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APPLICATIONS OF AERIAL PHOTOGRAPHY IN LAND SYSTEM MAPPING

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Abstract

Land systems are patterns of landscape recognised on aerial photographs and mapped to define areas of similar terrain with a similar environment. Breaks of slope often form the major boundaries both between and within land systems. They can be usefully mapped from aerial photographs even if their significance can only be deduced after ground investigation. Many of the characteristics of land systems can be appreciated from aerial photographs and measurements made on the photographs can improve their quantitative description.

LAND SYSTEMS

THERE are many ways in which aerial photographs can be used to aid land-use investigation and development. This paper describes their use in reconnaissance investigations of land resources in which the object is to describe large areas of land and to select within those large areas smaller areas which appear to have the greatest potential for development. Such investigations have two main purposes; to describe the land resources and to ensure that the usually limited resources of trained personnel and finance are channelled to the most appropriate parts of the country.

Climate, topography, soil and vegetation are major components of the natural environment, each of which must be carefully considered when the potential of an area is being investigated. Frequently in the past only one aspect of the environment has been considered, with the result that assessments have been based on an incomplete picture and wrong conclusions have been drawn. The combined effect of all the contributory factors and the interactions between them must be appreciated before an accurate assessment of land potential can be made.

There are two important ways in which the constituent factors of the natural environment can be investigated; each factor can be studied separately so that final appraisal will depend upon consideration of the combined results of these studies, or the area can first be subdivided into landscapes, each of which is recognised as a unique entity defined by a special combination of factors. In the second method, the pattern of relief, soils, vegetation and water supplies within each of these unique landscapes can be investigated and described in sufficient detail to permit planning of land-resource development. This paper describes the second of these methods of investigation, developed to make maximum use of aerial photography. Broadly speaking, the landscapes mapped are those which can be recognised on aerial photographs and can be defined at scales between 1 : 250,000 and 1 : 1,000,000. These landscapes are called *land systems* (Brink *et al.*, 1966).

The concept of mapping land systems was first described by Christian (1958). It was developed by the Land Research Division of the Commonwealth Scientific and Industrial Research Organisation and used in the Northern Territories of Australia and New Guinea (Christian and Stewart, 1953). The concept has been applied in other parts of the world and has been developed by the Land Resources Division of the Directorate of Overseas Surveys during projects in Botswana, Lesotho, Malawi, Nigeria, the Solomon Islands, the New Hebrides and the Cameroon Republic. It is based on the observation that different types of landscape are distinguishable on aerial photographs and can consequently be mapped. Its value lies in the further observation that within a consistent pattern of landscape, a consistent pattern of land development will usually be applicable.

The method of working involves, as far as possible, the study of an area from its gross features progressively to its more detailed features. The procedure therefore consists in the recognition and mapping of different landscape patterns on aerial photographs, the investigation of each pattern on the ground and subsequently the definition, mapping and description of land systems. The emphasis on preliminary aerial photograph analysis and interpretation avoids the risks inherent in any form of systemic ground survey, when vital evidence lying between traverse lines will be missed.

Photo-Analysis and Interpretation

In the first instance these gross patterns can usually be recognised on print laydowns or photo-mosaics at scales between 1 : 100,000 and 1 : 250,000. At this scale only macro-differences in the landscape are recognised and the components of any pattern are not necessarily known. Subsequently, by studying stereo-pairs of photographs selected from within the different patterns recognised on the print laydowns, the detailed patterns of landform and vegetation within any one of the gross patterns can be determined, and from variations of tone and texture it may be possible to interpret the composition and structure of the underlying rock, the main constituents of the vegetation and the nature of the soil. Also, by selecting stereo-pairs of aerial photographs lying across the boundary between two patterns recognised on the print laydown, the nature of that boundary may be determined.

Up to this stage in the investigation no lines or boundaries need have been mapped. The aerial photograph has merely been used as a source of descriptive information from which it is deduced that the regional landscape consists of several patterns, now called provisional land systems, that each pattern consists of a particular association of land forms and vegetation types and that the soils and underlying rocks have certain properties, some of which can be predicted. Considerably more detail can, however, be derived from the aerial photograph before field investigation is necessary, or indeed before the worker is fully prepared for field work.

There is, however, always a danger of deducing too much from aerial photographs at the preliminary stage of a reconnaissance and thereby introducing errors which could subsequently lead to wrong conclusions. It is, therefore, essential at this stage to concentrate on analysis or photo-recognition and to use for this analysis and its interpretation terminology and symbolisation which clearly distinguishes between identification of objects and deduction of their significance (Colwell, 1954). Breaks of slope and boundaries between physiognomic vegetation types can be identified on aerial photographs and come under the heading of recognition. Mapping breaks of slope or vegetation boundaries on aerial photographs thus provides an objective analytical framework which can subsequently be interpreted. The amount of local knowledge which the particular worker has will obviously control the amount of interpretation which he can make in a particular environment. The point which should be emphasised is that much useful aerial photograph analysis can be undertaken even without local knowledge.

The boundaries between provisional land systems and the characteristics of each of the *land facets* which make up a land system should be known before field investigations are undertaken and much of this information can be obtained from the aerial photographs. The boundaries between each provisional land system can be traced on stereo-pairs of photographs and compiled on a base map. At the same time, the land form and vegetation characteristics of each land facet can be observed and recorded, although boundaries between the land facets are generally not required at the reconnaissance stage. Many land system boundaries coincide with breaks of slope, which are also landform boundaries. Breaks of slope cannot be recognised with certainty on print laydowns and thus in many areas of complex terrain the landform pattern cannot be appreciated without a detailed stereoscopic analysis.

Description of Land Systems

After the field work, further photo-interpretation may be necessary before the land systems can be defined. Each system is defined primarily in terms of its landform, soil and vegetation (Christian and Stewart, 1953). The process of definition raises several further questions which aerial photographs can be used to answer.

The form of a land system can most readily be appreciated from a three-dimensional block diagram. These can be prepared, using perspective line-drawing techniques, from sketches or contoured or form-lined maps. However, these methods presuppose either that the scientist has the ability to sketch his requirements in perspective before handing them to the draughtsman or illustrator or that contours or form lines are available. The Directorate has developed a procedure (Carmichael, 1967) which enables the scientist to explain his requirements with a description and only a two-dimensional sketch. The block diagram is based on stereoscopic pairs of aerial photographs which are typical of a land system. A rough clay model is made from the stereo-model of these photographs by viewing them through a Stereosketch (Hilger and Watts Ltd.). The clay model is then photographed obliquely. This oblique photograph provides the desired perspective view and, after any necessary touching up, the photograph can be used directly as a block diagram.

Aerial photographs can also be used to improve the precision and reliability of landform descriptions. The usual practice in field investigations is to measure a necessarily limited number of slopes on the ground and to classify the land in terms such as gently undulating, rolling and rugged or the component slopes in terms of gentleness or steepness. Aerial photographs, used in conjunction with a computer, offer the opportunity of making and handling many more measurements. The frequency of the slope distribution can then be investigated and a more significant definition of the slope categories obtained. The range of slope within any one of these categories can also be determined more accurately.

The slope of a unit length of line can be measured with a parallax bar at each of a number of sample points distributed at random over the project area. The range of slopes can then be grouped by land system or land facet. Such a procedure assumes that any tip and tilt in the photography either is insignificant compared with the slopes being measured, or can be corrected for. An alternative to this overall sample would be to put the stereo-pair selected as typical of a land system in a suitable plotting instrument and to record the co-ordinates of the land surface at a series of random points over the model. The slope and altitude distributions within this type sample could then be taken as typical of the land system as a whole. Work on each of these procedures is only in the early stages, but by employing both it should be possible to test how typical is the type sample.

If a plotting machine is used to investigate the slope distribution in samples of land systems, it could be argued that the model should be contoured or in fact that contours should be drawn throughout an area and subsequently used for mapping breaks of slope. However, the detail provided by contours and form lines depends on the contour interval. Changes or breaks of slope of less than twice the contour interval cannot be readily appreciated from the contours, and the position of a break of slope, which is the boundary with which the geomorphologist is concerned, does not necessarily coincide with a change in contour separation. In areas where there is a marked difference in relief, changes in the contour separation and boundaries between different slope categories may coincide sufficiently for landform boundaries to be based on contour separation. But in areas of lower relief, the pattern provided by mapping breaks of slope cannot be obtained by analysing a contour map. Analysis of breaks of slope from aerial photographs allows the main structure of the landscape to be mapped quickly and relatively cheaply and provides an accurate starting point for interpretation and more detailed investigation.

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Résumé

Un "land system" est une zone écologique, reconnaissable sur une photographie aérienne et caractérisée par quelques éléments récurrents de relief associés avec des formations végétales spécifiques. Pour évaluer les ressources naturelles d'une région étendue, on commence par établir une carte présentant plusieurs zones écologiques. Les limites de ces zones sont souvent formées par des changements de pente qu'on discerne facilement sur la photographie. Par conséquence, il est utile de tracer les limites de ces changements sur la carte, même si leur signification n'apparaît qu'après une prospection au sol. On utilise la photographie aérienne non seulement pour déterminer les caractéristiques des zones écologiques mais aussi pour préciser la description quantitative des zones.

THE USE OF ELECTRONIC COMPUTERS IN LAND-USE SURVEYS BASED ON PHOTO-INTERPRETATION†

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INTRODUCTION

THERE can be few scientists who have not now come into contact with electronic digital computers in at least some aspects of their work. Most scientists will, indeed, have gone as far as to ask themselves how computers could help them in making their work more efficient and more effective. The danger, however, lies not in the possibility that scientists will neglect the use of computers, but in the fact that the question "How can computers make my work more efficient?" is the wrong question to ask. The correct question is: "What implication does the existence of fast, modern electronic computers have for the work in which I am engaged?"

To the majority of those who come into contact with electronic computers, the most important property of the computer would seem to be its speed. When arithmetic operations can be carried through at speeds of 1,000 to 1,000,000 operations per second, making possible mathematical and clerical processes that would otherwise take a lifetime to complete, it would seem that this property alone would justify the claim that the computer has introduced a totally new dimension to the field of human endeavour. For the first time, complex mathematical techniques can be applied to everyday problems, and clerical procedures which would normally demand numerous staff can be undertaken. Even more important, however, than the sheer speed of computation made possible by the electronic computer is its ability to store and obey its own instructions. The series of instructions stored in this way, known as a programme, provides a precise definition of the operations that must be performed, and usually includes all the necessary checks of the validity of the data submitted to the computer. Furthermore, once the programme has been written, preferably by the most appropriate expert in the field, it may be used by any other workers with similar problems. It is not necessary for later users of the programme to understand every aspect of the computation, although they will find a complete and unambiguous description in the programme, but the work of the original specialist is automatically made available, through the computer, to the widest possible range of practical users.

As experience with electronic computers has accumulated, an even more important benefit from their use has become apparent. Once data have been prepared for processing by computers, by punching them onto punched cards or punched tape, or have been stored by computers on magnetic tape or magnetic discs, these data are automatically available for further calculations, and for reference. With forethought, it is possible to create data banks, accessible through the computer, which ensure that all data are available to all the members of an organisation, or of many organisations. Where data are stored and used in this way, it is possible to see that future policy decisions can be made in the knowledge of existing data rather than in their absence, as happens frequently at present.

Given these three basic advantages of using electronic digital computers (i.e. speed of computation, explicit programming of operations, and the creation of data banks), this paper attempts to answer the question: "What are the implications of the

† This contribution by Mr. Jeffers followed the paper read by Mr. Bawden on 21st February, 1967. Subsequent discussion and questions involved both speakers.

existence of electronic digital computers to the planning and conduct of land-use surveys based on the analysis of aerial photographs?"

Basic Decisions

In considering this application of electronic digital computers, it is necessary to record three basic decisions:

(i) All calculations to be made during the course of the survey will be carried out by the computer.

(ii) The basic data from the survey will be recorded in such a way that they may be input to the computer without any manual intervention, e.g. no key-punching of hand-written data.

(iii) The final tables and maps, regarded as the end-product of the survey, will be produced by the computer in a form suitable for direct reproduction.

It is important to stress that these decisions should be made before the start of the survey. An attempt to introduce electronic computers after the survey has been commenced may result in some increases in efficiency, but the full gain from their introduction will not be achieved.

It is perhaps easiest to illustrate the implications of electronic digital computers by using a practical example of a land-use survey of one of the developing countries. The object of the survey is to determine, for certain administrative units and natural land types, the pattern of land-use within a number of defined categories. The survey is to be based on photo-interpretation of sample points superimposed on recent photography of the specified areas. One of a set of numbered templets is chosen at random for each photograph, placed on the photograph, and the land-use category on which each of the numbered dots on the templet falls recorded. The desired results from the survey are assumed to be as follows:

(i) Estimates of the proportions of the land surface occupied by each land-use category, together with standard errors of the estimates, for defined administrative and natural units.

(ii) Estimates of the area occupied by each land-use category, together with standard errors of the estimates, for defined administrative and natural units.

(iii) Maps of the land-use within broad categories at several different scales, for planning and illustrative purposes.

The plan for the survey would also contain details as to the required precision of the estimates, but these details will not be discussed in this context.

Computer Application

The flow diagram for such a survey, assuming that the three basic decisions are taken, is given in Fig. 1, in the form of a network planning diagram. The diagram assumes that, while the aerial photography is being done, the forms on which the basic data are to be recorded (assumed in this case to be cards) are printed, that the intensity of the sampling is calculated, and that the necessary templets are prepared.

The first stage at which the implications of the use of a computer become apparent is in the actual recording of the land-use categories observed on each photograph. The object is to create, at the point of recording, data which can be passed direct to the computer without any further manual intervention. It would be possible to provide each interpreter with an electric paper tape punch or card punch on which he could record his interpretations, but this would be a rather expensive expedient, and there may be difficulties in providing adequate visual proof of the correctness of the record to the interpreter at the time of recording. The two most practical solutions to this problem, at the present time, are the use of special forms, designed to be read by the English Electric Leo-Marconi Lector Document Reader (Jeffers, 1967) and the use of I.B.M. Port-a-Punch cards. In this paper, the use of Port-a-Punch cards will be assumed. This card is designed to receive the following information; photograph numbers, template number, administrative unit code number, natural unit code number, land-use category code number for sample points 1 to 14, and observer code number. The information is punched into alternate columns on partially pre-punched 80-column I.B.M. cards, using a simple numerical code. The cost of the cards is relatively low, and the punching is done on a special board, with a stylus, costing less than £10. The whole operation has been found to be quick and economical, with remarkably low error rates, even with relatively untrained staff. The advantage of recording data in this way is that they can then be read by means of a card reader directly into a computer, or, alternatively, the data on the cards may be converted to punched paper tape, and read by a paper tape reader on a computer. In either case, no manual intervention is required between the initial recording and the computer processing.

Having captured the basic data, it will usually be desirable to subject them to a fairly intensive and systematic check before proceeding to their analysis. This check will be carried out by the computer under the control of a special programme, and may include such features as a check that all sample points have been recorded on each photograph, that impermissible administrative units, natural units or land-use category codings have not been used, and that incompatible land-use categories do not occur on the same photograph. It may also be desirable to relate certain types of errors to observers. Any queries found in the process of this checking will be followed up, and the basic data amended and rechecked before continuing with the analysis.

When the correctness of the basic data has been confirmed, the calculation of the three major objectives of the survey can begin. In Fig. 1, these are shown as three separate and independent calculations and there are some advantages to this procedure. The programming of the calculations will preferably have been done before any data have been collected, tested and perfected on specially constructed test data, so that everything has been prepared for the processing of the actual data when they are recorded. The language in which the computer instructions are written will depend upon the particular computer being used, but will generally be one of the high-level, machine-independent languages ALGOL or FORTRAN. The programmes will undertake all of the calculations necessary to compute the estimates of the proportions and areas occupied by the land-use categories, and their standard errors, and will ensure that correct statistical procedures are used. Finally, the end-result of each programme will be the statistical tables specified by the originators of the survey, complete with all the necessary headings and captions, so that no annotation is required.

The programme to plot the maps of the distribution of land-use categories perhaps requires some further comment. The wider use of graphical output from computers has been long overdue, but many modern computers are equipped with digital incremental plotters on which maps of high quality can be produced, to almost any desired scale. As the basic data from the survey records the number of the photograph and the code number of the templet used, it is relatively easy for the computer to work out the co-ordinates of each of the sample points recorded, and from these to plot the sample points with distinctive symbols. In geophysical surveys (Merriam, 1964), computer programmes have been written which produce continuous interpretations of land form and geology from random or systematic sample points, and this technique can readily be extended to land-use surveys. It is probably unnecessary to state that there is no difficulty in programming the computer to insert the basic features of any map (e.g. towns, roads, coastline, rivers) at any desired scale.

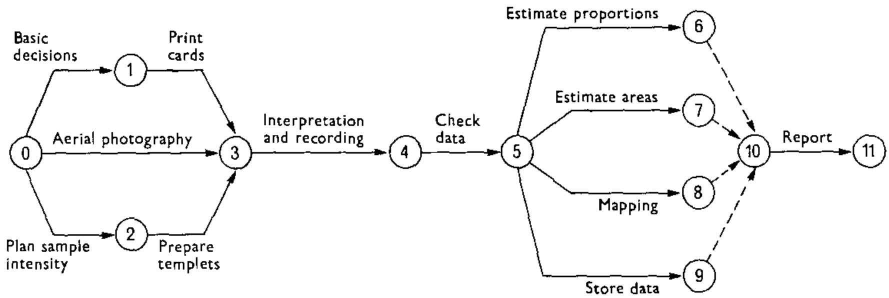

FIG. 1. Network diagram of stages in land-use survey.

The method of storage of the basic data will depend on the computer which is used for the survey. The simplest method of storage will be in the form of punched paper tape or punched cards which can be read into the computer for any subsequent investigations or enquiries. With more modern machines, it is likely that the data will be stored on magnetic tape or, where many enquiries are envisaged, on exchangeable magnetic discs. Whatever form of storage is used, the object is to provide a relatively simple way of obtaining subsidiary tabulations or of following up enquiries about particular records or groups of records.

Finally, an expanded and more detailed version of the network diagram of Fig. 1 can be used, in conjunction with an electronic computer, to undertake a critical path analysis of the whole project (Smith, 1965). Network planning and resource scheduling have proved to be very effective in completing complex surveys in the shortest possible time and with the best use of the available resources, and have the added advantage of providing a continuous review of the progress of the survey without detailed record-keeping and accounting.

CONCLUSION

The example of a land-use survey may seem far-fetched and idealistic. Apart from the planning staff and the photo-interpreters, no other persons are involved in the survey. No clerical staff are required, and there are no summaries or calculations to be produced by hand or on desk machines. All tabulations and maps are produced automatically, to the exact specifications of the objectives. The only possible source of errors lies in the interpretation of the land-use categories of the individual sample points and in the original recording, and all copying of data, the most usual source of errors, is made unnecessary. The basic data are also held in a form in which they may be readily consulted. In fact, land-use surveys using the methods described are already being undertaken for Malawi and Nigeria by the Directorate of Overseas Surveys, and a new survey based on the same principles is now being planned for Zambia. All of these surveys are being processed on a second-generation transistorised computer, an I.C.T. Sirius, which, by modern standards, is slow and of limited capacity, and no major difficulties have arisen. On faster, larger, third-generation computers, equipped with magnetic tape and exchangeable disc stores, the whole process could be made even faster and more efficient. Much has been made, in popular descriptions of electronic digital computers, of the difficulty of writing computer programmes, and of communicating with computers. With the growing use of high-level languages, it is fair to say that these difficulties have been grossly exaggerated, and it is now easier to instruct a computer to carry out a complex analysis than it is to instruct human beings to perform the same analysis. Computers have the marked advantage that they do exactly what they are told to do, no more and no less. They therefore require no additional supervision during the performance of their duties, where human beings require continuous and unremitting supervision. Certainly, the statisticians who will necessarily be responsible for specifying the methods of analysis will prefer to instruct a computer, probably by means of one of the general survey programmes (Yates and Simpson, 1960) than to undertake the responsibility of directing human beings.

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DISCUSSION

Mr. Brunt: I would like to ask two questions, one directed at Mr. Bawden and the second at Mr. Jeffers. There seem to me to be two possible snags in the methods which they have described so ably this evening. The first, and this is directed at Mr. Bawden, is the question of the accurate identification of the photo-image; no matter whether it is a land form, vegetation, or land-use image, this identification is in many cases subjective, and I know from some of my colleagues, in connexion with the survey of Malawi, that this has given some trouble. We've heard a great deal about making things less subjective and using automatic processes, but I would like to ask Mr. Bawden, and indeed anyone else who is present, what their thoughts are about removing this subjective element in photo-interpretation, and introducing a quantitative or semi-quantitative process which will reduce this element of human error. The second question, directed at Mr. Jeffers, concerns the checking of the card punching, which he possibly glossed over slightly by explaining that he could ask the computer to check a large number of things. How can you actually check mistaken punching on the part of the operator if he punches some of the 9 or 15 sample points per photograph slightly inaccurately, *but within the possible variation in land-use pattern in the actual natural area being analysed*?

Mr. Bawden: It is easy to define a category and then condemn the air photography because that particular category can't be identified. If however, the categories are subjective, then there must be a subjective element in the interpretation, or photography can be commissioned which is specifically related to the category in question.

Mr. Jeffers: As Mr. Bawden has said, if you have defined categories which are difficult to assess subjectively, you have chosen categories which are inappropriate for that particular type of photography. It is possible, of course, that the difficulty lies in marked differences between the abilities of individual observers and, for this reason, it is wise to record the identity of the observer on each card. It is also possible to detect systematic errors by the use of mathematical techniques. This may sound a rather odd thing to do but, in land-use analysis, we may expect to find particular patterns of land-use and an examination of these patterns, by some such method as the association analysis devised by Professor W. T. Williams for ecological work, very often reveals discontinuities which are due to misinterpretation. This sort of technique, carried out as a post-mortem or concurrently with the processing of the data, is therefore a very powerful method of checking the efficiency of the interpretation. On the second point, checking that the cards have been correctly punched initially is no different from checking that numbers have been correctly written on pieces of paper. Probably the best check of recording errors is for a supervisor to check a sample of the observations.

Mr. Brunt: Could I just follow that with a rider? Has that, in fact, been done with either of the projects you described this evening, and if so, what sort of percentage error is obtained in the punching?

Mr. Jeffers: I would have to ask the people concerned.

Mr. Tuley: It might be possible to re-punch a percentage of the total number of cards.

Mr. Jeffers: This would be another way of getting a similar sort of check.

Mr. Greenwood: I am somewhat disappointed that so very little has been said about the actual interpretation of photographs. Each time it was mentioned, you were very careful to add the rider that one must go on the ground to check, and even implied that one must not interpret too much. I would have thought that if this has been going on since 1940, there would now be sufficient evidence of what different species look like at different scales and in different parts of the country. I would like to ask Mr. Bawden if at the Directorate of Overseas Surveys, they train interpreters to analyse these data. I think that rather than have an interpreter to make a very rough estimate of a macro-region, he should be making a much more detailed interpretation of a micro-region. I know that one can identify mahogany in Borneo from aerial photographs, as well as identifying palm trees and various types of vegetation with a great deal of accuracy. Does the Directorate follow this procedure and really use interpretation to its full capacity? Secondly, Mr. Jeffers, I am never really happy about random points! It is quite impossible for a good interpreter to analyse an area on a land-use basis, and to draw this interpretation in magnetic ink in direct proportions, rather than accept random points that may, or may not, form part of a particular category?

Mr. Bawden: When there is doubt as to what is represented by the photo-image, then it is better not to be dogmatic. More errors are caused by saying that a certain feature is mahogany (when it may not be) than by stating that the feature is a very tall tree, with a crown of a particular size, and that there is a certain number of similar trees in a given area. A subsequent field visit can then confirm the particular species.

Mr. Greenwood: I think Mr. Bawden has queries about individual interpreting skills. The point at issue is the contribution which photo-interpretation can make as a basic discipline. Why not make full use of the individual skills and experience of the trained interpreter?

Mr. Bawden: In that case I would prefer to use "recognition" rather than "interpretation" as descriptive of the technique to be used. There is always the danger of the observer making a mistake, and we attempt to cut mistakes to a minimum.

Mr. Jeffers: While it is certainly possible to mark areas magnetically on a map and scan these with some automatic device, there are some very real advantages to the use of random sampling. First, the amount of work that one has to do in random sampling depends only on the variability of the population and the precision with which the estimates are required, and the economy of the sampling process can be very closely controlled by getting the users of the survey to specify the degree of precision that they require. Second, it is possible, by random sampling, to express estimates that are made in a convenient and practically useful way.

Mr. Warren: In order to carry out this fairly sophisticated process, is it really necessary to turn the Directorate into what appears to be a gaming saloon? The equipment chosen to obtain this random sample has been the roulette wheel; I think that there should have been a more scientific approach.

Mr. Jeffers: There are many ways of obtaining random numbers, for example by the use of special tables. The use of pocket roulette wheels was intended as a very simple method of obtaining random numbers so as to make the job interesting to the interpreters. It is doubtful whether such a series would be strictly random, but it might be near enough, provided that certain precautions were taken about where to start each day, and so on.

Mr. Warren: I'm sorry to pursue this theme. We have a small roulette wheel at home which I asked my daughters to spin and the results were far from random. Would this not apply to the small roulette wheel that you tried for this purpose. Unless you get a really well-balanced wheel that you could use in a gaming salon, would you obtain a random sample?

Mr. Jeffers: I have used small roulette wheels in class demonstrations fairly extensively, and I have seldom encountered one that was seriously biased, so I would prefer the use of such a wheel to the last column of 13-figure tables. As an alternative, the last digit of the numbers in the telephone directory is very nearly random.

Mr. Collins: I am very interested in Mr. Bawden's approach to his work. We have been concerned with studies of air photography for about six years now at the University of Leeds and I must say, in passing, that I fully agree with the Chairman when he says that air photo-interpretation ought to be included within photogrammetry. I have found over the last six years that the amount of strictly photogrammetric work has only increased slowly but that the air photo-interpretation work has increased enormously.

We have recently completed a pilot study in the West Indies. This is a very detailed study which we have approached in a completely different way to that suggested by Mr. Bawden. It seems to me that there will be different approaches according (a) to the source material available and (b) to the scale of photography. I would like to emphasise what Mr. Greenwood has said about achieving the maximum amount of detailed interpretation from the air photographs. In all our air photo-interpretation studies, whether concerned with geology, soils, land-use, or population forecasting, we first send the student into the field to build up a key so that there is no question of him not knowing 90 per cent of what is on the photograph when he returns. In this way the field work is done, and experience built up, prior to the photo-interpretation.

Mr. Bawden: May I ask one supplementary question? At what scale are you working?

Mr. Collins: In one particular land-use study it was 1 : 12,500, and we identified twenty-one different types of land-use after the field-work study.

Mr. Bawden: I was talking specifically of reconnaissance, using photography at scales smaller than 1 : 30,000. I prefer even smaller scales, so that larger areas can be covered. Scale appears to be the basic factor in accounting for the different approach. By completing field work as the last step in the process, we reach the field with a draft land system map already prepared, and we are armed with it and a series of questions designed to test the validity of the map.

Mr. Collins: As I said earlier, I think there is a need for a different approach and technique according to whether you are engaged in reconnaissance work, as you are, or in detailed analysis of a comparatively small area.

Mr. Bawden: Yes, I think the essential difference is that in your position, you are dealing with a much larger scale, a smaller area and more detail.

Mr. Norman: I should like to support Mr. Bawden's views concerning photo "keys". After a number of years of photo-geological work I have become convinced that the number of variables affecting the appearance of different rock types make it impossible to be certain that one is dealing with the same rock even a short distance away. A good example is to be found in a paper given to the Institution of Mining and Metallurgy (*Trans. I.M.M.*, 70 (9), 1960–1) by Dr. J. A. E. Allum of the Directorate of Overseas Geological Surveys. One illustration is of a stereoscopic pair of air photographs of a granite mass that stands up well above the surrounding country, with prominent lineations, due to fractures, giving it the distinctive appearance of a very hard rock resisting erosion. Next to this illustration is another pair of photographs of granite, but in this case portraying a feature depressed in the ground appearing as relatively soft material; yet it is only 8 miles away and as far as one can tell, it occurs in the same type of environment. I cannot help feeling that it is too facile an assumption to think that natural features can be understood from air photographs in every instance, merely from a simple key which has been prepared after one or two visits to the field.

I should like to put some questions to Mr. Jeffers. As far as I understand, the random sampling is done photograph by photograph; but how could this be satisfactory for a whole area when the photographs are not necessarily properly oriented relative to each other? I expect a number of those present have had the experience of finding photographs where one flight line crosses or lies on top of another due to an error of navigation. Would it not be better to sample on a predetermined grid designed to cover the whole region systematically?

What was the reason for choosing the "portable" punched card in preference to a "mark-sensing" card which can be marked by pencil during the actual data collection?

Have you considered the possiblity of automatic processing? I.B.M. have been conducting experiments in digitising air photographs. I gather they record sixteen tonal levels. Having achieved this, I would have thought that with a computer one could start calculating slopes, instructing it to recognise tree shapes, measure tree heights, work out the significance of tonal patterns and drainage distribution, and even analyse some land forms. I would have thought to a certain extent, a lot of the work done by an interpreter could, in theory, be automated. In practice, I would hate to have to use up all the available statisticians to programme the computer!

Mr. Jeffers: The method that is being used in the present surveys is two stage-sampling. There are some theoretical advantages in the use of this method, and quite a number of practical advantages, and we think it is preferable to laying down a grid of sampling points. For one thing, we obtain a valid estimate of the sampling error, and the amount of work involved in the sampling is proportional to the precision of the estimates that are required. We are also avoiding any possibility of having the grid coinciding with catenary effects on the ground.

We rejected mark-sensing as a method of recording. It is, for one thing, relatively expensive, and less reliable than the reading of Port-a-Punch cards. Mark-sensing also places severe limitations on the amount of information that can be recorded on one card.

Finally, I personally believe that direct pattern recognition from aerial photographs will be available within about five years. It is not, however, a practical proposition at the present time, and in this talk I have been careful to describe only those techniques which are readily available now.

Mr. Mott (*Chairman*): I think this has been a most stimulating discussion and I regret having to bring it to an end. It has shown the tremendous amount of interest which exists in this subject and emphasises the need for more papers and discussions on specialist forms of interpretation. While there already exists a great deal of available knowledge, there is still much to be done in the study of air photography as an aid to land-use analysis and the accompanying problems of regional development, as well as in many other disciplines.

I was a little surprised that no mention has been made of the use of colour film. There can be little doubt that these new materials (both colour and false colour) provide a significant break-through in the field of photo-interpretation.

I feel sure that all will wish to join me in thanking our two speakers for a most interesting contribution to the interpretative aspect of photogrammetry. It is to be hoped that the success of tonight's discussion will encourage other experts in the special sciences, who have made use of photo-interpretation techniques, to come forward and give us the benefit of their experience.