Roadway Plans from a Total Airphoto Technique without Ground Control

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ABSTRACT: *Maximum utilization of airphotos, photogrammetry and photo interpretation has allowed the development of a successful method of producing roadway plans for secondary gravel roads in remote areas. All ground survey is avoided in most cases. Preliminary location is made by interpretation of existing airphotos. Detailed location, soil and rock data, drainage areas, topography, clearing data, gravel sources, are all extracted from fresh, low level, radar-controlled airphotos flown along the selected route. Final plans are evolved directly from the data produced from the airphotos. The first ground survey of the road is in the form of stake-out immediately in front of construction operations*

INTRODUCTION

The object of this article is to describe a technique that has been used successfully to produce plans for secondary gravel surface roads in Northern Canada. The author hopes that this method may be of interest to others working in remote areas.

The economic development of much of Canada's latent resources depends on construction of a primary network of all weather roads to open the presently virgin terrain.

It was desirable to develop a technique that would economically locate a road between given points and then to develop construction plans for the chosen location. It was essential to use minimal ground surveys, or none at all, due to the inaccessible nature of the sites. These roads are designed to open inaccessible areas and are, therefore, per se in areas where ground access is expensive. The final plans produced were to be suitable for at least a "per-mile" type bid and construction.

Development roads of this type require careful location from the viewpoint of engineering economies. Roadway plans for bid and construction purposes are necessary, but do not need to be as accurate or refined as for a normal rural highway. Roads of this type cost only $10,000 to $20,000 per mile of construction if they are well located. Conventional location and design methods can be most expensive in inaccessible areas and may not be justified if sufficient information can be developed without ground work.

More than 200 miles of roadway design in four projects have been completed using this method. Some are constructed and in use as shown in the example of Figure 1. Others are in various states of ground layout and construction.

It has been found that actual method varies slightly for each project due to the type of existing data and the nature of terrain. The project locations vary from Quebec Province to Yukon Territory. To permit a general description of the method developed, a proposed 93 mile road in northern Quebec will be used as an example. This road is now under construction. The road will open the potential prospecting territory along the east side of Lake Mistassini, including the reported iron and sulphide mineralization near Albanel and will extend road access to some 120 miles north of Chibougamau to the Timascamie River. No ground access exists in this area at present. Figure 2 shows typical terrain of this area. The project was initiated and supervised by the Quebec Department of Natural Resources and is part of the province's program for opening northern Quebec.

The initial specifications for the road were for a 28-foot gravel surface with $4\frac{1}{2}$-foot shoulders and minimum sight distance of 955 feet where terrain permits. Maximum grade was specified as 6% except where economi-

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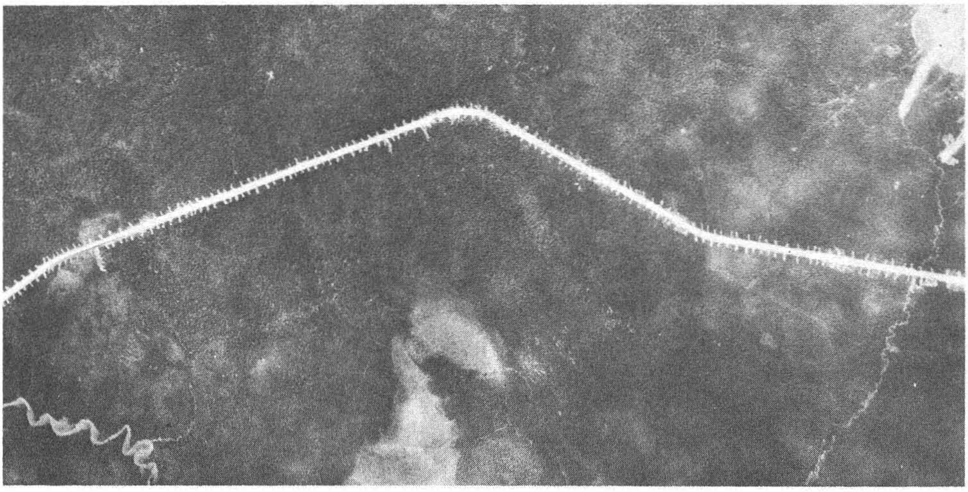

FIG. 1. Airphoto of the access road to Matagami Townsite. This road was located and constructed following the method described. (Scale: 1 inch = 1,000 feet.)

cally unfeasible. By judicious initial route selection, a design speed of 60 m.p.h. was maintained or bettered throughout the project and final roadway specifications were based on this criterion.

In order to clarify the method, a synopsis of the various steps will be presented before a detailed description. Basically, the method consists of six phases:

1. Airphoto-interpretation of existing high-level airphotos to select a route corridor.
2. Flying this route corridor with low-level airphoto and airborne profile recorder.
3. Detailed airphoto interpretation of low-level photo, field checking of terrain and soil conditions and detailed corridor selection.
4. Topographic mapping by photogrammetry of a corridor 1500 to 2000 feet wide, and final horizontal alignment.
5. Completion of plan and profile drawings based on the alignment and topography obtained through the photogrammetry.
6. Selection of reference points for P.I. position and compilation of aids for the field survey of the line.

Detailed Description of Method

The overall method has been summarized

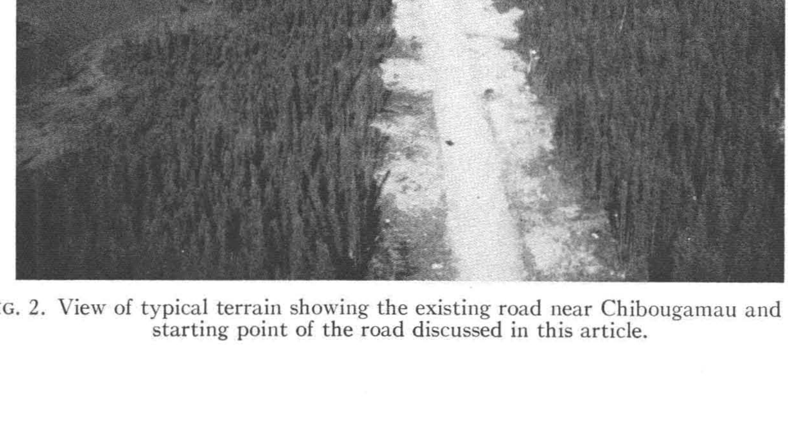

FIG. 2. View of typical terrain showing the existing road near Chibougamau and the starting point of the road discussed in this article.

above and a more detailed description is given below in eight steps.

(a) The entire region between Chibougamau and Lac Albanel was examined from 5,280′ to 1″ scale, publicly available, RCAF airphotos. This area of 25 miles×100 miles was subject to a broad terrain analysis. An airphoto mosaic at a scale of 1 inch = 1 mile was composed and used to compile the information. A general route corridor became evident from this analysis. This corridor took maximum advantage of old glacio-fluvial spillway valleys which were expected to contain granular soil.

The major river crossings were reduced to a minimum, swamps and muskeg areas were avoided where possible.

As a result of this study, over 50% of the route was located on gravel or sand; rock-cut and rough terrain was kept to a minimum.

A typical high-level airphoto is shown in Figure 3 to indicate the nature of interpretation at this scale.

(b) Following approval of the route corridor by the Department of Natural Resources, new photography at a scale of 1 inch = 1,000 feet was exposed in June, 1961. The line direction was parallel to the route corridor. Two parallel lines with 60% lateral overlap were flown, both with simultaneous vertical radar profiles (Airborne Profile Recorder). This provided two profile lines for control on each photo line, one down the centre of the line and the other from the adjacent flight line being along the edge of the first line. In this way an effective width of more than 2 miles was covered by vertically controlled photography and either line could be levelled in the plotting instrument for mapping.

(c) The route alignment was re-examined and preliminary detailed soil interpretation was made using the new photography. Field check points were selected along the route to allow ground examination of the typical photo pattern of each soil type and of any hazard areas. Check points were selected for convenience to helicopter landing wherever possible.

(d) Every check point, landing area (with alternate) and field access method was decided in the office. Two engineers made the field soil study, both working separately from the single helicopter so that the machine was

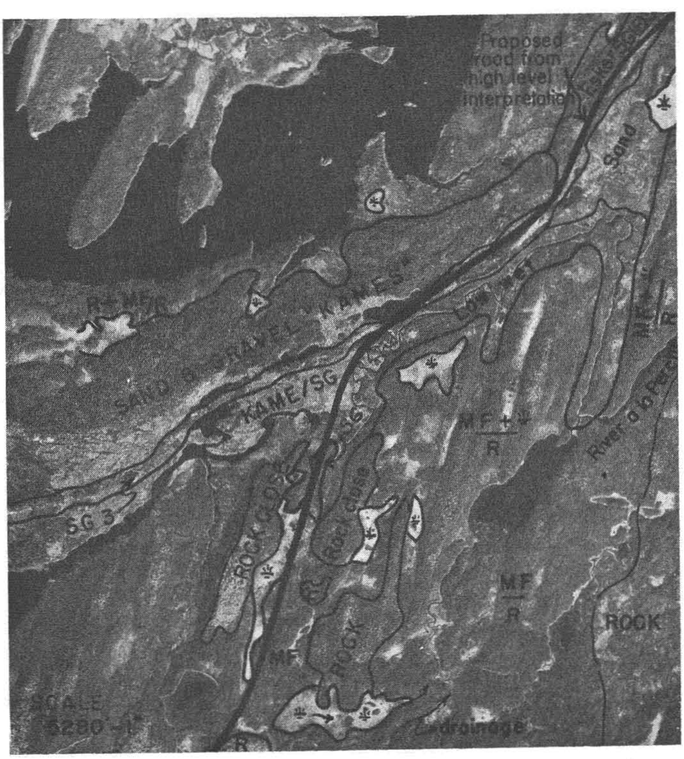

FIG. 3. A portion of the initial photo-interpretation from high-level airphotos for corridor selection. (Photo courtesy RCAF.) (Scale approximately 1 inch = 6,300 feet.)

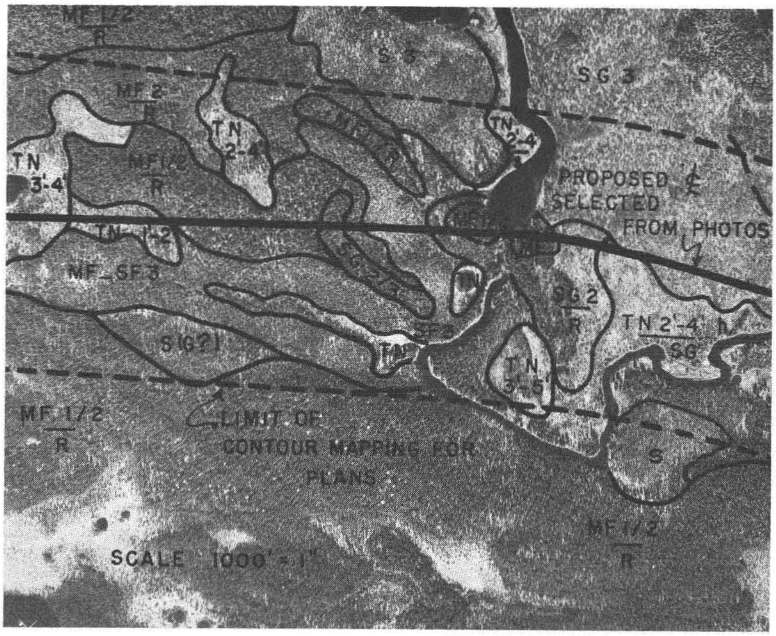

FIG. 4. A portion of the low level airphoto showing the soil mapping from detailed interpretation. (Scale: approx. 1 inch = 1,375 feet.)

in constant use, leap-frogging between the engineers on the ground.

Between 50 and 60 points were visited this way in a total of about 10 field days, good weather helping. Only manual sampling was made in the field. Equipment consisted of an 8-foot flight auger, shovel, a 15-foot sectioned steel probe, sample bags and airphotos.

(e) The results of the field operations provided information for final detailed interpretation of soil data and subsequent selection on the airphotos of a definite route corridor 1,500 to 2,000 feet wide for topographic mapping. A typical annotated low-level photo is shown in Figure 4.

(f) Vertical control for photogrammetric mapping was computed from the airborne profiles. Horizontal control was made by bridging from high level photography from Government established triangulation stations.

Topographic mapping was performed at a scale of 1 inch = 200 feet with 5-foot contours and enlarged to a scale of 1 inch = 100 feet for the plan.

(g) Final horizontal alignment was made on the 100′ to 1″ plans and agreed with Mr. Guy Paradis, P. Eng., of the Department of Natural Resources. A few changes were made and additional plans prepared. Bearings of tangent sections, chainages and P.I. positions were computed from the co-ordinate grid system.

Vertical alignment and drainage computations were made following the normal practices but with maximum use of the airphotos as discussed in detail below.

(h) To assist in layout of the line, reference points to P.I. positions were chosen wherever possible. These references and the P.I. were shown on the plans and also on a photo-enlargement of the vicinity.

Many of the techniques used in this method are well known to the practicing highway engineer and photogrammetrist. The sequence and application as described above is sufficient explanation for most of the phases. Certain phases of the method are critical to the successful and complete bridge between photogrammetry and engineering plans. The methods applied to the completion of soil and terrain analysis, drainage design, quantities, accuracy and final ground layout deserve some expansion and verification.

TERRAIN ANALYSIS

The terrain analysis in both phases was based on a regional geomorphological approach keeping in mind the end purpose of highway engineering. Initial interpretation of the high level airphotos was restricted to broad terrain classification of landform-soil complexes and included a regional hypothesis of glacial geomorphology tied to airphoto pattern so that broad areas such as erosionally glaciated bedrock terrain, spillway valleys, esker-kame complexes, marginal moraine masses, drumlin fields and lowland marshy-ground moraine areas could be extracted and plotted. After the terrain analysis several possible route corridors became evident. Each of these was examined in as much detail as the airphoto scale allowed. The final selection was based on distance, major river crossings, and the sub-grade soil type.

Detailed interpretation of terrain from the low level airphotos had the benefit of field checking so that a factual soil map could be compiled. The interpretation also formed the basis for the route corridor location and the report on construction materials, clearing characteristics and bridge site reports. Initially, the detailed soil and terrain study extended over some two miles but this width was quickly reduced to some 1,000 to 1,500 feet over most of the route by an appreciation of local topography, soil and hazard areas. Within the band considered feasible for the route, soil data was compiled to a legend convenient to highway engineers.

The soil along the route has a predominantly granular texture. The soil types were shown in detail on the roadway drawings. The types and depths mapped are listed below:

TYPE OF SOIL

Bedrock	R
Ground Moraine	MF
Silt	L
Clay	A
Sand	S
Sand and gravel with boulders	SG
Esker	SG (E)
Organic Material	TN

SOIL DEPTH

Soil of 1 to 3 feet	1
Variable depth with the range of 1 to 8 feet	$\frac{1}{2}$
Soil depth of 3 to 8 feet	2
Soil depth of more than 8 feet	3

Note: Depth of organic muck is shown in feet. The soil is described on the drawings by a combination of these symbols, e.g. (MF 2)/R indicates a ground moraine soil of depth 3 to 8 feet over bedrock. (TN 2′–4′)/S indicates organic muck of 2–4 feet depth (see note above) over sand of unknown depth. The apparent lack of connection between soil type and abbreviation is due to the original drawing having been prepared in French.

Such detailed interpretation has been found quite feasible. As detailed interpretation progressed, a hypothesis of local geomorphology was formulated and this assisted in the soil mapping. The phases of detailed interpretation, field work and hypothesis of local glacial history were all pursued simultaneously. The method of identification of the soil types and bedrock depths is beyond the scope of this article. The theory and descriptions of broad interpretation are well

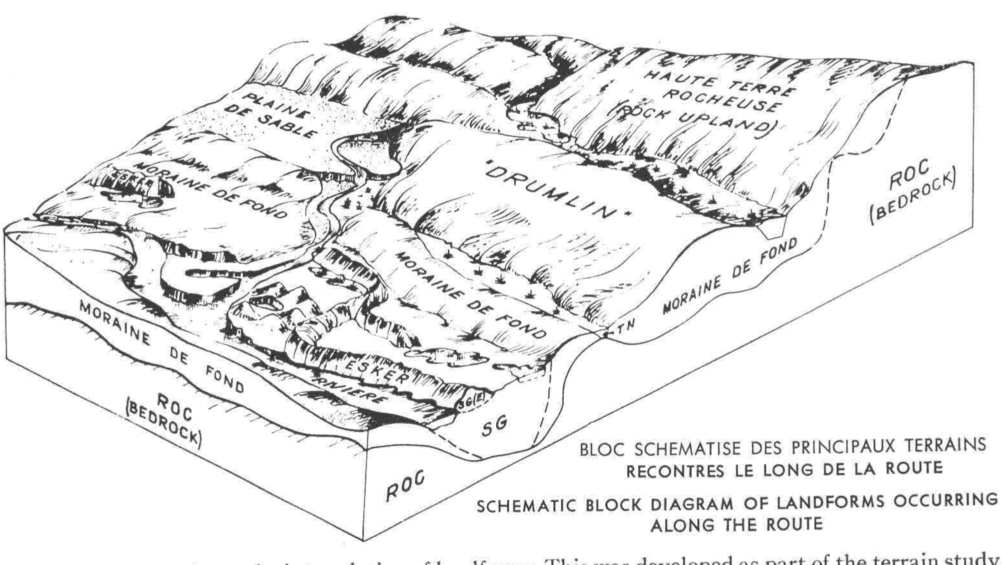

FIG. 5. The diagram shows the interrelation of landforms. This was developed as part of the terrain study.

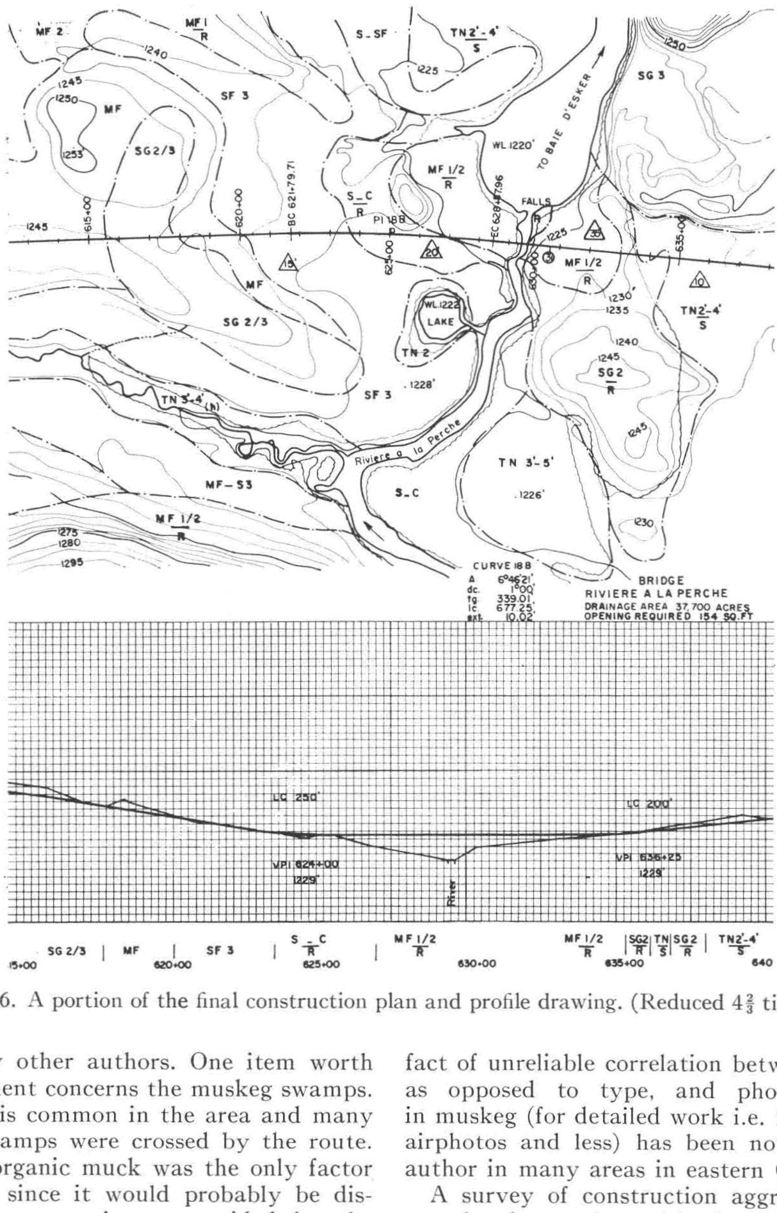

FIG. 6. A portion of the final construction plan and profile drawing. (Reduced $4\frac{2}{3}$ times.)

covered by other authors. One item worth brief comment concerns the muskeg swamps.

Muskeg is common in the area and many muskeg swamps were crossed by the route. Depth of organic muck was the only factor of interest since it would probably be displaced in construction or avoided by the route. Following the excellent work of N. W. Radforth (Defence Research Report 124, Ottawa, 1958), an attempt was made to predict depth based on either vegetation or photo pattern. This was only broadly successful and exceptions to our rudely developed method were found. As depth of muskeg affected roadway quantities, it was necessary that swamp depth be classified as accurately as the other items in the legend. It was found that this could be done only by intensive probing and with reliance on photo pattern only to show the extent of the swamp and for minimal pattern-extrapolation. This fact of unreliable correlation between depth, as opposed to type, and photo pattern in muskeg (for detailed work i.e. 1,000′ to 1″ airphotos and less) has been noted by the author in many areas in eastern Canada.

A survey of construction aggregates was completed, together with the soil mapping along the route corridor. In areas where sand and gravel were not found immediately adjacent to the route, the photo-interpretation search was expanded laterally to a width of up to 2 miles. All potential sources were field checked. Volume estimates and pit access route locations were made so that a complete summary of aggregate sources, haul distances and anticipated quantities could be incorporated into the location report.

To assist in estimates and bids on clearing operations, tree heights were added by photogrammetry along the right of way and field comments were made of vegetation conditions. In all phases of the project, the airphoto technique was used to maximum advantage so that construction could be initiated immediately behind field stakeout operations.

DRAINAGE

Some eight major drainage ways were crossed by the proposed route together with many smaller creeks and swales. The extent of each watershed intersected by the route was defined by stereo analysis of the airphotos. Smaller creeks were generally contained within the low level airphotos. Larger watersheds were defined using the high level airphotos. All watershed areas were measured directly from the airphotos and notation was made for the run-off factor of the more significant creeks. This run-off factor was determined from the photo appreciated vegetation cover, terrain slope and natural ponding areas.

Culvert design for the smaller creeks was based on the arbitrary Talbot formula using the watershed area and run-off factor obtained from the airphotos. Rainfall intensity was obtained by interpolation of regional climatic data and correlation with other published data. A minimum culvert diameter of 30″ was used as protection against icing and for ease in maintenance.

Drainageways deserving bridges or major, custom-designed culverts were subject to further examination at the time of the ground check. Preliminary design information for each major crossing was provided by a report including terrain description, observed flood level, flow, depth and watershed. Cross-section and local topography was provided from the photogrammetry. An enlarged airphoto was made for general site appreciation, together with ground stereo views of the crossing wherever possible.

Quantities and Accuracy

The quantities required for either unit price bids or as a basis for per-mile bids comprise various items, including clearing and stripping, paving materials, culverts, earthwork, rock excavation, safety appurtenances. Each of these items can be extracted from the plans. Bridge and other structure quantities can be extracted from their individual design drawings.

The clearing acreage can be measured directly from the plans, broken down into tree covered and clear areas and further classified by tree height or forest type. Variations in cleared width for changes in alignment or section type are evident on the plans. The accuracy depends only on the horizontal scale of the plans. Paving materials can be measured in the same way as clearing areas and with the same accuracy.

Culvert quantities are summarized from the plans. Diameter has been determined by design and length is computed from fill height as indicated on the plans. Backfill and foundation requirements can be computed based on the soil and terrain data.

Earthwork quantities are generally estimated by the centreline profile method, although cross-sections based on the five-foot contours could be drawn. The method of vertical control leaves the possibility of gradual straying off datum. Therefore, it is normally suggested that the grade line should be staked as based on the cut and fill heights indicated on the plans instead of following absolute datum or using the grades indicated without reference to the cuts and fills. This might mean that a 3% grade called for in the plans would be constructed as 2.9% or 3.1% to comply with the cut and fill heights shown. Thus, the accuracy of the earthwork quantities depends on only the relative accuracy between a set of contours along any given grade.

Rock excavation is estimated based on the field checked airphoto interpretation from the soil data shown on the plans. The accuracy of this item depends on the interpreter and the area, and thus cannot be forecast in general terms. If rock is to be paid by a unit price, additional exploration may be required in critical areas. This exploration can be in the form of pitting, augering or seismics in locations indicated by the photo interpretation.

The safety items, such as guard rail, signs, etc., can be extracted directly from the plans, to normal accuracy.

The accuracy of the plans themselves will depend on the photogrammetry. If a horizontal accuracy of 1 in 500 is assumed, which is most conservative, then the items such as clearing, paving, etc., would have one dimension in error by 0.2%, which is quite acceptable for estimating and bidding purposes. The relative vertical accuracy of the plans should be within normal photogrammetric criteria and errors can be expected to be largely compensating. Percentage error will depend on fill heights, if a relative error of 2 feet is assumed at one end of a 100 foot length of 15 feet cut or fill, then the percentage quantity error would be about 3%. Smaller fill heights would give larger percentage errors, but the deeper cuts and fills make up the larger part of the quantity total. The cumulative errors will tend to be compensating to some extent over a contract length of, say, 5 or 10 miles. Thus, it might be estimated that the overall percentage error should be within 10% to 15%. Since contouring will soften true terrain features, the total computed quantity would be expected to be lower than the actual construction quantities.

Two roads have been checked in detail over 5 miles by ground survey crews doing independent layout work. The analysis of comparable ground vs. photogrammetric readings is itself too lengthy to present here. The conclusions we have reached in hindsight are more significant and are listed below.

(a) In open ground or leaf-free deciduous forest, the mean error approaches zero. It was found to be 0.0075 foot over a 6 mile test using 500 feet to 1 inch photography and tight ground control. The average error (in excess of the gentle datum slopes from the A.P.R.) stays around the expected figure based on the photo scale. It is normal within tolerance specified for preliminary quantities. (Ref.—Specifications for Aerial Surveys & Mapping by Photogrammetry for Highways—1958, Bureau of Public Roads).

(b) In areas of dense coniferous tree cover where the ground is completely obscured, the accuracy is apparently reduced to an average error of 2 to 3 feet with the mean error approaching zero over long lengths. There are random errors up to 10 feet at certain stations but these are exceptional and the profile still describes the terrain shape in a relatively accurate manner. It is imperative that the instrument operator is familiar with the terrain and vegetation of the area since much is dependent on this interpolation and interpretation. The computed quantity estimates become inaccurate in these areas and can be used only as a guide for comparing various routes. Bid estimates for earthwork quantities (the only quantity effected) can be formulated for these areas by attaching experienced arbitrary adjustments to the figures and allowing a large over-run percentage for the owner over these sections. These limitations are due to the failure of our present photo sensor systems to penetrate dense vegetation adequately.

(c) The A.P.R. control without block bridging introduces gentle slopes of datum up to a noted maximum of 0.3% which occurred across an overlap of rough terrain with no water bodies for local correlation or correction of the A.P.R. The error introduced by this slope could be removed in practice by adjustment of the roadway grades in layout.

(d) The radar profile (A.P.R.) method of vertical control should be subject to a thorough vertical bridging operation. We have not yet used the horizon camera method; this may have advantages although with secondary road construction we are more concerned with the best possible *relative* accuracy.

In unobscured ground it appears that the approximate quantities evolved by the method described above are sufficient for bidding purposes. If payment is based on unit prices, the cross-sections quantities must be measured on the ground immediately in advance of construction. The method has been used under these conditions since it permits plans and bids to be made in advance. Ground layout and cross-sectioning can be done as the construction camps are set-up.

The most satisfactory final application of this method appears to be for a per-mile fixed bid on earthwork, clearing and paving with measured-in-place extras based on bid unit prices for culvert pipe, rock excavation and other variables suggested for any particular contract by the engineers involved.

LAYOUT OF ROUTE

Field layout of the pre-selected and computed alignment is a critical operation. It is necessary that the horizontal turning points (P.I.'s) shown on the plan be staked on the ground in their correct position. It has been found that natural points of detail can be selected in apparently featureless bush and these points can be used as local references to the point to be staked. Several points are chosen and co-ordinated in the plotting instrument. A local set or sets of triangulation are computed so that the turning point can be surveyed in on the ground. If the layout surveyor has sound photo identification experience, this aspect presents no great problem.