*Potential Future Use of Photogrammetry in Highway Engineering**

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THE Highway Program which is now under way is a tremendous undertaking. It will require vast sums of money to accomplish and will produce demands on engineering manpower exceeding the presently conceivable supply. However, this is by no means the first time our country has faced such a situation. Our way of life is made up of a continuous series of such encounters with seeming unconquerable obstacles and their conquest by new, efficient and frequently unorthodox methods. Therefore, the Highway Program will progress with ever-increasing momentum because we will devise, develop, perfect and accept new machines, methods, and procedures to reduce the cost and save the critical manpower.

One of the most promising approaches to the reduction of cost and manpower lies in the field of Photogrammetry. This is not a new position for Photogrammetry. It has already provided valuable aid to general mapping, medicine, geology, forestry and many other fields. In topographic mapping, for instance, the cost and manpower requirements have been reduced to 10 per cent of what was earlier required. Think of it, an expenditure of 90 per cent of the effort for mapping an area is no longer needed. Why was this accomplished? Because we could not wait on the old planetable methods and we did not have sufficient manpower to produce the amount of completed mapping we had to have in the time allowed.

Of course there were many skeptics who would not accept the new ideas. They contended that the use of the planetable in the field was necessary for proper results; they also questioned the accuracies. Seldom do you now hear of those skeptics. Why? Because they checked the photogrammetric results and found them superior to the planetable methods in all respects; they became sold on the new method. As Photogrammetry continues to come into its own in Highway Engineering it is certain that there will be those who will be skeptical and prone to question accuracies and reliabilities. They must be convinced, and they will be once they have made comparative checks. Fortunately, this type of person usually becomes the most enthusiastic user eventually.

Many State Highway Departments have already proven the economy of using photogrammetry, and practically all are beginning to apply it. To me, results on record are very convincing. Photogrammetry applied in survey operations for highways has saved 80 per cent in manpower and 40 per cent in cost. Later in the design stage the savings have been 50 per cent and 30 per cent. And, of course, there are other savings which have not yet been properly analyzed and recorded.

Just what are the photogrammetric procedures which can accomplish such savings? First, photogrammetry itself. I will not quote the dictionary definition: if not already known, you may desire to look it up. Rather, in simple terms, I will mention some of those things which have application to highway work. For instance, the aerial survey. This consists of taking successive overlapping photographs from an aircraft to cover the terrain of interest. The old and very true adage—"A picture is worth a thousand words"—immediately

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† At the time this paper was read, the author was the President of ASP.

comes to mind. This is a characteristic peculiar to the photographic approach. Everything capable of being recorded (that is, of a size and appearance in keeping with capabilities of the photo process being used) will be recorded. Although you visit or walk through an area many times you will never see or note everything. This is one of the reasons for the superiority of photogrammetric procedures over planetable work in mapping; even the best planetable operator will miss or overlook things. In Highway Engineering, each specialist will look over the area with his particular interest in mind and in each case there is danger that something will be overlooked. All can benefit by using the photographic coverage and photogrammetric methods.

The next step is use of aerial photography. The photographs have been taken with sufficient overlap to make stereoscopic study, plotting and measurement possible. In other words, any two successive photographs, when viewed in a stereoscope or stereo plotting device, present a view of the covered area in three dimensions; a "birdseye view" of the area.

The plotting machines have the capability of tying one stereo pair of pictures to another and matching them to the earth's surface by the use of ground-control. If these individual stereo pairs or models can be fitted together at a fixed and uniform scale with respect to the earth's surface which they represent, we will have a faithful model of the terrain with which to work. (This model is just as adaptable to measurement for application to the earth's surface that it represents, as a model of an internal combustion engine, ship or aircraft is to the production of the actual item.) By utilizing a limited amount of ground-control, the stereo pairs are adjusted into agreement with each other and into an exact match with the terrain. Through the use of dots or fine crosses, appearing in the viewing devices of the stereo instruments and calibrated motions for moving the dots around in the three dimensional field of view, measurements can be made in the stereo model of an area. The action is like measurement on the ground, but much faster. In the field you get the distance between two points by chaining; with the stereo model the floating dot is moved from one point to the other and the necessary readings on the instrument dials or scales are made. In the field, elevations are determined by a level or barometer; in the stereo model the floating dot is placed wherever an elevation is desired and the elevation is then read. Likewise, by using the plotting accessories, profiles, cross-section, contours, planimetry—anything seen in this scale model or birdseye view of the terrain can be drawn in as a map or plot, or transferred to a computing machine.

Just as models are used for calculations and design in other fields of engineering, so can these stereo models be used in Highway Engineering.

There should be little doubt as to the time and effort that can be saved. In plotting a profile, cross-section or contour the floating dot moves at the rate of about 30 to 40 miles an hour on the ground. That speed in field surveying cannot be approached. Also, once you have your photographs and control data, who cares how much it rains, snows, or gets muddy, or how far away from the office the area is located—the model or the data from the model is always available.

The place where most of the skeptics are met is in regard to accuracy. Because measurements are made in millimeters or fractions of an inch rather than in meters or feet a great deal of doubt is created. But this should not exist since the measurements are well within the practical limits of precision reading from both the mechanical and human standpoint. For reconnaissance surveys and work up through the point of final route selection, the regular photogrammetric mapping procedures have been accepted by a sufficient number to assure that total acceptance will soon come. Precise topographic maps are available for anyone to check. The important thing is that much additional use is possible. Measurements to the nearest foot or even less in elevation can be made with proper photography and equipment.

We have been informed that on a highway project, a certain state had a professional photogrammetric concern photograph a section of highway at a scale of 1 to 1,200, and then plot profiles and cross-sections using some of the most accurate types of equipment and the most precise procedures. This work was field checked by research personnel of the highway department. It is understood that 90 per cent of the points checked on these profiles and cross-sections were within .25 of a foot. It is reported that at least two other companies are involved in a similar type of work in other states. Of course, it must be realized that such accuracies are not possible under all conditions. Even though fatithful, the photographs can record only what is visible; thick grass or weeds can be several inches high. Also, it takes much professional skill and experience. But since such professional photogrammetric engineering companies exist, their capabilities should be used just as we use lawyers, doctors and other professional people. Therefore, let us put photogrammetry to work in the more detail operations.

It is true that in the field for cross-sections or profiles you read rod elevations to the nearest tenth, and at times hundredth, of a foot. But remember these are spot heights with interpolation in between, whereas the floating dot runs continuously along the ground selecting every indication of a change of elevation as a point for height determination. I believe the averaging in one case offsets the other. At least comparative results seem to indicate this.

What about errors? As long as human beings have anything to do with the matter, there will be errors. They are possible in photogrammetric work just as they have always been in field surveys. The important thing is that due to the reduction in the required time and effort, more checks are possible; the whole system is more adaptable to having several different people run over or repeat the measurement or drawing results, than is permitted in field survey procedures.

As a summarization let me repeat that just as there are models of engines, machines, ships or airplanes made to precise scale in order to permit making measurements from which speed, mechanical functioning, hydrodynamic or aerodynamic data are determined, so we have a model or models of the earth's surface on which we can plan highways and make layouts, determine construction data, obtain legal information, secure economic facts, and present such information to individuals or groups in a clear and concise manner, with a minimum of time and effort.

In most cases, the efficient procedure is to have personnel with experience and practice do the measuring or make the required maps or drawings, in the same way that a surveyor is used for field measurement. The photogrammetric engineers can give data as required, whether these be contour maps, profiles, or cross-sections. Figures can be provided for computing machines. However, experts in other fields of engineering, with a little practice, have become proficient in using the stereoscope and have provided themselves with a "birdseye" of the terrain of interest. They quickly learn to recognize the details pertaining to their field of interest and to use the stereoscopic study as a supplement to, or in many cases, a substitute to visits to the field.

I have been involved in photogrammetric work of one type or another for over 25 years and I have watched professional people in different fields of endeavor learn to use aerial photographs with a stereoscope, for application to their particular work. I have been amazed at their proficiency in recognizing and gleaning information pertinent to their fields. Their basic knowledge and experience in say geology, forestry, soils, etc. enable them to correlate what they see in the photographs and stereomodels with how things would appear in the field. Thus they are aided in their field work, and are able to eliminate a considerable portion. While I can plot topography and make precise measurements photogrammetrically, I would need a greater knowledge of geology, forestry or soils to see all that these others see in these fields. I therefore suggest that engineers and specialists consider this approach to their specific interests, and leave plotting and precision measurement to the professional photogrammetric engineers.

With photography taken at low altitudes at large scale you observe the details. With photography flown at higher altitudes the scales are smaller, the area is larger and the details less minute. In other words, with the one type you can see the tree and with the other, the entire forest. The general area can be scanned or one spot can be given a close study. The smaller scale photography, or maps covering larger areas, are most favorably adapted to reconnaissance, planning and the like. The best general highway location can be determined. The drainage pattern, the soil types and surface geology, the character of the terrain, the traffic and economic requirements, general property ownership and legal matters can be worked out. By this approach much field work is eliminated and property owners and local people are seldom disturbed or aroused.

When the best route alignment has been determined, taking all things into consideration, then the lower altitude, larger scale photography becomes important. This photography along the selected route covers say from $\frac{1}{4}$ mile to 1 mile in width, depending on the scale which should be used for the accurate or precise measurement. The exact scale of this photography depends on the type of terrain, vegetation or land use and plan of procedure. Contour maps, planimetric maps, profiles, cross-sections, numerical data for computing machines, any other measurements can be provided from this photography for cut and fill estimates, road building materials estimates and other similar requirements. These photographs or the maps from them also assist greatly in survey work such as staking for construction. Also, the individual photographs and the other products are used throughout the construction program.

I firmly believe that another aerial survey at low-altitude and of large-scale, like the one I have just described, should be flown immediately after completing construction or at the most favorable moment thereafter. I am certain that data from this photography could serve to determine work accomplished, such as amount of excavation and fill, materials used, etc., for the purpose of payment of contracts, settlement of claims, etc. I do not have the details but I have been told that this action has been taken on at least one occasion. Many commercial companies today in other fields of endeavor determine inventories by a similar approach. Lumber in stacks and piles of coal or other minerals are photographed and photogrammetrically measured. Accuracies of 1 or 2% are obtained. I could mention a great number of similar applications. A number of photogrammetric engineering concerns exhibiting here can give examples of work accomplished and the names and addresses of customers; they can provide a verification of my statement. I further believe that this photography and the resultant photogrammetric work following construction operations would pay for itself through the benefits to maintenance work in future years.

A frequent question is "what is the place of photogrammetry in the kind of highway engineering work my organization does?" That depends on your mission, the size of your organization and the amount of work you have ahead of you. For example, if you have a small vegetable garden you probably dig it up yourself. But if you decide to build your own house you probably hire someone with a bulldozer and other earth moving equipment for the excavation and landscaping work. And if you start building houses on a large scale you will probably obtain your own earth-moving equipment.

Let us apply the foregoing to photogrammetry. I believe that every engineer on any part of the highway program should learn to use aerial photographs stereoscopically. Stereoscopes are not expensive. Also, simple parallax bars to use with them are not too difficult to obtain and they permit making some measurements. As for photographs, most all the United States has been covered by photography at one scale or another by either governmental or private concerns. Information is available on how to obtain these photographs.

To progress further and get into stereoplotting and more or less precise measurement equipment! Unless you have a steady, continuous flow of work for such equipment it is better to have it done by contract. The cost of these machines is high and they and the men who operate them must be kept busy to secure best results and for economic stability. Also, the manpower shortage is very real and skilled photogrammetric engineers are hard to find. Larger concerns might have a stereoplotter for checking and minor jobs, but in general, contracting is best.

Practically all aerial photography should be obtained by contract. Few if any concerns primarily engaged in other work can afford to maintain photographic aircraft and other equipment, as well as trained personnel. Also, the photographic pilots and cameramen not only become proficient as a team but develop effective working systems with the photogrammetric engineers of the company they work for. Different companies may use different equipment but those with experience have developed a system which gives results comparable with the others.

With the hope of further illustrating what I have been talking about, I will attempt to follow through a typical Highway Engineering project wherein photogrammetry is applied. I use the word typical with the understanding that it is, in itself, subject to question. What is normal in one place is not in another. However, let us assume that a highway is to be constructed between two points or cities. Due to the nature of the terrain there are several possible routes included in an area which is about half as wide as it is long, stretching from one city to the other. The first step is to find out what information of the area already exists.

As mentioned before, practically all the United States has been covered with some type of photography and in a number of places by topographic maps. If photographs or maps exist and these are of proper scale, they can be used to select the most promising routes. If the scale of this material is sufficiently large perhaps the most suitable route can be determined.

However, in this case, the maps may be old, inaccurate and too small in scale, and such photography as exists is old, of poor quality and incomplete. Therefore, a new aerial survey is necessary. As mentioned earlier there are a number of aerial survey and photogrammetric companies. These firms have been in the business of aerial surveys and photogrammetry for a long time, in most cases. They are capable and willing to give advice as to what photograph and map scales should be obtained, based on the nature of the terrain and the precision desired. Also they know the best seasons of the year for aerial photography in different areas, etc. Weather and seasonal tree cover are quite important. At least two or more of the firms should be contacted for discussions regarding mapping the area. Information from these discussions will be of benefit in preparing invitations to bid and in writing specifications in accordance with organizational requirements. For proper procedure and method of presentation of solicitation to bid, the publication entitled "Reference Guide and Outline of Specifications for Aerial Surveys and Mapping by Photogrammetric Methods" will adequately serve the need. This publication is the result of about four years work by a joint committee from the American Society of Photogrammetry and the American Congress on Surveying and Mapping. This committee was very ably guided by Mr. William T. Pryor of the U. S. Bureau of Public Roads who, as Chairman, not only directed the work but personally contributed a great portion of it.

While the aerial survey is being planned the survey ground control existing in the area should be checked. Thanks to the U. S. Coast & Geodetic Survey there is in each state a considerable amount of control in the plane-coordinate system. The surveys for topographic maps made by the U. S. Geological Survey and surveys by other agencies, both governmental and private, usually reduce the field work to a minimum. In our example let us say there were enough control points in the area to control a map at the scale selected with a minimum of field surveys, consisting of short ties between control points and identifiable points on the photos, and that this could be done on existing roads. When the aerial survey is complete and there are several sets of the photographs and a topographic map of the area, the various experts then go to work on the project. They study the drainage, traffic requirements, amounts of cut-and-fill, right-of-way problems, curves and gradients, safety features, etc. of each route. Using the photographs stereoscopically and the maps, questionable points can be checked and re-checked until the most advantageous route is determined beyond any doubt.

Let us assume now that the final route has been decided and has been marked on a set of the maps. Due to the nature of the terrain a more precise aerial survey and photogrammetric measurement is desired of a strip, of between 1 and 2 tenths of a mile width, along this route. We contract for this as before or this work could have been included in the original contract. This time the photography is flown so as to permit the construction of maps at 1″ = 40′ and 1 foot contours, or the drawing of profiles and cross-sections to the nearest foot. More field surveys will be needed but by study and planning, this survey control can be so located as to prove beneficial in construction-survey work.

With the large-scale photos and 1″ = 40′ maps, as well as profiles and cross-sections, construction estimates for earth moving, bridges and culverts, surfacing materials, etc. can be made. Also, final legal steps regarding right of way can be worked out. It should be noted that up to this stage there has been a minimum of work required in the field. Until the location and grade stakes have been set, the local people and property owners will be subject to little or no disturbance. Also speculation regarding the highway location will probably be avoided.

Throughout the construction period the availability of the photographs, maps, profiles and cross-sections will greatly facilitate the work and will save much time and effort.

When the construction of the highway has been completed another aerial survey along the route at a large scale and covering the right-of-way width would prove to be of great value. The construction accomplished can be checked in most cases. The amounts of earth moved and perhaps other work can be measured for payment. It is important to note that in former procedures, once the construction has been accomplished the record of the original appearance of the terrain along the route exists only in survey notes and profiles or in cross-sections plotted from them—all subject to human error. But, in the photogrammetric approach, we have the large-scale photography with its faithful rendition of the original terrain; it can be checked and rechecked as often as desired.

In summation, aerial surveys and photogrammetry provide:

a. In reconnaissance, assistance in studies of topography, surface geology and soils, drainage patterns, land use, property ownership, traffic requirements.

b. A considerable reduction in field surveys, for reconnaissance, final location and construction. Little if any field survey is necessary except on finally determined route.

c. The larger scale and more precise photogrammetric data and measurements for assistance in planning, in design, in estimates, in construction, in determining payments and later, in maintenance.

For all engineers and specialists whose work is in one way or another related to the earth's surface and what is taking place on it, Photogrammetry offers assistance. I urge you to consider it and use it. It will save you time and effort which you will need in view of the magnitude of the job and the manpower and fund shortages.

*Using New Methods in Highway Location**

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ABSTRACT: *Photogrammetry and airphoto analysis combined with computers can and will become the most important tools which the highway engineer has at his disposal for the complex job of highway route selection.*

INTRODUCTION

THE location and planning of today's modern highway has become a job of tremendous complexity. Our way of life depends on a delicate balance of economy. This economy centers largely around the ability to transport goods and people quickly and cheaply. Today a larger proportion of the total economy is going into the building of highways than ever before. Also, we are more largely urban than previously. Urban planning and development are almost by definition more complex and difficult than rural. With the rising cost of urban land the engineer is steadily being forced to use less desirable locations. The public demands highways of higher standard today than ten years ago. These de-

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