14th Congress of the International Society of Photogrammetry

Hamburg 1980

Commission VII Interpretation of Data

Working Group VII/3 Environmental Monitoring:
Interpretation of Urban Areas

Drs. V.F.L. Pollé

Senior Lecturer ITC - URBAN SURVEY

Invited Paper

The size of the net residential area on airphotos as input for population and housing estimates in large cities from developing countries.

Abstract

The technique of measuring the size of the net residential area is an alternative to counting houses on airphotos. It is explained why this alternative is useful in the situation of mass housing in the large cities of developing countries. The choice of a particular definition of net residential area, suitable for airphoto-interpretation, is analysed for its methodological consequences.
Experiments with this technique are analysed on two aspects. Firstly, in terms of interpreter behaviour, interpreter ability, training requirements, and accuracy that can be reached. Secondly, in terms of applicability in surveys for estimating population sizes and housing stocks.

International Institute for Aerial Survey and Earth Sciences - ITC,

P.O. Box 6, 7500 AA Enschede, The Netherlands, 053 - 320330.

Introduction

Research on the production of quantitative data on housing and population with the help of aerial photographs has been strongly influenced by the wish to produce data as accurate as those from the census of population and housing. Planners and managers of cities certainly need data on population and housing. Their first priority is however not so much accuracy as well up-to-date information. And their complaint in the case of developing countries is that the data are not reliable. Another complaint is that the areas for which aggregated data are available do often not coincide with planning areas. A lot of effort has to be made by them to convert the data into estimates for these planning areas. Planners, working in developing countries, report therefore often that they have produced their own data using airphotos complemented by fieldwork. The advantages are clear:

- the information is up-to-date; it is astonishing how often airphoto coverage of recent date is available, or can be made available,
- the information is reliable; the data are produced under the planners control and reliability checks can be made,
- the data areas are suiting the planners needs; the user determines his own areas prior to the measurements, which means an enormous saving in time and cost.

The planners face however a number of problems when using airphotos:

- they do not know in advance what the best method is; so far there is no generally accepted best method; a lot of time is spent by the individual planner to devise his own interpretation and measurement procedure,
- they underestimate training requirements; interpretation and measurements are time consuming and the work is delegated to assistants; but the planner does not know how much and what kind of training is needed in order to obtain relevant and reliable data,
- the planner also wants to know how accurate the data will be; accuracy testing is sofar strongly biased towards western (planned) housing types and residential lay-outs; for more irregular housing areas no test results are available.

This paper is meant to help solving these problems by analysing one possible technique: the measurement of the size of the net residential area. (See also C.A. de Bruijn et al., 1976)

Area measurement and unit counting as alternative techniques

Two alternative techniques are available when data on population and housing are collected with aerial photographs.
One can count the houses or dwellings in an area. These data on housing are multiplied with an occupancy rate (people per house) to obtain population data.
The alternative is the measurement of areas: the urban area, the gross residential area (as on land use maps) or the net residential area (as described in this paper). These area data are multiplied with the housing density or with the population density to obtain data on housing and population.
For many types of residential area the houses are visible on the airphoto and can be counted in sample areas to obtain the housing density. For population data however some form of counting in the field has to be done. In this respect require the two techniques the same amount of fieldwork. The differences ly in the kind of photo interpretation and the amount of work in interpretation.
For the technique of unit counting one must be able to define the unit. This is no great problem in the USA and Western Europe, and in other cities with the same style of housing. In developing countries we find the colonial cities with their european quarters and the new housing projects (serie built housing). With the recent strong urbanisation in these countries this type of housing becomes an ever smaller proportion of the total housing area. Unplanned, irregular lay outs and makeshift housing is growing much faster. In some of these areas the houses can still be counted on airphotos (e.g. in Ankara and Tehran); in others it is difficult to distinguish between the main house and secondary buildings like kitchens, barns etc. (e.g. in Cape Coast and Paramaribo).
For this type of residential area it is more suitable to use the area approach. Especially when one realises that with the unit counting technique all houses in the area have to be interpreted seperately. The area approach allows a more general interpretation. Time consuming detailed interpretation can be limited.
In the humid tropics with an abundance of trees in the medium and low density housing areas (e.g. in Yogyakarta) the area approach is the only feasible technique.

The net residential area

The chosen definition of the area that should be measured on airphotos has a great influence on the amount of interpretation work, the amount of fieldwork and the suitability of the data as indicator for the size of the population and the number of houses. The amount of work increases in this order: urban area, gross residential area and net residential area; but also the suitability as indicator. In each case the definition should be chosen so that fieldwork is minimised. Detailed fieldwork in the city centre and reconnaisance fieldwork in the other parts of the city.

For the experiments we decided to take the most suitable indicator: the net residential area defined as follows:

-- all land use is classified as residential, except when it is clearly identifiable on aerial photographs as non-residential; classified as non-residential will be: airfields, parks, university compounds, cemeteries, industrial areas, transportation (railroads, harbour, bus stations etc.), roads and streets, commercial land use, governmental buildings, vacant land, and so on. A walled-in terrain without building: non-residential. A house under construction, i.e. no roof, no garden: non-residential.

The difficulty in interpretation is found at the transition zone between residential and non-residential. Some buildings in an area are just too large to be a house IN THAT AREA. The main rule here is that larger buildings along a main street are not considered to be residential; mostly they contain shops, work places, repair places, garages and offices. Evidence is often that there is no garden or a garden too small for a large house. -- (1)

The uncertainty in the definition lies in the formulation: "except when it is clearly identifiable as non-residential" . The big non-residential elements are recognisable even on small scale photography. But the smaller non-residential uses only at large scale photography. However, the difference in interpretation possibilities between the scales 1 : 5,000 and 1 : 10,000 (which are mostly used in cities) are not expected to be of much importance. (2)

A more important factor will be proficiency in photo interpretation. Being able to "identify" is highly depending on the frame of reference

of the interpreter and on the amount of previous experience. The problem is only partly remedied by the (oraly given) explanation: "in case of doubt: classify as residential, because it is for you not clearly identifiable as non-residential".
That means that the definition is inclusive; where the land use is not clear it is included in the class residential.
Because of these considerations the following research questions were chosen for the experiments:

- When this definition is applied, are then the data produced by different interpreters for the same area equal ?
- Which training procedures are advisable ?

The experiments

In order to be able to judge with a minimum of staff time the interpretation results the technique of the systematic dotgrid was used. For each dot on the airphoto the interpreter had to decide: residential or non-residential. With this technique a great number of individual yes/no decisions are made. These are easily checked and discussed when wrong. It is possible with this technique to make and instruct a set of decision rules for boundary cases and to apply these strictly.
The experiments made, can be subdivided as follows:

- the pilot experiment: the written instructions are minimal, procedures have not yet been streamlined, the feedback is still haphazard,
- the repeated experiments: the written instructions are used without changes in succesive experiments, procedures have been streamlined to ensure the maximum of feedback for training purposes,
- the parallel experiment: written instructions minimal and no feedback.

For the pilot experiment and for the repeated experiments the interpreters were participants of the ITC-URBAN SURVEY course US 1. They had minimally a bachelor degree in civil engineering, townplanning, architecture etc. The experiments were held after they had made at least the basic exercises during two months. Their cultural background was however very diverse and no one had local knowledge of the city used for the experiment.
For the parallel experiment university teachers in social geography interpreted their own city. So they had local knowledge, but no previous interpretation experience.

The results of the experiments

1. The pilot experiment

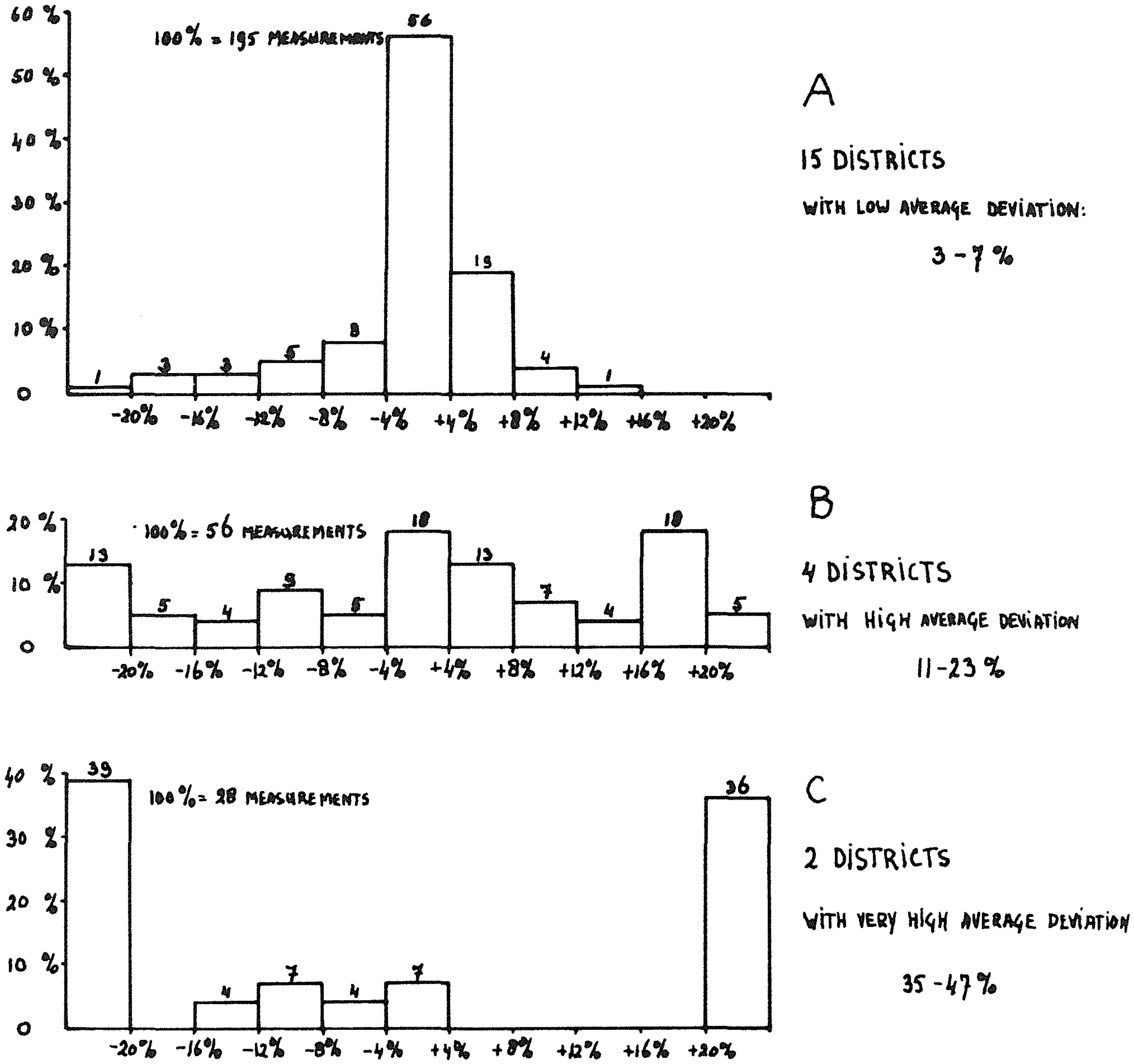


Figure 1. Measurements of the size of the net residential area in 21 districts, by 14 interpreters each. Measurements with dotgrids. Total area 200 ha, covered by 5000 dots. Total number of interpretation decisions 14 x 5,000 = 70,000. Frequency distribution of the deviations in percent from the average for each district from 14 interpreters. (3)
A. outer districts B. city-centre-fringe districts
C. city-centre districts.

The experiment shows clearly (see figure 1, page 5) that in the city centre and its fringe area, the interpreters become so uncertain that the data produced become highly unreliable. For the outer districts (in most cities the location of the fast growing residential areas) the results are very satisfactory. Average deviations are there between 3 % and 7 %.
The high deviations are concentrated on a few interpreters. They need either more training or they have no aptitude for the work.
There is a slight skewness in the frequency distribution that indicates an attitude of excluding, contrary to the inclusive character of the definition. In later experiments this character was more stressed, and this skewness was never repeated.
These results were discussed with the interpreters. After that another 136 districts were interpreted and measured each two times. The average of each two measurements was used as standard and the deviations computed. The results can be seen in figure 2 below.

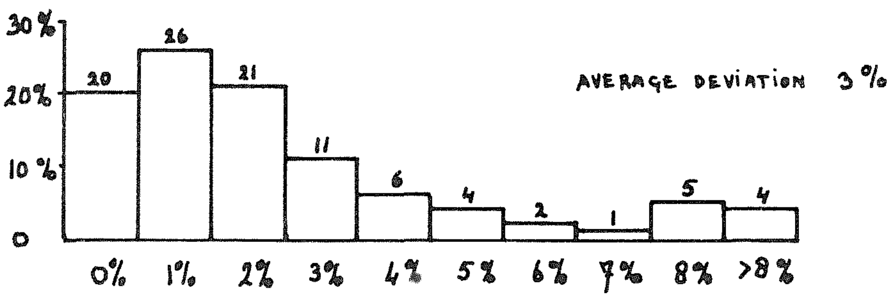


Figure 2. Measurements of the net residential area in 136 districts in 7 different sectors of the city. Each district measured twice. Frequency distribution of the deviations from the average of two measurements in percent.

One may conclude from this experiment that double measurements for the sake of computing the average, are hardly worthwhile. The average of two measurements will on the average not more deviate than 3 % from the individual measurement. When one takes into consideration that the interpreters without aptitude were not removed, and that the high deviations were again found more often with them, it becomes clear that selection of suitable interpreters pays more than double measurements.

2. The repeated experiments

The first question posed was: how difficult is the interpretation, what is the percentage of decisions causing difficulties ?

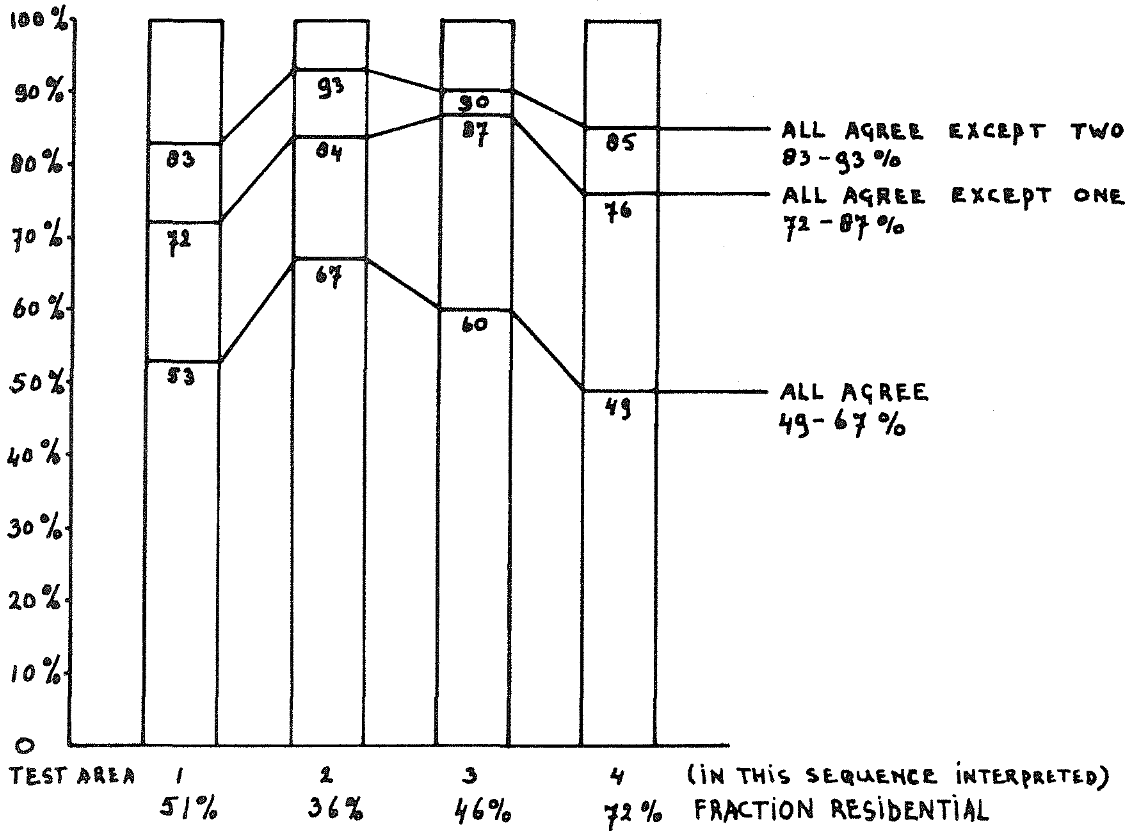


Figure 3. Agreement between interpreters on the classification of the individual dots as residential or not-residential.
Based on 7200 interpretation decisions by 9 interpreters.

From figure 3 above one may conclude that for about 1/2 to 2/3 of all interpretation decisions there is no difficulty. All interpreters agree on the interpretation.

For 1/4 to 1/3 of the decisions only a minority (one or two interpreters) seem to have a difficulty.

Only between 7 % and 17 % of all decisions are difficult for a third or more of the interpreters.

For training purposes the groups have therefore been divided in teams of two. They make independently their interpretation, and compare their results dot by dot.

Where they find differences in interpretation, they look again at the airphoto and discuss what could be the right decision. They also try to find out the cause of the interpretation difference (the error made by one of them). Table 1, page 8 gives the result of these analyses.

Table '. Classification of errors made during interpretation of 5 test ares by 7 teams of two interpreters. Based on their own judgement.

DEF - definition	7 %	the definition of net residential area
DEL - delineation	5 %	the boundaries between land uses
POS - position	26 %	the position of the dot and the land use
INT - interpretation	28 %	the interpretation of the land use
MIS - mistake	22 %	no explanation of the error
interpreters do not come to an agreement		
EQA - equality	6 %	dot yes or no on boundary
EVI - evidence	6 %	land use yes or no residential
TOTAL	100 %	= 879 errors = 13 % of 7000 decisions.

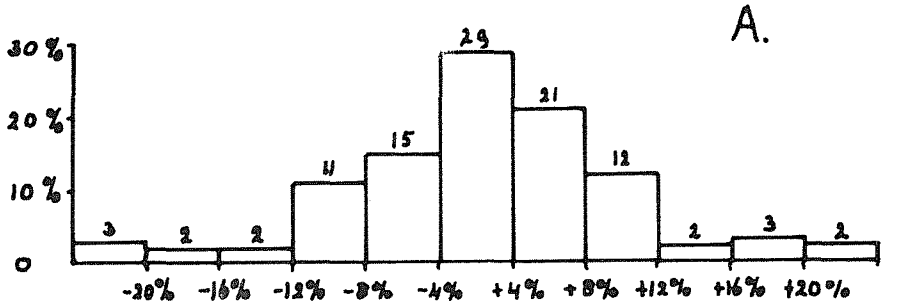
As the errors are spread over a number of causes and even the largest single cause (interpretation of the land use) occurs at only 3.5 % of all decisions, it will be difficult to device procedures to remove these errors. They will remain a "white noice" in the data produced. But the comparison (as different from just taking the average) of the two interpretations and re-interpretation does improve the results as can be seen in figure 4, page 9.

Of all measurements 76 % are falling between + 8 % and - 8 %; this was 65 % before the comparison. And errors larger than 16 % (bad interpreters !) are completely removed.

A seperate comparison was made with the standard interpretation prepared by the staff. The size of the net residential area as measured by the interpreters differed on the average 6 % before pairwise comparison and 5 % after pairwise comparison from the real value. But the number of wrong interpretations was on the average 11 %. About half of the errors cancel each other out, the other half is causing a real deviation of the data.

The number of wrong interpretations differed from area to area and from group to group. The lowest value observed was 6 % wrong and the highest 17 % wrong. The average was 11 % over all repeated experiments.

The conclusion must be that pairwise comparison by the interpreters removes part of the errors and is as such a good training method. But comparison with a standard interpretation remains a better instrument. Part of the errors are not detected by pairwise comparison.



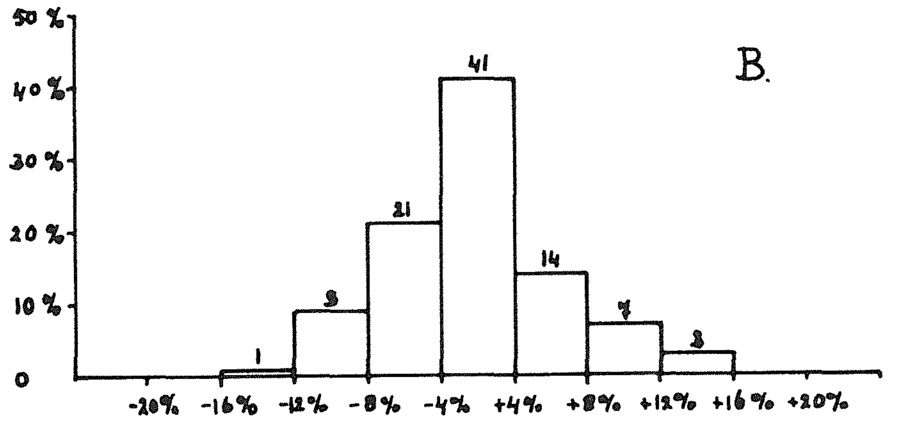


Figure 4. Measurements of the size of the residential area in 5 test areas by 7 teams of two interpreters.
Frequency distribution of the deviation in percent from the average of 14 interpretations for each test area. (3)
Total number of interpretation decisions 14,000.
A. Before pairwise comparison of the interpretations.
B. After pairwise comparison and discussion of the differences between the interpretations by the members of the team.

After the training on the test areas was finished the interpreters were asked to produce data on 9 city districts. Every district was measured independently by 14 interpreters. Then the results were again compaired pairwise and differences re-interpreted.
The result of this experiment is found in table 2, page 10.
The group average for the number of dots classified as residential is hardly influenced by the pairwise comparison and re-interpretation of part of the dots. This indicates that the deviations from the average have a random character: they cancel each other out.
But the group's standarddeviation is reduced by 2/3: apparently does re-interpretation reduce the overall size of the deviations of individual interpreters.

Table 2. Measurements of the size of the net residential area with a dotgrid in nine districts by 14 interpreters. The interpretations are independent, but compaired pairwise after completion and improved through re-interpretation of found differences.

	before comparison		after comparison	
District	average (3) (dots)	standard-deviation (%)	average (dots)	standard-deviation (%)
1	33	9 %	34	7 %
2	87	5 %	86	2 %
3	71	3 %	71	3 %
4	95	5 %	94	3 %
5	66	4 %	66	3 %
6	65	10 %	66	10 %
7	205	4 %	203	3 %
8	65	5 %	64	4 %
9	79	6 %	79	2 %
Total	766	3 %	763	2 %

Another tendency can be read from table 2. If the number of decisions increases, e.g. by aggregation of districts, than the standarddeviation becomes lower. Apparently the effect of errors cancelling each other out.

The whole procedure has also the effect of comforting the interpreters. They can make their first interpretation without much mental strain. Gross errors will be detected in the comparison and a correction can than be made. It can however be expected that for a more experienced interpreter this is hardly worthwhile. The procedure can be limited to the training period.

3. The parallel experiment

In the parallel experiment about 3000 interpretation decisions were made by inexperienced interpreters with local knowledge of the town. It was direct production of data; no training sessions with feedback and no pairwise comparisons. Only a comparison with a standard interpretation. About 1900 dots were classified as net residential area.

Although the districts were larger (about two times the amount of dots) than those from table 2, the deviations instead of smaller were larger. The average deviation was 18 %, against 5 % in table 2. Aggregated data for the whole area resulted in a deviation of only 2 %. Again the errors cancelled each other out. Individual results were up to 56 % wrong. The main cause was misunderstanding of the definition of net residential area. It proves that production of data without training sessions is giving unreliable data.

Applicability of the technique

The usefulness of data on the size of the net residential area for the production of data on housing and population must be judged in the light of the sensitivity of the models in which these data are to be used.

Planning models contain normally **sets of ratios** whose values can vary greatly in reality, but are given a limited number of arbitrarily chosen values during the computations. For example, the amount of water to be distributed in the city depends not only on its number of inhabitants. The distribution method, the wealth of the people and their habits are determining the waterconsumption per head. This ratio can vary greatly from 20 liter per head per day to over 200 liter per head per day. This difference (1:10) is large compared to an accuracy of 10 % in the estimate of the residential area. Approximate data are in these models often sufficient.

Considering this one may conclude that the accuracy reached with the measurement of the size of the net residential area (5 % or better, provided proper training of the interpreters) makes it a useful technique for the planner.

Conclusions

1. The technique of measuring the size of the net residential area on airphotos can be applied by planners for the production of data on population and housing. The accuracy of the technique is sufficient.
2. The accuracy of the data produced by photo interpretation can be 5 % or better, provided a proper training of the interpreters.
3. Training of interpreters should serve two aims:
   - to make sure that the interpreter understands the definition and the procedure, and applies this knowledge consistently
   - to be able to remove from the group interpreters with insufficient

aptitude for airphoto interpretation.

4. In the training period is working in teams of two advisable. The interpreters should make independent interpretations and compare these afterwards. Where differences occur re-interpretation leads to improvement of the data.
5. A standard interpretation should be available to make further checks and to remove errors that still remain after pairwise comparison.
6. Without proper training errors of over 50 % may occur in the data produced.
7. For developing countries conclusion 2 (on the accuracy) is only valid for interpreters with sufficient schooling (minimal bachelor degree). No experiments have been made with interpreters of technician level.
8. A general training in the interpretation of urban areas prior to the specific training for these measurements seems advisable.
9. The dotgrid is most suitable for this type of training because there is a clear right/wrong, which makes checking of the interpretation feasible.
10. The technique is not applicable in the central parts of the town (the city centre and its fringe) without elaborate fieldwork.

Notes

(1) For the experiments airphotos of Tehran were used. The definition is partly based on observations made during fieldwork there. When used in other cities it may be necessary to make small adjustements to suit local conditions.

(2) When satellite data with pixelsize of 10 m become available, it is necessary to reconsider this point. The same applies for monitoring urban change with very small scale photography, i.e. 1 : 100,000.

(3) The group average does not deviate significantly from the value of the standard interpretation. (See page 8.)

CENDATE - LITERATURE on population estimates and measurements of residential areas or urban areas

The majority of the publications listed here are based on research in industrialized countries, with an emphasis on the U.S.A. The publications based on material from developing countries are marked with an asterix (*).

*ALLAN, J.A. and ALEMAYEHU, Rural population estimates from air photographs: an example from Wolamo, Ethiopia. In: ITC-JOURNAL 1975 - 1 pp. 85-100

ANDERSON, D.E. and Ph.N. ANDERSON, Population estimates by humans and machines. In: Photogrammetric Engineering Vol. 39, no. 2, February 1973, pp. 147-154

*BASSIAKOU, Miss P. and A. REPOULIS, Residential capacity and growth in Teheran. In: Case Studies Vol. I, URBAN SURVEYS, ITC, Enschede, 1974

*BRUSH, J.E., Spatial patterns of population in Indian cities, 1968. In: The city in the third world, ed. D.J. Dwyer, 1974

BURAKOM, Miss S., KARSOM, J.M. KYUKA and A.P. RAJAN, Densities in some residential areas. In: Enschede field work, Urban Area Studies, ITC, Delft, 1971

COLLINS, W.G. and A.H.A. EL-BEIK, Population census with the aid of aerial photographs: an experiment in the city of Leeds. In: Photogrammetric Record, 7(37) April 1971, pp. 16-26

DAVIES, S., A. TUYAHOV and R.K. HOLZ, Use of remote sensing to determine urban poverty neighbourhoods. In: The surveillant science, Holz, R.K., editor, Boston, 1973, pp. 386-390

*DAYAL, H.H and B.A. KHAIRZADA, The first national demographic survey in Afghanistan: the role played by airphotos and photo-counting techniques. In: ITC-JOURNAL 1976-1.

*EYRE, L.A., B. ADOLPHUS, M. AMIEL, Census analysis and population studies. In: Photogrammetric Engineering, Vol. 36 no. 5, May 1970, pp. 460-466

*EYRE, L.A., Shanghai - world's second city? In: Professional Geographer, 23 no. 1, January 1971, pp. 28-30

GREEN, N.E., Aerial photographic analysis of residential neighbourhoods: an evaluation of data accuracy. In: Social Forces, December 1956, Vol. 35, pp. 142-147

GREEN, N.E., Scale analysis of urban structures: a study of Birmingham, Alabama. In: American Sociological Review, 1956, Vol. 21, pp. 8-13

GREEN, N.E., Aerial photographic interpretation and the social structure of the city. In: Photogrammetric Engineering, Vol. 23, 1957, pp. 89-96. With a review by M.M. Witenstein and an answer by N.E. Green.

GREEN, N.E. and R.B. MONIER, Aerial photographic interpretation and the human ecology of the city. In: Photogrammetric Engineering, vol. 25, 1959, pp. 770-773

HENDERSON, F.M. and J.J. UTANO, Assessing general urban socio-economic conditions with conventional air photography. In: Photogrammetria, 31, September 1975, pp. 81-89

HERBERT, D.T. and D.J. EVANS, Urban sub-areas as sampling frameworks for social survey. In: Town Planning Review, Volume 45 no. 2 (April 1974), pp. 171-188

* HERNÁNDEZ, G. - Villalobos, La fotointerpretación en la investigación social. In: Memorias del primer congreso panamericano y tercero nacional de fotogrammetria, fotointerpretación y geodesia, Mexico, julio 1974, pp. 1238-1259

HIGGS, G.K., Multispectral approach to urban neighbourhood analysis and delineation. In: Proceedings of the Fall Convention of the American Society of Photogrammetry, October 1975, Phoenix, Arizona, USA, pp. 444-465

HOLZ, R.K., D.L. HUFF and R.C. MAYFIELD, Urban spatial structure based on remote sensing imagery. In: Proceedings of the sixth international symposium on remote sensing of the environment, Vol. II, October 1969, pp. 819-830

HOWLETT, B.E., Determining urban growth and change from aerial photograph comparisons, Highway research record number 19, 1963

JOHNSTON, R.J., Urban residential pattern, an introductory review, LONDON, 1971

KRAUS, S.P., L.W. SENGER and J.M. RYERSON, Estimating population from photographically determined residential land-use types. In: Remote sensing of the environment, 3, 1974, pp. 35-42

LINDGREN, D.T., Dwelling unit estimation with color-ir photos. In: Photogrammetric Engineering, Vol.37, April 1971, pp. 373-377

McCOY, R.M. and E.D. METIVIER, House density vs. socioeconomic conditions. In: Photogrammetric Engineering, vol. 39 no. 1, January 1973, pp. 43-47

MONIER, R.B. and N.E. GREEN, Aerial photographic interpretation and the human geography of the city. In: The professional geographer, 9, no. 5, September 1957, pp. 2-5

MONIER, R.B., Verification of aerial photographic analysis of urban residential structures: a study of Rochester, New York,
Air Force personnel & training research centre, Development report, January 1958, AFPTRC-TN-58-4, ASTIA document no. AD 152 113

OGROSKY, Ch.E., Population estimates from satellite imagery. In: Photogrammetric Engineering and Remote Sensing, vol. 41, no. 6, June 1975, pp. 707-712

SHIN-YI HSU, Population estimation. In: Photogrammetric Engineering, vol. 37 no. 5, May 1971, pp. 449-454

SIGNALEMENT, De luchtfoto als quantitatieve informatiebron, Chr.v. Welsenes. In: Tijdschrift voor Sociale en Economische Geografie, Sept-Oct. 1971, pp. 318-320

SILBERMAN, L., Sociogrammetry. In: Photogrammetric Engineering, vol. 25, 1959.

THOMPSON, D., Small area population estimation using land-use data derived from high altitude aircraft photography. In: Proceedings of the Fall Convention of the American Society of Photogrammetry, October 1975, Phoenix, Arizona, USA, pp. 673-696

TOBLER, W.R., Satellite confirmation of settlement size coefficients. In: Area 1969 (3)

WALKER, R.L., Urban sub-areas as sampling frameworks, a further development. In: Town Planning Review, vol. 46 no. 2, April 1975, pp. 201-214

WITENSTEIN, M.M., Photo sociometrics - the application of aerial photography to urban administration and planning problems. In: Photogrammetric Engineering, 1954, pp. 419-427

WITENSTEIN M.M., Uses and limitations of aerial photography in urban analysis and planning. In: Photogrammetric Engineering, 1955, pp. 566-571

WITENSTEIN, M.M., A report on application of aerial photography to urban land-use inventory, analysis and planning. In: Photogrammetric Engineering, vol. 22, 1956, pp. 656-663

WRAY, J.R., Census Cities project and atlas of urban and regional change, Reprinted from proceedings of NASA third Annual Earth Resources Program Review, Manned Spacecraft Centre, Houston, Texas, December 1970, Vol. 1, Geology and Geography, section 2, pp. 1-16

* D'ALLEUX, EINSELE and H.J. KARPE, Metropolitan Lagos, Water-Supply Demand Analyses, preliminary report, GKW Consulting Engineers, Dortmund, 1975.

* HINDERINK, J. and J. STERKENBURG, Anatomy of an African town, a socio-economic study of Cape Coast, Ghana, Utrecht, 1975, Geographical Institute, Heidelberglaan 2, Utrecht, page 18 - 24.

* MASSER, Ian, Planning with incomplete data, population growth and metropolitan planning in the third world, Town Planning Review, Vol 45 no.2, page 157 - 169.

* BRUIJN, C.A. de, W.G.L. de HAAS, P. HOFSTEE, A.B.M. HIJL and V.F.L. POLLé, Urban survey with aerial photography: a time for practice, IN: ITC Journal, 1976 - 2, page 190 - 197, data on urban population and housing.