foot contours. In the event that a larger scale and a smaller contour interval are required, photography would be performed at a different scale, or in conformity with present planning, work would be performed on a stereoplanigraph which will provide larger scale without any sacrifice in the accuracy of product.

In executing this work the photogrammetrist delimits the extent of timber cover where density is such that he cannot see the ground. While contours are carried through such areas as an aid to the engineer in subsequent steps, the limits of timber cover shown on the strip map serve as a red flag to the road designer. It conveys the message that within the timbered area, the accuracy of work is questionable and a field check is necessary. The extent of check is limited, however, since the accuracy outside the marked area will be commensurate with equipment capabilities and can be used as the the initial and closing points for the ground check. Unless there is found an error of major magnitude which will result in a sizeable shift of location, field work is limited to heavily timbered areas.

This one factor has brought about considerable savings in connection with our work. Our roads traverse not only open but densely wooded areas. Photogrammetry can be employed to procure accurate quantitative data in any area where the ground is visible. Only approximate data can be procured where the ground is not visible; field work to obtain accurate information is limited to areas which cannot be seen by the photogrammetrist.

Completed strip topography becomes the basis for drawing board design of the road. The design is accomplished following standard procedures. A profile is plotted from the contours and cuts and fills are roughly balanced. Bearings, distances and elevation ties for tangents are made from reference points to P.C.'s and P.T.'s. These reference points are put in as often as practicable.

It now remains to transfer the data to the ground. After verified reconnaissance and prior to aerial photographic operations, ground targets were constructed and hubs were left in place. These ground targets appeared on the aerial photographs and their positions were plotted on the strip map. The strip map in turn was based on ground control. Ties from these points to a point on the center-line of the road are computed. The transit can be set up over the ground target, an azimuth determined, the tie from target to point on the center-line run, and the road survey initiated. Ties can be made as frequently as ground targets were constructed.

In summary it will be noted that qualitative information is secured by photographic interpretation. Long laborious field work is replaced by a more rapid office procedure, thereby making a study of several possible routes possible in less time than is normally required for a single route.

Photogrammetry, which is not hindered by bad weather or conditions that hamper foot travel through an area, provides dimentional data dictating the most feasible route. These data are recorded for a limited width within which a road of stipulated standards can be located. This permits procurement of individual strips of photography approximately centered over the final center-line location.

Topographic information is no longer required for a wide area thereby greatly reducing the time requirement in providing a base for drawing board design.

Reference has been made in Forest Development Road location and design to smaller scales (1 inch = 200 feet) and larger contour intervals (5 feet) for strip mapping than is required for highway engineering This is because more leeway in geometry and quantity estimates can be tolerated in designing most development roads.

The methods in use by the Forest Service are equally applicable to highway problems. By lower-altitude photographic flights, larger scale, smaller contour-interval coverage can be secured to the same accuracy with less expensive equipment than would be required for the highway type map in terrain where most forest roads are built. The low-altitude photography is possible since hazardous flying conditions do not prevail and dense timber cover is lacking.