Maurice E. Lafferty*
Great Basin Aerial Services
Elko, Nevada 89801

Accuracy/Costs with Analytics

Photogrammetric measurements can offer the survey engineer not only savings in costs and time but also adequate or improved accuracies.

Abstract: *The cost of the photogrammetric cadastral project is related to the terrain characteristics, the project area and the accuracies specified by the survey engineer. Some relationships have been developed between these factors which allow reasonably accurate cost estimates to be prepared. These relationships can assist the photogrammetrist and the survey engineer towards a rational decision on the use of analytical photogrammetric measurements.*

Introduction

The evidence seems well established that analytical photogrammetric measurements are sufficiently accurate for use on land boundary and geodetic control surveys; a selected bibliography of recent articles is included herein. In spite of the evidence it has been our experience that photogrammetry has not gained the confidence of many survey engineers who might benefit from its use. We have analyzed costs and accuracies on twenty-four cadastral projects† completed during the past five years. Our findings are presented in the hopes of improving the confidence in aerial measurement as a land-survey technique.

In most instances we have found that the acceptibility of aerial measurements can be aided by the presentation of quantitative data relating those elements of greatest interest to the survey engineer:

- The cost benefits that can be anticipated.
- The accuracies to be expected from the overall project.
- The savings in time that might be realized.

Photogrammetric Survey Cost Estimates

The survey engineer charged with planning project survey requirements should prepare a cost estimate for each proposed survey technique.

The method used by us for estimating photogrammetric costs is similiar to the method for estimating engineering and surveying projects. Completed projects are analyzed for correlation of unit costs for similiar types of work. These unit costs are often combined into the most comprehensive unit of work that will yield reliable estimates on different projects.

We have found that photogrammetric cadastral projects can be reliably estimated using four work units developed from the project characteristics:

- ★ Corner search and premarking,
- ★ Field survey control,
- ★ Photogrammetric costs and
- ★ Calculations and final monumentation.

Basis of Cost Data

Unit costs included in this paper were developed from the 24 projects shown in Table 1. Two projects were located in Louisiana with extremely difficult conditions of cover and access. The remaining projects were located in the western United States and varied from flat open prairie to precipitous mountain slopes. Cover varied from none to heavy forest canopies requiring points eccentric to the true corner locations.

The field survey cost data have been adjusted to the prevailing rates in 1972 for a two-man survey crew. Materials have been

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† Some of the projects were completed during the author's association with Western Photoair of Bakersfield, Calif.

TABLE 1. PROJECT DATA FOR DEVELOPING UNIT COSTS

Name	Photo Scale 1:	s/1%	Terr.	Cover	Area Sq. Mi.	No. Cont. Pts.	Total Pts.	Year
a. Wheeler Ridge 1	12,000	25	1	A	109	84	785	1966
b. Wheeler Ridge 2	12,000	25	1	A	104	73	512	1967
c. Buttonwillow	6,000	60	1	A	42	63	239	1972
d. San Jose Hills	6,000	60	3	C	4	12	424	1971
e. Sierra Hilands 2	12,000	25	3	C	9	6	132	1970
f. Sierra Hilands 3	12,000	25	2	B	11	8	72	1971
g. Sta. Maria Ranch 1	12,000	60	4	C	6	5	131	1972
h. Sta. Maria Ranch 2	12,000	60	4	D	14	9	191	1972
i. Sand Canyon	6,000	25	4	A	3	6	325	1970
j. Stallion Springs*	12,000	60	3	C	24	19	324	1971
k. Kennedy Meadows 1	12,000	25	2	C	6	7	32	1970
l. Kennedy Meadows 2	12,000	25	3	C	8	9	46	1971
m. Red Bluff	12,000	60	3	D	4	5	27	1971
n. Kelso Valley	12,000	25	4	A	8	8	43	1970
o. Squirrel Valley	12,000	25	4	B	3	6	24	1970
p. Lake Catahouchie	24,000	25	1	D	32	10	61	1968
q. Fayetteville	6,000	25	1	D	4	9	40	1969
r. Battle Mountain	6,000	25	1	A	4	9	26	1970
s. Mt. Rose	6,000	25	4	C	3	7	37	1969
t. Tehachapi	6,000	25	3	C	33	21	189	1971
u. Montello	24,000	60	3	A	43	13	133	1972
v. Onyx Valley	12,000	60	4	C	27	13	127	1972
w. Paiute Mtn.	6,000	25	4	D	2	5	28	1970
x. Mojave	12,000	25	2	B	6	8	23	1970

Terrain Codes: *1* = slopes to 10%; *2* = slopes to 30%; *3* = slopes to 50%; *4* = slopes to 100%
Cover Codes: *A* = open; *B* = 30% cover; *C* =60% cover; *D* = 100% cover

* This is a different project than reported on at San Francisco ASP-ACSM 1971 convention

included but travel and subsistence are excluded. It should be emphasized that hourly rates of field survey work will vary considerably from region to region and with the experience and proficiency of the field personnel. Photogrammetric costs shown have also been adjusted to 1972 prices but will vary depending on the prevailing labor rates, the equipment used, and the procedures followed.

FIELD CORNER SEARCH AND PREMARKING

These two steps involved in the search for field corners and in premarking points are usually performed as one operation and we include them together. The variables affecting costs of this work are terrain type, cover, and the average interval between the points. It should be noted that this step is common to all photogrammetric cadastral projects and is not directly related to project accuracy except for the size of the premarking target.

TERRAIN AND COVER

Terrain can be segregated by the maximum slopes found within the project. Projects having diversity of slope values may require division into areas of equal slopes for purposes of cost estimation. Figure 1 shows the maximum slopes which we have divided into four categories according to percentage of slope. Cover conditions that impede survey progress also affect the cost of corner search and premarking. We have also divided cover into four "percentage groups" as shown on Figure 2.

Figure 1 should be used to find the preliminary point cost for searching and premarking based on the average spacing between the points and the terrain type. The cost per point from Figure 1 is to be used as an entry into Figure 2 which adjusts the cost per point for the effects of cover.

GROUND CONTROL SURVEYS

Costs to be estimated for this item should include field reconnaisance for control point locations, the survey measurements, and premarking of the selected control points. The variables affecting control costs are the ease of vehicular access and the required positional point accuracy for the project. Figure 3 shows the correlation between the required number of ground control points, the project area and the photographic scale or point ac-

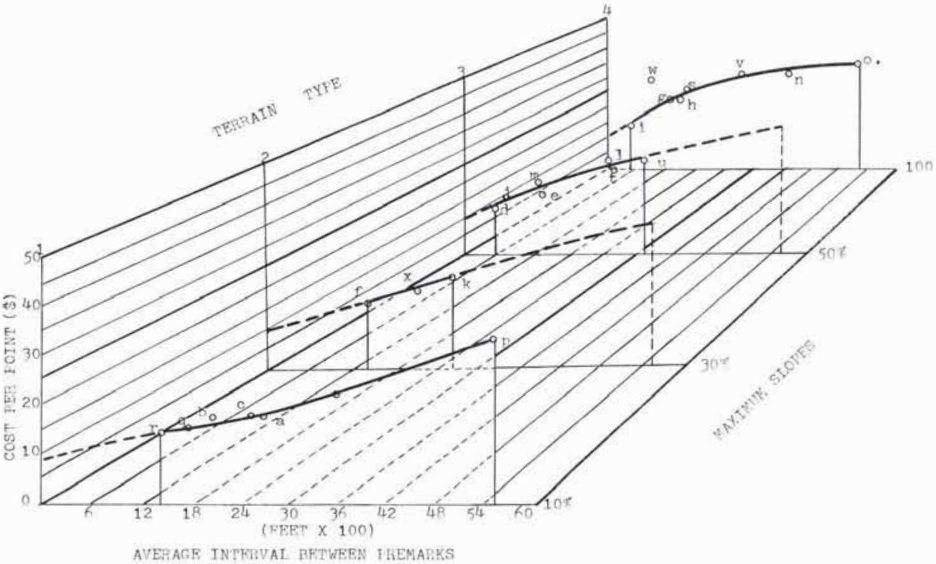

Fig. 1. Corner search and premarking costs relative to terrain slope.

curacy. The relationship between scale and required accuracy is discussed later. Briefly, we consider the ease of vehicular access, the required horizontal accuracy and the project area as the variables in estimating ground control costs.

GROUND CONTROL COSTS

The control survey methods used on these projects included trilateration, triangulation, and EDM traversing. We observed no significant differences between the costs and accuracies of the three methods except that closures on some of the steeply inclined traverses suffered.

Figure 3 should be used to find the average number of horizontal control points for the required point accuracy and the project area in square miles. *It should be noted that this figure uses the concept of positional accuracy for a point** rather than the accuracy ratio more commonly used by surveyors

* Italics added by Editor.

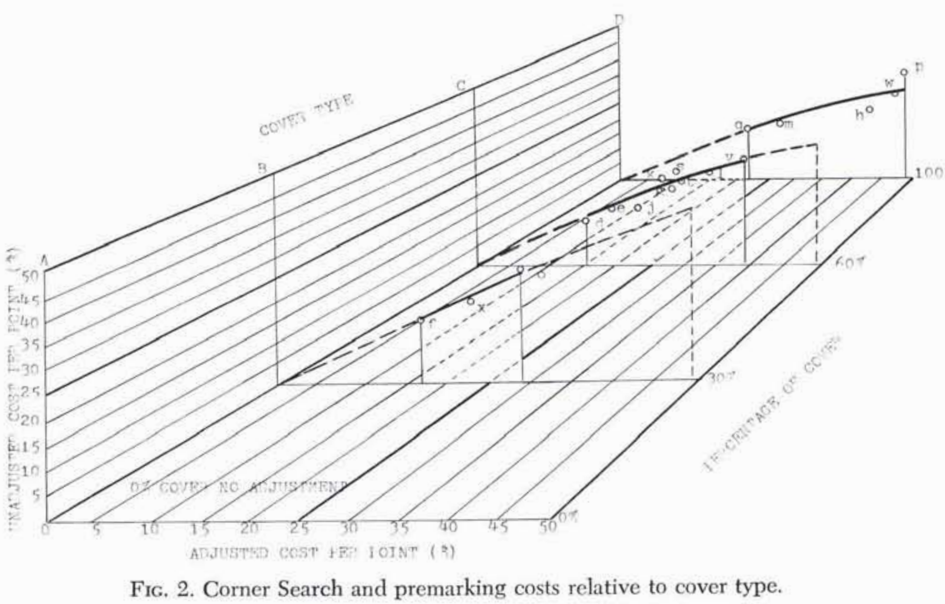

Fig. 2. Corner Search and premarking costs relative to cover type.

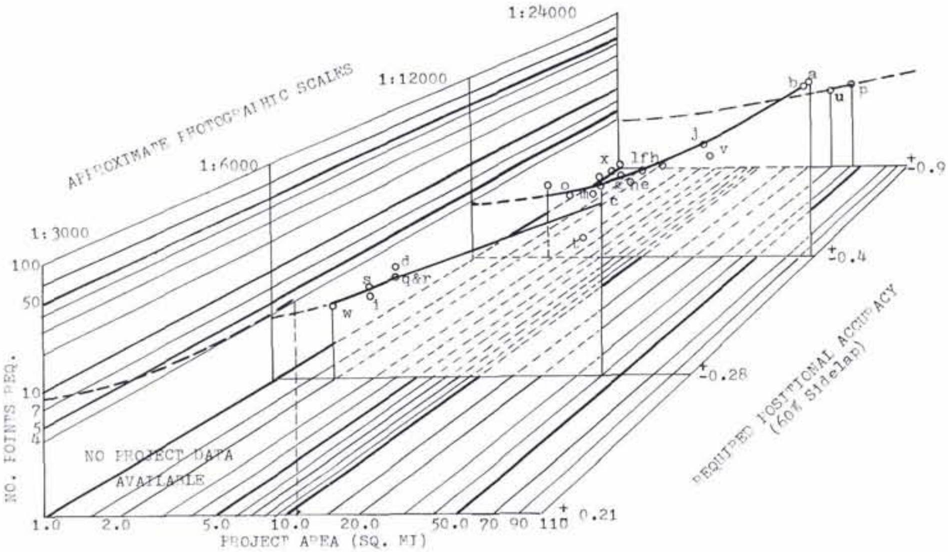

Fig. 3. Required ground control.

based on the distance between two points. It was noted that in most projects on which we have worked the actual number of control points established exceeded the theoretically minimum number. We attribute this to the limitations in intervisibility throughout the project and find that we set one control point for each four to five exposures on the average.

Vehicular access was divided into four categories ranging from no access (zero percent) to unrestricted access (100 percent). Figure 4 is used to find the approximate cost per control point based on the estimated

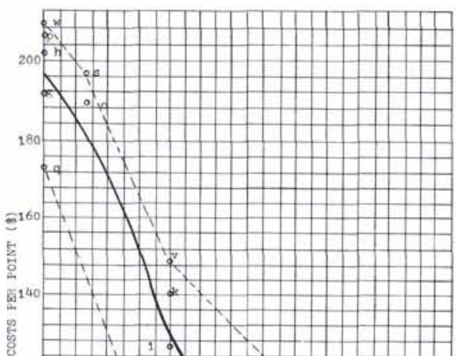

Fig. 4. Ground control costs.

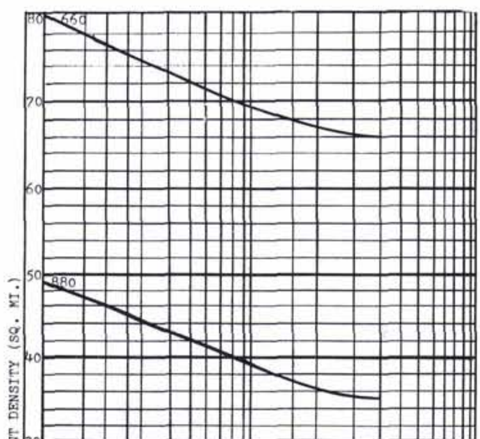

Fig. 5. Point interval-density curve.

project conditions of vehicular access. The total costs for the survey control would, of course, be the extension of this value and the total number of control points required from Figure 3.

Photogrammetric Costs

Photogrammetric costs for the cadastral survey include the costs for aerial photography, the necessary editing and point transfer work, comparator (or stereoplotter) measurements, and computer costs. These costs can be related to the number of points to be measured and the size of the project. Initially a density of estimated points per square mile should be computed for the proposed project. Most projects require points at common fractions of mile such as 660, 1320, 2640 and 5280 feet. Figure 5 estimates the density of points per square mile from the project area and average spacing between points for some common intervals.

Using the project point density, the photogrammetric costs per point for the specified accuracy can be read from Figure 6. It should be noted that the figure shows a fraction of the total projects in the study. The projects shown are those that have been completed within the last two years on which 60 percent sidelap between strips was used. Projects performed with sidelaps less than 60 percent would require acquisition of fewer photographs and reduced measurement costs.

Figure 6 shows the convergency of the different accuracy curves towards similiar point costs in two instances. It would be expected that this convergence would hold also for other accuracies and the conclusion can be drawn that for high densities of points there is no great economy to be gained from lower accuracy specifications. A nominal allowance of 50 miles is included for aerial photography cross-country (remoteness) charges but an additional allowance should also be made if the project is remote from the aircraft base of operations.

Photogrammetric Accuracies

Eighteen of the 24 projects used in this study were subjected to field checks. In all instances except one, at least 7 percent of all measured points were checked by field surveys. In the one instance, 5 percent of the points were checked. The results of these checks are shown on Figure 7.

Figure 7-left shows the accuracies obtained using semi-analytic methods during the 1960s. Contemporary techniques and equipment would undoubtedly show an improvement over our early results.

Figure 7-center shows the improvement in accuracies that were obtained using a monocomparator using fully analytical procedures and 25 percent side overlap. Figure 7-right represents the present stage of our development using flight lines with 60 percent sidelap and the use of a block *pre-assembly* routine. The curve in Figure 7-right comes close to equalling the best accuracies

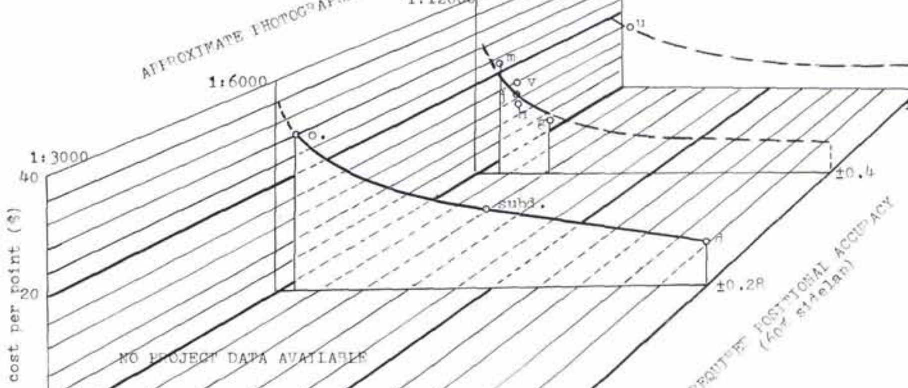

FIG. 6. Photogrammetric costs.

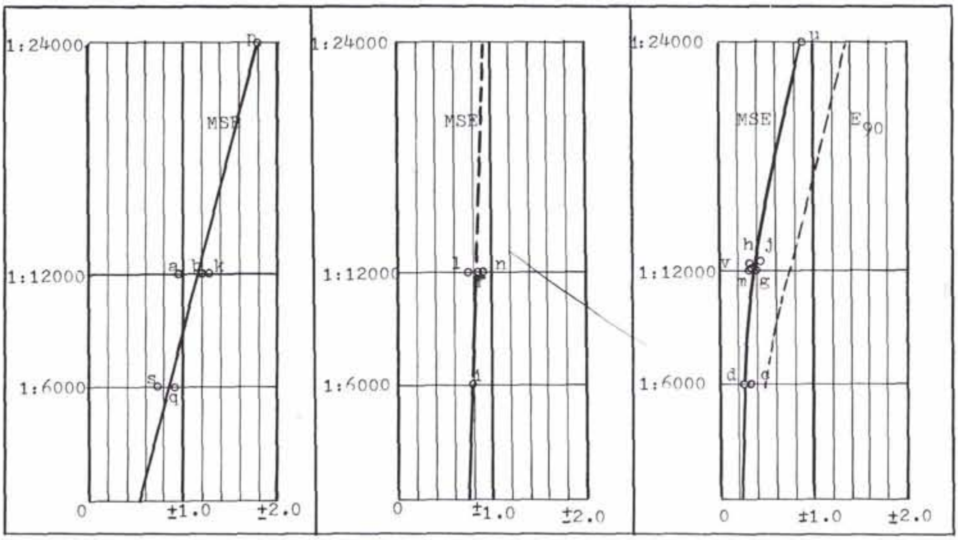

FIG. 7. Root-mean-square errors in feet obtained from field tests. *Left*—Semi-analytical methods in the 1960s. *Center*—Fully analytical method with 25 percent side overlap. *Right*—Analytical block pre-assembly routine with 60 percent side overlap.

obtainable today by conventional survey methods.

In our experience, these accuracies equal or exceed the accuracies obtained by conventional survey methods in areas of heavy cover or steep terrain. The block *pre-assembly* described at the San Francisco ASP-ACSM Fall Convention in 1971 has also furnished us with an excellent method of testing photogrammetric accuracies and for isolation of field control errors.

We believe that the accuracies in Figure 7-C do not represent the ultimate accuracies obtainable. They are the best that we can consistently accomplish at this time, and were adopted as the design accuracies in this study.

Final Monumentation

Two associated steps of computation and monumentation are usually necessary to complete the cadastral survey. The computation of the true corner positions can easily be performed using a coordinate geometry routine such as COGO programed to read point coordinates directly from the block adjustment output. We have added some special cadastral subroutines for single- and double-proportioning and for offsetting of points for the latitudinal curve.

The costs for these calculations run around $1.00 per point including a closed traverse with area around each parcel. The same program is used to precalculate angles and distances from premarks to final corner positions for use by the survey crews.

Records should be kept by the field surveyors of points which are intervisible during the initial search and premarking. This allows the necessary calculations to be performed in the office.

Our cost information on the final monumentation of corners is incomplete for the four types of terrain and cover although indications are that costs are similiar to the cost of searching and premarking points. We use the point cost developed from Figures 1 and 2 for the point cost of final monumentation. Hopefully additional data will be compiled from which we can derive more specific costs for this step.

Cost Savings

The estimated cost savings to be realized from the photogrammetric project requires a cost estimate be prepared for the project

TABLE 2. PHOTOGRAMMETRIC COSTS FOR A SAMPLE PROJECT

Project Conditions: Slopes to 40% with 67% estimated cover. Vehicular access to 50% of project.
Project Area: 13 Square Miles
Project Requirements: Recover and set all section and quarter corners including center quarter corners with an accuracy of 1:500 = ± 0.38 ft.
Interval of corners: 2640 feet
No. of cors premarked: 71
No. of cors established: 36
Cost per pt. (30% slopes from Fig. 1) 2640 ft. = \$ 22.50
Cost per pt. (50% slopes from Fig. 1) 2640 ft. = \$ 25.00
Calc cost per pt. for 40% slopes = \$ 23.75
Adjusted cost for cover conditions (Fig. 2) = \$ 29.00
No. of ground control pts. for ± 0.39 (Fig. 3) = 8
Cost per pt. for ground control (Fig. 4) = \$110.00
Pt. density of project (Fig. F Curve 2) 5 pts. sq. mile
Photogrammetric costs per pt. (Fig. 6) \$ 23.00

Time and Cost Summary

Corner search and premark	71 @ \$ 29.00	\$2059
Ground Control	8 @ 110.00	880
Photogrammetric work 71 + 8 =	79 @ 23.00	1817
Calculations	71 @ 1.00	71
Set final monuments	36 @ 29.00	1044
Total Costs		\$5871
	Sq. Mile	\$ 450

Critical path time 40 cal. days

using conventional procedures. We suggest that the survey engineer interested in a comparative analysis utilize his own cost data for the estimated cost of the conventional survey approach.

We have included in Table 2 a sample calculation for a cadastral project using the photogrammetric approach. Table 3 gives the estimated costs for the same survey performed by conventional methods. The estimated costs shown would not apply for all areas or even for different survey or photogrammetric firms in the same area. Within reason, though, we have found that field survey costs for the photogrammetric project vary in the same fashion as the costs for the conventional approach. This tends to equalize costs and preserve cost benefits

TIME SAVINGS

The time for completion of the photogrammetric cadastral project should be estimated if required for comparison with conventional procedures. A quick calculation of field survey time requirements can be made using the total estimated field costs divided by the prevailing cost per hour of the survey crew to be used.

Estimating the time requirements for the photogrammetric work is more complex and depends on weather, work load of the photogrammetrist and completion of the field search and premarking. Generally we plan on one week for completion of the aerial photography and one additional working day for each three photographs for editing, measurement and computer processing.

TABLE 3. CONVENTIONAL SURVEY COSTS FOR A SAMPLE PROJECT

Corner Search 2 mean	29 hrs. @ \$32.00	\$ 928
Angle and dist. measure.	158 hrs. @ 32.00	5056
Office calcs. and adjust.	140 hrs. @ 12.50	1750
Set final mons.	25 hrs. @ 32.00	806
Total Costs		\$8540
	Sq. Mile	\$ 657

Critical path time 52 cal. days
Approx. horiz. accuracy obtained ± 0.25 ft.

EFFICIENCIES

The comparative efficiency of one particular survey procedure over another can be expressed as ratios of costs, time or accuracies. Using the appropriate values from Tables 2 and 3 we could express the combined efficiency of the photogrammetric over the field method:

$$E = \frac{(\$8540)(52)(0.25)}{(\$5871)(40)(0.39)} = 1.21$$

A ratio greater than 1.0 favors the photogrammetric procedure.

The relative benefits of reduced costs, time saved and accuracies cannot always be treated by mathematical relationships, nevertheless consideration of these may crystalize the importance of each item for the survey engineer and assist him to a rational method of selecting his survey methods.

CONCLUSIONS

Cost accounting and time estimation on photogrammetric cadastral surveys can produce useful relationships to the photogrammetrist and the survey engineer for evaluating the benefits of the aerial approach.

Analytical photogrammetric measurements can offer the survey engineer not only savings in costs and time but also adequate or improved accuracies under certain conditions.

Little cost-per-point savings accrue from *low-accuracy, high-altitude* projects where point densities are high.

BIBLIOGRAPHY

BERNS, THOMAS B., 1970, "The Use of Electronic Distance Measuring Devices and Photogrammetry in the Small Land Surveying Firm," *Technical Papers from the 30th Annual Meeting ACSM*, pp. 20.

BERNS, THOMAS B., 1971, "Analytical Photogrammetric Methods as Applied to Land Surveying Problems," *Proceedings of the 1971 ASP-ACSM Fall Convention.*

CHAVES, JESSE R., 1968, "A Comparison of Two Methods of Analytic Aerial Triangulation for Highways," *Papers from the 34th Annual Meeting, American Society of Photogrammetry*, pp. 91.

LAFFERTY, MAURICE E., 1971, "Photogrammetric Control for Subdivision Monumentation," *Proceedings of the 1971 ASP-ACSM Fall Convention.*

TEWINKEL, G. C., 1970, "Accuracy of Block Aerotriangulation," *Papers from the 1970 ACSM-ASP Technical Conference*, pp. 435.

TEWINKEL, G. C., 1971, "Photogrammetric Geodesy," *Symposium Papers ASP-ACSM Fall Convention.*

TEWINKEL, G. C., 1972, "Aerotriangulation for Control Surveys," *Surveying and Mapping*, 32:1 pp. 39-51.