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USES OF CONVENTIONAL AERIAL PHOTOGRAPHY IN URBAN AREAS: REVIEW AND BIBLIOGRAPHY

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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Interagency Report
NASA-131
September 1968

Mr. Robert Porter
Acting Program Chief,
Earth Resources Survey
Code SAR - NASA Headquarters
Washington, D.C. 20546

Dear Bob:

Transmitted herewith is one copy of:

INTERAGENCY REPORT NASA-131

USES OF CONVENTIONAL AERIAL PHOTOGRAPHY

IN URBAN AREAS

REVIEW AND BIBLIOGRAPHY*

by

Ashraf S. Manji**

The U.S. Geological Survey has released this report in open files. Copies are available for consultation in the Geological Survey Libraries, 1033 GSA Building, Washington, D.C. 20242; Building 25, Federal Center, Denver, Colorado 80225; 345 Middlefield Road, Menlo Park, California 94025; and 601 E. Cedar Avenue, Flagstaff, Arizona 86001.

Sincerely yours,

William A. Fischer
Research Coordinator
EROS Program

*Work performed under NASA Contract No. W-12570, Task No. 160-75-01-35-10
**Northwestern University, Department of Geography

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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ABSTRACT

This paper is divided into two parts. Part I presents a review of some of the past uses of aerial photography in urban areas. The empirical studies reviewed are divided into two broad categories depending on whether inventory compilation is by direct or indirect observation. Studies using inventory by direct observation are further divided into land-use studies and transportation studies. Part II identifies some problem areas for future research.

FOREWORD

This report serves as a partial basepoint for studies of the utility of remote sensors as data sources for urban areas. Conventional aerial photography provides a useful source of data in the study of a wide variety of urban problems such as land-use, traffic, etc. The comparative utility of other remote sensors rests upon their ability to provide additional data, more accurate data, data at a lower unit cost, more timely data or upon some combination of these attributes. Without some knowledge of the present state of the art it is indeed difficult to discuss the relative merits of more exotic remote sensors.

It is interesting to note that many of the reports listed here deal with descriptions of the use of aerial photography while only a handful deal explicitly with cost and accuracy considerations. Unless additional information is uncovered on these topics it will undoubtedly be necessary to develop it in the course of current attempts to evaluate the relative merits of other remote sensors.

The material contained in this report was originally developed as an independent research effort. It has been expanded and is reproduced here because of its direct utility to our present investigation. Any corrections and additions are, of course, welcomed. They should be addressed to the Remote Sensing Laboratory of the Department of Geography.

Duane F. Marble
Professor and Principal Investigator

USES OF CONVENTIONAL AERIAL PHOTOGRAPHY IN URBAN AREAS: REVIEW AND BIBLIOGRAPHY

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Aerial photography has come to be an extremely useful tool for collecting data, especially since World War II. It has proved to be a valuable aid in geology, forestry, agriculture, and a number of other fields, but its use in urban areas seems to have lagged behind that in other fields. However, this lag is more apparent than real. *Ad hoc* inquiries have revealed that aerial photography occupies an important place in a large number of city planning departments and is being employed for a variety of purposes. A large number of these uses, however, are not presented as formal reports, and very few, indeed, are ever published.

The objective of this paper is to review some of the past uses of aerial photography in urban areas. The paper is divided into two parts. Part I, which forms the bulk of the paper, presents a review of those empirical studies which may be considered representative of the type of work done in the past. Only those studies which the writer feels make a contribution in terms of developing special research techniques, finding new uses for aerial photography, and evaluating its utility as an urban data source are included here. References to additional available published works are provided in the bibliography. Part II identifies some problem areas for future research.

PART I

A review of some methodological developments in the field of urban photo interpretation is presented first as an introduction to the subsequent review of empirical studies. Methodological contributions have been very limited, and hence the presentation here is brief.

The use of aerial photography in urban areas may be said to begin with the studies by Lee [1920], Joerg [1923], and Birdseye [1940], all of whom were aware of the potential value of aerial photography for collecting urban data. Most of the early applications, however, were concerned primarily with supplementing conventional field work rather than with the use of aerial photographs as a basic data source.

World War II brought a tremendous increase in the use of aerial photography for military purposes, and, since the appraisal of urban area photographs for strategic purposes involves such aspects of urban areas as land use, transportation, and the type and density of buildings, the rapid strides made in military photo interpretation gave great impetus to the growth and development of the field of photo interpretation for urban areas (Walsh, 1948).

1. Branch (1948)

In 1948, Branch published a study entitled *Aerial Photography in Planning and Research* which attempted to acquaint the city planner with the uses of aerial photography. The description of the actual applications of aerial photography in urban areas is incidental to the main emphasis of this study, which was to develop the notion that urban photo interpretation consists of *identification* and *classification* of various urban features under the following five headings:

1. Land--topography, and land-use such as parks, parking lots, vacant land, coal yards, etc.
2. Water--marshy land, irrigation ditches, shore lines, beaches, river rapids, waste outflow, etc.
3. Structures--buildings, streets, sidewalks, railroads, highways, docks, water and fuel tanks, etc.

4. Movement--information primarily on traffic flow.
5. People--the density, arrangement, spacing, and the type of houses which indicate the way of living of the inhabitants.

Most of the uses of aerial photography in urban areas (until about 1950) use a variation of this basic approach.

2. Stone (1956)

Stone presented a method for the use of aerial photography in geographic research in which he outlined a step-by-step procedure of interpretation. It is based on the idea that photo interpretation is largely a deductive process and hence, analysis should proceed from the readily discernible features, such as transportation arteries, to progressively more difficult features, such as drainage, surface configuration, vegetation, agriculture, and finally, rural non-agricultural and urban features.

3. Witenstein (1956)

Witenstein [1956, p. 657] extended Branch's operati ; of identification and classification by carrying the study of urban land-use through the sequence of *inventory, analysis and planning.* In *inventory,* three classes of data are taken into consideration:

1. Location and classification--of all features as distribution patterns.
2. Measurement--for example, of size and capacity, in order to develop basic statistical data assemblies.
3. Computation--for example, the ratio of land used and land zoned.

In *analysis* the inventoried data, such as number of cars per dwelling unit, are combined with planning multiplier factors, such as road capacity per thousand vehicles. Detailed ground sampling and literature checks are used to improve the accuracy of the multipliers. Then a second reading of photographs is made to locate reasons for outstanding planning problems. Finally, in *planning*, engineering standards are applied to land-use features in order to plan the size, capacity, and location of facilities, and to estimate the amount of work entailed in preparation of site. In his treatment of planning, Witenstein [1955, p. 566] restricted attention to the relation of engineering standards to land-use features; however, a consideration of social, economic, and legal standards is equally important. Witenstein's work has provided the basis for several more recent studies, which tend to emphasize *analysis* and *planning* rather than *inventory*.

The remaining part of this section presents a review of some of the past uses of aerial photography in urban areas. It is recognized that all such applications begin by taking an inventory; hence, the studies reviewed are divided into two broad categories depending on whether inventory compilation is by direct or indirect observation.

Inventory by Direct Observation

This method provides data relating to phenomena which are directly observable on photographs. Specific types of studies include identification of present land-use, determination of rate of land-use change, identification of sources of air and water pollution, determination of the extent of flood damage, estimation of public utilities and services needed in a developing area, determination of route locations for streets and highways, traffic counts, parking surveys, etc. For the purpose of this paper, the studies reviewed in this section are divided into the two categories of land-use studies and transportation studies. However, it must be noted that in practice there is often a great overlap.

1. Land-Use Studies

Traditionally, most land-use data have been obtained by some form of ground survey. This method is generally expensive, laborious, time-consuming, and often inaccurate (Turpin, 1964, p. 126). It is felt that much of the data required can be obtained quickly and economically by photo interpretation. Panchromatic vertical photographs are adequate for many purposes, but stereoscopic coverage, when available, greatly facilitates interpretation, as does the use of oblique photographs and color film (Hadfield, 1963, p. 4, and Stallard and Biege, 1966, p. 36). In land-use classification, for example, photo interpretation keys can be used to delineate areas as residential, commercial, industrial, institutional, etc., and to obtain detailed data in each of these categories (e.g., Hadfield, 1963). Any *change* in land-use pattern can be determined by comparing a time sequence of air-photos (e.g., Howlett, 1963).

Three empirical studies are reviewed here. The first study illustrates the application of aerial photography in urban planning. The second study is primarily concerned with testing the reliability of photo interpreted data. The third study demonstrates the use of a statistical sampling technique for obtaining land-use data.

1. <u>A Land-Use Study of Rockville, Maryland (Witenstein, 1956)</u>

The CBD of Rockville, Maryland, a satellite town in the Metropolitan Area of Washington, D.C., was laid out before 1949 to serve the older western portion of the city. At that time, this portion comprised the entire city and the CBD was more centrally located. However, the business community had failed to anticipate the rapid expansion in the eastern part of the city, which, by 1956, accounted for six-sevenths of the population. Streets and parking facilities in the CBD were far from adequate to handle this tremendous growth. In addition, competition was imminent from two new shopping centers in the east which would offer more attractive shops as well as facilitate access and parking.

Witenstein [1956] described how aerial photography was used to provide a basis for some remedial action. The method used consists of taking an inventory of the commercial area, transportation routes, and parking spaces, and making a detailed analysis of traffic flow and parking facilities in order to plan expansion of the CBD.

Delineation and measurement of land-use types on aerial photographs revealed that 17 percent of the total land area of Rockville was in commercial use but the CBD occupied only 9 percent of the total commercial area. Analysis of traffic flow and parking facilities showed that eight routes approached the CBD from the west with a total potential traffic flow of about 1000 cars. On the other hand, only one narrow street approached the CBD from the east with a traffic potential of about 6000 cars. Furthermore, cars approaching from the east had to drive the full length of the business district before they could turn into parallel streets and reach parking lots.

The plan for solving this problem consisted of two stages. The first stage proposed some remedial measures for short range development. Photo interpretation revealed that there was enough vacant land in the CBD to double the existing parking capacity and that the peripheral parking areas could be made more accessible by constructing a few access streets and a number of passways between parking lots and stores on the main street. The second stage suggested a program for long range development of the rest of the commercially zoned land based on Rockville's location on the main railroad line.

This study provides a fine example of the use of the sequence of *inventory*, *analysis*, and *planning* as advanced by Witenstein. The problem tackled in this study is typical of the problems encountered by city planning personnel, and the method used here can be readily adapted to fit specific cases. In particular, it is often used for engineering planning projects. David Warnick

[1954] reported on the use of aerial photography for small engineering projects which incl[illegible] the development of a water distribution system, planning of a sewage collection system and treatment plant, route selection for power transmission lines, and the analysis of the approach zones to the Harrisburg State Airport; unfortunately, the lack of detail with which these studies are reported precludes a review here.

2. Evaluation of Data Obtained from Aerial Photography (Hadfield, 1963)

The Urban Research Section (URS) of the Illinois Division of Highways carried out a traffic study of the Fox River Valley region in Illinois. The objective of the study which is of interest here is the evaluation of aerial photography as a method of collecting the following types of data:

1. Measurement and classification of non-residential floor area into 42 categories depending on the type of use.
2. Land area classified by the general non-residential use types as in (1) above and by "residential" and "vacant."
3. Dwelling unit and residential structure counts classified as multiple or single family.

The survey covered an area of 200 square miles located 45 miles west of Chicago. Photographs enlarged to a scale of 1" = 400' in the developed areas and 1" = 1000' elsewhere were used, together with some supplementary low-altitude oblique photographs. The basic unit for collecting data was the "block," either a city block, or, outside cities, an area with identifiable natural boundaries.

The photo-interpreted data were subjected to extensive accuracy tests in order to guarantee accuracy for this study and to establish the reliability of the method for general application. To accomplish this, thorough checking was undertaken by the URS using a separate systematic sample of each type of data. The sample blocks accounted for about eleven percent of the total dwelling units, and for about eight percent each of the total floor area and land area obtained from photography. The sample size needed was estimated in advance on the basis of data from a small preliminary test.

Non-residential floor area measurements for the test sample were obtained from fire-insurance atlas maps whenever these were available and by direct measurement in the field in other cases. Using these as the check measurements, it was found that the photographic survey measurements underestimated all types of non-residential floor area taken together by 13 percent.

The accuracy of land area measurements was tested by repeating measurements from original photographs since no source superior to aerial photographs was available for the sample area. Some variation among repeated measurements is inevitable because the definition of land use boundaries is necessarily inexact, but the results were generally close and the error was considered to be negligible.

Two separate accuracy tests were used for the dwelling unit counts: (1) census figures for 1960; and (2) counts obtained by URS field surveys. The latter were based on the observation of doorbells, mail boxes, and utility meters as indicators of the number of dwelling units. Census data were superior to field counts, but the field survey was conducted because the boundaries of census districts did not coincide with study area boundaries and some parts of the study area were not covered by the census. It was found that the original aerial survey dwelling unit count was approximately 10 percent less than the census count; however, the results of sample field counts were used to provide correction factors, and the corrected aerial survey count differed from the census count by only 0.4 percent. The nature and development of correction factors are not described in detail.

The study required an accuracy sufficient for making trip estimates for an origin-destination study. In general, the required accuracy level was met, but only after applying correction factors obtained by independent sample checking. Aerial photography as a source of floor area and land area was found to be inferior to fire-insurance atlas maps, which provide more accurate land-use data more easily at half the cost. The accuracy and comparative costs for dwelling unit counts by field survey and from photographs were closer. The total cost of collecting the aerial survey data and the data used for checking was approximately $10,000. This works out to approximately $51.00 per square mile, excluding the central business districts. These figures do not include the cost of planning the project, designing the sample, and analyzing and tabulating data.

3. A Land-Use Study Using a Sampling Technique: NIPC-CATS, 1965

The Northeastern Illinois Planning Commission (NIPC) and the Chicago Area Transportation Study (CATS) cooperated in a project the main purpose of which was to update land-use data for the six counties comprising the Northeastern Illinois Metropolitan Area (Northeastern Illinois Planning Commission, 1965). The primary data source was vertical panchromatic air photo enlargements with a scale of 1" = 400'. Each enlargement covered a block of four sections of a township in the land survey system, an area of four square miles.

Owing to limitations of time, personnel, and money, a sampling technique was used instead of the traditional method of identifying land-use in each parcel of the study area. A stratified systematic unaligned sample was used (Berry, 1962, pp. 2-14) because it combines the advantages of random, stratified and systematic sampling while avoiding any possibility of bias because of the presence of periodicities. In particular, it provides greater accuracy than a random sample of the same size and gives unbiased estimates of land-use whether occuring in regular or irregular patterns. In this study the sample was stratified so as to have one point for each four square inches of photo area, which gave approximately 44 sample points per square mile.

Very little field checking was undertaken because of the time and expense involved and because of the difficulty of locating sample points in the field. Instead, the following method was used to test the sampling procedure. One photo enlargement was selected as being representative of the planning area with respect to the pattern and variety of land-use and the size of parcels. A detailed photo interpretation of land-use was carried out for all four square miles and the percentage of area in each type of land-use was calculated for each square mile as well as for the entire four square mile area. These figures were considered to be true values for the populations sampled and were used as a control against which to test the results of the sampling procedure. In a test case, the percentage of land in various classes, calculated for eight sample points taken from this area, were found to be very close to the percentages found from the control measurements of land-uses. CATS carried out an independent test and obtained similar results.

The results of the sampling study were stored on IBM cards, one for the quarter square mile surrounding each sample point. This made it possible to obtain valid results for irregularly shaped areas, such as individual villages, by approximating their boundaries with lines drawn along quarter mile section boundaries. The proportions of various land uses cannot be calculated for each quarter square mile because the sample is not valid at this scale; instead, proportions can be calculated for data aggregated for townships or quarter townships (nine square miles).

It should be noted here that this method can be used to sample other types of data obtained by photo interpretation, such as floor area or building height. It can also be used to provide detailed land-use data for areas smaller than those for which data can be validly aggregated from one sample. This can be achieved by using essentially the same sampling technique but taking several samples instead of one. The percentage of total area allocated to a given land-use category can then be calculated by taking the mean of the percentage of each sample in the category. Future studies may be improved by using rectified photographs which allow a direct measurement of areas and provide a detailed and accurate source for the preparation of base maps. Other improvements might include the use of a computer for locating sample points, prepunching by machine of the locational code for each point, and the use of the geodetically correct State Plane Co-ordinate System for location coding instead of the two different systems used by CATS and NIPC in this study.

2. Transportation Studies

In the discussion of urban transportation in this paper attention is focused on motor vehicle transportation as relatively little attempt has been made to apply photo interpretation to other types of transportation in the urban area. Planning for motor vehicle transportation entails obtaining data on three basic aspects: 1. land-use, 2. traffic patterns, and 3. parking facilities (Turpin, 1964, p. 125).

A consideration of land-use is important for three reasons. First, it indicates the value of land in the area. This is an important factor in planning the location of routes and obtaining the right of way (Turpin, 1964, p. 125). Second, it indicates the extent of the development and the opening up of the area likely to come about as a result of added transportation facilities. Third, it can be used as a basis for traffic generation studies (e.g., Hadfield, 1963).

Traffic and parking studies are made in order to survey existing facilities and to assess future needs. A variety of data may be necessary (Turpin, 1964, pp. 125-126). For example, data obtained in traffic studies may include location of places that generate traffic or cause bottlenecks, a count of the number of vehicles in transit at a particular time, and even pedestrian counts.

Parking lot data obtained may include the total number of vehicles likely to use a given area at a given time, the total number of places available, their location (on or off street), their ownership (private or public), and the intensity of current use (density and rate of turn over).

Again, the data collection methods generally available to the transportation planner are inadequate (Turpin, 1964, p. 126). A survey of existing facilities often requires an "on-the-spot" investigation. For example, in a parking survey, the number of vehicles parked in the CBD of a town might be counted during a specific hour, but the number will vary on different days; hence, the process has to be repeated a number of times before valid results can be obtained. The method ties up a large labor force for a considerable period of time.

Aerial photography seems to be particularly suitable for meeting the needs of transportation planners. Land-use data can be obtained by using the methods described in the section on land-use studies. Traffic data can be obtained using a number of techniques (Turpin, 1964, p. 128). For example, continuous strip photography can be used to study traffic congestion by determining vehicle speeds, positions, and spacing. Regular aerial photographs can be used for the same purpose if the flying height and exposure time can be established accurately. In addition, ground photography, both moving and still, taken from high vantage points such as overpasses and high buildings can be used for determining driving habits, number of persons per vehicle, and for making a record of accidents in order to shorten the investigation time at the scene, thereby minimizing the time needed to clear the road again.

Much of the desired information on parking facilities can be obtained from aerial photographs if a suitable scale is used (Turpin, 1964, pp. 128-129). For example, photographs with a scale of about 1" = 500' will show paint marks on the street and the number of places in use as well as their pattern. At larger scales, the size and type of vehicle can also be assessed. A series of photographs taken at different times of day and on different days of the week could easily provide a relatively complete inventory of parking facilities, and if the scale is large enough, the adequacy of parking space size, congestion created by parking spaces located too close to entrances or exits, and the type and size of vehicles could be determined.

Three studies are reviewed here in an attempt to indicate the use of aerial photography in transportation studies. The first study provides a general statement of the extent to which photo interpretation is used in the highway field. The other two are empirical studies and illustrate the use of aerial photography for traffic surveys. One uses "density contour maps" for determining the source, duration, and extent of traffic congestion; the other demonstrates the use of a method for collecting accurate data on traffic flow.

1. Utilization of Photo Interpretation in the Highway Field (Rib, 1966)

Rib indicates the extent to which photo interpretation has been utilized in the highway field based on questionnaries sent to 53 major highway organizations. A total of 50 organizations replied and Rib summarized the results in two ways: (1) by the major areas of photo interpretation applicable to highway engineering; and (2) by the stages of highway engineering in which photo interpretation can be utilized. Only the latter summary, which is based on the answers to the "Photographic Interpretation Surveys" portion of the 1962 Questionnaire on the Use of Aerial Surveys (Committee on Photogrammetry and Aerial Surveys, 1963), is presented here.

Approximately 65 to 75 percent of the organizations polled utilized photo interpretation in highway planning, reconnaissance survey of area, and preliminary survey of alternate routes. However, only 15 to 30 percent of the organizations made "extensive"[1] use of photo interpretation in these stages. Aerial photography is considered most useful in these early stages of highway location because a number of the environmental factors affecting the economics of highway location (topography and soils, for example) can be easily evaluated using aerial photographs.

About 70 percent of the organizations used photo interpretation in the preliminary survey of a selected route in order to obtain data for the final design, but only 16 percent of the organizations made extensive use of photography in this phase. Approximately 55 percent of the organizations used photo interpretation in location surveying and staking of the designed location, more than half of which made fairly extensive use. However, only a small number of organizations utilized photo interpretation in the stages of traffic surveys, construction surveys, condition and inventory surveys, and maintenance surveys.

2. A Study of Traffic Operations Along a Freeway (Wagner and May, 1963)

In 1961, a study was conducted in Los Angeles for the California Division of Highways to investigate the feasibility of using time-lapse photographs (photographs taken at short intervals of time) for studying traffic operations along a freeway (Wagner and May, 1963). The photographs were taken from a height of 6,500 feet using a 7-inch focal length lens.

In this study, attention was focused on measurement of traffic density primarily because it is a good indicator of traffic service (speed) and through-put (number of vehicles) on the freeway and because the measurement of traffic density using aerial photographs is relatively simple. The density

[1]The extent of use within each stage was determined by grouping the various items listed in each stage into the major areas of photo interpretation (land-use, soils, geology, drainage, etc.) and calculating a weighted percentage based on the number of major areas of photo interpretation in each stage and the possible degree of utilization of photo interpretation in each major area. The rating "extensive" designated at least two-thirds maximum utilization in each stage.

is given in terms of the number of vehicles per lane-mile and is obtained by dividing the vehicle count on a subsection of the freeway by the product of the subsection length (generally ¼ to ½ mile) and the number of lanes. The vehicle count was made by photo interpretation. Freeway overpasses were used as subsection boundaries since they are easily identified and the exact distances between overpasses were readily available from plans on file.

A method of studying variation in traffic density over both time and distance simultaneously was devised by constructing "density contour maps." Such a map is constructed by computing traffic densities as above for each subsection photographed at short periods of time and plotting the results on a distance-time graph. Points of equal traffic density are then joined to form density contours which graphically portray the source, duration, and extent of traffic congestion.

The time-distance-density contour map developed in this study is an important technique and has a number of potential uses. For example, it can be used to compute the average density during the time period and for the freeway length shown on the map. This can be done by dividing the product of the areas enclosed by various contour lines and the average density between the lines by the total area of the map. It can also be used to estimate traffic demand, i.e., the number of vehicles intending to pass through a given point. This can be done by supplementing the information contained on density contour maps with data on the number of vehicles on the neighboring entrance and exit ramps. Data on average density and traffic demand is highly important not only for regulating traffic operations but also for making any changes in freeway capacity.

3. Investigation of Traffic Flow (Treiterer and Taylor, 1966)

Treiterer and Taylor described the development of a method designed to obtain data on the movement of vehicles along a roadway. The main objective was the measurement of vehicle spacings and speeds for a platoon of vehicles at short intervals of time. The procedure consisted of placing a test vehicle in the traffic stream and following it in a helicopter from which photographs were taken at fixed intervals of time. Photographs were taken from a height of about 3,000 feet which provided a road coverage of approximately 2,250 feet with a scale of 1:12,000. The test vehicle served three purposes. First, by carrying a distinctive mark on its top, it served as a guide for the helicopter. Second, when instructed by the helicopter pilot, it generated disturbances in order that certain traffic situations might be studied. Third, it carried equipment to record velocity and acceleration against which the data obtained by aerial photography could be checked.

A detailed analysis was made of a sequence of 101 photographs. First, ground control points adjacent to the freeway were selected using photo interpretation. These points consisted of such objects as lamp poles, manhole covers, guardrail posts, and ends of curbs. The ground coordinates of these points were measured using standard ground surveying techniques, and the negatives were inserted in an Analytical Stereoscopic Plotter for measuring the photographic x- and y-coordinates of each ground control point, the front center of each vehicle, and the center of the photograph. Next, a computer program was used to convert photographic data to ground data using appropriate transformation equations and to compute headways and velocities of the vehicles using the cumulative distance traveled by each vehicle in each photograph and the time interval between photographs. The cumulative distance values for each vehicle corresponding to various time values were then plotted on a distance-time diagram to obtain vehicle trajectories. Error analysis (not included in the report) showed that the standard error was no more than 1.0 m.p.h. for velocity measurements and no more than 1.0 ft. in spacing measurements.

This is the first study to provide accurate flow data continuous over space and time, and this method for measuring traffic movement is particularly suitable for testing and extending some of the existing theories of traffic flow. For example, a number of theories have been proposed for describing the reactions of a trailing vehicle to changes in velocity of the leading car, but comparatively little is known about the propagation of disturbances in a platoon of vehicles and its effect on traffic primarily because of a lack of suitable data (Treiterer and Taylor, 1966, p. 1). This study has provided one method of collecting data for such investigations.

Inventory by Indirect Observation

This method provides information relating to phenomena which are not directly observable on the photographs but whose existence can be inferred from the presence or absence of certain other features which are observable on the photographs and which are known to be consistently associated with the phenomena for which the inventory is being compiled. The method, sometimes called "inventory-by-surrogate," consists of four basic steps: (Moore and Wellar, 1968)

1. Identification of those elements which can be observed on photographs and which are consistently associated with the phenomena of interest. These can be determined either inductively, through association of elements observable on photographs with a ground survey, or deductively, using known functional relationships.
2. Derivation of suitable measures for elements observed on photographs.
3. Establishment of a quantitative relationship between the elements observed on photographs and the phenomena for which the inventory is being compiled.
4. Testing the consistency and reliability of this relationship in several cases.

This method of inventory compilation has been utilized to a much lesser extent than inventory by direct observation. However, its importance should not be underestimated. Three studies are reviewed here which illustrate some of its applications. The first study shows how inventory-by-surrogate can be used to delineate urban poverty areas. The second study uses photo interpretation to provide accurate data on residential areas from which conclusions were drawn about urban social structure. The third study presents an accurate method for making dwelling unit counts.

1. Urban Poverty Study (Mumbower and Donoghue, 1967)

Mumbower and Donoghue report on a study which utilized aerial photography to obtain data on urban poverty areas. The method involves carrying out a detailed photo interpretation of residential areas in order to delineate areas exhibiting characteristics commonly associated with poverty and validating the results by comparison with census data. Color and panchromatic photographs of eight cities in the U.S. (Huntington, W. Va.; Gadsden, Ala.; Wilkes-Barre, Pa.; Reading, Pa.; Jacksonville, Fla.; Columbus, Ohio; Buffalo, N.Y.; and Baltimore, Md.) and of San Juan, Puerto Rico, were examined having scales ranging from 1:8,000 to 1:30,000. In the case of Baltimore, Md., photographs taken during four different years were used and attention was focused on detecting change and updating existing data. The report states that close correlation was found between the census and photo-data, but detailed results are not cited.

Small scale photography (approximately 1:30,000) proved to be useful for identifying transportation features and for delineating areas as residential, industrial, commercial, recreational, and institutional; however, it was difficult to extract data on the structural and environmental characteristics associated with poverty. In particular, it was difficult to assess multiple family dwelling units and dwelling units in commercial buildings with respect to the number of units and whether or not they could be included in poverty areas.

On large scale photography (approximately 1:10,000) poverty areas were identified more easily and more accurately. The indicators taken into consideration include structural deterioration, debris, clutter, vegetation, sidewalks and streets, junk-yards, warehouses, and small businesses. At this scale, it was also possible to evaluate each individual housing unit in the block. Structures containing commercial enterprises on the first floor and dwelling units above were generally easy to evaluate but in the core areas it was difficult in some cases to determine whether or not dwelling units were present.

San Juan provided the opportunity to investigate the effect of scale and color. Scale range used was from 1:15,000 to 1:30,000 in panchromatic and 1:10,000 and 1:15,000 in color. As expected, the larger scale panchromatic gave better results whereas color photography facilitated interpretation and increased the precision in delineating poverty areas.

The study attempted to achieve some level of generality by using nine different cities which provide a representative cross section of urban areas with respect to population size and regional location. Furthermore, this study uses different scales and also color film, although the number of different scales used is no large enough for making definite statements about each scale and the treatment is limited to a discussion of "large scale" and "small scale." A larger number of scales needs to be investigated and a thorough analysis must be carried out before more specific statements can be made. Some type of statistical analysis would also be useful for ascertaining the necessary and sufficient set of indicators for delineating poverty areas with a given accuracy. This would help to reduce the cost of interpretation. Research of this type can be profitably expanded, both in depth and scope. One avenue that is currently being explored is the measurement of housing quality (e.g., Wellar (1967) and (1968)).

2. A Study of the Urban Social Structure (Green, 1957)

Green carried out a study in which photo interpretation was used to provide data on the social structure of cities. His method consists of finding a statistical association between a number of physical and sociological variables. In the analysis of Birmingham, Ala., for example, census tracts were divided into subareas which were used as units of study. Aerial photographs were used to provide data in each of the following categories:

1. *Location of residential area realtive to three concentric zones centered at the main business district.* These zones were determined by noting major breaks in land-use, building type, terrain features, and transportation arteries.
2. *Description of the residential area in terms of internal and adjacent land-use.* Each subarea was classified as having favorable, neutral, or unfavorable attributes as a place to live. The classification was based on street patterns, house and lot sizes, mixture of land-use, the age and quality of construction, and the presence or absence of trees, sidewalks, and industrial, commercial, or railroad facilities.
3. *Prevalence of single-family homes.* In this category, data was obtained on the occurrence of single-unit, detached dwellings; the residential subareas were labeled as "high," "medium," or "low" depending on the prevalence of single family homes.
4. *Density of housing.* Density was expressed as the average number of dwelling units per block. Each subarea was qualitatively labeled as "high," "medium," or "low."

Interpreting photographs to obtain data on zonal location and land-use is straightforward and its accuracy was not questioned. On the other hand, data on the prevalence of single-family homes and housing density required somewhat specialized techniques and, hence, an accuracy test was considered necessary. The test, which covered a sample of seventeen areas, correlated ground observations with data obtained by stereoscopic examination of photographs using previously developed recognition keys. The keys were based on such features as form and structure of roofs, yards, driveways, entranceways, the size, shape, and height of structures, and their spatial relationship to other buildings. The findings showed that 99 percent of the residential structures were correctly identified, but the total number of dwelling units was underestimated by 7 percent. The Spearman Rank correlation coefficient between the two sets of data was 0.988. One finding of particular interest was that the errors were systematic: The number of single-family homes was consistently overestimated and the number of double-unit residences was consistently underestimated.

The near-perfect rank orderings indicate that photo interpretation can be reliably used for describing residential areas according to physical characteristics. Extension of similar research to six U.S. cities showed that high statistical association does exist between each of the four data categories and several variables of sociological interest. However, any one photo-data category considered as a single variable has only a limited predictive value and hence an attempt was made to combine various categories of social and physical data. This was accomplished by adapting the Guttman Scalogram model[2] for constructing a "residential desirability scale" based on the four physical structural attributes and a "socio-economic status scale" based on the following

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[2]The Guttman scale analysis technique, conventionally used in social psychology, provides a convenient method of combining several qualitative variables which, if scalable, form a single continuum defining the rank of each object in relation to every other object in the sample. For more details see Samuel A. Stouffer, et al., *Measurement and Prediction*, Princeton, N.J.: Princeton University Press, 1950.

five social data items: (1) median annual income, (2) prevalence of within dwelling crowding, (3) prevalence of home ownership, (4) prevalence of social disorganization, and (5) educational achievement. A correlation of the two scales in the case of Birmingham showed that the residential desirability scale accounts for 78 percent of the variation in the socio-economic status scale.

Green's study has been criticized by Wellar (1967, pp. 14-16) who feels that the four photo-data categories are too broad and that there are too many exceptions to each category. An example of the exceptions he points out is the increasing number of high rise apartment buildings in the central city area which are highly desirable despite the fact that they are multiple-unit structures and that they are frequently located in the inner-most zone and close to commercial establishments. The implication is that the character and desirability of residential areas are constantly changing and hence the simple classification used by Green is inadequate for describing residential desirability. While the points that Wellar makes are well-taken and while it is agreed that residential desirability depends on several factors not determinable from aerial photographs (a criticism made by Witenstein, 1957), it is still significant that Green's scale of residential desirability does explain 78 percent of the variation in the socio-economic status scale.

This study has demonstrated that aerial photography is a feasible method for obtaining accurate data not only on aggregate characteristics of housing units but also on the socio-economic characteristics of areas; hence, it can be used to supplement or even replace existing data sources. The potential for extending this method to explore further the urban social structure need hardly be emphasized.

3. Estimation of the Number of Dwelling Units (Binsell, 1967)

Binsell investigated the nature of errors accompanying estimates of the number of dwelling units derived from aerial photographs. His method consisted of estimating the number of dwelling units on the basis of photo interpretation keys and checking the results with ground counts of doorbells and mailboxes. Ektachrome continuous photography with a scale of 1:5,240 was used, but no special benefit appeared to accrue from the use of color. In the initial test, the following keys were used:

1. Roof divisions and number of chimneys
2. Number of sidewalks and sidewalk irregularity
3. Size, shape, and height (in stories) of the structure
4. Outside porches and fire escapes
5. Arrangement of windows
6. Roof area and type (i.e., flat or peaked)
7. Number of parking spaces

A total net error of underestimation of 12.6 percent was obtained for a sample area consisting of 19 subareas (including approximately 15,000 dwelling units) of Chicago. However, an important finding was that errors tend to be quite consistent both in magnitude and direction. In particular, it was found that

1. the number of dwelling units in multiple family structures is underestimated
2. the number of single-family detached units is overestimated
3. association of error increases with increase in the prevalence of multiple-family structures

Similar results were obtained by Green (1955) and Hadfield (1963). The systematic nature of errors not only suggested the use of correction factors, but also led to the conclusion that errors are inherent in photo interpretation keys. Three types of correction factors were developed: the first is analogous to the type used by Green (1955); the second is of the type used by Hadfield (1963); and the third is based on regression lines for photo- and field-observed number of dwelling units per structure. As expected, the use of correction factors produced greater accuracy.

Working on the premise that errors are inherent in photo interpretation keys and that improved keys will result in more accuracy, Binsell attempted to estimate the number of dwelling units in a subarea of northern Chicago using improved keys. He tested the hypothesis that the number of dwelling units in a structure can be determined by multiplying the number of roof sections by the number of stories. The operating rules may be summarized as follows:

1. For each subarea containing small multi-unit structures, find one structure which has roof divisions clearly demarcating the boundary of a single dwelling.
2. Divide the entire roof area by the roof area of the clearly demarcated unit to obtain the number of roof sections.
3. Count the number of stories in the structure.
4. Multiply the number of roof sections by the number of stories.
5. Repeat operations 2 to 4 for all structures in the subarea or for a sample of structures and add the results.

The application of this method to a small high density suburban area (containing 25 blocks with an average of 23.9 dwellings per structure) resulted in a net error of underestimation of 1.97 percent, which compares favorably with the net error of 2.0 percent obtained by the census count for 1960 for all of the United States.

The generality of Binsell's work is limited by a small data set and by a lack of variation in housing types in the study area, but he has shown that accurate counts can be obtained by indirect observation, provided that suitable surrogates can be found. The method can be extended to other types of data involving measurement or count. A special advantage of this technique is that accuracy is obtained by using an improved key and hence it does not entail a pilot study (as in the case of Green, 1955) or concomitant field checking (as in the case of Hadfield, 1963) for developing correction factors. Consequently, the method can readily be applied to different urban areas.

PART II

The review in Part I indicates that aerial photography can be successfully used for obtaining data on a wide range of urban problems. The developmental nature of most of the work carried out to date, coupled with a scarcity of control experiments, precludes any definitive statements about the relative merits of aerial photography and ground surveys as methods of data collection. It is felt, however, that for large surveys, aerial photography provides data more quickly and economically than ground surveys. Furthermore, these data are generally as accurate and reliable as those derived from ground survey. A major drawback is that the effective operation of the conventional camera is limited to daylight and clear weather conditions.

In the remaining part of this paper, some of the more important problem areas for future research are identified. It is evident from the preceding survey that most of the work done has been designed for a specific purpose and for a specific area. One of the foremost concerns of further research, therefore, is to extend the same type of investigation to other cities--first in the U.S. and then in other countries--to see if any meaningful generalizations can be obtained. In addition, there is a great need for more rigorous structuring of experiments. Emphasis should be placed on formulating various hypotheses and obtaining data to test them. Only in this way can a body of standard procedures and field-tested methods be developed.

There is a need for the specification of urban data requirements and an assessment of the capacity of aerial photography to provide data that satisfy these requirements. Moore and Wellar (1967, pp. 1-11) consider (1) timeliness, (2) flexibility, (3) reliability, and (4) compatibility, to be the most important.

Consideration must also be given to such aspects as the cost of obtaining and interpreting photographs, data reduction, and its subsequent storage, retrieval, and processing, which are important factors in the development of urban information systems. Particularly important in connection with this is the development of hardware and techniques for automatic photo interpretation. For small, specific studies such as inventory of land-use in some part of a city, it is generally possible to interpret photographs visually, but for large cities and for securing a variety of data, automatic photo interpretation becomes a necessity.

The various film and filter combinations now available for aerial photography should be evaluated. A variety of film types exist, but comparatively few are in general use. Particularly limited is the use of color film, primarily because of its high cost which makes coverage of large areas impractical. Some of the past attempts to evaluate the utility of color film (e.g., Stallard and Biege, 1966) have indicated that the higher cost of color prints can be offset by the speed of interpretation and the higher quality of data. In addition, it is anticipated that increased use of color film together with more efficient production methods will bring about a marked reduction in cost within the next few years.

Another important area of research is preparation for the future use of spacecraft imagery. While such imagery will not be readily available for a few years to come, preliminary investigation is certainly in order. For example, high altitude, low resolution imagery could be simulated by downgrading imagery collected from aircraft. This will provide some understanding of the problems connected with the use of low resolution imagery and permit the development of appropriate equipment and techniques of analysis.

A methodical evaluation should be made of the utility of multiband, infrared, and radar imagery for securing urban area data. Well-designed experiments should be carried out in order to compare such imagery with conventional photography and determine the specific benefits and limitations of each type. It is known that the capacities of various sensors for providing data are often complementary, but again very little work has been done to investigate the advantages of combining data from a number of sensors.

Clearly, the work done to date represents only the beginning of the exploration of a whole new field and a great deal more has yet to be done. If research effort is channeled in these problem areas, it can reasonably be expected that the next two decades will bring great advances in the use of aerial photography in urban areas.

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