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Cost Analysis for Aerial Surveying

A flexible system enables forecasting for almost all possible operational circumstances.

ABSTRACT: *A semi-empirical cost estimating and scheduling determination procedure for aerial surveying operations is based on a detailed analysis of more than 200 aerial surveying projects ranging from $500 to $250,000 in value, and covering 12 years of domestic and foreign experiences. The result of the procedure is a cost estimation deviating no more than 12 per cent from the actual cost of the operations, and covering from aerial photography and ground control up to map reproduction.*

COST ESTIMATING AND SCHEDULING of engineering projects are two of the most important responsibilities of the management of any engineering firm. A poor estimating procedure will produce either a loss of money or unrealistically high prices. Poor scheduling normally will end in client dissatisfaction, unexpected delays, low technical efficiency, and most of the time will result in loss of clients and future jobs.

Good guide lines, for estimating and scheduling, are not generally available. Cost estimating and scheduling, normally, are not taught at any university and the interested individual usually learns it by the famous "trial and error procedure." Consequently, his technical approach and working philosophy will depend on the type, frequency, and complexity of the projects that he has handled.

A young engineer, almost immediately after his graduation, will face two of the most important questions in technical business: *How much?* and *How long?* In civil engineering construction projects we have the construction unit price system. This system has worked with very little difficulty and the beginner can master it in a relatively short time. In aerial surveys, on the other hand, the unit price system has faced many difficulties. Many have tried to develop a cost per acre, or draw cost curves, but this has only been successful when the physiographic, cultural, and technical circumstances, and client's desire could be standardized. This is an oversimplification that seldom occurs.

THE PROCEDURE DESCRIBED in this article is based on the civil engineering philosophy of

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TABLE 1

COST RANGE

Project Cost (Dollars)	*Percentage of Total*	*Number of Projects*
500–1,000	17	40
1,000–5,000	52	123
5,000–20,000	23	55
20,000–100,000	7	17
100,000–250,000	1	2
	100	237

TABLE 2

AVAILABLE INFORMATION

Information Available	*Number of Projects (Per Cent)*	*Cost of Projects (Per Cent)*
Total Price	15	31
Major break-down	20	69
Detailed break-down	65	

unit prices adapted to aerial surveying. The units are not acres, photos, square inches, nor models, but a combination of several of these units, because it is impossible to estimate the cost of aerial surveys based upon a single unit expression.

The data analyzed comprises information obtained from 237 aerial surveying projects ranging from $500 to $250,000 in value. The distribution of projects by cost range is shown in Table 1. The amount of information obtained varies from only a total cost up to detailed information about the individual steps in the projects; the information available versus number of projects and their costs is shown in Table 2. Projects were done in California and Cuba, proportional price conversion, based on salary ranges, were necessary and West Coast standards were chosen for the analysis and presentation of the data. The number of technical personnel ranged from a minimum of 12 to a maximum of 35 and included civil engineers, land surveyors, photogrammetrists, aerial photographers, draftsmen, and laboratory technicians. Field control comprised work done by traversing, subtense bar three-tripod technique, trilateration and triangulation, and differential trigonometric and barometric leveling, using such instruments as the optical theodolite, precise tilting level, automatic level, and electrotape.

Photogrammetric work was done with the Wild A-8 autograph, and with the Kelsh and Multiplex plotters, using analog and analytic techniques. Types of projects ranged from regular topographic and planimetric mapping to sophisticated cadastral and land evaluation mapping. The data gathered included work done in pencil, ink and scribing; highly developed map presentations and complicated reproduction techniques involving automatic lettering machines, press work, color separation, half tone work and use of copying camera. The project areas ranged from a few acres up to a whole county. The data available extends through 12 years of continuous work, from 1952 to 1964. (Table 3)

USING ALL THE DATA available, the cost per acre was computed for each project. It was found that the cost per acre, for the same scale and contour interval, varied within broad limits, so a set of graphs were constructed showing the maximum and minimum cost per acre for each of the following scales—40, 50, 100, 200, and 400 feet per inch (Table 3). On each graph three curves were drawn representing the total cost per acre for aerial photography, map manuscript preparation, and drafting. These graphs are shown in

TABLE 3

SCALES

Type of Work	*Scale*	*Number of Jobs (Per Cent)*	*Cost of Projects (Per Cent)*
Topographic and Planimetric Maps	1 in. = 20 ft.	2	65
Topographic and Planimetric Maps	1 in. = 40 ft.	20	
Topographic and Planimetric Maps	1 in. = 50 ft.	23	
Topographic and Planimetric Maps	1 in. = 100 ft.	37	
Topographic and Planimetric Maps	1 in. = 200 ft.	12	
Topographic and Planimetric Maps	1 in. = 400 ft.	3	
Cadastral-Inventory	1:3,000	2	3
General Planning	1 in. = 500 ft.	1	32

Figures 1 and 2. The scale of 20 ft. per inch was discarded because of the small number of projects available in that scale.

In this general analysis it was found that the approximate average time of completion of an aerial surveying project could be expressed by the following relation.

$$t = 0.01T$$

where t is the time of completion in days, after receiving the aerial photos, and T the total cost of the project in dollars.

From the 237 projects analyzed, 74 per cent were within the cost per acre values indicated by the graphs in Figures 1 and 2; 15 per cent showed a maximum deviation of 25 per cent from the curves plotted, and the remaining 11 per cent showed a maximum deviation of 50 per cent. As was expected, the cost per acre was found to be an inverse function of the project acreage; the cost per acre tended to be constant where the project area approached a large value; and this project area value depended on the particular map scale in question and increased as the scale diminished.

These graphs are useful only as general guide lines and not as reliable estimates.

To develop a more sophisticated cost-scheduling estimate, the work was divided into 10 main man-hour generating phases, 0 to 9, as shown in Table 4. These phases were subdivided, in minor steps up to a total of 40. The dollar generating phases, or expenses were grouped in 12 major divisions, A to L, as indicated in Table 5. These expense items were subdivided into smaller units up to a total of 23. Reporting forms were prepared and circulated for office and field employees to fill out and return, indicating the amount of work performed, the time taken to do it, and the expenses or dollar generating units used.

With the detailed data gathered during the four years of using the above system plus the fractional information of previous years a system of formulas was developed for computing the number of man-hours and dollar amounts employed to perform each of the operations of an aerial surveying project based upon a system of units and two sets of constants that weighed each physiographic, cultural and technical condition required to perform the job. Two sets of constants—the field constants and the office constants—were developed because it was impossible to intermix or weigh the field and office circumstances at the same time and under the same weighting system.

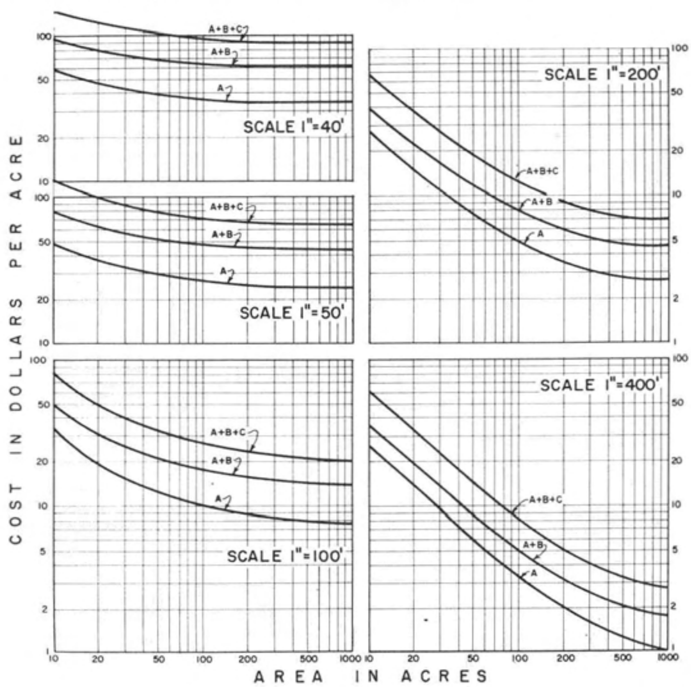

FIG. 1. Maximum cost versus area. A—aerial photography and map manuscripts. B—Drafting. C—Ground control. $t=0.01\ T$. T—Total cost. t—Approximate time of completion (days after receiving the aerial photographs).

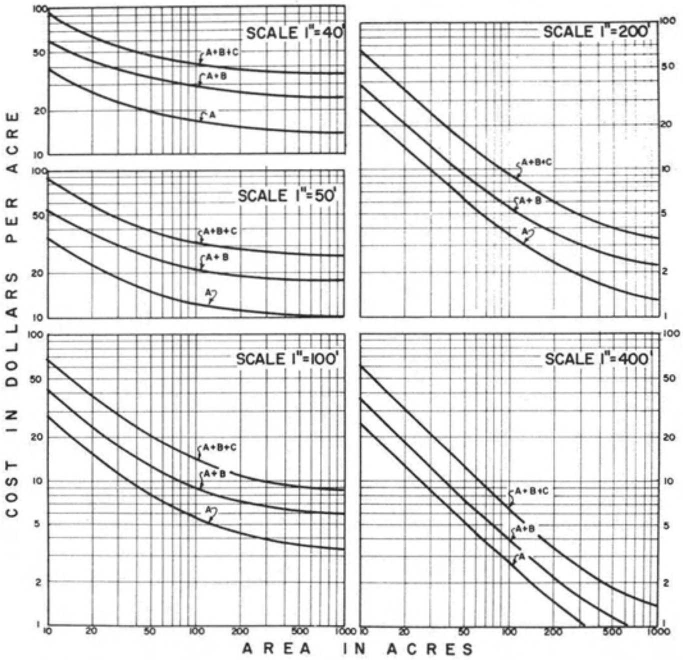

FIG. 2. Minimum cost versus area. *A*—Aerial photography and map manuscripts. *B*—Drafting. *C*—Ground control. $t=0.01\ T$. *T*—Total cost. *t*—Approximate time of completion (days after receiving the aerial photographs).

THE LIST OF THE 18 field constants is shown in Table 6. The list of the 26 office constants is shown in Table 7. 183 combinations and circumstances were tabulated, analyzed, and weighed, after which sets of environmental factors, (*F*-factors) were developed, one for each of the various operations up to a total of 63.

Each environmental *F*-factor was a function of the sets of office or field constants and the mathematical expression varied for each *F*-factor. We concluded that, from the practical point of view, it was sufficient to consider the *F*-factor as a straight summation of constants, affected by suitable coefficients with the exception of a few cases, where multiplication of constants was necessary. This simplified the computational procedure and considerably reduced the time necessary for the preparation of an accurate estimate.

The set of environmental-technical factors (*F*-factors), their formulas and range of values are shown in Table 8.

The following is a description of the main man-hour generating steps, and expense items, its scope, formula and notation.

TABLE 4

MAN-HOUR GENERATING PHASES

Group	*Phase*
0	Direction
1	Aerial Photography
2	Ground Control
3	Photogrammetric Control
4	Restitution
5	Edition
6	Cadastral Work
7	Field Completion
8	Drafting
9	Reproduction and Completion

TABLE 5

DOLLAR GENERATING PHASES (EXPENSES)

Group	*Division*
A	Aerial Photography
B	Photo-enlargements
C	Reproduction
D	Surveying Instrumentation
E	Per Diem
F	Transportation
G	Control Identification
H	Photogrammetric Control Instrumentation
J	Restitution Instrumentation
K	Drafting Material
L	Reproduction Material

TABLE 6

FIELD CONSTANTS

Circumstances	*Constants*
Measuring method	*A*
Precision of measurements	*B*
Relief	*C, H*
Travel ground conditions	*D, J*
Ground coverage	*E*
Traffic conditions	*F, K*
Computation methods	*G*
Crew-members	*L, M*
Surveying instrument used	*N*
Pre-marking and signalization	*P, S*
Monumentation	*Q*
Weather conditions	*R*

OPERATION NO. 2—Ground Control (man hours)

Scope

Number of man hours necessary to perform all ground surveying measuring operations, travelling, monumentation, and signalization to provide horizontal and vertical control to stereoscopic models. Does not include ties to existing horizontal control points and bench marks; these tie-in operations have to be computed using the same following formula based upon hypothetical stereoscopic models running from the existing points to the mapping area.

Formulas

$$F1 = .002(sh)$$

$$F2 = .001(sv)$$

$$F3 = .0006(w)$$

$$(F20)(nh)(F1)(R) \quad (2a)$$

$$+ (F21)(nv)(F2)(R) + (F22)(nv)(F3)(R) \quad (2b)$$

$$\left.\begin{aligned} &+ (F23)(Mo)(.2)(R) + (F24)(Pm)(.2)(R) \\ &+ (F25)(Dh)(.02)(R) + (F26)(Dv)(.02)(R) \\ &+ (F27)(Dt)(.02)(R) \end{aligned}\right\} (2c)$$

$$+ (F28)(2a)(.5) + (F29)(2b)(.5)$$

Notation

sh = Scale of models to be horizontally controlled (ft/in)
sv = Scale of models to be vertically controlled (ft/in)
w = Vertically controlled flight width (ft)
nh = Number of models to be horizontally controlled
nv = Number of models to be vertically controlled
Mo = Number of monuments established in the field
Pm = Number of signals and pre-marks erected in the field
Dh = Miles of travel for horizontal control measurements
Dv = Miles of travel for vertical control measurements
Dt = Miles of travel from base and/or office to working area
F20 to F29 = Environmental and technical factors of the operations
R = Weather-crew men factor.

OPERATION NO. 3—Photogrammetric Control

Scope

Man hours necessary to perform photogrammetric operations and calculations to extend the horizontal and vertical controls established on the ground by field methods.

Formulas

$$(F30)(mc)(1.2) + (F31)(Nc)(.12)$$

$$\left.\begin{aligned} &(F32)(nc)(.24) + (F33)(nc)(.12) \\ &\quad + (F34)(nc)(.12) \end{aligned}\right\} (3a)$$

$$(F35)(h)(.01) + (F36)(v)(.005) + (mc)(.2) \quad (3b)$$

Notation

mc = Number of manuscript sheets
Nc = Number of ground horizontal controls available
nc = Number of stereoscopic models to control
h = Number of horizontal control points to establish
v = Number of vertical control points to establish
(F30 to F36) = Physiographic, cultural and technical factors

OPERATION NO. 4—Restitution

Scope

Man hours necessary to perform all the photogrammetric operations for the compilation of maps in manuscript form.

TABLE 7

OFFICE CONSTANTS

Circumstances	*Constants*
Urbanization conditions	*A*
Relief	*B*
Vegetation	*C*
Visible ground	*D*
Scale factors	*J, K*
Photogrammetric Instrument	*E, Z*
Drafting techniques	*F*
System of coordinates	*G*
Plotting technique	*H*
Photogrammetric orientation procedure	*I*
Scale and contour interval	*L*
Lettering technique	*P*
Title & Notes	*Q*
Scale ratio	*U*
Screen processing	*V*
Base of drafting materials and reproduction	*W*
Emulsion of reproduction material	*X*
Flying distance	*Y*
Quantity of aerial photography items	*O*
Urbanization details	*M*
Vegetation details	*N*
Symbols	*R*
Reproduction printing technique	*S*
Reproduction processing technique	*T*

TABLE 8

ENVIRONMENTAL-TECHNICAL FACTORS

F-Factor	*Formula*	*Range*
F20	$A+B+C+D+E+F$	1 to 12.8
F21	$A+B+C+D+E+F$	1 to 12.8
F22	$A+B+C+D+E+F$	1 to 12.8
F23	$Q+H+J+K+M$	.05 to 9.1
F24	$P+H+J+K+M$	0 to 10.1
F25	$1+H+J+K$	1 to 5.1
F26	$1+H+J+K$	1 to 5.1
F27	$1+H+J+K$	1 to 5.1
F28	$G\div R$	.5 to 11.2
F29	$G\div R$	.5 to 11.2
F30	$.2\mathrm{F}+G+H$	.1 to 2
F31	H	.1 to 1
F32	$.3B+D+E+I$	1 to 7.9
F33	$.1B+.1D+E+I$	1 to 2.9
F34	$.1B+.2D+E+I$	1 to 3.3
F35	$.1B+E+I$	1 to 5.8
F36	$.2B+E+I$	1 to 6.1
F40	$.2F+G+H$	.1 to 1.6
F41	H	.1 to 1
F42	$.3B+D+E+I$	1 to 7.9
F43	$.1B+.1D+E+I$	1 to 2.9
F44	$.1B+.2D+E+I$	1 to 3.3
F45	$A+.1B+.2C+E+AF+AJ+AM+N$	.03 to 391.4
F46	$.1A+B+.2C+E+BF+BK+BL$	0 to 20.4
F52	$.1B+I$	1 to 2.3
F55	$A+.1B+.2C+AJ+AM+N$	.03 to 391.2
F56	$.1A+B+.2C+BK+BL$	0 to 20.2
F80	$.2F+G+H$	.1 to 2
F81	H	.1 to 1
F82	$A+.1B+AF+AJ+AM+N$	.03 to 391.2
F83	$.1\mathrm{A}+B+BF+BK+BL$	0 to 20.2
F84	$A+AJ+AP$	0 to 7.4
F85	$B+BK+BL+BP$	0 to 16.4
F86	$P+Q$	0 to 3
F87	R	0 to 1.4
F94	$A+AJ+AP+.1S+.1T$	.1 to 8.2
F95	$B+BK+BL+BP+.1S+.1T$	.1 to 17.2
F96	$P+Q+.1S+.1T$	.1 to 3.8
F97	$R+S+T$	.1 to 8.4
F98	$S+T$	.1 to 7

Formulas

$$a = 43{,}560\,\frac{\mathrm{Am}}{\mathrm{S_r}^2}$$

$$\left.\begin{aligned}&(F40)(m)(1) + (F41)(Nr)(.1)\\&+(F42)(n)(.2) + (F43)(n)(.1)\\&\quad + (F44)(n)(.1)\end{aligned}\right\}\ (4a)$$

$$\left.\begin{aligned}&+ (F45)(a)(.008) + (F46)(a)(.008)\\&\quad + (m)(.2)\end{aligned}\right\}\ (4b)$$

Notation

Am = Mapping area (acres)
Sr = Scale of Restitution (ft/in)
a = Area of Compilation (sq-in)
m = Number of manuscript sheets
Nr = Number of horizontal control points to plot on manuscripts
n = Number of stereoscopic models to restitute
F40 to F46 = Physiographic, cultural and technical factors

OPERATION NO. 5—Edition

Scope

Man hours necessary to perform the operations of checking and editing the map manuscripts prepared during the restitution.

Formula

$$(m)(.1) + (F52)(a)(.005) + (F55)(a)(.001)$$
$$+(F56)(n)(.001) + 1$$

Notation

m = Number of map manuscripts to edit
a = Area of mapping at manuscript scale (sq-in)
(F52 to F55) = Physiographic, cultural and technical factors

OPERATION No. 8—Drafting

Scope

Man-hours necessary to perform the drafting and finishing of the map manuscript, in sheets of suitable and convenient size, format and orientation, including hand-drawn lettering, titles, symbols and notes.

Formula

$$ad = 43{,}560(Am/S_d^2)$$

$$(F80)(Ds)(1) + (F81)(Nd)(.1) + (F82)(ad)(.007) + (F83)(ad)(.007) + (F84)(ad)(.001) + (F85)(ad)(.001) + (F86)(Ds)(1) + (F87)(ad)(.002)$$

Notation

Am = Mapping area (acres)
ad = Drafting area (sq-in), (Mapping area at drafting scale)
Sd = Drafting scale (ft/in)
Ds = Number of drafting sheets
Nd = Number of available horizontal control
F80 to F84 = Physiographic, cultural and technical factors

OPERATION No. 9—Reproduction

Scope

Man hours necessary to perform the preparation of titles, names, and symbols by means of reproduction techniques such as diazo, photographic, etc., also to reproduce the drafting sheet by contact copying. No scale copying has been considered under this operational item.

Formula

$$(F94)(ad)(.001) + (F95)(ad)(.001) + (F96)(Ds)(1) + (F97)(ad)(.002) + (F98)(rm)(.0001) + (Pr)(.1)$$

Notation

ad = Drafting or mapping area (sq-in)
Ds = Number of drafting sheets
rm = Area to reproduce or copy (sq-in)
Pr = Number of sheets to copy or reproduce

EXPENSE A—Aerial Photography

Scope

Amount of dollars necessary for the taking of the aerial photographs; printing and processing aerial negatives, prints, and glass diapositives. Labor, material, overhead and profit included.

Formula

$$(F10a)(50) + 100 + (F11a)(Np)(7) + (F12a)(Op)(5) + (F13a)(Pp)(1)$$

Notation

Np = Number of aerial negatives
Dp = Number of glass diapositives
Pp = Number of prints
(F10a to F13a) = Technical factors

EXPENSE B—Photo Enlargements

Scope

Amount of dollars necessary for the preparation of photo enlargements of existing aerial photos. Un-rectified and semirectified, continuous and half tone photo enlargement; labor, material, overhead and profit included.

Formula

$$(F14b)(pm)(.01) + (F15b)(Pe)(1) + 30$$

Notation

pm = Material area of photo enlargement (sq-in)
Pe = Number of photo enlargements produced
F14b to F15b = Technical factors

EXPENSE C—Reproduction

Scope

Amount of dollars necessary for the preparation of enlarged, reduced, or contact copies of maps using continuous or half tone processing. Includes labor, material, overhead, and profit.

Formula

$$(F16c)(em)(.01) + (F17c)(Ec)(1) + 20$$

$$(F18d)(cm)(.01) + (F19d)(cc)(1) + 10$$

Notation

em = Material area of enlarged-reduced copy (sq-in)
Ec = Number of enlarged-reduced copies
cm = Material area of contact copy (sq-in)
cc = Number of contact copies produced
F16c to F19d = Technical factors

EXPENSE D—Surveying Instrumentation

Scope

Amount of dollars for depreciation recovery or instrumentation rental.

Formula

$$(F20a)(2a)(2) + (F21a)(2b)(2)$$

(2a)(2b) See Operation No. 2

F20a to F21a = Technical-rate factors

EXPENSE E—Per Diem

Scope

Amount of dollars for subsistence allowance (food and lodge) paid to overnight employees.

Formula

$$(F22b)[(2a) + (2b) + (2c)](.12)$$

(2a)(2b)(2c) See Operation No. 2

F22b = Rate factor

EXPENSE F—Transportation

Scope

Amount of dollars for depreciation recovery fund and for maintenance cost; or rental cost of vehicles.

Formula

(F23c)(Dh)(.1) + (F24c)(Dv)(.1) + (F25c)(Dt)(.1)

Notation

Dh, Dv, Dt—See Operation No. 2
F23c to F25c = Technical-rate factors

EXPENSE G—Control Identification

Scope

Amount of dollars necessary for covering the cost of erection or construction of monuments, pre-marking and signals necessary for control identification both from the air and ground.

Formula

(F26d)(Mo)(2) + (F27d)(Pm)(1)

Notation

Mo, Pm = See Operation No. 2
F26d to F27d = Technical-cost factors

EXPENSE H—Photogrammetric Control Instrumentation

Scope

Amount of dollars for depreciation recovery, or rent for instrumentation for photogrammetric control.

Formula

(F30a)[(3a) + (3b)](10)

Notation

(3a)(3b)—See Operation No. 3
F30a = Technical-rate factor

EXPENSE J—Restitution Instrumentation

Scope

Amount of dollars for depreciation recovery or rent for instrumentation for photogrammetric restitution.

Formula

(F40a)[(4a) + (4b)](10)

Notation

(4a)(4b)—See Operation No. 4
F40a = Technical-rate factor

EXPENSE K—Drafting Material

Scope

Amount of dollars for covering the cost of drafting medium including paper, stable film, scribing film, etc. if this is a major item in a project.

Formula

(F31b)(ac)(.001) + (F41b)(am)(.001)
+(F80a)(dm)(.001)

Notation

ac = Sq. in. of manuscript material necessary in Operation No. 3
am = Sq. in. of manuscript material necessary in Operation No. 4
dm = Sq. in. of drafting sheet material necessary in Operation No. 8
F31b to F80a = Technical factors

EXPENSE L—Reproduction Material

Scope

Amount of dollars for covering the cost of reproduction medium such as paper or film with sensitive emulsion on it.

Formula

(F90a)(ar)(.001)

Notation

ar = Sq. in. of reproduction material required in Operation No. 9
F90a = Technical-rate factor

THE DATA FOR operation No. 6, Cadastral Work, and No. 7, Field Completion, was not sufficient to provide the statistical background for developing the empirical-environmental factors. The operation No. 0—Direction was found to be approximately 10 per cent of the sum of all the man-hours involved in phases 1 to 9. For aerial surveying organizations without in-house aerial photography facilities, a 10 per cent of the cost of expense A converted to man-hours and listed as Operation 1—Aerial Photography proved sufficient for handling the processing and filing of orders and materials subcontracted.

Knowing the man-hours of all the operations of an aerial survey project; and the prevailing local hourly wage for typical available employees for each operation, a simple multiplication of these elements plus expenses A to L gave the cost of a project. Or, if preferred, the cost of the project to the client may be obtained by multiplying the hourly-rate by the estimated man-hours, and then adding a mark-up factor based on a percentage of the man-hour cost. This mark-up factor will contain salary paid to employees plus fringe benefits, taxes, building or floor space rent, general office maintenance expenses, and profit.

Knowing the man-hours required for each step, it will be easy to determine the total man-hours in a job, scheduling every operation, and determining the number of shifts necessary to meet a fixed delivery date.

THE RESULTS OBTAINED with the previous set of formulas are summarized on Table No. 9. The best results are obtained in the range of $1,000 to $5,000 jobs as should be expected because 52 per cent of the projects handled were located in that bracket. The amount of

TABLE 9

MAXIMUM COST DEVIATION

Project Cost (Dollars)	*Maximum Deviation between Actual and Estimate Cost (Per Cent)*
500–1,000	12
1,000–5,000	3
5,000–20,000	7
20,000–100,000	11
100,000–250,000	12

time consumed in processing orders, in filing, and unfiling, in cost control, and other small but always additive office operations, that are necessary parts of any business have been empirically incorporated into the formulae presented. These are the elements that vary from organization to organization. The technical elements are in general very similarly handled provided capable technical direction and experienced employees are available. In order to be effective, the described cost-scheduling estimation procedures have to be adapted or tailored to the particular conditions of each surveying organization, modifying the environmental-technical factors by adjusting the field and office constants to the local circumstances.

The system presented is a very flexible one and will accommodate almost all possible circumstances that a client could imagine. It permits computing in advance the time and cost involved in producing small or large projects and practically figuring them map sheet by map sheet, manuscript by manuscript, even model by model, and to control the performance and cost of subcontractors without the risk involved in guess-work.

Eight programmed forms are necessary for computing the cost estimate and schedule of aerial surveying operations. Using these forms, the man-hours expended in the preliminary planning and estimating can be computed using the following expression:

$$t = 0.5 + 0.0001T$$

t = Average man-hours expended in preliminary planning and estimating

T = Estimated total mark-up cost of the project (dollars).

WE HOPE THAT we will be able in the future to complement our investigation and develop our system further to cover the cadastral and field completion work we have omitted. We also plan to develop further the photogrammetric control formula, presently limited to the so called "high-low flight technique," toward the inclusion of both analytical and analog aerial triangulation technique and to study and develop man-hour formulas for the aerial photography operations.

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