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Aerial photography and related products| Aids in expediting the construction and development of urban land-use maps

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AERIAL PHOTOGRAPHY AND RELATED PRODUCTS--AIDS IN EXPEDITING THE CONSTRUCTION AND DEVELOPMENT OF URBAN LAND-USE MAPS

By

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CHAPTER I

INTRODUCTION

Urban geography is a search for order or regularity in man's organization of the urban sphere. It deals with the spatial aspects of urban development. Urban areas are distinctive settlement patterns. They are generally the foci of nodal regions and the sites for exchanging goods and ideas between regions. As such, geographers study the city from the viewpoint of the basic urban concepts of location, character, morphology, internal structure, and growth. In part, their concern is to determine and analyze the areal patterns associated with urban centers and to explain these arrangements. An understanding of land uses is basic to this geographic research.

For the urban geographer, the land-use map is an important aspect of his research. The geographer must find or construct an adequate base map for his purposes. Quite often the available maps are not suitable, since they include streets and subdivisions that have been planned but have not yet materialized; conversely, some recent side streets may not be shown. Since most base maps carry extraneous information or are otherwise not suited for land-use purposes, numerous alterations are required. Furthermore, the researcher must devote time and effort in the collection of extensive information to complete the map. Some of this land-use data must be obtained through field work, although Sanborn maps may be used for some detailed descriptions.[1] However, since these maps are intended primarily for fire insurance purposes, some portions of the city may not be covered. Aids are available to the geographer to assist him in the construction and development of a map. But how does one approach the problem of inadequate information to make an accurate, up-to-date base map?

This thesis investigates and analyzes the application of black and white aerial photography, combined with various cartographic techniques, in providing the geographer with methods for the rapid construction of complete, current base maps. The application of aerial photography and basic cartographic techniques is not only of significance to the geographer, but it is of equal importance to anyone involved in urban research. This is true, for an up-to-date land-use map is fundamental to understanding the urban phenomenon. Several questions will be pursued in depth. What basic information does an urban analyst normally require from his

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[1] Sanborn maps show streets, railroad tracks, lot lines, the dimensions of buildings, the nature of building materials, etc.

map? What data can be gleaned from aerial photography at various scales? What equipment is best suited for the development of urban base maps from aerial photography? Is there other information available from these photographs which might provide additional land-use information?

The following steps were taken to obtain this information: (1) research and determine the types of base maps normally used by urban geographers; (2) describe the general land-use classifications associated with these various base maps; (3) determine the type and amount of required information which is available from aerial photography of various scales; (4) determine the aerial photography and equipment best suited to the task based on the maps and classification information needed; and (5) provide an example with a cost estimate.

The operations necessary to interpret aerial photographs for urban use are described. The interpretation sequence shows the development from the single image to more complex problems. Missoula, Montana is used as an example in developing information to determine the cost of procuring and processing aerial photography.

Some information needed for the construction and development of land-use maps is presently being obtained from aerial photography and related products. Material needed to provide the land-use classifications has been to some extent interpreted from these photographs. In most urban areas of the United States, land-use changes are progressing at a very rapid pace. In such places, many of the present time-consuming methods used in the construction of these maps cause the final product to be grossly out of date before completion. Alternative approaches are needed to provide timely maps portraying recent changes.

As perceived, the principal contribution of this thesis is to provide a treatise for the rapid construction of urban land-use maps. This is accomplished through a synthesis of data gathered from various sources, combined with information from the author's fifteen years of experience in the mapping field.

CHAPTER II

CHARACTERISTICS AND USES OF PRESENT LAND-USE MAPS

Description of Land-Use Maps

The United States has detailed maps of topography, geology, soil, population, etc., yet there are no land-use maps produced of the country as a whole in similar detail. Several states issue generalized land-use maps, but few detailed large scale maps are available. In many European countries land use is indicated to a certain extent on topographic sheets. However, in this country maps rarely show more than the generalized location of man-made features.

Great Britain approached this problem by producing a map at a scale of 1:10,560 (six inches to the mile) of the whole country, upon which every field is shown. The United States does not produce such a large scale map but aerial photography is available for most of the country. On these photographs, man's activities are fairly visible. In addition, the Ordnance Survey, Britain's governmental mapping agency, has determined that major towns should be shown at a scale of 1:1,250 and minor town and rural areas at a scale of 1:2,500.[1] Some principal map scales, as representative fractions and inches per mile, are shown in Table 1.

TABLE 1

A TABULATION OF THE PRINCIPAL SCALES
(Expressed in Two Common Forms)

Representative Fractions	Inches to the Mile
1:1,250	50.69
1:2,500	25.34
1:10,560	6.0
1:24,000	2.64
1:25,000	2.5
1:31,680	2.0

Source: T. W. Birch, Maps--Topographical and Statistical (Oxford: Oxford University Press, 1964), p. 23.

A map which shows business functions is fundamental for city planning and urban geographical research. The various categories normally used are shown by colors or color tints. If tints are used, the darker tones usually denote the more valuable tracts, somewhat in the following order:

Business centers.
Industrial areas, warehouses.
Public buildings, schools, hospitals.
Apartments.
Residences.
Railways.
Parking lots.
Parks, playgrounds, stadiums, airports, cemeteries.
Empty lots.
Farmland.
Water areas.

[1] T. W. Birch, Maps--Topographical and Statistical (Oxford: Oxford University Press, 1964), p. 23.

City engineers sometimes have maps of a scale of 1:5,000 or 1:10,000; these are large enough to be annotated. Zoning maps are available for most cities but actual land use may not conform to the zones as shown. The street maps of the United States Bureau of Public Roads show types of pavement, business districts, and other data, and can be often used as base maps, or for general information. The fire insurance maps of the Sanborn Map Company have good detail, showing most houses in many cities.[2]

Several Types of Related Maps

Some examples of land-use maps which are related directly to urban geography are maps of manufacturing, transportation systems and marketing areas. Manufacturing is usually concentrated in and around cities. The social scientist is not only interested in the economic value of the various products but he is also interested in the workers and whether they are employed by large factories or small shops.

Transportation or the shipping of goods is frequently shown by traffic-flow lines. They are usually diagrammatic and show the general routes of shipment. Cartograms depicting movement of iron ore, coal, and grain in the Great Lakes area are published by the U.S. Army Crops of Engineers.

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[2] Erwin Raisz, Principles of Cartography (New York: McGraw-Hill Book Company, 1962), pp. 236-38.

The cartographic design of marketing area maps is difficult because consideration must be given not only to the density of the population but also the density of the kind of population interested in a particular business. There is a great deal of overlap of marketing areas. Marketing maps are published by the Map Division of the Library of Congress. The Production Marketing Administration of the Department of Agriculture also publishes marketing maps.[3]

Development of Land-Use Maps

The oldest sketch map known today is a small clay tablet showing the location of an area in Mesopotamia dating from about 2800 B.C. The Egyptians staked out their land and measured and mapped it for taxation purposes. The Chinese also developed cartography to a high degree in very early times.[4] However, it was not until 1450 in England that land-use mapping came into its own. This was brought about by the development of new and better techniques which reduced the amounts of distance-measuring by relying on measured angles. By the late sixteenth century angle-measuring instruments such as the plane table set were in use. At the same time contemporary developments in printing, first from wood blocks and later from engraved copper

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[3] *Ibid.*, pp. 246-51.

[4] *Ibid.*, pp. 3-4.

plates, made possible the cheap mass production of these maps.[5]

The next period of mapping activity began with the longitudinal measurements of the French Academy at the end of the seventeenth century. The maps produced from these new methods were much more accurate (and far less decorative) than their predecessors. The major achievement of this age was the triangulation and topographic mapping of France.[6] This series set the pattern for the national surveys of the nineteenth century. Large scale topographic maps and charts of a nation can be produced only by a large organization. The tasks of the independent cartographers were narrowed mostly to specialized maps, a division which still persists. The nineteenth century witnessed a great diversification of maps; geologic, economic, educational, transportation, etc. New engraving processes, such as lithography, wax engraving, photoengraving, and color printing made new techniques possible.

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[5] G. C. Dickinson, Maps and Air Photographs (London: Edward Arnold (Publishers) Ltd., 1969), p. 30.

[6] Raisz, Principles of Cartography, p. 7.

CHAPTER III

USES OF AERIAL PHOTOGRAPHY AS A METHOD OF DATA GATHERING

History and Background

The history of the use of aerial photography in geography is closely connected with that of photo interpretation in general. Of particular importance to American geographers during the early part of this century was the organization of the first aerial mapping firms. These firms, mostly under contract to federal, state, local, and foreign governments, gradually collected photographic coverage which proved useful for geographic studies. Some of this aerial photography was taken for the Tennessee Valley Authority and the Department of Agriculture. These two organizations were among the first to employ geographers in aerial photo interpretation.[1]

The developments in photo interpretation brought about by World War II had significant influence on geographic work. Chief of these influences was the training and the employment of geographers in military photo interpretation.

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[1]Photo interpretation refers to aerial photographic interpretation and will be used as such throughout the remainder of this thesis.

In the United States, geographers were employed normally as military photo interpreters by intelligence organizations and mapping agencies within the armed services. In Germany, geographers not only interpreted military information from aerial photos but interpreted related geographic information.[2] Photo interpretation, as it relates to geography, has made considerable progress in the last thirty years. Presently, many colleges and universities offer courses in photo interpretation.

Geographers have made less use of aerial photography than their colleagues in other earth sciences. There appears to be three reasons for this lack of use. First, some geographers, whose training predates the development of aerial photo methodology, are unacquainted with the extent of photo coverage, how to obtain photos of regions of interest, or how to interpret the photos once obtained. Second, the geographer's work is complex. Not only must he be well acquainted with all images relating to his own special field of interest, but since geography considers all phenomena on the earth's surface, he should be able to identify and interpret almost every image on any photograph. Possibly some geographers shun photo interpretation because

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[2] John H. Roscoe, et. al., "Photo Interpretation in Geography," in Manual of Photographic Interpretation, ed. by Robert N. Colwell (Menasha, Wisconsin: The George Banta Co., Inc., 1960), p. 735.

they cannot easily identify these photo images. The variety of photographic images is numerous, and no one can know them all. Third, the geographer's services do not command the same price in the commercial market as those of the geologist, the forester, or the engineer. Profits accrue to those who can produce oil, cut timber, or build highways faster and cheaper. High costs have forced many specialists to employ the rapid techniques of photo interpretation. The work of geographers is more often institutionally sponsored than commercially demanded. Consequently, some of them have remained conservative in their methods and techniques.[3]

Some geographers claim that their profession is not doing enough in this field.[4] However, the American Society of Photogrammetry has recently formed a Remote Sensing and Interpretation Division, and it is of note that the Geography Applications Committee of this division includes urban and regional planning as an integral part of geography.[5] In addition, architects and engineers are now outnumbered on city planning staffs by a combination of other professions. Geographers presently hold more

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[3]<u>Ibid</u>., pp. 735-37.

[4]J. Spelt, "Downtown Toronto: A Look at an Air Photo," <u>The Canadian Geographer</u>, X, No. 3 (1966).

[5]George H. Lantis, "The Remote Sensing and Interpretation Division," <u>Photogrammetric Engineering</u>, XXXVI, No. 5 (May, 1970), 498-99.

positions on these staffs than any other professional group.[6] Although geographers in general have made little use of photo interpretation, the same can be said for many urban analysts.

Information Available from Aerial Photography

Photo interpretation is an analytical tool which can be of significant value to the social scientist involved in urban studies. The use of the technique is increasing and it probably will continue at an accelerated rate. Nearly anyone can interpret and analyze air photos. It is an operation that does not require a special knowledge of photographic and photogrammetric processes.[7] Aerial photos provide a basis for defining problems, getting acquainted with study areas, planning field investigations, and studying inaccessible areas. Photos may be used as map substitutes and as a base upon which to record information obtained elsewhere. The photos are also of value as permanent records of specific times and places of the continuously changing landscape.

Tone and Sharpness

The urban analyst, like others who engage in photo interpretation, generally would derive the most information

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[6] Melville C. Branch, City Planning and Aerial Information (Cambridge: Harvard University Press, 1971), p. 18.

[7] Kirk H. Stone, "A Guide to the Interpretation and Analysis of Aerial Photos," Annals of the Association of American Geographers, LIV, No. 3 (September, 1964), 327.

from photos having the greatest number of different tones in the gray scale and the steepest gradients between adjacent tones. But these qualities exist at the expense of one another and a balance must be obtained for optimum sharpness. For most purposes, the analyst chooses, if he has a choice, the photography possessing the greatest number of tonal values.

Scale and Ground Resolution

Many parts of the world are covered by several sets of photos at different scales. The analyst may then select the scale that best suits his purpose. For most tasks the scale required is the same as in related fields. The biogeographer, for example, uses the same scale as the forester, soil scientist, or plant ecologist.

The scale of 1:20,000, a very common one in photography flown for federal agencies, is excellent for study of rural areas. For urban areas, intensive study of small rural areas, and some types of census work, the best scales are 1:10,000 and larger. But large scale photography has such disadvantages as high cost, the additional time required to work with a larger number of photos, and the inconvenience of handling and storing the increased bulk.

Since scale is more widely understood than the factors of tone and sharpness, and since scales are easily computed and expressed, there is a tendency to regard the quality of aerial photography as a function of scale without consideration of these other factors. A gauge of the interpretability of a photo in terms of its ground resolution, is to measure the smallest object on the ground which can be seen on the photo. This illustrates the importance of tone and sharpness, since both are a function of ground resolution.

The photo interpreter requires a ground resolution sufficient to identify the smallest object of interest. At a ground resolution of 100 feet, urban and industrial areas, land transportation routes, and most objects with an observable edge gradient and at least one horizontal dimension of 50 feet can be observed. If ground resolution is 20 feet, most objects with one dimension of 10 feet or more, such as buildings and vehicles, can be seen. If it is 5 feet, such objects as shrubs and larger animals are visible.

Stereoscopic Model

For some purposes, such as certain census operations, the analyst may avoid using stereoscopic coverage in order to reduce the cost of photography. Normally, however, the stereoscopic effect is an essential perspective which the analyst requires. It also enables him to identify many objects that cannot be identified or detected in single photographs.

Photographic Coverage

If more than one set of photographs is available, the analyst selects the best set based upon its interpretability and the problem at hand. He may also use photographs taken in other seasons or years in order to learn more about the changing characteristics of the landscape. Photos of a different type may provide a supplementary set of image characteristics. In addition to the photos, the analyst examines all the available data on flight navigation, camera operation, and laboratory processing. His interpretation may be modified in light of this information, or its reliability may be verified.

Types of Photography

Vertical stereoscopic photos are generally the most useful.[8] Consideration should also be given to the use of aerial photos made from hand-held cameras. This method is inexpensive and may be a perfectly satisfactory solution in some circumstances.

Urban Information

In years past, urban analysts have often been handicapped in the pursuit of their field work by considerations of time, expense, distance, and weather. Now aerial photos

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[8] Roscoe, Manual of Photographic Interpretation, pp. 736-41.

can be used to increase the efficiency of urban field work. In some circumstances they provide the near-equivalent of field conditions. When used in the laboratory, photographs often reveal details that cannot be seen on the ground and show spatial relations which may not be realized in the field. When used in the field, photographs enable the urban analyst to increase the speed, accuracy, and detail of his survey.[9] The urban analyst is partially concerned with the activities of people in cities; where people live and work; and how people and goods travel between areas.[10]

The application of aerial photos in urban development provides the following advantages:

1. In mapping--An . . . inventory of the physical features of the urban area; the topography of its site and surrounding area, the drainage pattern, built-up and open areas, the road pattern and other means of communication, and the location and identification of individual installations.
2. In analysis--The classification of the features of the urban area as land-use patterns of function, structure-type and built-up area density, so as to characterize the population distribution, industry, commerce, community services and facilities and the movement of people and goods.
3. In planning--The relating of engineering standards to land-use features, in order to

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[9]John Kesseli, "Use of Air Photographs by Geographers," Photogremmetric Engineering, XVIII, No. 4 (September, 1952), 737.

[10]James R. Wray, et. al., "Photo Interpretation in Urban Area Analysis," in Manual of Photographic Interpretation, ed. by Robert N. Colwell (Menasha, Wisconsin: The George Banta Co., Inc., 1960), p. 667.

> plan the size, capacity and location of facilities and to estimate the amount of work entailed in site preparation.[11]

Inventory is the first step in any land-use study. It permits the analyst to assess the town's resources and to gain an over-all appreciation of urban problems. Three principal categories of information are considered in the inventory:[12] (1) Location and classification of all features, as distribution patterns. (2) Measurement of size and capacity, to develop basic statistical data. (3) Computation of ratios of land used and land zoned, service availability and facility accessibility to residential, commercial and industrial needs.

Many urban research problems arise because rarely do the political or census boundaries coincide with the actual limits or urbanization. Here photo interpretation plays an important part. For example, examination of aerial photos can provide information leading to the density of housing to provide the exact urban boundary in accordance with this criterion.

The delineating of urban boundaries is only one aspect of urban analysis where aerial photos are useful as a source

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[11] Matthew M. Witenstein, "Uses and Limitations of Aerial Photography in Urban Analysis and Planning," Photogrammetric Engineering, XVI, No. 4 (September, 1955), 566.

[12] Matthew M. Witenstein, "A Report on Application of Aerial Photography to Urban Land-Use Inventory, Analysis and Planning," Photogrammetric Engineering, XXII, No. 4 (September, 1956), 657.

of information. For example, one can correlate field data and urban function (service, transport or special purpose, such as mining); evaluate the site; determine the city structure; investigate and identify types and areas of urban land uses; and study and delineate rural-urban fringes, and suburban settlements.

Photo interpretation is particularly helpful in other applications of geography to urban study. One application concerns the expansion needs of urban areas. Analysts are aided in determining the type of land required for future use, inventorying adjacent lands, and recommending appropriate parcels for urban annexation.[13]

City slums and suburban residential areas each have individual features, which normally are similar for cities throughout the United States. These features may include dwelling types, density of population, and standard of living. In aerial photos these functional parts can be delineated by the use of indicators, and their physical size may be measured.[14] With large scale photography, housing units and their surroundings exhibit indicators of poverty. These indicators include conditions and items such as structural deterioration, debris, clutter, and sometimes the

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[13]Roscoe, Manual of Photographic Interpretation, p. 766.

[14]Matthew M. Witenstein, "The Application of Photo Interpretation to Urban Area Analysis," Photogrammetric Engineering, XVIII, No. 3 (June, 1952), 491.

lack of vegetation (trees and lawns), walks, curbs, and paved streets. In these areas, junk yards, warehouses, and small businesses may be found interspersed in the housing areas.[15]

The urban area may be delimited by population density, activities, and structures on the land space. Its limits could be just beyond the area of block street pattern or other boundary. Delimiting the urban area in this way is useful for analysis of its internal structure.

There are several problems in the utilization of aerial photos in population studies. One problem is that height can be estimated for multi-story housing units; however, the actual use of lower stories for business premises can only be estimated.[16]

After delimiting the urban area, it can be divided into small segments. The segments may be census tracts or groups of city blocks given to particular land uses. Then appropriate data are assembled from aerial photos, census records and other sources, according to the purpose of the analysis, and summarized in maps and tables.[17]

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[15]L. Mumbower and J. Donoghue, "Urban Poverty Study," Photogrammetric Engineering, XXXIII, No. 6 (June, 1969), 616.

[16]L. Alan Eyre, et. al., "Census Analysis and Population Studies," Photogrammetric Engineering, XXXVI, No. 5 (May, 1970), 464.

[17]Wray, Manual of Photographic Interpretation, pp. 668-69.

Urban analysis is considered the province of several disciplines rather than an independent field of study. However, urban analysts have a primary interest in urban study since they are concerned with the interpretation and description of the areal differentiation and order in terrestial space.[18]

Publications which deal with urban photo interpretation normally do not go beyond the recognition of urban objects. In addition, most work in this field is deficient in measurement and comparison of objects after they are identified and counted. Thus, the beginning interpreter hardly knows where to start, what to measure, or what to do with measurements once made.[19]

The use of a systematic approach in interpretation reduces confusion and allows the compilation of more meaningful information from photos. Stone suggests three rules to follow:[20] (1) Interpretation should be done methodically; (2) It should be done from the general items to specific items; (3) It should progress from the known to the unknown.

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[18] L. Quam, "The Application of Photo-Interpretation to Geographic Research," Photogrammetric Engineering, XVIII, No. 2 (April, 1952), 500.

[19] Wray, Manual of Photographic Interpretation, p. 667.

[20] Kirk H. Stone, "Air Photo Interpretation Procedures," Photogrammetric Engineering, XXII, No. 1 (March, 1956), 123-24.

Urban Interpretation Study Examples

The study of land use consists of organizing the cultural features of each area of the city into distinct patterns which can be readily determined on the photograph. As an example, these patterns could be function, structure-type, and density of roof cover. The function pattern represents the major land-use categories such as industrial, commercial, governmental, institutional, recreation, port, railroad, or residential. The structure-type pattern consists of the categories of warehouses, storage yards, factories, commercial buildings, schools, churches, and various residential apartment, row, and single dwellings. The density of roof coverage pattern indicates the arrangement, organization, and limits of dense, moderate, and sparsely built-up areas.[21]

These three patterns are interrelated. Function is the major component, which is subdivided by its structure types. The structure types are modified by the degree of density in roof coverage. For example, residential areas may be delineated as in Table 2.

The function is residential with two types of structures. Each structure type is built-up to two different

[21] Matthew M. Witenstein, "Photo Sociometrics--The Application of Aerial Photography to Urban Administration and Planning Problems," Photogrammetric Engineering, XX, No. 3 (June, 1954), 421-23.

degrees of density. The construction features and arrangement of these patterns follow design standards and economic factors which generally apply throughout large geographic or political areas.

TABLE 2

A RESIDENTIAL FUNCTION WITH STRUCTURE TYPE AND DENSITY

Structure Type	Density
Single Dwelling	Sparse (5 or less buildings per acre) 5%-20% roof coverage
	Moderate (6 to 10 buildings per acre) 20%-40% roof coverage
Apartments (3-4 story)	Moderate 20%-40% roof coverage
	Dense over 40% roof coverage

Source: After Matthew M. Witenstein, "Photo Sociometrics--The Application of Aerial Photography to Urban Administration and Planning Problems," Photogrammetric Engineering, XX, No. 3 (June, 1954), 422.

Organizing these design standards into a series of relationships of area to quantity permits the collection of statistical data by measurement of the size of each type of area on the photos. To the residential types indicated above may be added, for example, per acre estimates of population and the demand for water. (See Table 3.)

This tabulation example indicates that for each acre of single dwellings of "sparse" density, there are 25 persons who require 2,500 gallons of water per day. With similar standards for all other residential types, the population and water consumption throughout the city may be estimated. Population estimates and water consumption estimates of this type lie within the degree of accuracy needed for planning purposes. The relationship of water demand to area was established through the density and estimate of population in each housing type.

TABLE 3

RESIDENTIAL POPULATION AND WATER DEMAND

Structure Type	Density	Population Per Acre	Water Supply
Single Dwelling	Sparse	25	2,500 gpd
	Moderate	40	4,000 gpd
Apartment (3-4 story)	Moderate	100	10,000 gpd
	Dense	200	17,000 gpd

Source: Matthew M. Witenstein, "Photo Sociometrics--The Application of Aerial Photography to Urban Administration and Planning Problems," Photogrammetric Engineering, XX, No. 3 (June, 1954), 422.

A major problem of city planning is the harmonizing of industrial, commercial, residential, and recreation areas with one another and with transportation and communication. This involves both the redesigning of existing facilities, such as traffic ways, and systematic planning for future growth and development. For such purposes a clear picture of existing geographic patterns provides the necessary starting points. Large scale aerial photos and mosaics provide an economical and efficient means of meeting that requirement.[22]

A general guide to those urban features that can be distinguished and outlined at various scales is found at Appendix I.

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[22]H. T. U. Smith, Aerial Photographs and Their Applications (New York: Appleton-Century-Crofts, Inc., 1943), p. 33.

CHAPTER IV

METHODS AND EQUIPMENT USED FOR MAP CONSTRUCTION

Aerial photos for mapping purposes are taken only occasionally. If administrative methods of maintaining map changes from municipal records are efficient, the retaking of photos within a period of several years should suffice for the cartographic resurvey. This survey is needed to correct errors and omissions which occur and for updating purposes. Rapidly growing parts of a city might need more frequent resurveying. Although in 1972 there are maps or survey sheets of most cities in the United States, there are still places without the accurate, up-to-date maps necessary to provide a basis for effective urban planning. The base maps of other cities need revision to make them current or improve their accuracy.

Types of Maps

The various maps and map substitutes which can be constructed from aerial photography are described below.

Topographic Maps

Topographic maps from stereophotographs require mechanical apparatus and trained operators available only at governmental and commercial agencies which regularly make maps.

> The use to which the maps will be put, the required scale and contour interval, and the map accuracy must be determined before anything else is done. Usually, the client knows what he needs and his requirements must be related to the proposed methods of preparing his maps. It is often a mistake to draw the map at a small scale and then enlarge it to meet final delivery requirements. The horizontal accuracy suffers in this process, and it is therefore not recommended . . . . Nearly all maps are drawn so that 90 per cent of all contours will be within one-half contour interval of their true ground elevation, 100 per cent of them within one full contour interval, and all planimetric features within .033 inch of their true position at map scale. This last is the criterion which dictates against enlarging the map to meet delivery requirements. .033 inches at 1 inch = 200 feet is 6.6 feet; if this scale is enlarged two times to 1 inch = 100 feet, the possible error of over 13 feet is usually too large. If the map is compiled originally . . . (at 1 inch = 100 feet) . . . with the same .033 inch accuracy, the maximum map error is 3.3 feet instead of 13 . . . . Ground control survey is a necessity for the photogrammetric engineer. Without it the map could not be drawn at any known, or certain, accuracy. And the accuracy of this ground control will directly affect the accuracy of the final map.[1]

When ground conditions or political or economic circumstances prevent normal field surveys, mapping control can be extended by photogrammetric methods. Inaccessible areas can be mapped without ground surveys on the project site.

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[1]John K. Mitchell, "Photogrammetry--Applications to Surveying" (paper delivered before the American Congress of Surveying and Mapping, San Bernadino, California, 1968).

Line Maps

By stereoscopic examination of photographic prints, ground relief can be seen, but approximate elevations must be determined separately. Further detail can be transferred from the stereophotos to the line map as needed, with an accuracy and speed determined by the photogrammetric methods employed and the available personnel.

Orthophoto Maps

An orthophoto map is an orthophotomosaic which has been prepared from individual photos and positioned to control points plotted upon a standard quadrangle projection, generally at 1:24,000 scale. A limited number of name places, cartographic symbols and marginal information is generally added, and the map may be printed in several colors. The orthophoto map has marginal latitude and longitude marks. It may also have a rectangular grid system.

Orthophoto maps combine the metric qualities of a line and symbol map with the visual qualities of a photograph. Their obvious advantage is the addition of much more information concerning surface features and conditions on the ground than is included in line maps. If contours are added, the use of the maps is further extended. When the planimetric accuracy of a topographic map is combined to form a background mosaic of vertical photographs fitted to the cartographic control, costs increase.[2]

> The first commercial application of orthophoto mapping in the United States has been implemented (1970) in the State of Vermont Base Map Program . . . at two scales, (R. F.) 1:12,000 and 1:6,000. Keyed to the Vermont State Grid Coordinate System, the maps provide a unified, accurate pictorial base for the management of state resources and will complement a comprehensive program for orderly development within the state.[3]

Because the orthophoto map is practically free of errors caused by tilt and relief displacements, any distance or azimuth or direction between two points can be measured directly. Areas may also be measured directly, and any identifiable point may be directly related to any other image. Property lines and even small parcels of land, have a correct geometric relationship to those on other precision maps.[4]

Photo Mosaics

When aerial photos are fitted, cut, and mounted in one continuous representation of the ground, they constitute a photo mosaic containing much more information than is shown

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[2]Melville C. Branch, City Planning and Aerial Information (Cambridge: Harvard University Press, 1971), pp. 63-66.

[3]"Engineering Reports," Photogrammetric Engineering, XXXVI, No. 6 (June, 1970), 520.

[4]David Landen. "Photomaps for Urban Planning," Photogrammetric Engineering, XXXII, No. 1 (January, 1966), 139-40.

on a line map at the same scale. However, the line map provides a less cluttered appearance and may be more useful for certain purposes. If the map is also fitted to a network of cadastral control points on the ground, it can be used for accurate measurement. In planning, the photo mosaic of an entire community can be used as the background behind transparencies displaying various information.

The value of these mosaics comes from the over-all view of the city which they provide. Even a rough assembly of overlapping stereophotos covering an urban area gives a total view otherwise unobtainable. By portraying all parts of the community together, the photo mosaic provides the perspective of spatial interrelationships essential for urban analysis, such as for transportation systems, open space and built-up land, or growth at the urban periphery.

Mosaics do not provide stereoscopic vision. Duplicate prints of the photos used in their construction can be used separately for three-dimensional study of the ground. If the expense is warranted, contours can be developed from the original stereophotographs and either superimposed on the mosaic as a transparency or drawn directly on its surface. The following discussion of mosaics draws heavily upon work done by Branch.[5]

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[5]Branch, City Planning and Aerial Information, pp. 66-75.

Controlled mosaics

Controlled mosaics are made by assembling the central portions of vertical aerial photographs. The network of points on the mosaic retains the same relationships of distance and angular position that they have on the ground. In this way, the mosaic is given a degree of map accuracy dependent on the frequency and distribution of points in the network of cartographic control. When the terrain is approximately level, the controlled mosaic can be made as accurate as maps at the same scale constructed entirely by ground survey. When ground relief is irregular, inaccuracies within portions of the photographs used in the mosaic cannot be avoided. Since the detail of most maps made by ground methods is filled in by visual sketching, the overall reliability of the controlled mosaic, except when the terrain is mountainous is equal to most maps.

To serve as many purposes as possible, mosaics for urban analysis are usually constructed at the largest scale consistent with practical size. Since there is always some loss of sharpness in image detail with enlargement, prints of the same size or smaller than the original negative, produce mosaics with the sharpest detail. An enlargement of three diameters is normally maximum for vertical aerial photos which are to be assembled as a mosaic for urban purposes.

By this procedure, utilizing only the central portions of each photo, the displacements inherent in vertical air photographs caused by all differences or inaccuracies are minimized. The restrictions to enlargement are determined by the sharpness of image desired. With a camera focal length of 12 inches and aircraft altitude of 16,000 feet above the terrain, or focal length of 6 inches and altitude of 8,000 feet, a 9- x 9-inch negative includes a ground area of over 4 square miles at a scale of 1:16,000. Further enlargement increases proportionately the size and scale of the photomap made from a single vertical photo, but reduction in the sharpness of detail is apparent. Various combinations are possible with different camera focal lengths, aircraft altitude, size of photo negative, area on the ground shown in the photograph, enlargement, and cost.

Many cities possess base maps which are sufficiently accurate but need to be revised either by the addition and subtraction of detail within the ground area covered by the map or by extension of the map to include more territory. Aerial photos are the easiest means of noting changes, by direct comparison with previous photos.

Semicontrolled mosaics

Semicontrolled mosaics are made of vertical aerial photographs which have been cut and fitted to a network of ground control points less closely spaced. Accuracy is therefore correspondingly lower. Points in between this grid of few control points will vary slightly from their true position.

Uncontrolled mosaics

An uncontrolled mosaic is usually assembled with no control points. Photos are fitted to match pictorially with as few visual discrepancies as possible. Reasonable care is taken, however, that relative distances and directions are not so far off that its primary use is impaired. The uncontrolled mosaic provides a great deal of information as well as a complete overhead view of the city as it exists at the time of photography, but it does not permit accurate measurements.

Most urban studies do not require high map accuracy. Much information and many studies are independent of precise map measurement. Except when the exact size of some object or structure is needed for identification, land use does not require close scale measurement. Nor is high map accuracy required to study the citywide form, disposition, and pattern of land areas and transportation systems.

Although uncut stereophotos can be assembled by overlapping and stapling to give a continuous view of the ground covered, this is temporarily useful at best. The smooth surface of the permanently assembled mosaic is needed for direct tracing of land use and other information. When the cartographic qualities of the controlled or semicontrolled photomap are not necessary because adequate maps are at hand or because of the nature of the planning, an uncontrolled mosaic will serve city planning purposes. It is the least expensive type of mosaic, and it can be constructed in the planning office with minimum facilities.

Maps from Oblique Photographs

Oblique aerial photos are sometimes used for mapping, since they cover a much larger ground area than vertical photos taken from the same position in the air and with a similar camera. Multiple-camera systems combine two, four, and even eight contiguous oblique views around a central vertical picture, to allow small scale mapping of hundreds of square miles of countryside. Because the making of maps from these multiple photos requires the most expert photogrammetric cartographers, they are seldom made by urban analysts.

Plain oblique photos taken with a single-lens camera can be used for mapping in connection with city planning. When there is need for a quickly constructed and low-cost map of areas at the periphery of the city undergoing rapid urbanization, a few oblique pictures can be used to provide the cartographic base for preliminary work or general study for which fair map accuracy is sufficient. If the oblique is taken at a low altitude, as much as one-half of the picture in the background will be unseen or unclear. In addition, trees, buildings, and terrain features with vertical height may mask from view portions of the ground. In comparative urban research, when no better way of achieving the same end is at hand, maps developed from oblique aerial photographs may be the only or quickest way of delineating the urban pattern with limited scale precision.

Aerial Photographs and Enlargements

Contact prints and enlargements of aerial photographs are among the first tools needed and demanded by the urban analyst. Most of the photos being used for this purpose are taken with a camera having a focal length of 6 inches and a format of 9 by 9 inches. For planning purposes, this photography is obtained at various scales from 1:600 up to approximately 1:63,360, and sometimes even smaller. The scale of the photography to be selected for an urban-area study depends on the purpose for which the photos are to be used, the development or land use of the area, and the physical size of the project. Higher-altitude, small scale photographs often provide important economies in mapping, provided that precision-type, high-quality cameras are used. The larger area covered by such photographs enables the urban analyst to obtain a comprehensive view of the "setting" of an area. He can tie together many different details of geography, geology, vegetation, drainage, communication, and other factors in a single view.[6]

Equipment and Procedures

The urban analyst must have a basic understanding of the equipment and procedures used in the interpretation of aerial photography. He must know the basic steps of preparing photography for viewing and of constructing mosaics.

Stereoscopes

The simplest optical instruments for viewing objects in three dimensions are stereoscopes. Stereoscopic viewing instruments may be of the mirror (reflecting) type, the prism type, or the lens (refracting) type or combination of these. Of the various kinds of stereoscopes in use, the simple lens type is the most widely used and generally the least expensive. Its advantages include low cost, portability, and simplicity of operation and maintenance. Its disadvantages are the limitations as to range of magnification, difficulty of annotating photos while observing, narrow field of view, and limited capability of spreading photos while observing.

The mirror stereoscope usually is designed so that inspection must be made looking vertically downward. However, newer types are designed for more comfortable viewing.

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[6] Landen, "Photomaps for Urban Planning," p. 137.

Some advantages are that it affords full separation of the stereoscopic pair of photographs, provides full view of the entire stereoscopic model under normal observing (no magnification) conditions, and allows the use of mounted opaque prints as well as positive and negative transparencies which may be securely fixed in place for long-term viewing. Its disadvantages are the relative loss of illumination because of the number of glass surfaces involved and the distances light rays have to travel; increase in cost over the lens type, especially when binoculars are required for simulating comparable magnification conditions; its increase in maintenance over the lens type, especially if it is subject to excessive handling or exposure to moisture.[7]

Although much thought has been put into the manufacturing of stereoscopes, few people actually understand the proper method of setting them up for optimum three-dimensional study. Likewise, many people undergo undue eye strain because of their lack of appreciation of proper orientation of the photos. These simple steps should be followed for best results:

The first step in orienting a pair of photos under a stereoscope is their proper alignment. The light source for the first photo should be somewhere beyond its upper

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[7]Albert L. Nowicki, "Stereoscopy," in Manual of Photogrammetry, ed. by Morris M. Thompson (Falls Church, Virginia: George Banta Co., 1966), pp. 524-25.

left-hand corner. The photo is then rotated so that the shadows of prominent objects, such as trees or buildings, fall generally toward the right or away from the outside light source. The second photo, which usually contains about 60 per cent of the detail of the first photo, is then placed over this photo. Then each photo is moved outwards to place them under the corresponding lens (or mirror) of the stereoscope.

The next step of orientation is to insure that the photos are separated by the proper distance and rotated in the proper azimuth with respect to each other and with the axis of the stereoscope eye base. To accomplish this several preliminary steps must be taken. Some aerial photos contain a cross or some other small mark to denote the physical center or principal point of the photograph. Where no marks are present, the location of the principal point can be determined by drawing pencil lines between opposite fiducial marks located on the four sides of the photo. The intersection of these lines corresponds to the principal point. Since the adjacent photos overlap each other by about 60 per cent, the image detail at the principal point on one will appear on the other. By observation of surrounding detail, the positions can be transferred and marked on each of the corresponding photos. A total of four definite points (i.e., two on each photo) will exist in the stereoscopic overlap area of the two photos.

The left-hand photo is fastened to the table by means of a fine needle pushed through the principal point. Then the right-hand photo is fastened in place. The distance between the two photos must first be determined. This distance, which is measured from an image point in one photograph to the same image point on the other, is often provided by the stereoscope manufacturers in their descriptive handbooks. Separation distance varies from about two inches for lens-type stereoscopes to ten inches or more for the mirror-type stereoscopes.

After the right-hand photo is fastened to the table, a straight edge is laid across both photographs, the left-hand photograph is rotated slightly so that all four points are in line. Both photographs are then firmly attached to the table. With the two photographs properly oriented with respect to each other, the stereoscope can be set over them and brought into use.

Mosaic Construction

The Manual of Photogrammetry provides a clearly stated and simple procedure for the construction of photo mosaics. This procedure is particularly suited to the making of urban area mosaics and it is summarized below.[8]

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[8] Ibid., pp. 862-65.

The mosaic is assembled on a smooth, hard, nonporous or semipermeable surface, such as a masonite, plywood, chip board or aluminum sheet. The size of the board is limited only by convenience and available space. Generally, semi-controlled or uncontrolled mosaics to be used as wall presentations are made fairly large; the controlled mosaic is an engineering tool and is usually broken up into convenient sheet sizes. If the program includes topographic mapping, the mosaic sheets frequently conform to the size and scale of the map sheets. If the required mosaic is larger than the available size board, and if space allows, several panels may be fastened together with suitable backing strips. Screw holes in the face of the boards should be countersunk and covered. Tape may be mounted over the panel seams and sanded smooth.

Starting in the center of the board, the first print is prepared for mounting by pricking all radial-control points with a fine needle and circling them with a grease pencil. The print is trimmed just inside the border with a razor blade, and the edges are smoothed to make them less perceptible to the eye and to the copy camera.

Gum arabic, glue, rubber cement, and paste are satisfactory adhesives. Gum arabic is commonly used and allows good working time before drying; it has the disadvantage that the print edges may become brittle and crack.

This can be controlled somewhat by adding glycerine to the solution.

Rubber cement is satisfactory for single prints but not for large mosaics. It does not permit stretching the prints to fit control or to match detail, and its rapid setting makes speed essential in mounting. Glue is a good adhesive but presents a difficult problem of cleaning after the prints are mounted and also makes the print edges brittle. Paste and water is an excellent adhesive as it allows easy control of the print and cleans up very easily.

The adhesive is applied liberally to the back of the print or to the mosaic board, or to both, and the print is oriented to the control, using a pin point to fit the images to the plot. The principal point of the center print is positioned first and a pin is left in place as a pivot while the outer control points are matched. A squeegee is used to remove excess adhesive from under the print and any adhesive remaining on the face of the print is removed with a damp cloth or sponge. The adhesive is allowed to set before the next print is placed.

Before applying adhesive to the next print, it is oriented to control in the same way and a visual selection is made of the proposed cut line. The cut line is usually about midway between print centers and is selected to give the best image match between the prints. Tone match and photographic detail are considered so that the cut line will be less apparent. As far as possible, areas of identical tone without specific detail should be selected, but excessive straight-line cuts should be avoided except along roads or fence lines. If the cut parallels a road or fence, the feature is left in its entirety on the print being laid. The cut line is marked with a grease pencil, and then the edge is cut and smoothed.

After cutting, the match is checked by reorienting the print to the control, and any minor revisions that may be necessary in the cut line are made. The degree of fit between the control points and the plot indicates the amount of stretching that may be needed in the print. If the control fits well, the print must not be allowed to stretch; therefore, only a little glue is used and the print is quickly fastened into position. If the print is too small in scale, it may be moistened before the adhesive is applied. This causes it to expand in proportion to its saturation. Extra length may also be gained by working the print with the fingers or squeegee while fitting it into position. An infrared lamp may be used to speed up the setting and drying of the print to permit more rapid compilation or to prevent excessive shrinkage, especially when humidity is high.

After all the prints are laid, excess paste is removed with a damp cloth or sponge, the entire mosaic is checked for errors in image matching, edges are checked and repasted if necessary. Loose print edges, which occur frequently, may require a stronger adhesive, such as casein glue, to make them adhere.

When the area of interest cannot be fitted on one board, arrangements must be made to facilitate laying the mosaic across boards. Several alternatives are available. If two boards suffice, they can be held together by use of plywood backing running at right angles to the mosaic board, or the boards can be attached to a framework. Tape or paper is usually laid on the joints to prevent the mosaic from cracking. Brads are used for fastening the boards so that they can be pulled free of the framework through the back of the boards without marring the mosaic. There are practical limits to the size of such a framework, and it is sometimes necessary to extend a mosaic beyond these limits.

The "breakaway" method permits laying a mosaic of any size on any number of boards. Once a start has been made a number of boards can be compiled simultaneously. The first board is prepared by laying a six-inch strip of masking tape around the outside edge of the sheet or combination of sheets falling within the board. The mosaic is laid beyond the neatlines so that the sheet or sheets are completely covered.[9] Then, with a razor and straightedge, the mosaic

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[9]Neatlines are the lines that bound the mosaic portion of the sheet itself.

is cut along the neatline. The strip of mosaic outside the neatline is lifted from the board, and the masking tape is removed from the back of the prints. This strip of prints is then mounted inside the neatline on the board which carries the control and grid for the adjacent sheet. The images across this neatline are continuous and form a perfect match. After the first board is completed and the match strips transferred, work can proceed on all adjacent boards.

If space is available for joining boards together for the mosaic, the boards can be covered with muslin, using a very thin solution of paste or gum arabic. Butt joints are made between sections of the muslin to avoid ridges. The control and grid lines are plotted on the cloth, and the mosaic is laid on the cloth. As a sheet is completely covered with the compilation, it is cut along the neatlines, and the muslin containing the completed sheet is lifted carefully so that the sheet can be mounted on a copyboard for photographing.

Line Maps

Line maps can be made from aerial photos by a variety of methods. The simplest method is to trace streets, buildings and boundary lines directly from large scale aerial photographs or mosaics. In many cases line maps require only periodic updating. If the line map and photograph are at (or nearly at) the same scale, a vertical sketchmaster may be used. This portable "desk top" instrument uses a semitransparent mirror at the eyepiece and a surface mirror above the photograph. The observer views the line map through the semitransparent mirror and the photo by reflection from the semitransparent and surface mirrors. The instrument may be raised and lowered on its supports to adjust the photo image with the manuscript.

To draw an original line map or update an existing line map from aerial photos where there is a considerable difference in scale between the photos and the final product, a larger reflecting projector is needed. The wall-mounted Map-O-Graph is satisfactory for this type of requirement. It projects an image of the photograph directly onto any map or document on the drafting table.[10] The portion projected can be set to the same scale as the original or to any different scale from a five-time reduction to a five-time enlargement.

Photo Contour Maps

While photo mosaics are accurate enough for many purposes of city analysis, they do not include contours or elevations. Several methods can be used to add contours to

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[10] John T. Pennington, "Paper-Print Plotters," in Manual of Photogrammetry, ed. by Morris M. Thompson (Falls Church, Virginia: George Banta Co., 1966), pp. 541-42.

a photo mosaic. One approach is to enlarge or reduce the mosaic to the scale of a standard topographic base sheet (U.S.G.S. 1:24,000). Contours can be traced directly from the topographic map and added as an overlay to the photo mosaic.

Another method uses recently developed automatic stereoplotting instruments. For example, the B-8 Stereomat is equipped to produce orthophotographs. The rectified image is electronically displayed on a cathode-ray tube, where the scanned lines are then photographed and converted into an orthophotograph. The instrument also draws contours automatically--that is, without an operator--by sensing the stereoscopic images for shades of gray contrast, and determining their elevations by means of correlation techniques. However, both of these methods are expensive and are normally not used in urban research.[11]

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[11] Landen, "Photomaps for Urban Planning," p. 142.

CHAPTER V

PROBLEMS IN URBAN ANALYSIS

The available information from aerial photos can be more fully understood by using an example. The following paragraphs briefly summarize an aerial photo study of Peoria, Illinois by James R. Wray.[1] However, interpretation is only one problem of several that should be investigated. Detailed cost estimates are also important. A cost estimate for Missoula, Montana has been developed to show the relative costs of adequate photography and the construction of allied products.

Photo Interpretation Study--Peoria, Illinois

The Peoria mosaic was prepared at the same scale (1:24,000) as the U.S. Geological Survey topographic map of the area. Annotation of the mosaic, the starting point of the analysis, was accomplished by examination of stereoscopic pairs, ground reconnaissance, and inspection of all available map and library materials.

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[1] James R. Wray, et. al., "Photo Interpretation in Urban Area Analysis," in Manual of Photographic Interpretation. ed. by Robert N. Colwell (Menasha, Wisconsin: The George Banta Co., Inc., 1966), pp. 670-90.

To map land use by photo interpretation, two devices are required: a classification system defining the types of land use to be mapped and fixing the minimum size of the type area, and a suitable base for recording the type areas observed. The recording base was the photomosaic. The type area was any area not smaller than about twenty-three acres, having a land-use boundary visible in the photographs. The classification system consisted of six types or components of urban land use: residential, commercial, industrial, transportation, open improved, and open unimproved.

After mapping gross land use, the land use type areas were divided into statistical areas. Each statistical area was examined stereoscopically and selected data were recorded.

A map of land uses was first compiled from the data for the statistical areas. However, a land-use map is incomplete, as it treats all uses alike without weighting them according to variations in intensity. It is desirable to show variations in intensity of use. Building density was selected for mapping because about 80 per cent of the total area contains buildings, and population density was mapped because about 60 per cent of the urban land is in residential use.

Aerial Photo Specifications

Because photos will be useful for many municipal planning purposes besides map-making, their further utilization should be considered in determining final requirements. Photos in addition to those needed for a map or mosaic are procured at much less expense if they are taken on the mapping flights.

Good planning is impossible without a complete inventory of existing facts clearly presented in graphic form. Sometimes as many as six different maps are in use in a city. The majority of them are at different scales and some are so distorted that even the street pattern cannot be compared. A good set of maps showing graphically all of the necessary social, economic, physical, and topographic features presents most of a city's problems and makes coordination of the city's activities possible. In the past, the cost of obtaining this map information has been almost prohibitive; through photogrammetry it is now possible to secure the data at prices that cities can afford.[2]

The commercial firm taking the air photos will supply technical information and knowledge derived from experience, but the user of the photography should have a clear understanding of how he will utilize the aerial photos, how they

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[2]Louis A. Woodward, "Photogrammetry in City Planning Operations," <u>Photogrammetric Engineering</u>, XX, No. 3 (June, 1954), 521.

can be taken, and other municipal uses to which they may be put. In addition, he should be aware of the nature of technical problems confronting the commercial company which will produce the photographic product.[3]

Cost

Cost estimates for aerial photography are difficult to obtain. Some commercial companies are reluctant to disclose their specific costs for competitive reasons. Also, costs vary with small but critical differences in specifications. It is important in comparing costs to make sure that they are based on the same requirements and specifications. Usually, the most expensive elements of cost are the capital cost of the aircraft and its photographic equipment, and their utilization costs. These will vary with how far the photographic aircraft must fly to the site, how many runs it must make over the target area for complete coverage, whether local weather or smog causes delay, and whether the pattern of flight lines is easy to follow or difficult enough to require allowance for a probable follow-up flight. The resolution and quality of the photo negatives specified in the contract affect the flight plan, because they relate

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[3]Melville C. Branch, City Planning and Aerial Information (Cambridge: Harvard University Press, 1971), p. 75.

to enlargement of the negative to get positive prints at the required scale.[4]

If a photo mosaic of the city is specified, there is a significant difference in cost between the different types of mosaics. The cost of an uncontrolled mosaic is mainly that of fitting and mounting the photos so they are visually acceptable. Controlled mosaics can be very expensive depending on the measurement accuracy needed. The photographs must be rectified, cut, assembled, and mounted permanently so that they fit precise grid control points on the ground.[5] It is the skill and time required for this precision which increases the cost of controlled and semicontrolled mosaics over those which are uncontrolled.[6]

Requesting photos which require special cameras or other equipment greatly increase over-all costs. It costs less to procure photos for making mosaics than to procure them for stereoscopic coverage. The number of photos needed for full stereoscopic coverage would be about three times as many as needed for mosaic construction. This difference is due to the amount of overlap required for stereoscopic viewing.

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[4] Ibid., p. 54.

[5] A rectified photograph is a photograph transformed to a horizontal plane so as to remove displacement due to aircraft tilt.

[6] Branch, City Planning and Aerial Information, p. 55.

However, the increase in cost is only approximately 10-15 per cent, because the initial expense of getting the aircraft and photographic equipment are greater than the larger number of pictures and their processing. Throughout, unit costs are based on the standard forward-lap of 60 per cent for stereovision and 30 per cent side-lap between flight lines.

For these reasons unit costs are the best basis for approximating the total cost of aerial photographic coverage of the city. Those presented here meet federal specifications which are generally standard in the industry: less than an average of one degree tilt from the vertical, less than three degrees tilt in any one photo, and less than five degrees differentiated tilt between any two successive pictures. Requirements of resolution, photo quality, and accuracy of control are also standard. As indicated above, 60 per cent forward-lap and 30 per cent side-lap are also presumed. General costs for mobilization and each negative and contact print are shown in Table 4.

The number of vertical photographs required to cover an urban area of known size, with stereoscopic coverage having 60 per cent forward-lap and 15 per cent side-lap on two sides, can be estimated from Table 5. Ten per cent is added to the number of vertical stereophotographs determined from this type of table to insure covering the desired areas. A larger

TABLE 4

MOBILIZATION, EXPOSURE, AND CONTACT PRINT COST

Mobilization (Flight Preparation)	Number of Exposures	Per Exposure		Per Contact Print
		9- x 9-inch Negative	Photo Index[a]	
$125 for immediate area, plus $2 per mile (one way) for distances over 5 miles	1-10	$8	---	$3
	11-20	$6	$2	$2
	21-50	$5	$1	$1.50
	over 50	$4	$0.50	$1

[a]This shows which photographs cover which area and provides a key for numerical filing.

Note: Cost figures supplied by Montana Aerial Photography, Missoula, Montana.

TABLE 5

GROUND COVERAGE OF VERTICAL PHOTOGRAPHS OF DIFFERENT SCALES

Scale	Approximate Ground Coverage	
Representative Fraction (RF)	Acres	Square Miles
1: 2,400	21	.03
1: 4,800	83	.13
1: 9,600	333	.52
1:12,000	521	.81

percentage is needed for smaller areas. This is because the photography will not coincide exactly with boundaries, which are usually irregular and because showing some terrain outside these limits is desirable. The extra coverage also provides for normal discrepancies between actual and planned flight lines.

Table 6 shows that exposures are the largest element of cost in black and white aerial photography. Next in order is the cost of prints. Both of these change sharply as the photo scale is increased. Examples are provided in Table 7.

The cost of preparing controlled or semicontrolled mosaics depends on several factors such as the number of separate photographic prints which must be fitted and mounted in one mosaic; the amount of ground relief shown in the mosaic which requires additional effort to produce a good fitting between photos without mismatch or distortion; and the extent to which the mosaic will be controlled or fitted to improve its accuracy. Also involved is the extent of cartographic control points located on the ground and shown in the aerial photos which can be used to provide the map accuracy desired in a controlled mosaic. If these points are not available, a minimum number of them must be established by ground survey. Uncontrolled mosaics will generally range from $5-$10 per photo print; semicontrolled,

TABLE 6

EXAMPLES OF AERIAL PHOTOGRAPHIC COSTS[a]

	Mobilization Cost	Exposures Required and Cost per Exposure	Cost of Exposures	Contact Prints Required and Cost per Contact Print	Cost of Contact Prints	Cost of Photo Index	Total Cost	Cost per Square Mile
100 Square Miles; 20 Miles from Base; RF = 1:12,000; One Set of Contact Prints; One Photo Index	$155	(136) @ $4	$544	(136) @ $1	$136	$68	$903	$9.03
Same as Above Except RF = 1:9,600	$155	(212) @ $4	$848	(212 @ $1	$212	$106	$1,321	$13.21
Same as Above Except RF = 1:4,800	$155	(847) @ $4	$3,388	(847) @ $1	$847	$423.50	$4,813.50	$48.14
Same as Above Except RF = 1:2,400	$155	(3667) @ $4	$14,668	(3667) @ $1	$3,667	$1,833.50	$20,323.50	$203.24

[a]Cost figures are taken from Table 4. Numbers for exposure are taken from Table 5.

TABLE 7

COSTS OF ENLARGING PRINTS

Number of Prints[a]	Enlargements of 9- x 9-in. Negatives (Double Weight Matte Paper)	
	2 Times to 18 x 18 in.	4 Times to 36 x 36 in.
1-10	$6.50	$12.00
11-20	$5.50	$11.00
21-50	$5.00	$10.00
Over 50	$4.50	$ 9.00

[a]Normally, only every other stereophotograph is enlarged in making a photo mosaic, since they overlap 20% along the line of flight.

Note: Cost figures supplied by Montana Aerial Photography, Missoula, Montana.

from $7.50-$15; and controlled mosaics, from $15-$25. These are mosaics of vertical photographs assembled at the same scale as the original contact negatives.[5]

Preparation Example for Photo Interpretation--Missoula, Montana

The urban analyst, with mosaics of the proper scale, has a complete picture of the area. The guess work often encountered in smaller communities concerning the actual physical location of specific improvements is greatly

[5]*Ibid.*, p. 57.

reduced.[6] Mosaics are valuable in studying smaller American cities. Built-up areas normally are shown only on topographic sheets of the United States Geological Survey, where the scale is too small for the internal study of a community; or in real estate atlases, where the scale is so large that generalization is difficult.[7] However, aerial photographs are obviously only a tool added to others already in use by the analyst for many years.[8]

Special Considerations

Prior to the procurement of aerial photography for the Missoula area, certain planning steps must be taken. These steps are discussed in some detail to explain what photography and allied products are needed for a city the size of Missoula.

Preparation of urban base maps

A perfectly acceptable base map, for some purposes, can be made by tracing directly from the photographs. When

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[6] Volney J. Cissna, Jr., "Photogrammetry and Comprehensive City Planning for the Small Community," Photogrammetric Engineering, XXIX, No. 4 (July, 1963), 682.

[7] W. L. G. Joerg, "The Use of Airplane Photography in City Geography," Annals of the Association of American Geographers, XIII, No. 4 (December, 1923), 211. Joerg's comment is as true today as it was in 1923.

[8] John E. Kesseli, "Use of Air Photographs by Geographers," Photogrammetric Engineering, XVIII, No. 4 (September, 1952), 737.

using this method, it is desirable to employ prints with a scale of at least 1:4,800. This enables the draftsman to locate with relative accuracy the center lines of streets, and sometimes the right-of-way lines as well.[9]

The tracing method sometimes is less than satisfactory since photographic distortion, poor photography, substandard printing, and lack of clearly marked survey points may make measurements a matter of judgment. Nevertheless, lack of an alternative base map may make a somewhat inaccurate direct-tracing photo base map a serviceable and low cost tool for the urban analyst. The alternative, the preparation of a base map in the conventional manner by construction of a control grid, would necessitate considerably more time and expense.

Governmental interest

All city and county departments which might have an interest in using this photography and related products should be contacted prior to making the final arrangements. Several departments may need this type of information and may be willing to finance a portion of the project. In addition, local, state, and federal agencies should be provided with complete information on the scope and details of

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[9] Ben C. Withers, "Some Uses of Aerial Photographs in Urban Analysis," The Professional Geographer, XIII, No. 5 (September, 1961), 16-18.

the project. After all interested parties have stated their requirements (and made their commitments), a delineation of the land area and a photographic scale must be determined.

Scale

Normally an acceptable scale for aerial photos of built-up areas is 1:10,000 or larger.[10] It has been suggested that the optimum final photo scale for detailed urban studies is about 1:2,500. The extra cost involved (compared to the 1:10,000 scale photos) will be more than compensated by the extra benefits.[11] The Missoula example will assume that photos will be taken at a scale of 1:9,600, since a two times enlargement of these negatives will provide final prints at a scale of 1:2,400 or 1 inch equals 200 feet. It should be noted that this scale is a multiple of 10 and 50, thus enabling it to tie in directly with existing engineering and city planning maps at accepted engineering scales. This has been ignored frequently in flight planning in the past.[12]

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[10] B. C. Dickinson, Maps and Air Photographs (London: Edward Arnold (Publishers) Ltd., 1969), p. 251.

[11] W. G. Collins, "Population Census with the Aid of Aerial Photographs: An Experiment in the City of Leeds," Photogrammetric Record, VII, No. 37 (April, 1971), 22.

[12] Joseph T. Bill, "Use of Aerial Photography in Urban Planning," Photogrammetric Engineering, XVII, No. 4 (September, 1952), 760.

Area coverage

Area coverage for this exercise was determined from visual inspection of Missoula as shown on U.S.G.S. 7½ minute quadrangle sheets (Northwest Missoula, Northeast Missoula, Southwest Missoula, and Southeast Missoula, Montana), 1964. The urban area plus the important surrounding area equals approximately twenty-two square miles.

Land-use classifications

Choice of the number and content of classes of land use is determined by two considerations. To derive maximum value from the photos and allied products a detailed classification is desired; however, the extent of the classification is limited by the scale and quality of the photos.[13]

Updating

Urban expansion problems become evident to the analyst after using sequential aerial photos flown at convenient intervals. These sequential photos contain the information needed to periodically update city planning documents and maps. Cities under 50,000 in population have seldom used this method of updating.[14]

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[13] Robert R. Wagner, "Using Airphotos to Measure Changes in Land Use Around Highway Interchanges," Photogrammetric Engineering, XXIX, No. 4 (July, 1963), 646.

[14] Dennis M. Richter, "Sequential Urban Change," Photogrammetric Engineering, XXXV, No. 8 (August, 1969), 769.

Outline for Cost Development

Table 8 has been developed from material in the previous discussion. Specific information for the cost estimates are taken from Table 4 through Table 7.

TABLE 8

ILLUSTRATIVE COSTS OF AERIAL PHOTOS AND ALLIED PRODUCTS OF MISSOULA, MONTANA AT AN ORIGINAL SCALE OF 1:9,600

PART A

1.	Mobilization (base within 5 miles)	$ 125.00
2.	Exposure (black & white; 9 x 9 negatives); Scale: 1:9,600; (6-inch focal camera at 4800 feet average absolute altitude): 42 negatives @ $5.00 each	210.00
3.	Contact Prints (for stereoscopic study, reference, and file records): 23 prints (one-half of 42 plus 10% for full coverage) @ $1.50 each	34.50
4.	Enlargement of Prints (for analysis-display panels); every other stereophotograph: enlarged 2 times (18- x 18-inch print size) to scale 1:4,800; 23 prints @ $5.00 each	115.00
5.	Mosaic Control (photographic, enlarging, and mounting on tempered Masonite, U.S.G.S. Quadrangle sheets to scale 1:4,800, as reference base for uncontrolled mosaic below); 1 sheet @ $50.00 each	50.00
6.	Mosaic (uncontrolled; scale, 1:4,800; 18- x 18-inch print size): 23 prints @ $10.00 each	230.00
7.	Copy Negatives of Mosaic (6. above; scale 1:4,800; 18- x 26-inch size; each to fit one of 16 display panels): 16 negatives @ $20 each	320.00
8.	Final Prints (7. above enlarged 2 times to scale 1:2,400; 36- x 52-inch size): 16 prints @ $20.00 each	320.00
9.	Mounting of Final Prints (8. above on tempered Masonite panels 26- x 52-inch size); 16 panels @ $25.00 each	400.00
	TOTAL	$1,804.50

TABLE 8--Continued

PART B

Alternate Method--eliminating steps 5, 6, 7, and 8 (with high probability of visible mismatches and progressive discrepancies between the 16 separate analytical-display panels)

1.	through 3. same as above	$ 369.50
4.	Enlargement of Prints (for analysis-display panels; every other stereophotograph; enlarged 4 times to scale 1:2,400; 36- x 36-inch print size): 23 prints (one-half of 42 plus 10% for full coverage) @ $10.00 each	230.00
5.	through 8. eliminated	
9.	Mounting of Enlarged Prints (4. above, as an uncontrolled mosaic on tempered Masonite panels 26 x 52 inches in size); 16 panels @ $45.00 each	720.00
	TOTAL	$1,319.50

Table 8 shows that aerial photos, which meet the needs of the urban analyst and planner, can be procured and made into photomosaics at a reasonable cost to the taxpayers of a city of 50,000 persons. A complete listing of the various steps in the planning and operational procedures of a photogrammetric project can be found in Appendix II.

CHAPTER VI

FUTURE OUTLOOK FOR BASE MAPS

New Kinds of Imagery

Any discussion of future imagery requirements for urban analysis can only be presented in a very general manner. At the present time, little urban interpretative work has been done with either infrared or radar imagery. However, these two types of imagery appear to have future importance. The discussion of infrared photography and side-looking radar summarizes information provided by Mr. Harold Bockemuehl, Department of Geography, University of Montana and Melville C. Branch.[1]

Infrared Photography

Infrared black and white film is sensitive to most visible light and to infrared wavelengths just outside of the wavelengths seen by the human eye. With this added sensitivity, infrared photos cannot be interpreted like ordinary pictures. The cause of this difference is that the dark or light value is a function of the surface temperature

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[1]Melville C. Branch, City Planning and Aerial Information (Cambridge: Harvard University Press, 1971), pp. 129-31.

of the photographed object. Other conditions which also affect the picture are meteorological conditions, thermal properties of the object, and internal heat generation, such as warmed buildings.

Knowledge of the refractive and reflective physical behavior of near-infrared light is necessary to comprehend the different material and environmental factors which affect how features on the ground appear photographically. On infrared black and white photography, water shows dark in contrast with land, which appears lighter. However, when it is silt-laden or appreciably warmer than surrounding water, it appears photographically lighter in value. When vegetation is unhealthy and reflects less infrared light because of its reduced moisture and chlorophyll content, values are darker than similar healthy vegetation. Since red filters are normally used, the spectral colors of longer wavelength (red, yellow, green) register lighter in value, those of shorter wavelength (blue, blue-green, violet) appear darker. The influence of color on value in general is increased, for the range of colored light admitted to the film is limited by the filter which is used to minimize the blue of atmospheric haze, as well as the characteristics of infrared film.

In false-color infrared photos, where infrared radiation from healthy vegetation appears bright red, interpretation is simple. Lawns and landscaping in poorer neighborhoods are less well kept than in more prosperous sections of the city, false-color infrared may be used in identifying economically depressed areas.

For the average photo interpreter, familiarization with the altered values shown in infrared pictures is most readily attained by studying panchromatic and infrared aerial photographs of cities side by side. Knowledge of how colors are recorded photographically, and of the effect of filters, is needed.

Side-Looking Radar (SLAR)

Radar is an acronym for the descriptive title of Radio Aided Detection and Ranging. This title describes its function--radar is employed to detect objects and to measure their distances from its site. Only one radar mapping system is presently available commercially in the United States. It operates at three preferred altitudes: 20,000, 12,500, and 9,000 feet absolute altitude, with three ground-range sweeps of 21, 13, and 9 kilometers corresponding to the three altitudes. Film scale on the radar image ranges from a scale of 1:225,000 to 1:98,000. The scale depends on the size of the cathode-ray tube and the ground-range sweep selected.

A short pulse is transmitted by the antenna approximately at right angles to the flight path of the aircraft.

The outgoing radar signal is reflected from the ground with the first reflection received back from the inner or closest edge of the ground area "illumned" by the outgoing pulse. The intensity of the returning signal varies with the nature of the reflected target and the angle of incidence of the radar beam. The strength of this reflected signal determines the brightness of a point on the recording cathode-ray tube.

Signals reflected from points on the ground further away from the aircraft arrive sequentially later and are recorded on the cathode-ray tube as the electron beam sweeps across its face presenting a map-like appearance of the reflected objects on the terrain. The face of the cathode-ray tube can be photographed using ordinary photographic techniques.

At the present time, no radar system compares with aerial photography in planimetric accuracy; successive scans across the line of flight do not "fit" each other closely. The reasons for these deficiencies are: the pulse length error, or the error caused by the length of time during which the transmitter is emitting a pulse; the beam width error, or the error caused by the spread of the beam from aircraft to ground object; and the spot size error, or the error in size of display of the ground object due to the characteristics of the cathode-ray tube. There is also considerable target "break up" or "salt and pepper" effect in the image of urban areas.

Balanced against these disadvantages, side-looking airborne radar can "see through" haze, clouds, smog, and all but very heavy rain. The chances of radar images being affected by weather are therefore much less than with photography in the visual range. Radar black and white images can be translated into color-coded renditions. Stereovision can be obtained by combining thermal infrared and radar images.

New Approaches

Significant advances have been made possible in the processing of photographic and other imagery by the development of the electronic computer. A black and white photograph can be scanned electronically by a photometer recording differences in value and pattern which cannot be detected by ordinary observation.

Interpretation always has been a bottleneck in getting information from aerial photos. Differences in the interpretive skill among photo interpreters is a problem, and this phase of the total process is the slowest and most costly. Image characteristics, when properly expressed mathematically and programmed into a computer, are identified by light scanning. The correct symbol for each characteristic which they represent can be shown in its proper location on the computer print-out. Automatic pattern recognition may in time be applied to aerial interpretation. The problem of practical automatic recognition of imagery is one of the difficult parts of a broader field of study called the automatic recognition of form.

> This broader field includes the automatic recognition of the following, which are listed approximately in their order of increasing difficulty: (1) printed alphanumeric characters which are designed and stylized for automatic recognition; (2) geometric shapes . . . of random size and orientation; (3) printed or typewritten alphanumeric characters of conventional type; (4) handwritten alphanumeric characters; (5) handwritten script; (6) fingerprints; (7) signatures (verification against forgery); (8) images on aerial photographs; (9) human faces (identification of an individual); (10) photo interpretation. Methods have been . . . developed for items 1 through 5. Items 1 and 3 are in commercial use. Items 6 through 10 are not yet within the practical state of the art.[2]

New equipment, the computer and associated automatic devices will speed and facilitate the work of the interpreter. However, the use of this equipment will require more training on the part of the interpreter to include a knowledge of computer science.[3]

General Observations

Because the field of image sensing is still in the stage of research and development, it will be some time

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[2] Paul Rosenberg, et. al., "Photogrammetry in the Space Age," in Manual of Photographic Interpretation, ed. by Robert N. Colwell (Menasha, Wisconsin: The George Banta Co., Inc., 1966), p. 1082.

[3] Edward P. Devine, "The New Cartographer," Proceedings of the American Congress on Surveying and Mapping, XXXII (March, 1972), 82.

before definite interpretive conclusions are reached which are valid for the various types of sensing systems.

It is impractical to attempt to review here separately the appearance of the multitude of features in a metropolitan region as they appear in panchromatic, infrared, and multiband photographs, and in the different recordations of a number of non-photographic sensors. Also, many of the newer sensors are still experimental and their urban use still unresolved.

The potential scope of aerial interpretation and information is extensive, despite the limitations inherent in the directly overhead view and generally small scale of observation and analysis. An average ability to read aerial photos may be acquired without prolonged study and practice, but the capacity to use aerial information in city analysis, urban research, and urban studies is not easily or quickly acquired.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The urban analyst or planner is provided with a composite of information on the uses of aerial photos and allied products as they relate to the urban land-use map. An attempt has been made to cover the field as it is today, progressing from the general to the specific. Many urban analysts are active in work with city planning staffs. In fact, they are present in greater numbers than most other professions.

Aerial photography is not new; it has been in use many years. However, analysts have generally made little use of it. Land-use base maps have been constructed from Sanborn maps, engineering maps, and other sources, although photo coverage is available for many urban areas in the United States. For certain areas there is progressive coverage available for specific periods over many years. This sequential photography can provide detailed information to show trends in urban development.

The Peoria summary shows briefly the types and amounts of information which may be gathered from aerial photographs to develop information for land-use maps. The photos used in the Peoria study were originally taken for other purposes, thus no new photography was needed. The study demonstrates how photo interpretation procedes from the known to the unknown. The Missoula illustration provides an estimate of costs for adequate new photographic coverage, and the production of photo enlargements and mosaics needed for general urban study and analysis.

Stressed in this thesis is the necessity for project coordination and planning. It is sensible that all interested agencies be contacted prior to the procurement of new photography. Each may have specific needs which can be satisfied with little change in the original specifications. In addition, funding may be available from these agencies to cover a part (or all) of the project's costs. Planning must include a summary of needed information and methods for its interpretation, recording, and display. These methods for the interpretation of photography and land-use map construction must be kept simple if the urban analyst intends to do the whole job himself. If a portion of the work is done by contract, the requirements should be clearly and concisely stated. This basic simplicity of photo interpretation and map construction methods should reduce the final project costs.

New types of imagery and interpretative devices have been developed in the past few years. However, it appears that little of the information gleaned from infrared and radar sensing is being used by the urban analyst.

The general conclusions derived from this study are that: insufficient use has been made of aerial photos as aids for collecting urban information; aerial photos and allied products can be procured at reasonable cost; and simple equipment and methods are available for developing acceptable land-use maps and interpretative data.

Essentially all phases of modern urban analysis and planning can be done more efficiently through the use of photos, photomosaics, and photomaps. Although no one method can be considered the answer to all urban land-use analyses, photomaps are a basic and useful tool for the researcher.

APPENDIX I

URBAN PHOTO INTERPRETATION SCALES

The following chart provides a general guide to distinguishing and outlining urban features at various scales.

Scales of 1/70,000 - 1/30,000

1. Outline total built-up area with urban characteristics.
2. Outline the major transportation lines going through the city.
3. Outline the major transportation lines going into or out of, but not through the city.
4. Outline the major physical characteristics of the total built-up area and adjoining land (e.g., drainage, surface configuration, natural vegetation).

Scales of 1/30,000 - 1/10,000

1. Separate total built-up area into urban and suburban parts.
2. Outline the kinds of transportation areas in the city (e.g., railroad yard, port district, canal area).
3. Outline minor transportation lines through and only into or out of the city.
4. Outline areas of warehouses and open storage adjacent to the transportation lines.
5. Outline main heavy industrial areas by interpreting along major and minor transportation lines and particularly at transport junctions.
6. Outline recreational areas.
7. Outline cemeteries.
8. Outline residential areas along and between main transportation lines.
9. Outline areas of the city with respect to selected characteristics (e.g., age, street pattern, elevation, multiple residence).

Scales larger than 1/10,000

1. Outline the kinds of internal transportation routes (e.g., street car, small barge canal).
2. Mark the location of and identify individual structures and installations (e.g., school, railroad classification yard, sewage disposal plant, heavy industrial factory).[1]

[1] John H. Roscoe, et. al., "Photo Interpretation in Geography," in Manual of Photographic Interpretation, ed. by Robert N. Colwell (Menasha, Wisconsin: The George Banta Co., Inc., 1960), p. 774.

APPENDIX II

METHODS OF PHOTOGRAPHIC ANALYSIS

Geographical problems vary so widely in subject and scope that standardization of methods is not readily attainable. Certain general procedures have been recommended. The procedure suggested here consists of three steps in planning and ten steps in operation. It may be desirable to combine, omit, rearrange or vary these steps to solve a particular problem:

> (a) Objective determination. The formulation of the question to be answered is clearly prerequisite to the effective solution of the problem. A clear, concise definition of the problem to be solved, which defines and limits the goals to be achieved, and a statement of the purpose to be served by its solution will eliminate unnecessary effort and may also improve the quality of the work.
>
> (b) Capability evaluation. Once the problem has been properly stated, the geographer should evaluate the means at his command to solve it. These include his own professional skills and those of his associates, the equipment, time and funds available. If the means of research are not sufficient to solve the problem, either they should be supplemented or the scope of problem should be restated to match the available means of research.
>
> (c) Procedural selection. The type of problem and available means of research are considered in terms of the techniques to be used in the work. At this point the merits of photo interpretation and other geographic methods are weighed, and a suitable method or combination of methods is selected.
>
> (d) Documentary search. There are very few subjects in geography which are best studied by photo

interpretation alone. This is true even if all the information required can be obtained more quickly from other sources: local inhabitants and local histories, regional and systematic literature, telephone and business directories, maps and atlases. This information can then be checked against the photographs for accuracy and timeliness.

(e) Photographic search. The geographer performing academic or unsponsored research generally cannot afford to order special photographic coverage, but is dependent on existing photography. His search for photographs may be more complicated than his search for documents. Photography should be selected according to the size and complexity of the region . . . . Stereoscopic coverage is almost always desirable. Ground resolution must be sufficient to identify the smallest object of study.

(f) Photographic preparation. The photographs should be . . . (systematically) . . . organized and prepared for efficient use. Indexing, filing, orientation, computation of horizontal scale and vertical exaggeration, and mosaic making are recommended steps in preparation.

The photographs should be indexed on a base map of the largest scale suitable for use in the study. Generally a planimetric map or a Geological Survey Topographic Quadrangle serves well. If one type of systematic data is particularly important, the photography may be platted on a soils, vegetation, land-use, or other special type of map. The location of each photograph can be indicated by plotting its center, corners, or its whole boundary, and marking its number on the map. On small-scale maps it is sometimes better to plot only every fifth photograph, or the beginning and end of each flight line. If terrestrial photographs are used, they should also be plotted. Many agencies which sell aerial photographs also offer index mosaics or map sheets, which can be substituted for hand-plotted index maps. Once indexed, the photographs can be filed by number. If the flight lines are not north and south, it is sometimes helpful to place north arrows on the photographs.

If the scale of the photographs varies significantly because of relief displacement or changes in flight altitude, it may be necessary to compute the scale of each photograph or each important photograph. This can be done by comparing true distances between objects on the ground or on reliable maps with distances measured between images of these objects on the photographs. If it is necessary to know the ground resolution of the photographs, the smallest objects which can be detected should be measured on the photographs and on the ground. Other factors relating to interpretability, such as snow cover, dense foliage, clouds, haze and shadows, should be noted in terms of the amounts and kinds of information lost because of their presence.

(g) Mosaic making. If controlled photomaps or index mosaics are not available it may be desirable to make them. Controlled mosaics are seldom required for geographic studies; a semi-controlled mosaic can readily be made by enlarging a map to the scale of the photography and using it as a base on which to lay the mosaic.

(h) Preliminary interpretation. In the initial interpretation, it is usually best to work from small-scale to large-scale photography, from general patterns to individual features and from known to unknown images. If a mosaic has not been made, . . . the photography should be scanned for general patterns; if more than one set of photographs is at hand, the set of smallest scale should be used for scanning.

When general patterns have been noted, the elements which compose them are first scanned and then examined closely. The known images which are important to the study are temporarily marked with grease pencil on the photographs or on overlays. The photographs are then viewed stereoscopically in such a manner that every portion of each photograph is scanned methodically. A separate examination may be made for each type of feature or each group of closely related features. This procedure organizes the work of interpretation and obviates duplication and omission.

(i) Field plan. The information derived from the documentary search and the preliminary interpretation permits the photographer to establish a field plan for the most effective use of his time, to verify data inferred from the documents and photography, and to collect the required data not available from these sources.

(j) Field work. The geographer, who has already made a preliminary reconnaissance by air-photo traverse needs only to confirm observations or inferences already made and collect additional data at points chosen during the preliminary interpretation. Ground photographs of the more important landscape elements should be taken. These provide useful supplements to the annotated aerial photographs and field notes.

(k) Review of problem and method. The geographer reviews the original problem and the procedure he chose for its solution. He may now reaffirm these; or he may restate the question or alter his method for solving it in the light of new or uncontemplated information gathered by library research, photo interpretation or field work.

(l) Final interpretation, conclusion, and field check. A second and more rigorous examination of the photographs is now made. The geographer's notes and records containing the description of the region or system are completed, his conclusions drawn, and his report outlined. Before writing the report, he should if possible visit the area again to check things that were omitted or not closely observed in the field survey, or to answer questions which arose during the second interpretation of the photographs.

(m) Presentation. The data must now be arranged in meaningful form. The geographer may elect to display his findings in their true spatial relations by means of annotated aerial photographs and photomosaics, and support and explain these relations with field notes, statistics, and references to the literature. For final presentation a mosaic with one or more overlay maps is often desirable; this device not only isolates the important data but also shows how they relate to the whole.[1]

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[1] John H. Roscoe, et. al., "Photo Interpretation in Geography," in Manual of Photographic Interpretation, ed. by Robert N. Colwell (Menasha, Wisconsin: The George Banta Co., Inc., 1960), pp. 767-71.

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