A Measure of the Economic Impact of Urban Horizontal Geodetic Control Surveys

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey
National Geodetic Survey

PREFACE

This paper was originally presented as a thesis to the Faculty of the Graduate School of Cornell University for the Degree of Master of Science by Lieutenant Commander Phillip C. Johnson. Only minor changes have been made in the original text.

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INTRODUCTION

Accurate maps and charts have made a little recognized but significant contribution to our nation. These maps and charts are based on geodetic control surveys which determine the coordinates of permanently monumented points on the ground. These monumented control points are then used as the basic references by which all features, natural and cultural, are portrayed with precise relative position to each other on maps and charts.

There are three coordinates which can be associated with each monumented ground point. One coordinate defines the monument's vertical distance above mean sea level (elevation), and the other two coordinates define the monument's horizontal position on the earth's surface (these coordinates could be in feet or meters or geodetic latitude and longitude). Because the procedures used to determine elevations are significantly different from the procedures used to determine latitude and longitude, this has led to the natural division of geodetic control surveying into vertical control surveys and horizontal control surveys. This paper is concerned with the latter.

The history of horizontal geodetic control surveying in the United States began on February 10, 1807, when

Congress passed an act which authorized the President "... to cause a survey to be taken of coasts of the United States,..." [1]

> President Thomas Jefferson and the Secretary of the Treasury Albert Gallatin, men of learning and insight, recognized the necessity of starting this work properly. Jefferson asked the learned scientists of the American Philosophical Society to suggest qualified persons; then he asked those persons to propose methods for undertaking the work.
>
> Proposals were submitted within several months by Robert Patterson, Andrew Ellicott, John Garnett, Isaac Briggs, Joshua Moore, James Madison, and Ferdinand Hassler -- all recognized men of accomplishment. The best was that of Hassler's, a Swiss geodesist and scientist of outstanding reputation. It provided for the determination of true geographic position by astronomical means at key points near the coast, networks of precise triangulation between these points, a topographic survey of the coast, and a hydrographic survey of coastal waters controlled by triangulation.
>
> Hassler finally started geodetic work in 1816. His letters and reports indicated a lack of cooperation by some Government officials who probably lacked appreciation of the complexity of the task. He managed, however, to measure two baselines, in the vicinity of English Creek, near Englewood, N.J., and at Gravesend Village, Long Island, and to extend from these a small network of triangulation over the bay and harbor of New York in 1817. [2]

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1. A Joseph Wraight and Elliott B. Roberts, The Coast And Geodetic Survey 1807 - 1957, U.S. Department of Commerce, p. 5.

2. Ibid., p.7.

From 1816 until World War I, horizontal geodetic surveying in the United States progressed steadily. Original arcs of triangulation were "... in time completed from the Bay of Fundy to New Orleans and across the continent at the 39th parallel." [3]

After World War I, geodetic surveying activities by the federal government were greatly accelerated: "Intense coverage in many areas became necessary because of rapid industrial development and such wide scale operations as the Tennessee Valley project." [4]

Today the most acute need for geodetic control exists in metropolitan areas.

> It is ridiculous to embark, for instance, on the widening of a street, the building of an underpass or a new sewer, without precise knowledge of the configuration of the terrain and the nature and the location of all features in the area. For administrative purposes there is a very similar requirement imposed by the mechanics of tax distribution, the enforcement of laws and specifications ruling the physical development of the city. Then there is a deeply-rooted social requirement for securing the ownership of land and

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3. Ibid., p.26.

4. Ibid., p.47.

real estate which, in urban areas, is a particularly delicate problem requiring great precision and reliability.[5]

The agency presently charged with meeting the geodetic requirements of metropolitan areas is the National Oceanic and Atmospheric Administration (NOAA, Department of Commerce).[6] Operational and immediate management functions are delegated by NOAA to a management control center, the National Geodetic Survey (NGS).

The nation's most recent metropolitan geodetic goals were formulated by NOAA in a NGS memorandum, The Objectives for Geodetic Control, dated December, 1964. One objective was to "... provide a spacing of accurately determined control points ... that will meet the needs of ... urban development and renewal ... ." However, in practice, this was not the case and most of NOAA's geodetic resources were devoted to meeting the needs of federal users, primarily the Department of Interior's Geological Survey and various agencies of the Department of Defense.

But, in September 1967, the policy statement of 1964 was reasserted.

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5. T.J. Blachut, "Technical and Organization Problems in Urban Surveying and Mapping", The Canadian Surveyor, Sept., 1969, p. 411.

6. Authorizations: Public Law 373 - 80th Congress; BOB Circular A-80, dated January 31, 1967; BOB Circular A-16, revised May 6, 1967.

> Priority has been given to Federal requests, although it has been recognized that most of these requests could be satisfied with local low-accuracy surveys connected to the national network ..., improved equipment now enables other organizations to extend surveys satisfactory for their needs... . Undoubtedly the time is ripe for more consideration of non-federal requirements... It is the responsibility of the Coast and Geodetic Survey, [NGS], to assume the leadership, to evaluate national, as well as local needs, and to educate those who are in positions to benefit the public most through the use of geodetic control. [7]

<u>The Allocation of Resources for Geodetic Surveys in Metropolitan Areas</u>: Following the 1967 restatement of policy by NOAA, decisions regarding the allocation of federal resources for geodetic surveys in metropolitan areas have generally been based on three main criteria:

1. A priority listing of metropolitan counties based on an empirical formula which accounts for population density, population growth and station spacing. [8]

2. The degree of awareness by local officials, engineers, and surveyors on the significance and uses of geodetic control.

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7. Samuel P. Hand, Plan for Horizontal Control, DOC, ESSA, USC&GS, Rockville, Md., dated September 21, 1967, pp. i - iii.

8. For a fuller explanation of the formula, see: <u>North American Datum</u>, National Academy of Sciences, Washington, D.C., 1971, pp. 57-69.

3. The willingness of local agencies (or the community) to contribute resources toward the survey and to cooperate by establishing additional geodetic control of their own.

These are valid criteria, in part, for deciding on the allocation of resources, but in recent years government agencies have increasingly turned to benefit-cost analysis as a means of measuring a project's desirability in terms of efficiency, or its effect on the national economy.

The development of cost data for urban geodetic control is relatively simple by the use of known and projected cost for work of similar extent and quality. However, the evaluation of the economic benefits resulting from the use of horizontal geodetic control surveys has always been a challenge to the surveying profession.

The purpose of this paper is to develop the necessary methods to quantify benefits and costs, and to utilize existing techniques which will allow a benefit-cost analysis to be made of metropolitan horizontal geodetic control surveys. It is also essential to demonstrate the practicality of such an analysis. Benefit-cost analysis in horizontal geodetic work has, to the best of the author's knowledge, never been accomplished.

Outline of the Paper: Before examining the application of benefit-cost analysis in metropolitan horizontal geodetic control surveys, the first two sections of this paper provide some introductory material on geodetic surveying techniques and benefit-cost analysis. Section III is a complete mathematical derivation of the model used to quantify the benefits. Section IV explains how data can be obtained for use in the benefit model. Section V uses the benefit model and actual data to compute the benefits from an urban horizontal geodetic control survey in Monroe County, New York. Section VI provides additional information on benefit-cost analysis and explains how benefit-cost ratios are computed and used in a sensitivity analysis.

SECTION I

URBAN GEODETIC SURVEYING

A survey of a city can be computed as though the earth were a plane surface or several plane surfaces the size of the city. Consequently, a city may have its own unique mathematical reference system, or datum. Many cities do, but since various agencies engage in surveying within the same area, each may establish a different reference system. For example, a special improvement district may have its own datum, a county highway department may have its own datum, and a city public works department may use a third datum. When there are two or three different reference systems used in the same area, surveys for bridges and streets may not merge and considerable effort is wasted on duplicate surveys.

The National Net: A solution to this problem is to tie all surveys to the national network of stations maintained by the National Geodetic Survey. Basically the NGS has determined the latitudes and longitudes

> ... for many thousands of marked stations scattered over the United States. Surveys of small areas may be based on any of these marked points at any time with the assurance that they may be correctly coordinated in position with all precise surveys and maps of the entire country and with all local surveys so connected. The permanency of the results of surveys thus connected to

the national net is also assured since any marked points that become lost or that lose their integrity may be duplicated by new surveys based on nearby stations.[9]

Adequate Urban Geodetic Networks: Metropolitan areas have unique geodetic requirements in terms of station spacing and accuracy, and a special type of survey called an urban horizontal geodetic control survey has been developed to meet these needs.[10] This is a very precise survey with a relative linear accuracy of 1 part in 100,000 between control stations; that is, the distance between two stations a mile apart would be known within ± 0.05 feet. Within the United States there are twenty-three areas where the geodetic networks meet the Office of Managements and Budget's specifications for an adequate urban horizontal geodetic control system (see Table 1.1 for a listing of these areas).

Basic Utilization Technique: It is important to have some understanding of traversing which is the most widely used surveying technique for establishing horizontal positions in metropolitan areas of the United States.[11]

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9. Coast and Geodetic Survey, (NGS) Department of Commerce, Horizontal Control Data, Special Publication No. 227, p.1.

10. Urban horizontal geodetic surveys as defined by the Office of Management and Budget in "Classification and Standards of Accuracy of Geodetic Control Surveys", Bureau of the Budget Circular A-16, Exhibit C, dated October 10, 1958, pp. 8-10 -- hereafter cited as "Exhibit C". See Appendix A.

11. According to a 1971 geodetic users study sponsored by the NGS 88 percent of all horizontal surveys in metropolitan areas of the United States are accomplished by traverse.

Table 1.1

Areas with Completed Control
Classified as Urban Horizontal Geodetic Control

California
- Los Angeles County
- Napa County

Florida
- Palm Beach County
- Broward County
- Dade County

Hawaii
- Oahu Island

Louisiana
- East Baton Rouge Parish

Maryland
- Montgomery County
- Prince George's County

New Mexico
- Albuquerque Area,(Middle Rio Grande Council of Governments Jurisdiction Area)

New York
- Monroe County
- Nassau County
- Rockland Dounty
- Suffolk County
- Westchester County

Ohio
- City of Akron
- Cincinnati (central city)

Oregon
- City of Portland

Rhode Island (complete)

Texas
- City of Houston

Virginia
- Arlington County
- City of Alexandria
- Fairfax County

The system is similar to dead reckoning navigation where distances and directions are measured. In performing a traverse, the surveyor starts at a known position [control station] with a known azimuth [direction] to another point and measures angles and distances between a series of survey points [traverse stations]. With the angular measurements, the direction of each line of the traverse can be computed; and with the measurements of the length of the lines, the position of each control point computed. When the traverse returns to the starting point or another point of known position, it is a closed traverse, otherwise the traverse is said to be open.[12] See Fig. 1.1.

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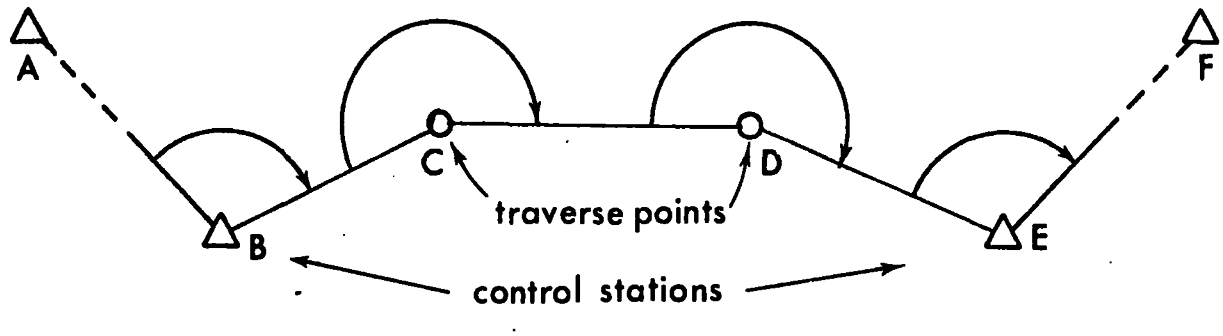
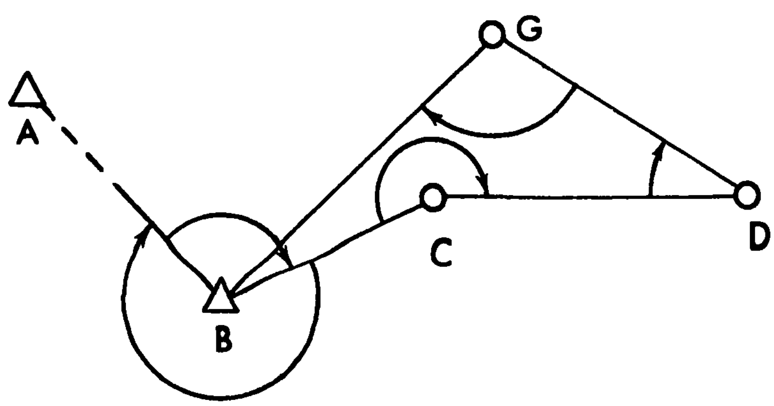
12. Capt. R.K. Burkard, Geodesy for the Layman, Aeronautical Chart and Information Center, St. Louis, Missouri, p. 23.

TYPES OF TRAVERSES

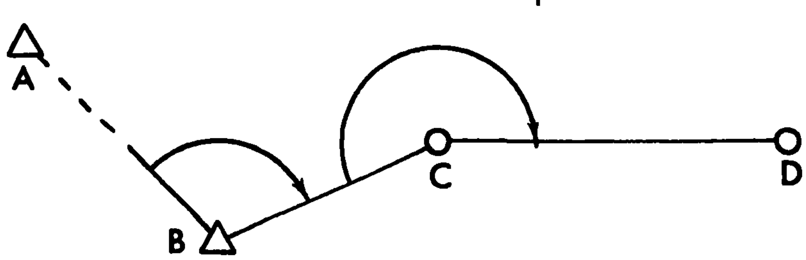
A Closed Traverse on Two Control Stations



A Closed Traverse on One Control Station



An Open Traverse



Known Data:	Position of control stations B and E Direction of line BA and EF
Measured Elements:	All Lengths All Directions
Computed Elements:	Positions of traverse points (traverse stations) C, D, G

Figure 1.1

SECTION II

THE BENEFIT-COST ANALYSIS CONCEPT IN BRIEF

Benefit-cost analysis has been defined as

> ... a practical way of assessing the desirability of projects, where it is important to take a long view (in the sense of looking at repercussions in the furthur, as well as the nearer, future) and a wide view (in the sense of allowing for side-effects of many kinds on many persons, industries, regions, etc.) i.e. it implies the enumeration and evaluation of all the relevant costs and benefits. [13]

This comparison of benefits and costs is not analogous to the determination of private profit. For example, an underground coal mine may be profitable to a private owner, but if all the social costs could be accounted for, such as black lung disease, loss of life and limb, water and air pollution, and loss to the scenic environment, the net value to society may be negative.

While the quantitative aspects of benefit-cost analysis are easily expressed, there are several parameters

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13. A.R. Prest and R. Turvey, "Cost - Benefit Analysis: A Survey," The Economic Journal, Vol. LXXI, December 1965, p. 683.

> ... which must be specified for use in the analysis which are based upon certain assumptions, which are not always realistic, and on value judgments which are not made explicit.... In addition, the conceptual treatment of risk uncertainty, secondary effects, and externalities [on benefits and cost are] ... critical to the analysis. Often small changes in the way one or more of these factors is specified or handled can have significant effects on the resulting analysis.[14]

Also, benefit-cost data can be combined in several different ways which may be used as indicators of a project's economic efficiency. A proper choice of efficiency criteria in terms of benefits and cost for urban surveys would be the benefit-cost ratio.

> The benefit-cost ratio, like any investment criterion, is suited only for certain kinds of investment decisions. The economic nature of the cost must be reasonably uniform; there must be no extreme variations of capital intensity. The benefits must be uniform at least at the conceptual level and must have roughly equal degrees of uncertainty. And the life spans of the projects among which choices are to be made must be of the same order or magnitude.[15]

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14. Unpublished notes by Associate Professor Robert J. Kalter, Spring 1971, Cornell University.

15. Otto Eckstein, Water Resources Development: The Economics of Project evaluation (Cambridge: Harvard University Press, 1968), p. 55. Hereafter cited as "Eckstein".

All urban geodetic survey proposals formulated within the last five years would meet, substantially, these requirements. A standard formula for the computation of benefit-cost ratios (for any economic evaluation) can be written as:

$$\frac{B}{C} = \frac{\sum_{t=1}^{T} \frac{B_a}{(1+i)^t}}{\left[\sum_{t=1}^{T} \frac{0}{(1+i)^t}\right] + K}, \tag{2.1}$$

where B_a = annual benefits in dollars; 0 = annual operating and maintenance cost in dollars; T = time period of the evaluation in years; K = fixed investment in dollars, and i = discount rate in decimal form.[16] The larger the benefit-cost ratio, the more desirable would be a project, while a benefit-cost ratio less than 1.00 would indicate a project was not economically justified.

The computed benefits and cost expressed in Formula 2.1 are discounted, or present-day amounts.[17] This is done so that annual operating and maintenance cost and benefits occurring in any future year can be referenced to today's values. For example, if an arbitrary discount rate of 6 percent is used, and if the benefits from a small

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16. L.W. Libby and R.J. Kalter, Critique of the Economic justification for the Genesee River Project at Portageville, New York, A.E.Res. 264, Cornell University, Ithaca N.Y. p.8.

17. The choice of a discount rate is a crucial factor in any benefit-cost analysis. This aspect will be discussed in more detail under <u>The Discount Rate</u>.

project are expected to be \$100 per year or \$500 in five years, then the present value of the benefits would be \$421.24, or the amount which if invested at 6 percent interest rate and compounded annually, would yield \$500 in five years. Annual operating and maintenance costs are viewed similarly.

The Basic Concept of Quantifying the Benefits: It is rarely possible in any economic analysis of a public investment project to be able to account for all of the benefits which are known to exist because all conceivable benefical uses of a project would have to be considered and quantified. The approach used in this thesis is to quantify only a segment of the known benefits; that is, the savings in traverse cost.

Using this approach a project can be economically justified if the quantified benefits are large enough in value to exceed the total cost. Since all of the costs are considered, additional unquantified benefits would only act to increase the project's net worth.

The model (or formula) to express the miles of traverse saved is based on the theory of probability and can be expressed in mathematical notation as:

$$B_a = B_{p,\,p'} = \left[1 - \frac{N}{N + N'}\right] (U_p - U_{p'})\ (C) \qquad (2.2)$$

An explanation of the variables used in this formula is contained in Appendix B. It should be noted that the output of this formula, the miles of traverse saved, needs to be translated into dollars saved.

The mathematical derivation of the formula is not difficult, but it is complicated and may not be of interest to all readers. For their convenience, a very brief explanation of the method of derivation follows:

1. Mathematically, the project area was divided into a checkerboard square pattern with the number of equal-size squares equal to the number of control stations. See Fig.2.1.

2. A control station was considered to occupy the center of each square. See Fig. 2.2.

3. The square assigned to each control station was then divided into a series of ring zones and four corner zones. The largest ring zone would be tangent to the sides of the square. See Fig. 2.3.

4. A mean area distance, D_j, from each ring zone and a mean area distance, D_c, from each corner zone, was computed so that a circle arc, as defined by radii D_j and D_c, would divide the zones into equal areas. See Fig. 2.4.

5. Based on a random distribution of points to be positioned, it is known that the probability of a measurement being made to or from any zone to a control station would be equal to the area of that zone divided by the area of the square enclosing the control station.

6. The total miles of traverse ties made to or from one zone area would be equal to:

PROJECT AREA DIVIDED INTO SQUARES
EQUAL TO THE NUMBER OF CONTROL STATIONS

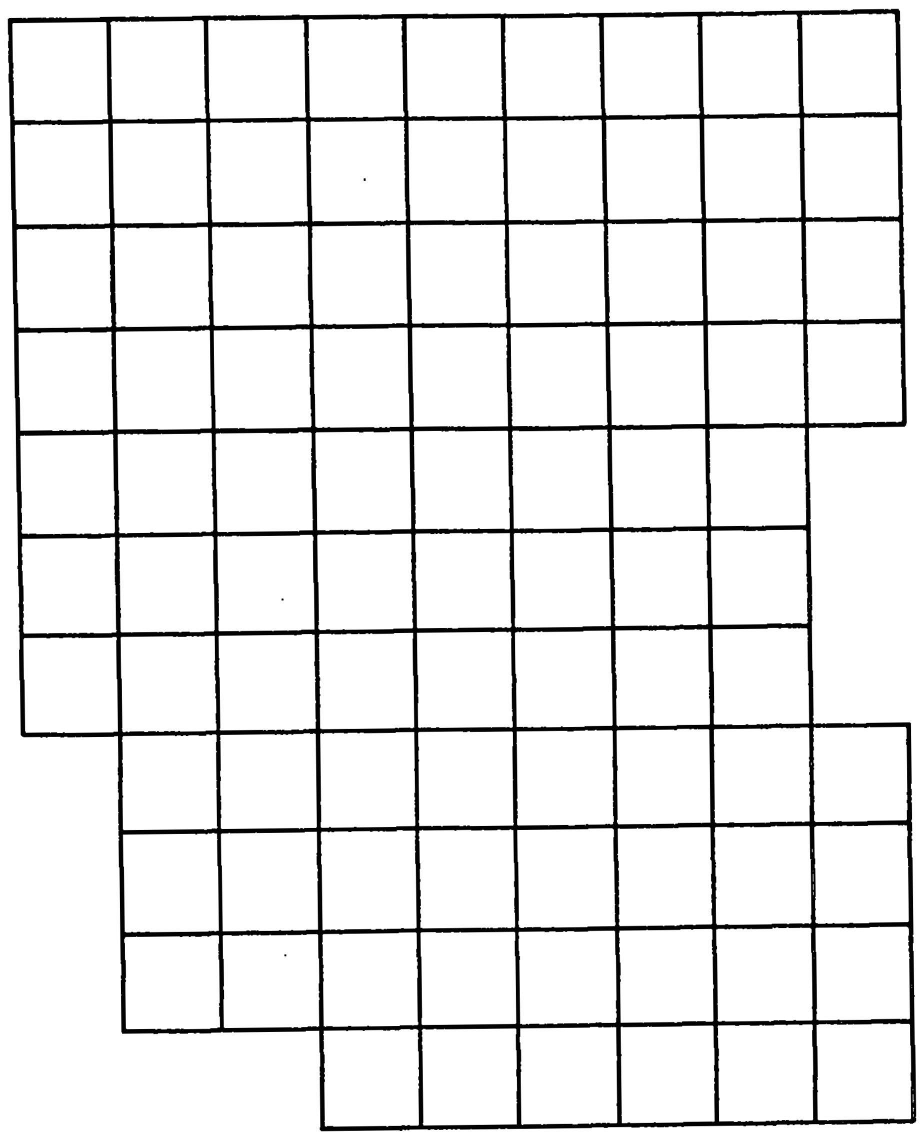


Figure 2.1

A CONTROL STATION WOULD OCCUPY
THE CENTER OF EACH SQUARE

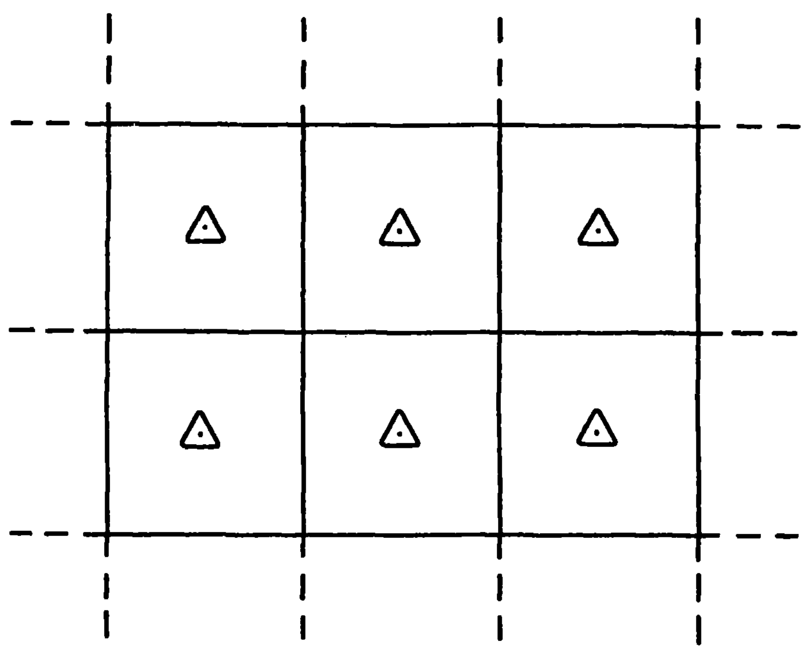


Figure 2.2

EACH SQUARE DIVIDED INTO ZONES

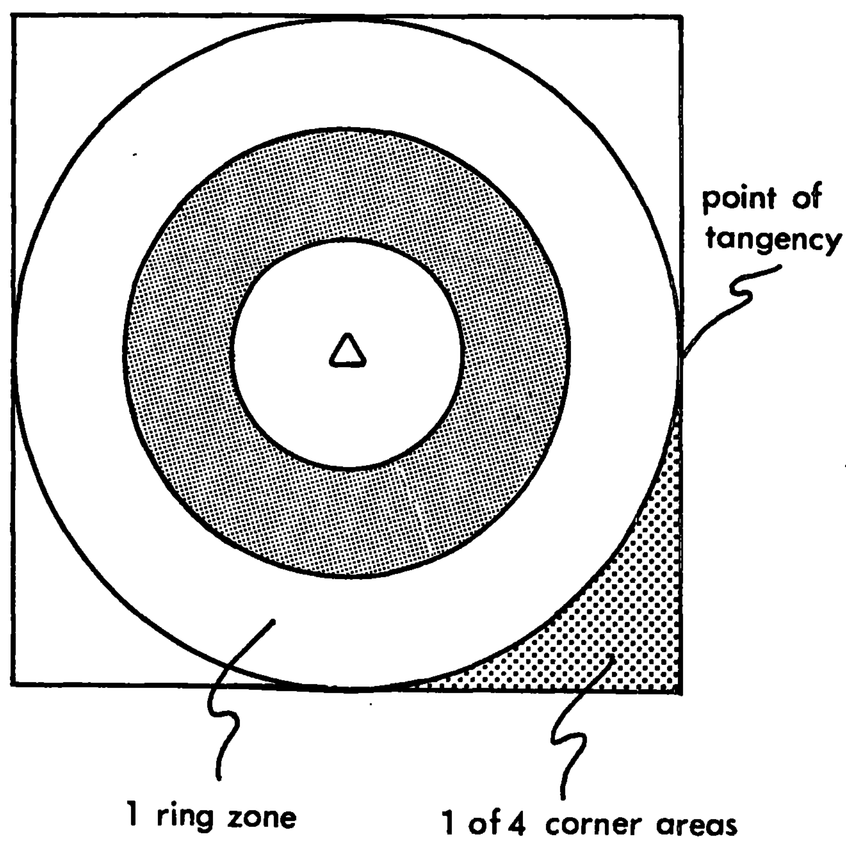


Figure 2.3

MEAN AREA DISTANCE FROM RING ZONE(S)
AND CORNER ZONE(S) TO CONTROL STATION

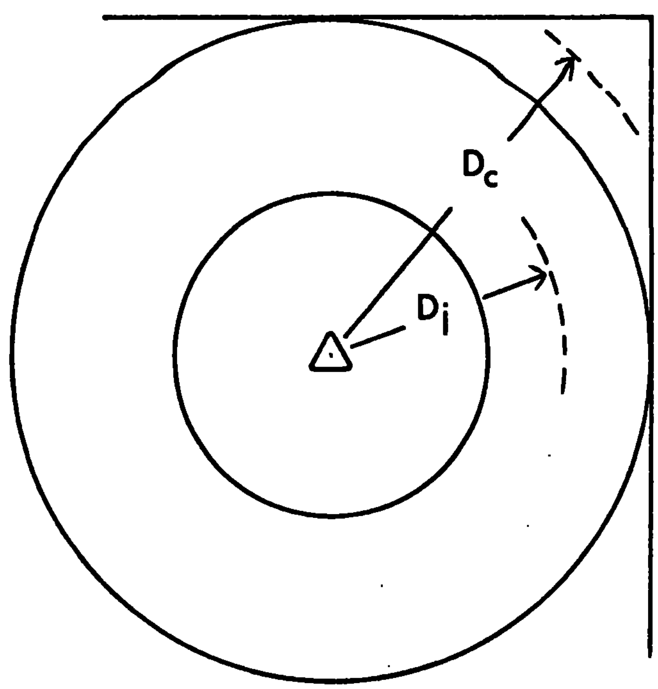


Figure 2.4

(the probability of a measurement being made to a zone) x

(the mean area distance to the zone) x

(the number of ties made within the square area).

7. Summation computations could then be made of the miles of traverse ties made before and after establishing the new stations and the difference between the sums would be the benefit expressed in miles of traverse.

The complete mathematical deviation of the model follows in the next section.

SECTION III

COMPLETE DERVIATION OF THE MODEL TO QUANTIFY THE BENEFITS IN MILES OF TRAVERSE SAVED

A very important benefit of an urban survey would be the cost savings in traverse miles necessary to make C direct connections[18] (C is a variable parameter) in the new control system (a densified network) as compared to making C direct connections in the old system.

Assumptions: The derivation of the benefit model is based on the following assumptions:

1. The original control stations will be treated as though they were spaced in a uniform-square pattern.

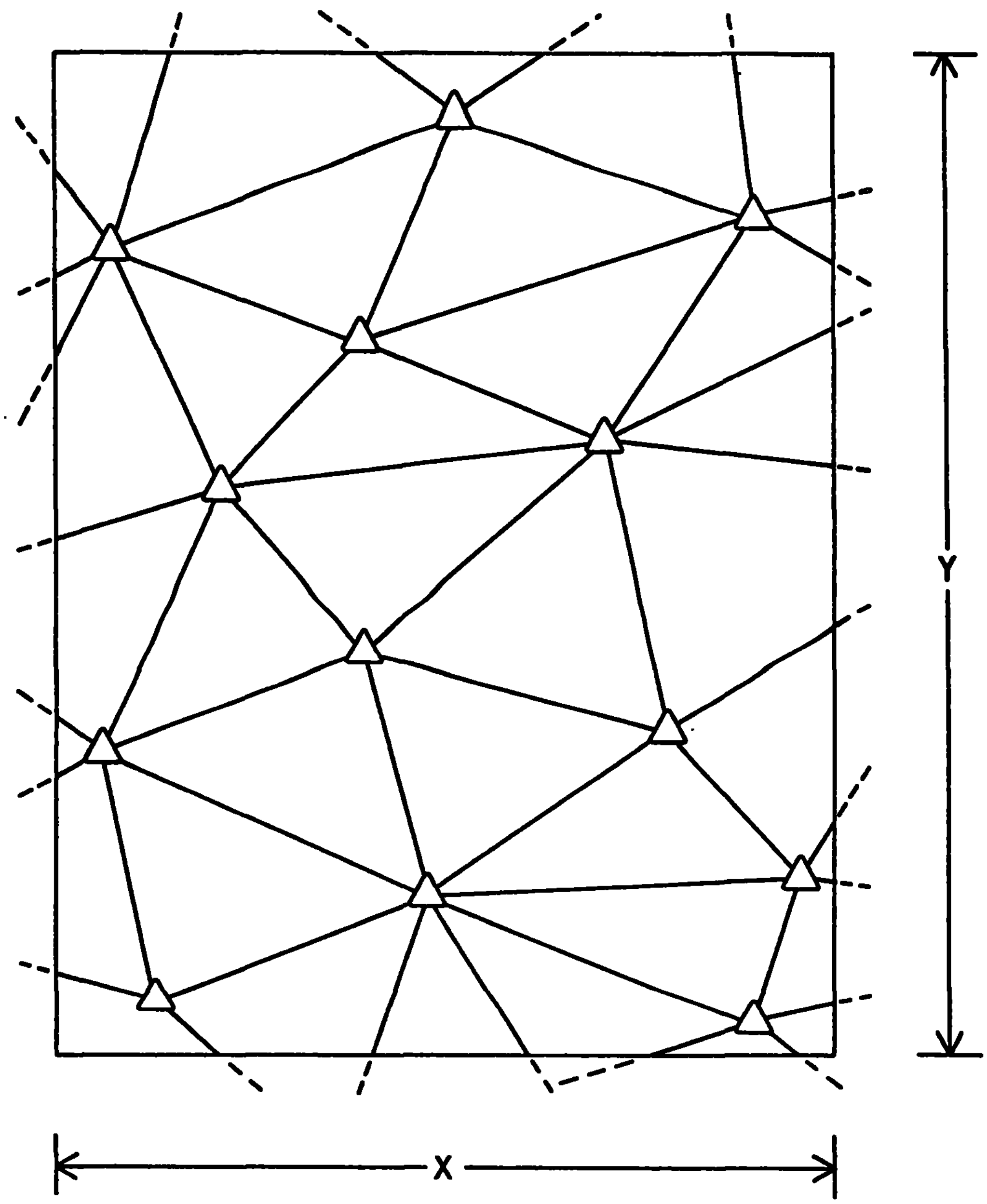
Consider an area X by Y miles enclosing N horizontal control stations. In a real system the control stations will usually be evenly distributed (see Fig. 3.1). Then in order to form a comparable and workable model, a uniform station spacing can be assumed where:

$$P = \sqrt{XY/N} \quad (3.1)$$

See Fig. 3.2. During the development of the model, the station spacing, P, will be chosen as a whole number resulting from

18. A direct connection is defined as the physical measurement between a control station and fthe first or last point in a traverse. See Fig. 3.3.

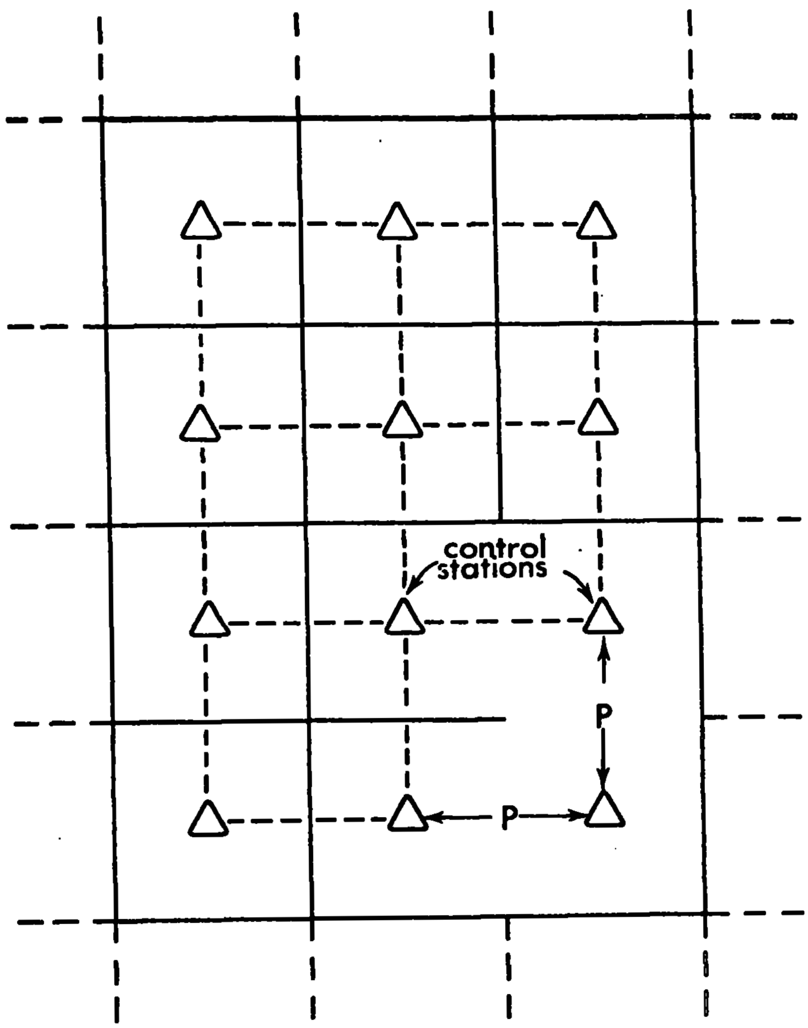
RANDOM DISTRIBUTION OF CONTROL STATIONS IN A REAL NETWORK



N = 13 control stations

Figure 3.1

SYMMETRIC STATION SPACING



$$P = \sqrt{\frac{XY}{N}}$$

Figure 3.2

$\sqrt{XY/N}$. However, in the final analysis the benefit, B_a, can be evaluated for all values of P.

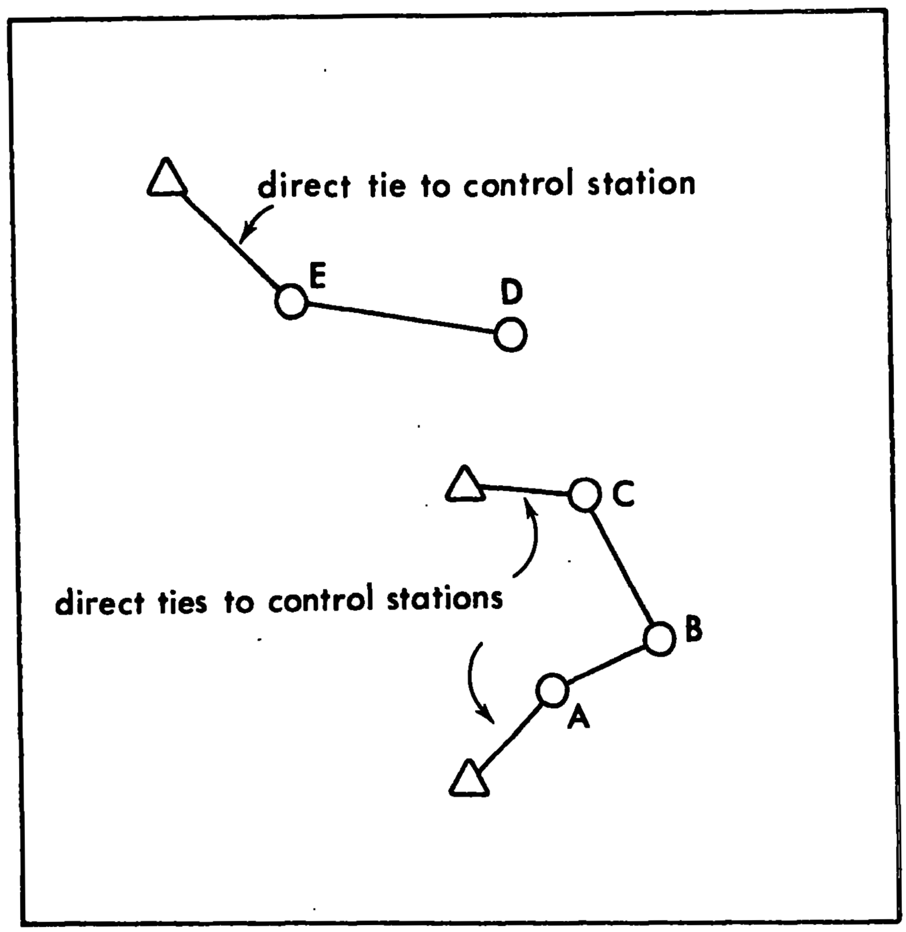
The author considers this a justifiable assumption because the same number of stations and the same area is considered that actually exists on the ground. Some discretion would have to be exercised in selecting the X and Y dimensions so there would be a homogeneous distribution of control stations. In some cases the project area may have to be considered as separate subareas.

2. Only the traverse as a method of use will be considered in the evaluation of benefits because it accounts for 88 percent of all horizontal surveying work in metropolitan areas of the United States.[11]

3. It is assumed all direct ties to all control stations can be transferred to one section (there are no unique sections) by retaining their relative relationship to the central control station; and, that the transformation of all ties to one section will result in a random distribution of ties around the control station. See Fig. 3.3 . Herein lies the fundamental premise on which the benefit model is based: <u>Within the utility limits of a geodetic control station the distances between the control station and any positions to be determined will be random</u>.

4. It is assumed that on the average all stations are equally accessible, and that direct ties between traverse stations and control stations are made to the nearest control

TRANSFER OF DIRECT TIES



Transfer of three direct ties A, C, E to the same section. Note: the relative relationship to the control station is retained, although for the model, only the distance is critical.

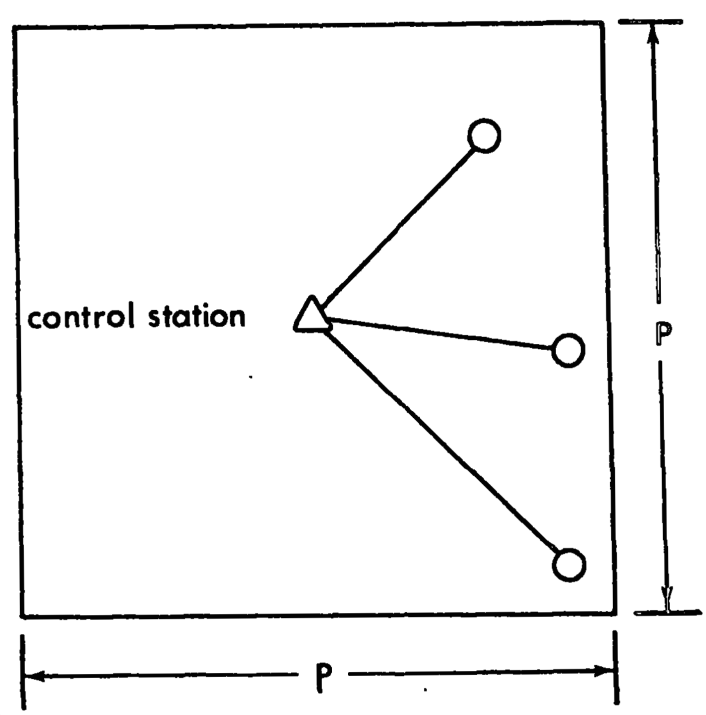


Figure 3.3

station. It is known that this would not always be the case. An occasional blocked line of sight, for example, might make it impractical to tie to the nearest control station. This distortion of the model would, on the average, tend to cancel out because of its applicability to both the original and densified models.

The Approach: If a point (traverse station) exists within the XY area (or project area) then its probability of being there is a certainty, or 1.00. Moreover, since all direct connections to a control station can, by Assumption 3, be treated as being in the same section, then their probability of being in that section would also be 1.00.

Next, a section can be divided into concentric circles originating from the center control station, and increasing in radius until a maximum radius

$$R_k = P/2 \tag{3.2}$$

is reached. See Fig. 3.4 . A ring zone, Z_j, is defined as the area between the radii R_i and R_j, and by definition

$$R_i - R_j \tag{3.3}$$

will always equal 1.00 mile unless $P<1.00$ mile or $P/2$ is not an even number.

The maximum distance a direct tie could be made to a control station, and still be within the section (corner areas only) would be

$$R_{max} = \sqrt{2(P/2)^2}\,. \tag{3.4}$$

See Fig. 3.4 .

The probability of a point being in a section is 1.00 and the probability, L_j, of a point being in any ring zone, Z_j, would be proportional to the area of the ring zone divided by the area of the section

$$L_j = Z_j/P^2 \tag{3.5}$$

where

$$Z_j = \pi \left[(R_j)^2 - (R_i)^2\right] \tag{3.6}$$

Should a point fall in one of the four corner sections, Z_c, the area would be

$$Z_c = P^2 - \pi(P/2)^2 \tag{3.7}$$

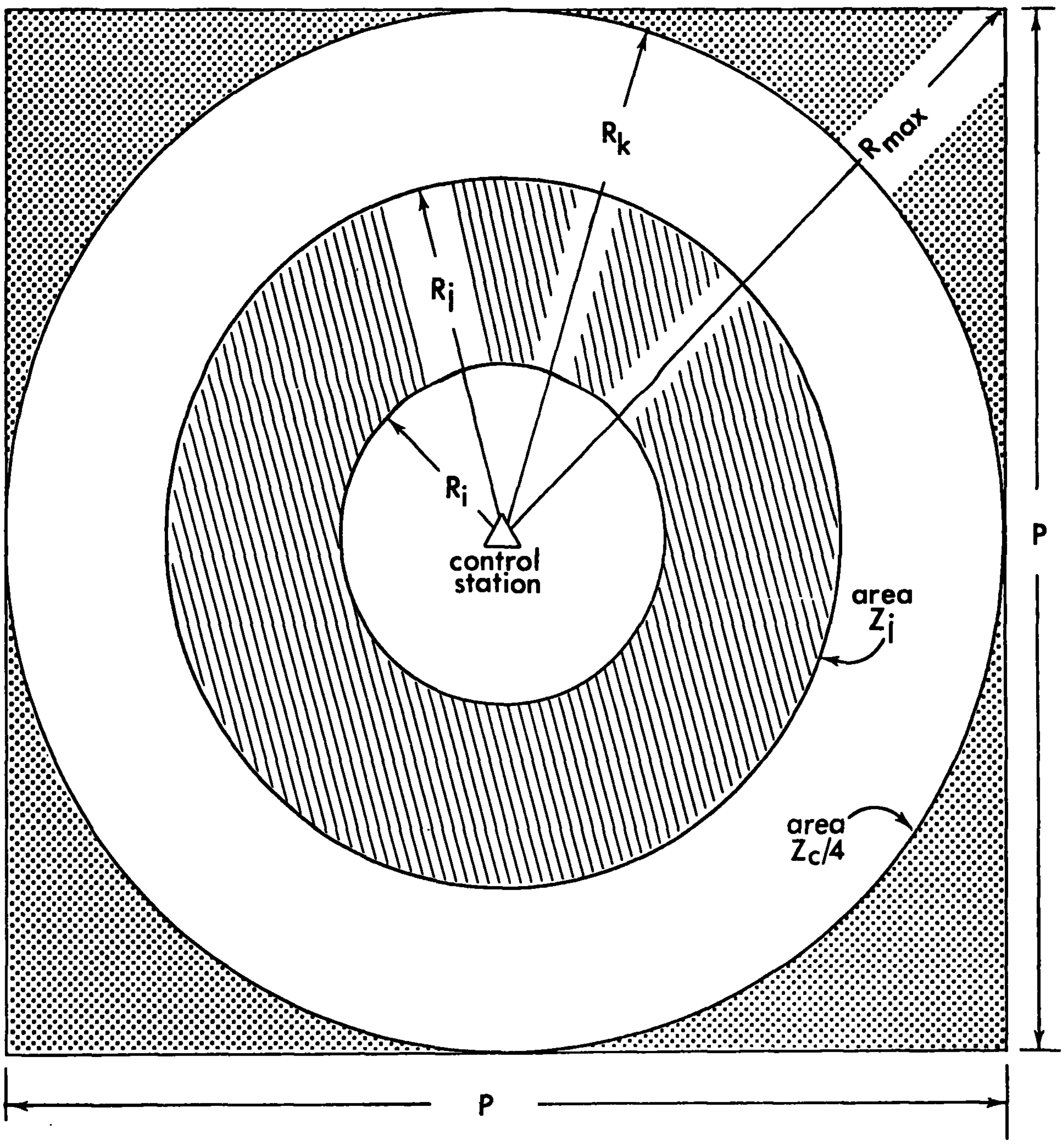
and the probability would be

$$L_c = Z_c\,/P^2 \tag{3.8}$$

Based on a maximum control station spacing of 10.00 miles, Table 3.1 gives the area for each ring zone, and Table 3.2 gives the area of the corner sections. Table 3.3 is the probability of a direct tie being to or from a ring zone or a corner area.

Example of Probability Computation: If the control spacing P is 7.00 miles, then the maximum radius of a ring zone would be

A SECTION DIVIDED INTO ZONES



$R_k = P/2$ Area $Z_j = \pi[(R_j)^2 - (R_i)^2]$

$R_{max} = \sqrt{2(P/2)^2}$ Area $Z_c = P^2 - \pi(P/2)^2$

Figure 3.4

Table 3.1

Area of the Ring Zones

R_i miles	R_j miles	Z_j square miles
0.00	0.50	0.78
0.00	1.00	3.14
1.00	1.50	3.93
1.00	2.00	9.42
2.00	2.50	7.07
2.00	3.00	15.71
3.00	3.50	10.21
3.00	4.00	21.99
4.00	4.50	13.35
4.00	5.00	28.27

$$Z_j = \pi \left[(R_j)^2 - (R_i)^2 \right]$$

Table 3.2

Area of the Corner Sections

P in miles	Z_c in square miles
1.00	0.21
2.00	0.86
3.00	1.93
4.00	3.43
5.00	5.36
6.00	7.72
7.00	10.52
8.00	13.73
9.00	17.38
10.00	21.46

$Z_c = P^2 - \pi(P/2)^2$

Table 3.3

The Probability of a Direct Tie Being Made to or from a Specific Ring Zone or to or from a Corner Area [a]

j	P miles	$L_{.5}$	L_1	$L_{1.5}$	L_2	$L_{2.5}$	L_3	$L_{3.5}$	L_4	$L_{4.5}$	L_5	L_c	$\Sigma(L_j)+L_c$
.5	1.00	.78										.22	1.00
1.00	2.00		.78									.22	1.00
1.50	3.00		.35	.43								.22	1.00
2.00	4.00		.20		.58							.22	1.00
2.50	5.00		.12		.38	.28						.22	1.00
3.00	6.00		.09		.36		.43					.22	1.00
3.50	7.00		.06		.19		.32	.21				.22	1.00
4.00	8.00		.05		.15		.24		.34			.22	1.00
4.50	9.00		.04		.12		.19		.27	.16		.22	1.00
5.00	10.00		.03		.09		.16		.22		.28	.22	1.00

$L_j = Z_j/P^2$ $\qquad$ $L_c = Z_c/P^2$

a. Blank spaces indicate a probability of zero, or a probability of occurrence in a ring zone which is not used in the summation of probabilities.

$$R_k = P/2 = 3.50 \text{ miles},$$

and the area of a section would be

$$P^2 = 49.00 \text{ miles}^2;$$

and taking the areas of the ring zones and corner sections from Table 3.1 and Table 3.2 it is seen that

$$\begin{aligned} Z_c &= 10.52 \\ Z_1 &= 3.14 \\ Z_2 &= 9.42 \\ Z_3 &= 15.71 \\ Z_{3.5} &= \underline{10.21} \\ P^2 &= 49.00 \text{ miles}^2 \end{aligned}$$

The probabilities can be computed from Formulas 3.5 and 3.8, or taken directly from Table 3.3, regardless:

$$\begin{aligned} L_1 &= .06 \\ L_2 &= .19 \\ L_3 &= .32 \\ L_{3.5} &= .21 \\ L_c &= \underline{.22} \end{aligned}$$

$$\sum_{j=1}^{K=3.5} (L_j) + L_c = 1.00 .$$

Specifically, if C direct traverse connections to control stations were made in the XY area, then

$$T_j = C \cdot L_j \tag{3.9}$$

would be the number of ties to, or from, area Z_j and

$$T_C = C \cdot L_C \tag{3.10}$$

would be the number of ties to or from the corner areas.

For a station spacing of 7.00 miles (P = 7.00), and a thousand direct connections (C = 1000), Table 3.4 gives the number of ties from each ring zone and the corner zones.

Benefit Determination: Knowing T_j, the number of ties to or from a particular ring zone, an approximation of the total miles of traverse run to or from one zone would be

$$W_j = D_j T_j \, . \tag{3.11}$$

D_j is defined as the radius of a circle, originating at the control station, which would divide the area Z_j into two equal areas. Consequently there would be an equal distribution of ties on each side of the circle and

$$D_j = \sqrt{\frac{(R_j)^2 + (R_i)^2}{2}} \tag{3.12}$$

would be the average distance to be traversed from each ring zone $_j$ to the various points.

Table 3.4
Sample Distribution of 1000 Ties Made to or from
Ring and Corner Zones

Zones Range of Distances from a Control Station in Miles	T_j Number of Direct Ties Made from Each Ring Zone	T_c Number of Direct Ties Made from the Corner Zones
0.00 - 1.00	60	
1.00 - 2.00	190	
2.00 - 3.00	320	
3.50 - 4.95[a]		220
	Σ 780	220

780 + 220 = 1000 connections made to control stations

a. R_{max}, see Formula 3.4

See Fig. 3.5. All values for D_j are given in Table 3.5. And

$$W_c = D_c \cdot T_c \tag{3.13}$$

would be an approximation of the total miles of traverse run from, or to, the corner zones. D_c is defined as the radius of a circle arc which would divide the four corner zones, each, into two equal areas. See Fig. 3.6.

$$D_c = R_k/0.9048 \tag{3.14}$$

All values for D_c are given in Table 3.5. The value for D_c was determined by a reiterative process and for completeness of the model, its derivation follows:

Let area of F equal area of G. See Fig. 3.6. Then

$$F + G = R_k{}^2 - \frac{\pi}{4} R_k{}^2$$

and

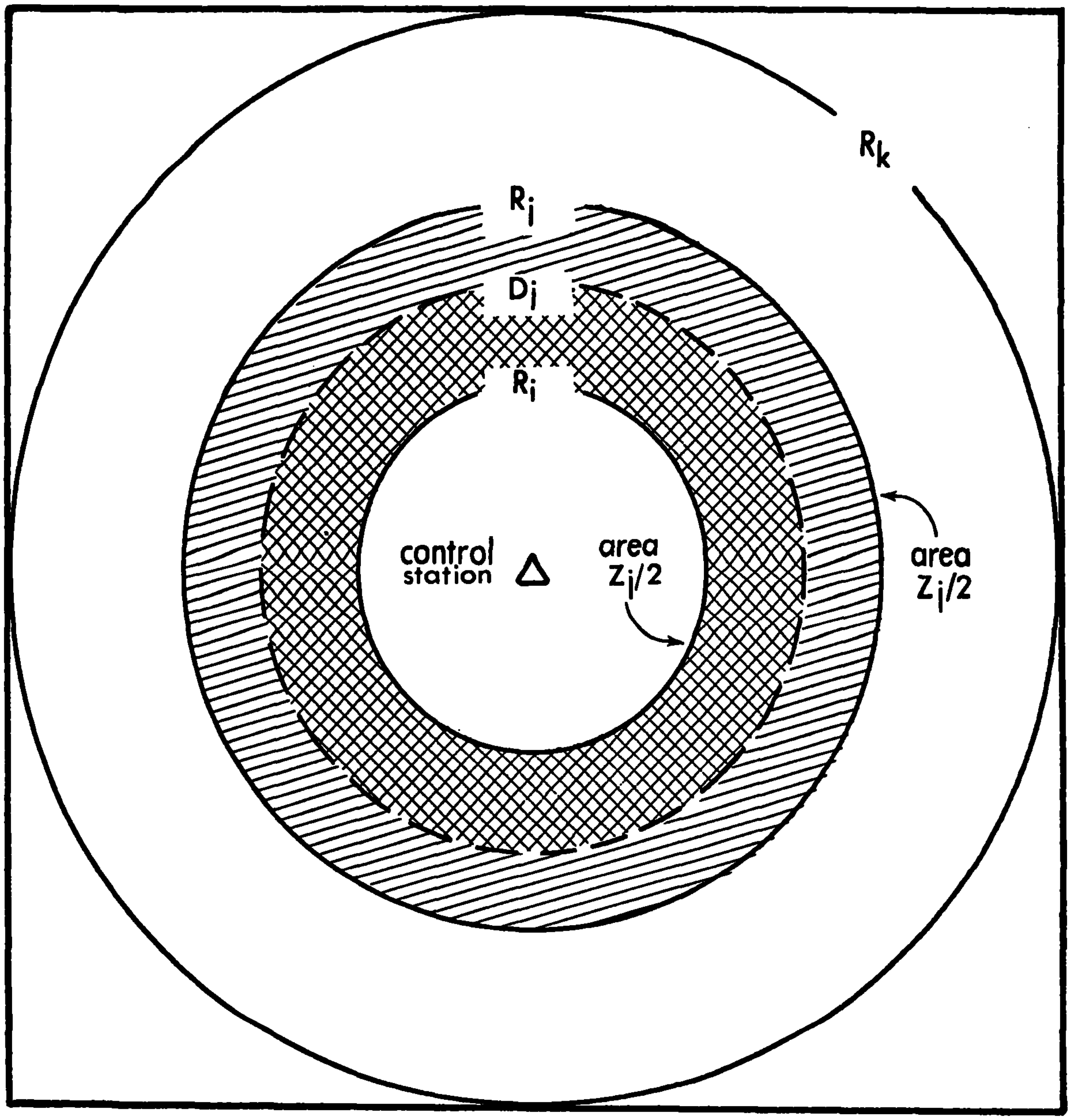
$$F = \frac{1}{2} (R_k{}^2 - \frac{\pi}{4} R_k{}^2)$$

The (area of segment H) = (area of sector a,b,c) - (area of triangle a,b,c) or

$$H = (\frac{1}{2} D_c{}^2\theta) - (\frac{1}{2} dR_k)$$

$$d = 2 \sqrt{D_c{}^2 - R_k{}^2}$$

RING ZONE Z_j DIVIDED INTO TWO EQUAL AREAS BY RADIUS D_j



$$\text{Radius } D_j = \sqrt{\frac{(R_j)^2 - (R_i)^2}{2}}$$

Figure 3.5

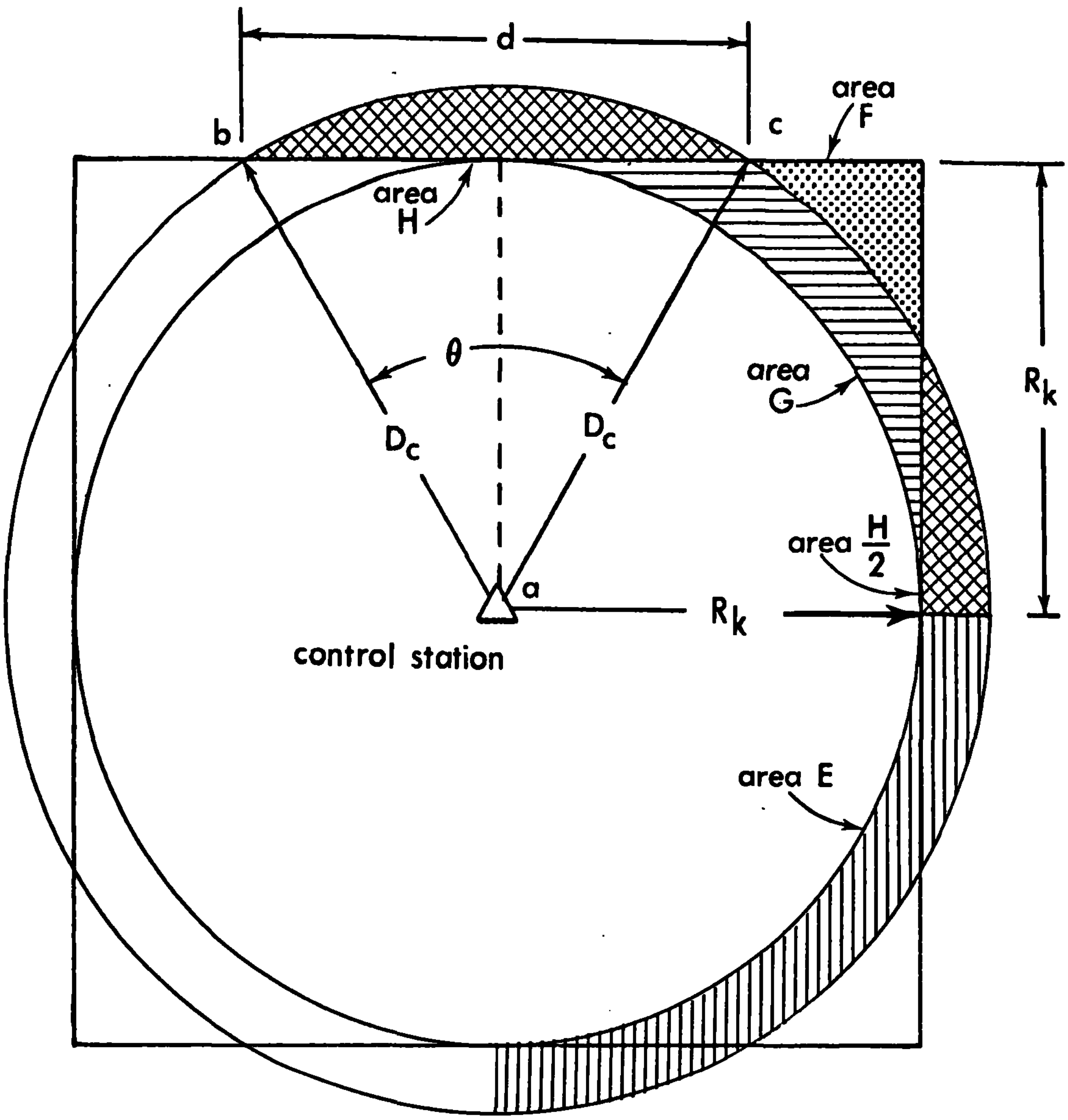
Table 3.5

Values for D_j and D_c, Mean Area Distances from the Ring Zones and Corner Zone Respectively

P miles	R_i miles	R_j miles	R_k miles	D_j miles	D_c miles
1	0.00	0.50	0.50	0.35	0.55
2	0.00	1.00	1.00	0.71	1.10
3	1.00	1.50	1.50	1.27	1.66
4	1.00	2.00	2.00	1.58	2.21
5	2.00	2.50	2.50	2.26	2.76
6	2.00	3.00	3.00	2.55	3.31
7	3.00	3.50	3.50	3.26	3.87
8	3.00	4.00	4.00	3.54	4.42
9	4.00	4.50	4.50	4.26	4.97
10	4.00	5.00	5.00	4.53	5.52

$$D_j = \sqrt{\frac{(R_j)^2 + (R_i)^2}{2}} \qquad D_c = \frac{Rk}{.9048}$$

CORNER AREAS DIVIDED INTO EQUAL AREAS BY RADIUS D_c



$$D_c = \frac{R_k}{.9048}$$

Figure 3.6

Table 3.6

U_p: The Sums of the Average Distances Multiplied by the Probability of a Tie Being Made from a Ring Zone or Corner Zone

P,P'	j	D_j	L_j	U_j	D_c	L_c	U_c	ΣU_j	U_p
0	0	0	0	0	0	0	0	0	0
1	.5	.35	.78	.27	.55	.22	.12	.27	.39
2	1.0	.71	.78	.55	1.10	.22	.24	.55	.79
3	1.5	1.27	.43	.55	1.66	.22	.36	1.10	1.46
4	2.0	1.58	.58	.92	2.21	.22	.49	1.47	1.96
5	2.5	2.26	.28	.63	2.76	.22	.61	2.10	2.71
6	3.0	2.55	.43	1.10	3.31	.22	.73	2.57	3.30
7	3.5	3.26	.21	.68	3.87	.22	.85	3.25	4.10
8	4.0	3.54	.34	1.20	4.42	.22	.97	3.77	4.74
9	4.5	4.26	.16	.68	4.97	.22	1.09	4.45	5.54
10	5.0	4.53	.28	1.27	5.52	.22	1.22	5.04	6.27

$U_j = D_jL_j$

$U_c = D_cL_c$

$$U_p = \sum_{i}^{j=k} (D_jL_j) + D_cL_c \text{ where } k = P/2$$

Example: if P = 5.0 then

$$U_p = \sum_{1.0}^{2.5} (D_jL_j) + D_cL_c = \sum_{1.0}^{2.5} U_j + U_c \text{ where } j = 1.0,\ j = 2.0,\ j = 2.5$$

$$= .55 + .92 + .63 + .61 = 2.71$$

Inputs to the Model: To use the benefit model, several types of information are necessary to calculate C, the number of direct ties, and to express the benefit, $B_{p,p'}$ the miles of traverse saved, in dollars. A description of these inputs and their uses in the model follows.

1. Percent of Surveys Tied to the National Net: There could be a tremendous amount of surveying done in an area, but if it is not connected to the national net it cannot be counted as a benefit. It is assumed, for example, that if 30 percent of all survey work in an area is tied to the national net before densification, then 30 percent will be tied to the national net after densification. Actually, the percent of ties to the national net should increase after densification, but, at the present time this cannot be fully substantiated.

2. Amount of Closed Traverse: The number of direct ties depends on whether or not a traverse is closed; that is, if a traverse is open there is only one direct tie made. The number of closed traverses should increase after the network has been densified simply because the control stations are closer and it would be easier to do so, but again, this cannot be fully substantiated.

3. Labor and Operating Cost: To express the benefits in dollars it is necessary to know the average number of men used per traverse party, the number of miles the party

can traverse in a specific time period, and the fee charged by the party per hour or day.

4. Number of Traverses Run Per Year Per Organization: This is the most critical data used in the benefit model. Fortunately, the data base provided by a 1971 NGS users study (see page 51) is large enough so that regional or national data can be used when the local data base is small.

5. The Number of Survey Organizations in One Area: The benefits in a project area can be determined by computing the average benefits per survey organization and multiplying this by the number of applicable survey organizations.

One method of determining the number of applicable organizations in an area as used in the NGS's study follows: It was requested that the questionnaire submitted to users [18a] be returned if it were not applicable. The net number of organizations to be included in the analysis for one area should be equal to the number of organizations on the mailing list minus the questionnaires not delivered by the Post Office, minus the number returned as not applicable.

6. Survey Cost, Area, and Number of Stations: Data for these inputs can be obtained from the National Geodetic Survey and any participating agencies.

An example of the use of the benefit formula (Formula 3.19) for Monroe County, New York is presented in Section V.

18a. See page 51.

SECTION IV

DATA ACQUISITION

So far this paper has developed a theoretical model for quantifying one segment of the benefits associated with an urban geodetic survey. Since the effective use of the model depends on a reasonable means of collecting input data, it is important to illustrate a suitable method of data acquisition.

During June 1971, the National Geodetic Survey mailed over two thousand questionnaires (see Appendix C) to all surveyors, civil engineers, appropriate government agencies, and utility companies listed in the classified telephone directories of 46 standard metropolitan statistical areas (SMSA)[19-20] (see Appendix D). Over five hundred were returned completed, or partially completed, for a response rate of 27.0 percent.

19-20. The Bureau of the Census recognized 243 standard metropolitan statistical areas (SMSA's) in the 1970 census. Except in the New England states, a standard metropolitan statistical area is a county or group of contiguous counties which contains at least one city of 50,000 inhabitants or more, or "twin cities" with a combined population of at least 50,000. In addition to the county, or counties, containing such a city or cities, contiguous counties are included in an SMSA if, according to certain criteria, they are socially and economically integrated with the central city. In the New England states, SMSA's consist of towns and cities instead of counties. Each SMSA must include at least one central city, and the complete title of an SMSA identifies the central city or cities.

An examination of the data indicates the mailing of questionnaires is a satisfactory way of providing the inputs to the benefit model. The response rate may have been increased by: shortening the questionnaire to cover only essential information, seeking the cooperation of local surveying associations, mailing the questionnaires during the winter "slack" season, and sending a follow-up letter if no response was received after several weeks.

Cost: The total cost of this project, including a computer tabulation of the results, was $3,775. See Appendix E for a complete breakdown of the cost. The largest single mailing was to Los Angeles -- 169 questionnaires, with an average of 54 questionnaires mailed to each SMSA. The estimated cost of gathering data from an average SMSA including postage should not exceed $1.75 per questionnaire, or $100.00 total.

Public Access to Information from the NGS Users Study: Data may be obtained by writing:

The Director
The National Geodetic Survey
Rockville, Maryland 20852

SECTION V

SAMPLE COMPUTATION OF BENEFITS

This sample computation of benefits is based on a project in Monroe County, New York which was completed as a joint effort by the Monroe County Geodetic Survey and the National Geodetic Survey.

The annual benefits will be calculated from the benefit model formula

$$B_{p,p'} = \left[1 - \frac{N}{N + N'}\right] (U_p - U_{p'}) (C).$$

For Monroe County (as of December 1971),

$N = 20$ stations before densification,

$N' = 532$ new stations,

and the area of the project

= area of Monroe County

= 673 square miles,

so that

$$\begin{aligned} P &= \text{the station spacing before densification} \\ &= \sqrt{XY/N} \\ &= \sqrt{673/20} \\ &= 5.8 \text{ miles.} \end{aligned}$$

and

$$P' = \text{the station spacing after densification}$$

$$= \sqrt{XY/\ (N' + N)}$$

$$= \sqrt{673/552}$$

$$= 1.1 \text{ miles}$$

Interpolating from Table 3.6 for values of U_p and $U_{p'}$ with arguments P and P' respectively

$$U_p = 3.18$$

and

$$U_{p'} = 0.43.$$

Table 5.1 was constructed to provide a comparison of the data from the Rochester SMSA, four central New York SMSA's (including Rochester), ten northern United States SMSA's, ten southern United States SMSA's, and the data for all SMSA's (all data is from the 1971 NGS users study).

Because the response from Rochester was small (10 questionnaires returned) it was decided to compute the benefits based on data from the four central New York SMSA's. This was a compromise measure; it was felt that the wider data base would best reflect the surveying characteristics of the Rochester area before densification, but that any unique characteristic of the Rochester area would receive some weight.

Table 5.1

Comparison of Data Used to Compute Benefits
(Underlined Data Used in the Benefit Calculation)

	Rochester SMSA	Four New York SMSA's[a]	Ten Northern SMSA's[b]	Ten Southern SMSA's[c]	All 46 SMSA's[d]
Percent of surveys tied to national net	51.0	37.5	30.7	17.5	23.8
Number of men per traverse party	*	*	*	*	3.4[e]
Miles of traverse per party per month	13.0	25.0	37.7	38.8	36.9
Number of traverses run per year per organization	19.1[f]	56.1	67.3	117.5	103.4
Percent of traverses not closed	*	*	*	*	7.0[e]
Number of questionnaires mailed	25	124	545	602	2432
Number of questionnaires returned completed	10	33	118	125	530
Number of active survey organizations	29	*	*	*	*

a. Albany, Buffalo, Rochester, Syracuse.
b. Akron, Boston, Buffalo, Cleveland, Columbus, Minneapolis, Albany, Detroit, Providence, Syracuse.
c. Birmingham, Houston, Baton Rouge, Ft. Lauderdale, Phoenix, Atlanta, Los Angeles, Durham, Albuquerque, Miami.
d. See Appendix B.
e. Varied insignificantly.
f. Based on two answers.
g. 490 questionnaires were included in the analysis because 30 were received too late for processing.

The total number of direct ties, C, made during one year in the Rochester area would be: (2.00 - 7 percent of the traverses not closed) x (56.1 traverses per year per survey organization) x (29 active survey organizations) x (31 percent of all surveys tied to the national net) = (1.93) (56.1) (29) (.31) = 973.4 direct ties.

The benefit

$$B_{p,p'} = \left[1 - \frac{N}{N + N'}\right] (U_p - U_{p'})\ C$$

$$B_{5.8,\ 1.1} = \left[1 - \frac{20}{20 + 532}\right] (3.18 - 0.43) \quad (973.4)$$

$$= (.96) \quad (2.75) \quad (973.4)$$

$$= 2570 \text{ miles of traverse saved} = B_a \ .$$

Expressing Miles of Traverse Saved in Dollars: The data from the four central New York SMSA's indicate one survey party can traverse 25.0 miles per month. This is lower than the average of the tabulated data for the southern and northern SMSA's, and it is lower than the national average. It is difficult to assess why. It may reflect the climatic conditions in Central New York; regardless, it would take one party 102.8 months, or based on 160 work hours per month, 16,448 hours to run 2570 miles of traverse.

The prevailing surveying fee in central New York during 1970 was \$33.10 per hour for a 3.4 man party. See Table 5.2. Therefore the cost of the field work for 2570 miles of traverse would be

Table 5.2

Prevailing Survey Charge for Central New York in 1969[a]

	3 Man Party	3.4 Man Party[b]	4 Man Party	Office Computing Rate
Eastern New York Society of Land Surveyors	$32.20 hour	$35.20 hour	$38.20 hour	$14.00 hour
Mohawk Valley Society of Professional Land Surveyors	$29.00 hour	$31.00 hour	$34.00 hour	$14.00 hour
Average Fee		$33.10 hour		$14.00 hour

a. Source: <u>Manual of Prevailing Fees for Land Surveying Service Through December 1970</u>, The American Congress on Surveying and Mapping, Washington, D.C.

b. Linear interpolation.

(16,448 hours) ($33.10) = $544,429 per year.

The reduction of cost of computing and adjusting the traverse miles saved would also be a benefit. Based on personal experience and consultations with the National Geodetic Survey in Rockville, Maryland, and the MacNeil Surveying Company in Cortland, New York, a conservative estimate would be three hours per eight hours of field work. The basic computing rate is $14.00 per hour. See Table 5.2. Therefore the computing and adjusting cost would be

(16,448 hours) (3/8) ($14.00) = $86,352 per year.

Then, the total annual savings in traverse cost as a result of the densified network in Monroe County, New York, would be

$544,429 + $86,352 = $630,781.

SECTION VI

BENEFIT-COST ANALYSIS AND THE COMPUTATION OF BENEFIT-COST RATIOS

This paper will not attempt to present a rigorous academic examination of the inherent value judgements, criterion forms, uses, and limitations of benefit-cost analysis as it pertains to public investment projects. Consideration will be given only to those aspects which directly affect a benefit-cost analysis of urban horizontal control geodetic surveys. For those readers who want additional information there are several reference works on benefit-cost analysis, such as R.N. McKean, Efficiency in Government Through Systems Analysis, or E.J. Mishan, Cost Benefit Analysis, and O. Eckstein, Water Resource Development.

Thus far a method has been developed whereby one segment of the benefits resulting from an urban horizontal geodetic survey can be quantified. It is now necessary to explain the use of the standard benefit-cost ratio formula:

$$\frac{B}{C} = \frac{\sum_{t=1}^{T} \frac{Ba}{(1+i)^t}}{\left[\sum_{t=1}^{T} \frac{0}{(1+i)^t}\right] + K} \tag{6.1}$$

In this formula the variables are based on <u>value judgements</u> as well as quantified data. A discussion of each variable follows.

<u>Annual Benefits, B_a</u>: The variable, B_a, (or $B_{p,p'}$, as it is expressed in the derived annual benefit formula) and the method of its quantification are presented in detail in Sections III and V.

<u>Annual Operating and Maintenance Cost, O; and the Capital Investment Cost, K</u>: It is essential to account for all costs incurred in the life of an urban horizontal geodetic survey. The obvious cost would be the total capital investment for establishing the survey (field work, administrative overhead, adjusting and computing, publication of data, etc.) and the annual operating and maintenance cost of the network system.

In a strict economic sense, other types of costs or spillover effects should be accounted for. These might include: uncompensated damage to personal property or the ecology; traffic delays because of survey operations; loss of a property owner's time while permission was sought to enter his property; or the sacrifice of some utility to the small parcel of land occupied by the survey mark.

Careful consideration of these and other possible diseconomies to the public indicates their negative effect on the analysis would be negligible.

The annual operating and maintenance cost for an urban horizontal geodetic control system, if two control stations were recovered per day, could be computed as

$$0 = \left(\frac{\text{The Number of Stations in the Network}}{2}\right) \times$$

$$(8 \text{ hours per day}) \times$$

$$(\text{The Prevailing Fee Per Hour for a One-Man Surveying Party}).$$

For example, in the Monroe County urban geodetic survey this would be

$$0 = \left(\frac{552}{2}\right)(8)\ (\$14.00)^{*} = \$30{,}912$$

The capital investment cost, K, would have to be obtained from the participating agencies. In the case of the Monroe County urban horizontal geodetic survey the total capital investment cost was \$555,000.[21]

<u>Discount Rate, i:</u>

> The choice of interest rate [or discount rate] for the design and evaluation of public projects is perhaps the most difficult economic problem and yet one of the most important ones faced in this field... Choice of a rate involves fundamental social value judgements about benefits accruing to different

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*. See Table 5.2.

21. Based on data from the National Geodetic Survey and the Monroe County Geodetic Survey.

generations and about the overall objectives. At the same time, it can help to assure that capital channeled into this field of investment yields as high a return as it would elsewhere.[22]

The dilemma of choice as far as federal agencies are concerned, has been alleviated by the Office of Management and Budget (OMB)[23]. The OMB requires that federal agencies use a discount rate of 10.0 percent. Non-federal agencies should rely on guidelines issued by their own fiscal bureaus.

Time, T, and the Concept of Accounting for Risk and Uncertainty in the Benefits and Costs: There are two primary considerations in projecting estimated benefits and costs through the "life" of a project. One is the project's true economic life and the second is the uncertainty and risk in the estimated benefits and costs.

"The more durable a project the larger will be the share of benefits which cannot be included in the analysis."[24] If it is properly maintained, an urban geodetic survey is an extremely durable project. Physically, it consists of a system of permanently monumented points and a data file that could last indefinitely. Its economic life would continue

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22. Eckstein, p. 94

23. Office of Management and Budget, Circular No. A-94 Revised, dated March 27, 1972. See Appendix F.

24. Eckstein, p. 83.

until it could no longer meet the accuracy requirements of the community; or was rendered obsolete by a "black box" system which would not require the monumented points. It would be conjecture to consider a point in time when either event might occur, and accordingly, the true economic life of an urban survey is not determinable.

The benefits and costs quantified today may not be accurate measures by which to gauge future benefits. Specifically, future benefits will be affected by changes in: population growth and distribution, labor cost, technology, property values, legislation, and professional standards. The aggregate effects of these changes are also impossible to predict.

Since the ultimate effects of these changes on benefits are not known, there are two adverse connotations: one, the overstatement of benefits could indicate an inefficient project was efficient; or two, the understatement of benefits could indicate an efficient project was inefficient. One approach for risk adjustment would be the systematic and arbitrary reduction of benefits at some point in the future years of a project. This approach as an adjustment for risk would not be satisfactory because the benefit model quantifies only one segment of benefits; and, numerous benefits, in addition to the reduction in traverse cost resulting from a densified network, are known to exist.

A suitable solution to adjust for risk and uncertainty might be the selection of an arbitrary economic life and to maintain a static level of benefits. According to Eckstein,

> ... capital intensive projects, with ratios of operating and maintenance costs to fixed cost of 0.01 or so [as in the case of urban surveys] are much more affected [by this method] than others. Since it is the fixed investment that is risky, the operating cost always being subject to suspension, it is sound that the capital-intensive projects should be penalized more by this risk adjustment, and this is one advantage of the method.[25]

However,Eckstein also notes that

> ... there are two serious drawbacks to this device for adjusting for risk, first it is capricious, since it only penalized projects with an economic life longer than an arbitrary number of years ... . In fact, extremely durable projects ... may be less risky than fairly durable installations with a clearly defined physical end, since the genuinely permanent installation [such as a geodetic urban survey network] may find uses in the future of which we cannot even conceive with present technology. In any event, there is no significance

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25. <u>Ibid.,</u> p.85.

> to ... [an arbitrary year for cutting off benefits],... and it merely obscures the true relative merit of different projects when there are differences in the expected economic life.[26]

It is true that an urban geodetic survey could be put to uses not conceivable today; however, Eckstein's main concern is that projects with different economic lives would not be penalized equally. This would not be true with an urban geodetic survey. Regardless of what their true economic life is, it is the same for all of them. That is, they are all equally accurate and equally susceptible to obsolescence.

Eckstein's second point is that a "limit on the period of analysis can also lead to systematic misplanning in the formulation of projects. Many installations ... can be planned for different economic lives." [27] This would not apply to the type of urban geodetic surveys established by the NGS because no known functional relationships exist whereby a survey could be planned for a specific economic life.

The selection of an arbitrary time period for the analysis of survey benefits seems to be a suitable means to account for risk and uncertainty, and the question becomes: What should be the time horizon for computing the benefits?

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26. Ibid.

27. Ibid.

and costs? Rather than directly answering this question, several time periods can be elected at perhaps five or ten year intervals, and benefit-cost ratios can be computed for each time period.

Sample Computation of the Benefit-Cost Ratios: Benefit-cost ratios are computed from Formula 2.1.

$$\frac{B}{C} = \frac{\sum_{t=1}^{T} \frac{B_a}{(1+i)^t}}{\left[\sum_{t=1}^{T} \frac{0}{(1+i)^t}\right] + K}$$

For example, if values for B_a, K, and 0 are taken from Table 6.1, and if we let i = .10 and T = 15 years, we get the benefit-cost ratio for the Monroe County project in its 15th year.

$$\frac{B}{C} = \frac{\sum_{t=1}^{15} \frac{\$631,000}{(1+.10)^t}}{\left[\sum_{t=1}^{15} \frac{\$31,000}{(1-.10)^{15}}\right] + \$555,000} = \frac{6.00}{1.00}$$

A ratio of 6.07:1.00 means that in the 15th year of this project's economic life society would have experienced a return of \$6.07 for each \$1.00 invested.

Sensitivity analysis: Federal agencies must use a discount rate of 10.0 percent to determine if a project is economically justified. However, it is usual to compute several benefit-cost ratios for each chosen time period by varying the discount rate or changing the scale of the expected annual benefits.

Table 6.1

Social Cost and Benefits of the Monroe County, New York, Horizontal Urban Geodetic Survey Rounded Off to the Nearest Thousand Dollars

Capital Investment	\$555,000[a]
Annual Maintenance Cost	\$31,000[b]
Annual Benefits	\$631,000[c]

a. See page 63.

b. See page 63.

c. See page 59.

This analysis of the sensitivity of the benefit-cost ratios to changes in the variable i, T, and B_a is essential for determining the range of conditions over which a project is economically justified.

Such a sensitivity analysis, Table 6.2, was made for the Monroe County urban horizontal geodetic control survey. In this analysis, none of the benefit-cost ratios are less than 2.67. This demonstrates (over the range of conditions tested) that this was a very desirable project in terms of economic efficiency.

Table 6.2

Sensitivity of Benefit-Cost Ratios to Changes in Interest Rate and Time Horizon[a]

Interest Rate	Time Horizon					
	5	10	15	20	30	50
	Benefit Cost Ratios					
5.00	3.96	6.13	7.47	8.35	9.40	10.28
7.50	3.75	5.64	6.72	7.38	8.09	8.55
10.00	3.56	5.20	6.07	6.56	7.02	7.26
12.50	3.37	4.81	5.50	5.86	6.16	6.27

Sensitivity of Benefit-Cost Ratios to 25 Percent Changes in Scale at 10.000 Percent Interest

Interest Rate	Time Horizon					
	5	10	15	20	30	50
	Benefit Cost Ratios					
10.00[b]	2.67	3.90	4.55	4.92	5.26	5.44
10.00[c]	3.56	5.20	6.07	6.56	7.02	7.26
10.00[d]	4.45	6.50	7.59	8.20	8.78	9.07

All benefit-cost ratios based on annual benefits of $631,000 per year except as noted.

a. Benefit-cost ratios computed from Formula 2.1.

b. Benefit-cost ratios based on annual benefits of $473,000.

c. Benefit-cost ratios based on annual benefits of $631,000.

d. Benefit-cost ratios based on annual benefits of $789,000.

SUMMARY

SUMMARY

It has been demonstrated that it is practical to make a benefit-cost analysis of an urban horizontal geodetic control network. Standard benefit-cost analysis techniques were used but it was also necessary to develop a model to quantify benefits. The derivation of the benefit model (which quantifies the annual savings in traverse cost) represents an original work.

As a result of the methods developed in this paper it is now possible for public administrators and other decision makers to use benefit-cost analysis as a rationale for deciding on the allocation of resources for urban horizontal geodetic control surveys. It also provides them with a means of justifying their requests for additional funds for geodetic control. Moreover, special interest groups, such as the associations for private surveyors, can use the same methods for influencing the spending of public monies.

Conceptually better benefit models may exist than the one used in this paper and their development should be encouraged. It may also be possible, by using the concepts developed in the benefit model and in the utilization of existing benefit-cost analysis techniques, to make a benefit-cost analysis of vertical geodetic control surveys. Work in this area is also encouraged.

APPENDICES

APPENDIX A

CLASSIFICATION AND STANDARDS OF ACCURACY OF GEODETIC CONTROL SURVEYS

Approved by the Bureau of the Budget and referred to in Bureau of the Budget Circular A-16, Exhibit C., dated Oct. 10, 1958.

CLASSIFICATION AND STANDARDS OF ACCURACY OF GEODETIC CONTROL SURVEYS

INTRODUCTION

The Government of the United States makes nationwide surveys, maps and charts of various kinds. These are necessary to provide basic information for the conduct of public business at all levels of government, for planning and carrying out National and local projects, and programs for the best use and development of natural resources, and for National defense. Principal types of maps are topographic, geologic, soil, and those which show timber and other natural vegetation. Principal charts are nautical and aeronautical. All maps and charts are originally based on surveys, and in addition the survey category includes surveys of the public lands (cadastral surveys), and hydrologic and meteorological surveys. State and local governments regularly cooperate in various parts of the total surveying and mapping program, and business and industry not only profit from survey results but in many instances make their own surveys.

In making surveys and maps of large areas, whether financed by public authority or by private corporations or individuals, it is first necessary to establish a framework of control survey positions. This not only insures that the detailed local surveys necessary for the construction of any map or chart sheet will be done most economically, but also that such sheets, when completed, will join properly along their borders. Surveys of large areas must take into account the curvature of the earth. For small areas, such as a farm, a city lot or even a small city, the curvature may be ignored. Larger areas must be surveyed by methods which recognize that the earth is a flattened sphere, or spheroid. Such surveys are called geodetic. They are executed with high precision, and are the framework of surveys to control National mapping and charting operations as well as large engineering projects. Geodetic surveys and control surveys are terms which are used almost synonymously.

Control surveys are of two classes, horizontal and vertical. Horizontal control surveys establish latitude and longitude positions and provide the basis for rectangular coordinates, including state coordinate systems. Vertical control surveys determine elevations referred to mean sea level.

Horizontal control surveys are carried out by triangulation (a procedure of determining the lengths of the sides of a system of joined or overlapping triangles by measuring occasional side lengths upon the ground and computing the others from angles measured at the vertices), and by transit and tape traverses. The lengths of triangle sides or of traverse distances may also be measured by electronic instruments, which measure the travel time of a beam of light or radio pulse. Recent progress in the development of such instruments indicates increasing use of such procedures.

Vertical control surveys are carried on by precise leveling. The instruments used are of higher precision than those used in ordinary spirit leveling for surveys of small areas, and the computations and final adjustment refer the resultant elevations to mean sea level.

The accompanying tables group control surveys into orders and classes, in accordance with certain standards of accuracy. The recommended spacing or distance between survey stations is also indicated. These standards are primarily intended for the guidance of Federal agencies in performing and classifying their control survey operations. They should also be useful to State and local governments, and to private corporations and individuals.

These classifications were prepared by the Bureau of the Budget in cooperation with the Federal agencies concerned in making control surveys or in utilizing their results. These include the Coast and Geodetic Survey, Department of Commerce; the Geological Survey and the Bureau of Land Management, Department of the Interior; The Forest Service and the Soil Conservation Service, Department of Agriculture; the Army, the Navy and the Air Force, Department of Defense. After being prepared by representatives of the Federal agencies, the standards of accuracy were referred to the American Society of Civil Engineers and to the American Congress on Surveying and Mapping for review and comment. The opinions of other organizations and individuals were also requested and received. After consideration of all comments the original draft was revised in this, its present form.

BASIC GEODETIC PROGRAM

A basic program for establishing geodetic control described in these classifications is in progress to provide adequate spacing as well as sufficient strength and accuracy to meet the needs and satisfy the requirements of engineers and scientists engaged in the development and conservation of the resources of the United States.

The horizontal control network of the United States consists of a framework of arcs of triangulation extending north to south and east to west and crisscrossing each other at intervals of about 60 miles. The areas between the arcs are subdivided with networks of single triangles, supplemental arcs, or traverses.

The basic program for the ultimate development of the vertical control net of the United States is to form loops of first-order lines spaced at 60-mile intervals, divided by lines of second-order leveling spaced at 25- to 35-mile intervals. In areas where the interest and need for leveling require closer spacing the first-order spacing may be less than 60 miles. In areas where conditions require it, a spacing of second-order lines at 6-mile intervals may be established. The reference datum shall be mean sea level.

HORIZONTAL CONTROL

Generally, the density of permanently marked control points should be in direct ratio to land values. In metropolitan areas and along interstate highway systems a spacing at 1 or 2 mile intervals may be required and in rural areas of high land value a spacing of 3 to 4 miles may be desirable. Although wider spacing may suffice for Federal topographic mapping, closer spacing may be needed for property surveys, highway programs, transmission lines, reclamation projects, and numerous other engineering activities. The more closely spaced stations should be so situated that they are readily available to local engineers.

TRIANGULATION

Economic, engineering, and scientific progress has brought an increasing number of requests for higher accuracies in basic first-order triangulation. The range of accuracies is so great that it is necessary to divide first-order into three classes so that satisfactory standards of accuracy can be established.

First-order, Class I: The high value of land in urban areas, the study of small systematic movements in the earth's crust in areas subject to earthquakes, and the testing of military equipment for the National defense require that the triangulation used by engineers and scientists in these varied activities should have an accuracy of at least 1 part in 100,000. Extensive surveys of this nature should make adequate connections with the arcs that make up the National triangulation network. Surveys of such accuracy are designated as Class I of First-order.

First-order, Class II: The basic National horizontal control network consists of arcs of triangulation spaced about 60 miles apart in each direction, forming areas between the arcs which are approximately square. The arcs are planned as chains of quadrilaterals or central point figures, so that the lengths of the sides may be computed through two different chains of triangles. The program for the completion of the network in the United States includes establishing area networks of triangulation within these squares or loops formed by the arcs. To maintain satisfactory mathematical consistency within the area networks, these basic arcs should be measured with an accuracy of at least 1 part in 50,000. Most of these primary arcs have closures in length and position which are of the order of 1 part in 75,000 or 1 part in 100,000. Triangulation of this standard of accuracy is designated as Class II of First-order.

First-order, Class III: There are many additional demands for first-order triangulation within this National framework, and in some cases even independent of the National net. State, county, and private engineering organizations as well as branches of the Federal Government have need for horizontal control that would have a minimum accuracy of 1 part in 25,000. Surveys of this accuracy have long been recognized both Nationally and internationally as first-order and have attained the status of a widely accepted standard.

In the adjustment of the first-order National network, the surveys of Class I will have precedence and should not be distorted to adjust them to surveys executed under the specifications of Class II. When the surveys of Class III are rigidly adjusted to the basic network, their accuracy should be improved.

The placing of first- or second-order control points within the loops of the basic network requires the extension of area networks, cross arcs, or traverses. These specifications list two classes of second-order triangulation.

Second-order, Class I: This class includes the networks covering the areas within the arcs of the basic network and, if area nets are not feasible, it includes the cross arcs which would be used to subdivide the area. The internal closures of this class of survey should indicate an average accuracy of 1 part in 25,000, with no portion less than 1 in 20,000.

Second-order, Class II: This class of triangulation is used to establish control for hydrographic surveys along the coastline and inland waterways. It may also be used for further breakdown of control within any of the higher classes of triangulation. This class of survey or any of the higher classes may be used by engineers for controlling extensive property surveys. The minimum accuracy to be allowable in Class II of Second-order is 1 part in 10,000.

Third-order triangulation: Triangulation of this order should be supplemental to triangulation of a higher order for the control of topographic or hydrographic surveys, or for such other purposes for which it may be suitable. Although it will usually be established as needed for a specific project, third-order triangulation should be permanently marked, and azimuths should be observed to visible prominent objects, so that the work may be available for future projects and miscellaneous uses in the area. Points located by third-order triangulation may be expected to have an absolute position determination within 10 feet or less in relation to the adopted datum defined by higher-order positions in the area. The work should be performed with sufficient accuracy to satisfy the standards listed in Table I.

Standards for surveys below third-order are not included in these classifications.

BASES

Bases for the control of the lengths of lines in the triangulation should be measured by appropriate methods and instruments, so that the standards in Table I are satisfied. Recent developments in electronics indicate that accuracies comparable to those obtained with invar tapes may be expected from the Bergstrand geodimeter or similar instruments. The intervals between bases should be such that the standards regarding strength of figure (ΣR_1) also are satisfied.

TRAVERSE

Traverses are used to supplement all orders and classes of triangulation, and to provide closer and more adequate spacing of horizontal control points. A triangulation net in an urban area provides a framework for a complete traverse network of first- and second-order accuracies. It is neither economical nor feasible to use triangulation for this closer spacing. There are some sections of the United States in addition to these urban areas where traverse can be used efficiently to subdivide the basic network and provide the fundamental spacing of control specified in the national program.

First-order traverses should preferably be connected to First-order triangulation stations of Class I or Class II. If they are connected to Class III of first-order they might be used and given some weight in the adjustment of this class of triangulation. The minimum requirement of accuracy for a first-order traverse is 1 part in 25,000, yet first-order traverse networks, properly executed, will average about 1 part in 40,000. This value is expected and desired. Detailed standards are listed in Table II.

Traverses of second- and third-order accuracy are tied to triangulation or traverse of the same or higher order. They are used extensively for cadastral or property surveys and mapping. For property surveys, the value of the property should, in general, determine the accuracy to be used. For map control, the scale of the map and the positional accuracy required usually govern. Details of these orders of traverse are also listed in Table II.

TRILATERATION

Electronic techniques are increasingly used for the measurement of distances and, through the geometric combination of these distances, networks of trilateration or traverse are developed. In general, the same standards in regard to position closure may be applied as are used in triangulation and traverse.

VERTICAL CONTROL

LEVELING

One of the most important items in the development of a control level net is establishing marks that will remain stable. Releveling has shown that there is considerable vertical movement of bench marks. In some sections of the country there are many factors contributing to vertical change, such as removal of underground water, removal of underground gas and oil, frost action, settling of the soil due to increased moisture content during the rainy seasons, changes in the underground water table, fault lines, earthquakes, etc. Some of these are so deep-seated that in some areas it is impossible to establish a mark that will remain stable. However, some of these vertical changes can be overcome by installing "super" or "basic" marks at intervals along the line of leveling. The usual practice is to establish a concrete-post type mark at one-mile intervals along a line of first- or second-order leveling, with a "basic" mark at 5-mile intervals. Releveling has shown so many vertical changes that it is advisable to consider releveling first-order lines at least at 25-year intervals, and, in areas where the vertical change is rapid, releveling at least at 5-year intervals. Where vertical change has reached a rate of one foot per year. releveling every two years may be advisable. In addition to the determination of the elevations of regular bench marks, which are installed along the routes of precise level lines, supplementary elevations should be determined at points such as road intersections, railroad crossings, etc., which can be readily identified in aerial photographs.

In first-order leveling the requirement is for a forward and backward running that agree within 4 mm. times the square root of the length of section in kilometers. If second-order leveling is run with the same equipment as first-order, it can be single run, with loop closures within the criterion 8.4 mm. times the square root of the distance around the loop. In remote areas where a second-order line is longer than 25 miles due to the fact that routes are unavailable for an additional network development, the line should be double-run. This is defined as Class I of Second-order. The single-run area leveling is defined as Class II of Second-order. Summaries of these classifications are listed in Table III.

Third-order leveling should be used to subdivide the area surrounded by first- and second-order leveling and should be performed so that the standards in Table III are satisfied. Trigonometric leveling may be considered as fourth-order leveling, and the elevations thus determined are listed with the triangulation data.

March 1, 1957

CLASSIFICATION AND STANDARDS OF ACCURACY

TABLE I

TRIANGULATION

	First-order			Second-order		Third-order
	Class I (Special)	Class II (Optimum)	Class III (Standard)	Class I	Class II	
Principal uses	Urban surveys, scientific studies	Basic network	All other.	Area networks and supplemental cross arcs in national net	Coastal areas, inland waterways and engineering surveys	Topographic mapping
Spacing of arcs or principal stations *	Stations: 1-5 miles or greater as required	Arcs: 60 miles. Stations: 10-15 miles	Stations: 10-15 miles	Stations: 4-10 miles	As required	As required
Strength of figure						
ΣR_1 between bases						
Desirable limit	25	60	80	80	100	125
Maximum limit	30	80	110	120	130	175
Single figure						
Desirable limit						
R_1	5	10	15	15	25	25
R_2	10	30	50	70	80	120
Maximum limit						
R_1	10	25	25	25	40	50
R_2	15	60	80	100	120	170

*Additional stations of same accuracy may be interspersed among principal stations

TABLE I
(continued)

	First-order			Second-order		Third-order
	Class I	Class II	Class III	Class I	Class II	
Base measurement						
Actual error not to exceed	1 part in 300,000	1 part in 300,000	1 part in 300,000	1 part in 300,000	1 part in 150,000	1 part in 75,000
Probable error not to exceed	1 part in 1,000,000	1 part in 1,000,000	1 part in 1,000,000	1 part in 1,000,000	1 part in 500,000	1 part in 250,000
Triangle closure						
Average not to exceed	1″	1″	1″	1″.5	3″	5″
Maximum seldom to exceed	3″	3″	3″	5″	5″	10″
Side checks						
Ratio of maximum difference of logs of sides to tab. diff. for 1″ of log sine of smallest angle	1.5	1.5-2	2	2-4	4	10-12
OR in side equation test, average corr. to direction not to exceed	0″.3	0″.4	0″.4	0″.6	0″.8	2″
Astro. Azimuths						
Spacing-figures	6-8	6-10	8-10	8-10	10-12	12-15
Probable error	0″.3	0″.3	0″.3	0″.3	0″.5	2″.0
Closure in length (also position when applicable) after side and angle conditions have been satisfied, should not exceed	1 part in 100,000	1 part in 50,000	1 part in 25,000	1 part in 20,000	1 part in 10,000	1 part in 5,000

TABLE II

TRAVERSE

	First-order	Second-order	Third-order
Number of azimuth courses between azimuth checks not to exceed	15	25	50
Astronomical azimuth: Probable error of result	0".5	2".0	5".0
Azimuth closure at azimuth check points not to exceed *	2 sec. $\sqrt{N}$ or 1.0 sec. per station	10 sec. $\sqrt{N}$ or 3.0 sec. per station	30 sec. $\sqrt{N}$ or 8.0 sec. per station
Distance measurements accurate within	1 in 35,000	1 in 15,000	1 in 7,500
After azimuth adjustment, closing error in position not to exceed *	0.66 ft. $\sqrt{M}$ or 1 in 25,000	1.67 ft. $\sqrt{M}$ or 1 in 10,000	3.34 ft. $\sqrt{M}$ or 1 in 5,000

N is the number of stations for carrying azimuth

M is the distance in miles

* The expressions for closing errors in traverse surveys are given in two forms. The expression containing the square root is designed for longer lines where higher proportional accuracy is required. The formula which gives the smaller permissible closure should be used.

TABLE III

LEVELING

	First-order	Second-order		Third-order
		Class I	Class II	
Spacing of lines and cross-lines	60 miles	25-35 miles	6 miles	Not specified
Average spacing of permanently marked bench marks along lines, not to exceed	1 mile	1 mile	1 mile	3 miles
Length of sections	1/2-1 mile	1/2-1 mile	1/2-1 mile	Not specified
Check between forward and backward running between fixed elevations or loop closures, not to exceed	4mm $\sqrt{K}$ or 0.017 ft. $\sqrt{M}$	8.4mm $\sqrt{K}$ or 0.035 ft. $\sqrt{M}$	8.4mm $\sqrt{K}$ or 0.035 ft. $\sqrt{M}$	12mm $\sqrt{K}$ or 0.05 ft. $\sqrt{M}$

K is the distance in kilometers

M is the distance in miles

APPENDIX B

APPENDIX B

LIST OF VARIABLES

B_a = $B_{P,P'}$

$B_{P,P'}$ = $\left[1 \quad \frac{N}{N+N'}\right] (U_P - U_{P'})(C)$ = the benefit, in miles of traversed for C direct traverse connections to control stations for a station spacing P before densification and a station spacing P' after densification.

C = The number of direct connections.

D_j = $\sqrt{\frac{R_j^2 = R_i^2}{2}}$ = The radius of a circle that would divide a ring zone, Z_j into two equal areas and therefore be the average distance from the ring zone to the control station for direct ties made from that ring zone.

D_c = $\frac{R_k}{.9048}$ = The radius of a circle that would divide the corner zones into equal areas and therefore be the average distance from the corner zones to the control stations for the direct ties made from the corner areas.

L_j = The probability of a tie being made from ring zone Z_j.

L_c = The probability of a tie being made from the corner zones Z_c.

N = The number of stations in an undensified control system, or a general designation for the number of control stations.

N' = The number of new stations in a densified network.

$P = \sqrt{\frac{XY}{N}}$ = The station spacing before densification or a general representation of the station spacing.

$P' = \sqrt{\frac{XY}{N'}}$ = The station spacing after densification.

R_i = The radius of a circle defining the inner boundary of a ring zone Z_j.

R_j = The radius of a circle defining the outer boundary of a ring zone Z_j.

$R_k = \frac{P}{2}$ = The radius of the maximum outer boundary of a ring zone that would be within the section.

$R_{max} = 2(P/2)^2$ = The maximum distance a point could be from the control station and still be within a section.

$T_j = CL_j$ = The number of ties made to or from a ring zone Z_j.

$T_c = CL_c$ = The number of ties made to or from the corner zones Z_c.

$U_p = \sum_i^k (L_j D_j) + L_c D_c$ = The sum of: the probabilities of a point being in a zone multiplied by the average zone distance.

U_p' = The same as U_p except for a densified network.

$W_p = CU_p$ = The total miles of traverse miles run to or from a control station within the boundaries of a section.

W_p' = The same as W_p except it is for a densified network.

W_c = D_cT_c = The number of miles of traverse run to or from the corner areas.

W_j = D_jT_j = The miles of traverse run to or from the ring zone Z_j.

X = One dimension of the entire project area.

Y = The second dimension of the entire project area.

XY = The area of the whole project area

Z_c = $P^2 - \pi(P/2)^2$ = The corner zone (the area of all four identical corner areas).

Z_j = $\pi[(R_j)^2 - (R_i)^2]$ = The area of the ring between the circles defined by the radius R_i and R_j.

APPENDIX C

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SURVEY
Rockville, Md. 20852
National Geodetic Survey

June 19, 1972

Dear Sir:

During June 1971, the National Geodetic Survey conducted a study of horizontal surveying activities in metropolitan areas of the United States. As part of this study, the National Geodetic Survey mailed over two thousand questionnaires to all surveyors, civil engineers, appropriate government agencies, and utility companies listed in the classified telephone directories of 46 standard metropolitan statistical areas (SMSA).

Over five hundred questionnaires were returned completed, or partially completed, for a response rate of 27.0 percent. This high percent of responses reflects the strong personal and professional interest surveyors in the United States have in their profession. The National Geodetic Survey gratefully acknowledges the cooperation of those who participated in this study.

Data from the questionnaires were used by Lieutenant Commander Phillip C. Johnson in a Masters of Science Thesis at Cornell University titled, "A Measure of the Economic Impact of Urban Horizontal Geodetic Control Surveys." This thesis develops the necessary methods to quantity benefits and cost of horizontal surveys, and it utilizes techniques which allow a benefit cost analysis to be made of metropolitan horizontal geodetic control surveys. The National Geodetic Survey may publish this thesis in mid-August 1972. Those who are interested should write:

The Director
National Geodetic Survey
6001 Executive Boulevard
Rockville, Maryland 20852.

The summarized responses of the questionnaires for all SMSAs are contained in Appendix C.

Sincerely,

Leonard S. Baker

Leonard S. Baker
Captain, NOAA
Director, National Geodetic Survey

APPENDIX C

Results of the Questionnaire: A Study of Urban Geodetic Surveying Activities.
Approved OMB No. 41-571039

(1) What percent of your horizontal surveying effort is devoted to:

A.	Property surveys		38.79%
B.	Engineering surveys		35.28%
C.	Highway surveys		9.88%
D.	Control surveys		10.20%
E.	Other horizontal surveys		5.85%
		Total	100.00%[a]
F.	Traverse		88.48%
G.	Triangulation		8.82%
H.	Trilateration		2.70%
		Total	100.00%[a]
I.	Horizontal surveys, including property surveys, that are tied to the national network and are of first- or second-order accuracy		23.76%

a. Based on 490 replies.

(2) Does your city, county, or state require that property surveys be tied to the National network?

A.	City	Yes - 11.57%	No - 88.43%[a]
B.	County	Yes - 10.20%	No - 89.80%[a]
C.	State	Yes - 19.54%	No - 80.46%[a]
D.	If your answers were all No, and assuming one-mile control station spacing was available, would you like to see this as a requirement for your area?	Yes - 80.29%	No - 19.71%[a]

a. Based on approximately 440 replies.

The answers to questions 2 A, B, C indicates the percent of organizations replying to the questionnaire who do surveying in areas where it is required that surveys be tied to the national net. It does not mean, for example, that 19.50 percent of all States require property surveys be tied to the national net.

E. Why? Representative answers to this question follow:

Yes: "It would reduce property disputes and litigation and force lax surveyors to become more responsible."

Yes: "If data was easily obtainable and one local agency was responsible for filing the surveys."

Yes: "It would make the retracement of a survey much easier."

No: "At least not in California where seismic activity would cause chaos with the monument."

Yes: "Points would never be lost."

Yes: "It would allow a uniform, coordinated data system for one whole region."

No: "It is not practical for single lot subdivisions. Too costly."

Yes: "Gores and overlapping would be avoided."

(3) Answering for the categories that apply to your surveying operations, what would be the minimum accuracy you would require if using the national network for control?

	(1)	(2)	(3)	(4)	(5)	(6)
	1:100,000	1:50,000	1:25,000	1:20,000	1:10,000	1:5,000 or less
A. Property[a]	2.27%	8.62%	12.93%	19.27%	48.07%	8.84%
B. Engineering[b]	1.16%	7.89%	13.69%	18.56%	45.01%	13.69%
C. Highway[c]	1.62%	11.69%	14.29%	18.83%	42.21%	11.36%
D. Control[d]	12.36%	25.00%	21.63%	24.43%	14.33%	2.25%

a. Based on 441 replies.
b. Based on 431 replies.
c. Based on 308 replies.
d. Based on 356 replies.

(4) Answering for the types of horizontal surveying you conduct, what would you consider as the maximum desirable control station spacing:

A. Property	1.18 miles[a]
B. Engineering	1.56 miles[b]
C. Highway	2.30 miles[c]
D. Control	2.95 miles[d]

a. Based on 433 replies.
b. Based on 414 replies.
c. Based on 293 replies.
d. Based on 338 replies.

(5) What percent of the marks established by you at the end of the legs of your traverses could be recovered for use, if not disturbed, at the end of a ten-year period?

57.09%[a]

a. Based on 426 replies.

(6) A. Do you recover national network marks in an area before commencing a survey?

Yes-56.68% No-43.32%[a]

B. What percent of the marks do you find destroyed?

27.20%[b]

a. Based on 263 replies.
b. Based on 298 replies. This probably reflects the percent of marks searched for but not found. The National Geodetic Survey does not consider a mark destroyed unless there is physical evidence, for example the disk itself. This was not made clear in the question.

(7) What percent of your traverses have a total length of:

A.	1 mile or less	57.97%
B.	1 to 3 miles	22.20%
C.	3 to 5 miles	10.48%
D.	5 miles or more	9.35%
		100.00%[a]

What is your average traverse length?

2.10 miles[a]

a. Based on 422 replies.

(8) On the average, how long are the individual legs in one of your traverses when the traverse has a total length of:

	Total length	Leg length
A.	1 mile or less	.18 miles[a]
B.	1 to 3 miles	.35 miles[b]
C.	3 to 5 miles	.56 miles[c]

Total length	Leg length
D. 5 miles or more	.84 miles[d]

a. Based on 428 replies.
b. Based on 428 replies.
c. Based on 276 replies.
d. Based on 232 replies.

(9) What percent of your traverses, within each length classification: (1) close on the starting point; (2) close on another control mark besides the starting point; (3) are not closed to the starting point or to other control.

	(1) Close to starting point	(2) Close to another point	(3) Not closed	Total
A. 1 mile or less[a]	74.98%	17.97%	7.06%	100%
B. 1 to 3 miles[a]	62.90%	30.10%	7.00%	100%
C. 3 to 5 miles[a]	47.13%	46.04%	6.83%	100%
D. 5 miles or longer[a]	34.76%	57.81%	7.43%	100%

a. Based on approximately 490 replies.

(10) What are your reasons for not connecting traverses to first- or second-order national network control marks?

A. Uneconomical	Yes-92.24%	No- 7.76%[a]
B. Not consistent with accuracy required	Yes-68.82%	No-31.18%[b]
C. Other: Please explain		

a. Based on 361 replies.
b. Based on 263 replies.

D. Why? Following are some representative answers:

"Client will not pay the extra cost."
"Control not available."
"Control stations not accessible."
"Stations spaced too far apart."
"Stations available to us are too sparce and inaccessible. Note: In the long run it <u>is</u> economical to use high order nets <u>if</u> stations are accessible and <u>if</u> your goal is reliable work."

"Most of our work is 100 acres or less and we always close to the starting point."
"Towers are generally needed, and this makes it impossible for us."
"Most of our surveys are to establish property boundaries and we see no advantage to tie into the national control."
"No official place to file calculations."

(11) How many additional hours would you be willing to spend to close a traverse to first- or second-order control marks connected to the national geodetic network rather than closing the traverse to control of lesser accuracy which is not part of the network?

average = 4.5 hours[a]

a. Based on 367 replies.

Because of the wide variation of replies to this question, a further breakdown of answers was made.

15.80% would spend 0 hours to tie to the national net.
37.06% would spend 1-4 hours to tie to the national net.
18.53% would spend 5-8 hours to tie to the national net.
6.27% would spend 9+ hours to tie to the national net.

22.34% replied in terms of a percent of the total work time for a particular project.

(12) What type of angle measuring equipment do you use?

A. Second-order instruments Yes - 77.78% No - 22.22%[a]
EXAMPLE - Wild T-2, DKM 2, Zeiss TH 002

B. First-order instruments Yes - 9.86% No - 90.14%[b]
EXAMPLE - Wild T-3, DKM 3

a. Based on 459 replies.
b. Based on 426 replies.

(13) What type of distance measuring equipment do you use?

A.	Standardized tape	Yes - 88.03%	No - 11.97%[a]
B.	Invar tape	Yes - 19.02%	No - 80.98%[b]

Electronic distance measuring instruments

C.	Infrared	Yes - 16.81%	No - 83.19%[c]
D.	Lightwave, Laser	Yes - 7.91%	No - 92.09%[d]
E.	Lightwave, Non-laser	Yes - 23.97%	No - 76.03%[e]

If applicable, how long have you owned electronic distance measuring equipment?

Average of 4.8 years[f]

a. Based on 468 replies.
b. Based on 447 replies.
c. Based on 458 replies.
d. Based on 455 replies.
e. Based on 463 replies.
f. Based on 157 replies.

Due to an unfortunate oversight, the category of <u>microwave</u> instrument was not included.

(14) How many men do you normally use on a single traverse party?

Average of 3.4 men[a]

a. Based on 462 replies.

A further breakdown of results shows that:

6.06% use 2 men per traverse party.
51.95% use 3 men per traverse party.
37.23% use 4 men per traverse party.
3.46% use 5 men per traverse party.
1.30% use 6 men per traverse party or more.

(15) How many miles per month would you expect this traverse party to measure?

An average of 36.86 miles per month[a]

a. Based on 295 replies.

(16) What was the total miles of traverse your organization ran in:

A.	1965	160.88 miles[a]
B.	1968	173.19 miles[b]
C.	1970	198.79 miles[c]

How many traverses did you run in 1970? 103.35 traverses[d]

a. Based on 223 replies.
b. Based on 264 replies.
c. Based on 297 replies.
d. Based on 290 replies.

(17) It is possible that the U.S. will adapt to the metric system of measurement within the next few years. Do you think this would be beneficial to the surveying profession?

Yes - 58.25% No - 41.75%

A. Why? Following are some representative answers:

Yes: "Most of the new instruments are set up in the metric system."
Yes: "The metric system is easier to work with."
Yes: "But new measuring tapes would be expensive."
No: "The cost and loss time would justify the advantage of our present workable English System."
No: "It is no easier to work with than feet and hundredths."
Yes: "It would standardize feet, yards, rods, chains, varas, links, inches, tenths and hundredths of feet to one workable unit."
Yes: "Probably, it would make calculations easier."
No: "Hell No."
No: "All past records are in English System."
Yes: "It would eliminate the horrible mess we how have."
Yes: "But the reasons are too numerous to list."
Yes: "1. The units are of a more workable length.
2. We are using the metric system more and more and are converting back to feet.
3. Standardized units should be worldwide.
4. The conversion of decimal values of feet to inches give the construction people fits."

APPENDIX D

APPENDIX D

Standard Metropolitan Statistical Areas to Which the Questionnaires Were Mailed

City	County	State
Akron	Summit	Ohio
Albany	Rensselaer	New York
Albuquerque	Bernalillo	New Mexico
Atlanta	Fulton	Georgia
Baton Rouge	Baton Rouge	Louisiana
Birmingham	Jefferson	Alabama
Boston	Suffolk	Massachusetts
Boulder	Boulder	Colorado
Buffalo	Niagara	New York
Cleveland	Cuyahoga	Ohio
Columbus	Franklin	Ohio
Dallas	Dallas	Texas
Dayton	Montgomery	Ohio
Denver	Denver	Colorado
Detroit	Wayne	Michigan
Durham	Durham	North Carolina
Ft. Lauderdale	Broward	Florida
Ft. Worth	Tarrant	Texas
Hartford	Hartford	Connecticut
Honolulu	Honolulu	Hawaii
Houston	Harris	Texas
Indianapolis	Marion	Indiana
Jacksonville	Duval	Florida
Little Rock	Pulaski	Arkansas
Los Angeles	Los Angeles	California
Louisville	Jefferson	Kentucky
Memphis	Shelby	Tennessee
Miami	Dade	Florida
Milwaukee	Milwaukee	Wisconsin
Minneapolis	Hennepin	Minnesota
Nashville	Davidson	Tennessee
Nassau	Nassau	New York
Oakland	Alameda	California
Oklahoma City	Oklahoma	Oklahoma
Phoenix	Maricopa	Arizona
Pittsburgh	Allegheny	Pennsylvania
Portland	Multnomah	Oregon
Providence	Providence	Rhode Island
Raleigh	Wake	North Carolina
Richmond	Richmond City	Virginia
Rochester	Monroe	New York

City	County	State
Salt Lake City	Salt Lake	Utah
San Diego	San Diego	California
Seattle	King	Washington
Syracuse	Onondaga	New York
Washington, D.C.	D.C., Prince Georges, Montgomery, Fairfax	Maryland & Virginia

APPENDIX E

APPENDIX E

QUESTIONNAIRE COST[29]

A Study of Urban Geodetic Surveying Activities

CONCLUSIONS - Cost:

Total cost of the questionnaire was $3,775, or $1.55 for each mailed questionnaire. The variable costs, costs related to the number of questionnaires, was $1,815, or $0.75 for each mailed questionnaire. This was an efficient operation, and the only means of reducing costs would be to use a mailing list better than the phone directory. Fixed cost was $1,960, or $0.80 per mailed questionnaire. Using professional programmers, this cost could be reduced to approximately $1,000.

29. Prepared by Lieutenant P. Hodgson, National Oceanic and Atmospheric Administration.

QUESTIONNAIRE - COST BREAKDOWN

JOB	LABOR (LTJG Hodgson)	LABOR (Secretaries)	LABOR (Key Punch)	SUPPLIES & PRINTING	TIME*	TOTAL $$
Prepare Questionnaire	$ 400. (80 hrs)	$ 20. (5 hrs)		$100		$520.00
Mailing lList	600 (120 hrs)	160 (40 hrs)				760.00
Code & Mail	400 (80 hrs)	40 (10 hrs)		80		520.00
Check Returns	100 (20 hrs)	160 (40 hrs)				260.00
Key Punch & Check	100 (20 hrs)		175 (50 hrs)			275.00
Programs	1,200 (240 hrs)				240 (4 hrs)	1,440.00
TOTAL $$	$2,800.00	$380.00	$175.00	$180.00	$240.00	$3,775.00
LABOR PER HOUR	$ 5.00	$ 4.00	$3.50		$ 60.00	

2,340 = Questionnairs Mailed
490 = Used in Study (20 percent)
525 = Estimated Returns (22 percent)

1,815 ÷ 2,430 = $0.75/Questionnaire Mailed
1,815 ÷ 490 = 3.70/Questionnaire Used
1,815 ÷ 525 = 3.46/Estimated Returned
(Variable Cost)

* Computer Time

3775 ÷ 2430 = $1.55/Questionnaire Mailed
3775 ÷ 490 = 7.70/Questionnaire Used
3775 ÷ 525 = 7.19/Estimated Returned

ITEM	FIXED COST	VARIABLE COST
Prepare Questionnaire	$520.00	$760.00
Mailing List		$760.00
Code & Mail		520.00
Check Returns		260.00
Key Punch		275.00
Programs	1,440.00	
Total $$	$1.960.00	$1,815.00

APPENDIX F

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

March 27, 1972

CIRCULAR NO. A-94
Revised

TO THE HEADS OF EXECUTIVE DEPARTMENTS AND ESTABLISHMENTS

SUBJECT: Discount rates to be used in evaluating time-distributed costs and benefits

1. Purpose. This Circular prescribes a standard discount rate to be used in evaluating the measurable costs and/or benefits of programs or projects when they are distributed over time.

2. Rescission. This Circular replaces and rescinds Office of Management and Budget (OMB) Circular No. A-94 dated June 26, 1969.

3. Scope.

a. This Circular applies to all agencies of the executive branch of the Federal Government except the U.S. Postal Service. The discount rate prescribed in this Circular applies to the evaluation of Government decisions concerning the initiation, renewal or expansion of all programs or projects, other than those specifically exempted below, for which the adoption is expected to commit the Government to a series of measurable costs extending over three or more years or which result in a series of benefits that extend three or more years beyond the inception date.

b. Specifically exempted from the scope of this Circular are decisions concerning water resource projects (guidance for which is the approved Water Resources Principles and Standards), the Government of the District of Columbia, and non-Federal recipients of Federal loans or grants.

c. The remaining exemptions derive from the secondary nature of the decisions involved; that is, how to acquire assets or proceed with a program after an affirmative decision to initiate, renew, or expand such a program using this Circular. Thus:

(1) This Circular would not apply to the evaluation of decisions concerning how to obtain the use of real property, such as by lease or purchase.

(2) This Circular would not apply to the evaluation of decisions concerning the acquisition of commercial-type services by Government or contractor operation, guidance for which is OMB Circular No. A-76.

(3) This Circular would not apply to the evaluation of decisions concerning how to select automatic data processing equipment, guidance for which is OMB Circular No. A-54 and OMB Bulletin No. 60-6.

d. The discount rates prescribed in this Circular are:

(1) Suggested for use in the internal planning documents of the agencies in the executive branch;

(2) Required for use in program analyses submitted to the Office of Management and Budget in support of legislative and budget programs.

This Circular does not supersede agency practices which are prescribed by or pursuant to law, Executive order, or other relevant Circulars. Agencies should evaluate their programs and projects in accordance with existing requirements and, in addition, summarize the present value costs and/or benefits using the discount rate prescribed in this Circular.

4. Definitions. Analytic documents submitted to the Office of Management and Budget should be based on the following concepts where relevant:

a. Expected annual cost means the expected annual dollar value (in constant dollars) of resources, goods, and services required to establish and carry out a program or project. Estimates of expected yearly costs will be based on established definitions and practices for program and project evaluation. However, all economic costs, including acquisition, possession, and operation costs, must be included whether or not actually paid by the Federal Government. Such costs not generally involving a direct Federal payment include imputed market values of public property and State and local property taxes foregone.

b. Expected annual benefit means the dollar value (in constant dollars) of goods and services expected to result from a program or project for each of the years it is in operation. Estimates of expected yearly benefits will be based on established definitions and practices developed by agencies for program and project evaluation.

c. Expected annual effects means an objective, non-monetary measure of program effects expected for each of the years a program or project is in operation. When dollar value cannot be placed on the effects of comparable programs or projects, an objective measure of effects may be available and useful to enable the comparison of alternative means of achieving specified objectives on the basis of their relative present value costs. These effects should be estimated for each year of the planning period and are not to be discounted.

d. Discount rate means the interest rate used in calculating the present value of expected yearly costs and benefits.

e. Discount factor means the factor for any specific discount rate which translates expected cost or benefit in any specific future year into its present value. The discount factor is equal to $1/(1+r)^t$, where r is the discount rate and t is the number of years since the date of initiation, renewal or expansion of a program or project.

f. Present value cost means each year's expected yearly cost multiplied by its discount factor and then summed over all years of the planning period.

g. Present value benefit means each year's expected yearly benefit multiplied by its discount factor and then summed over all years of the planning period.

h. Present value net benefit means the difference between present value benefit (item g) and present value cost (item f).

i. Benefit-cost ratio means present value benefit (item g) divided by present value cost (item f).

Attachment A contains an example that illustrates calculation of the present value information.

5. Treatment of inflation. All estimates of the costs and benefits for each year of the planning period should be made in constant dollars; i.e., in terms of the general purchasing power of the dollar at the time of decision. Estimates may reflect changes in the relative prices of cost and/or benefit components, where there is a reasonable basis for estimating such changes, but should not include any forecasted change in the general price level during the planning period.

6. <u>Treatment of uncertainty</u>. Actual costs and benefits in future years are likely to differ from those expected at the time of decision. For those cases for which there is a reasonable basis to estimate the variability of future costs and benefits, the sensitivity of proposed programs and projects to this variability should be evaluated.

The expected annual costs and benefits (or effects) should be supplemented with estimates of minimum and maximum values. Present value cost and benefits should be calculated for each of these estimates. The probability that each of the possible cost and benefit estimates may be realized should also be discussed, even when there is no basis for a precise quantitative estimate. Uncertainty of the cost and benefit (or effects) estimates should be treated explicitly, as described above. The prescribed discount rate should be used to evaluate all alternatives. Specifically, the evaluations should <u>not</u> use different discount rates to reflect the relative uncertainty of the alternatives.

7. <u>Discount rate policy</u>. The discount rates to be used for evaluations of programs and projects subject to the guidance of this Circular are as follows:

a. A rate of 10 percent; and, where relevant,

b. Any other rate prescribed by or pursuant to law, Executive order, or other relevant Circulars.

The prescribed discount rate of 10 percent represents an estimate of the average rate of return on private investment, before taxes and after inflation.

To assist in calculation, Attachment B contains discount factors for the discount rate of 10.0 percent for each of the years from one to fifty.

8. <u>Interpretation</u>. Questions concerning interpretation of this Circular should be addressed to the Assistant Director for Evaluation, Office of Management and Budget (395-3614).

GEORGE P. SHULTZ
DIRECTOR

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