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ANALYTICAL PLOTTER FROM THE USER'S PERSPECTIVE

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1. Introduction

The recent availability of analytical plotters has created the need for their critical evaluation from the user's point of view. This need does not only emerge from the high investment for the purchase, but also from the new potentials, limitations and requirements of such equipment.

Thus the objective of this paper is to outline the problem area from the user's perspective, to structure it orderly and to reveal the criteria and procedure of evaluation.

The approach is a pragmatic one, based on principles of systems engineering. In order to make it attractive for practice - abstract theoretical considerations will be bypassed, and to make it efficient in application - extensive practical experiences are not a prerequisite.

A systems' approach applied from the users' perspective does not necessarily correspond with that of the system (AP) developers, though both may overlap considerably. The manufacturers' approach is essentially an inductive one, dominated by the overall state-of-the-art in the specific field and by the market situation. The users' approach has, on the contrary, an analytical accent, is dominated by the specific organisational environment, and is application oriented. The sequence of analysis is often from the final information products towards the initial inputs, and it includes the equipment software and operational procedures.

The users' views may be classified into the overall (or general) and the specific (or organisational) ones (Fig. 1).

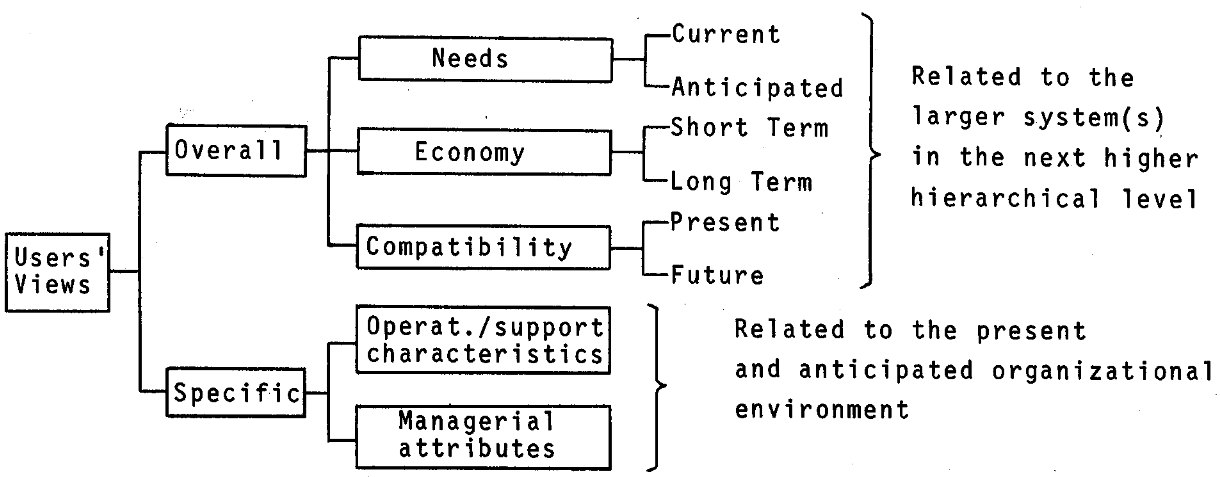

Fig. 1
Major Users' Views

These different aspects tend to establish the basis for identification of the evaluation criteria and subsequently for the collection of the pertinent information.

The potential users' incentives can be reviewed as follows:

i - Preliminary inquiry - to provide an overall idea about the new technology. It should be followed by a tentative, crude judgement of the feasibility both, from the viewpoint of the overall state of the art and in the light of the specific organisational environment.

ii - Inquiry prior to purchase - which is the most vital stage, including the following issues:
- identification of the needs
- collection of more detailed information
- evaluation and decision

iii - Purchase, covering the following main issues:
- installment and take-over tests
- training for operation and support
- initiation of operation

iv - Operation - concerning, in addition to the current production:
- optimisation of the procedures (accuracy, speed, operating ease)
- modifications of the software
- maintenance of the equipment

v - Potential extensions of the system, e.g.
- application to new problem areas
- attachment of additional subsystems, e.g. for automatic image processing
- integration into a larger photogrammetric/ cartographic system.

In addition to the information needed for evaluation, consideration will also be given to the procedure of evaluation itself. A comprehensive evaluation is a very involved and thus complex process. In order to make it practicable certain controlled simplifications and restrictions are necessary. These can be summarised by the following general guide lines:

i - suppress the less significant influencing factors and those on which information is not (yet) available

ii - bypass those factors which affect equally the values of all AP variants considered

iii - reject successively the clearly inferior variants.

Thus the evaluation procedure should be dynamic, in order to permit adaptations to the changing environment and upgrading according to new information and increasing insight in due time. With some modification, the evaluation system, outlined in this paper, is applicable to any man-made multi-function system.

The contents of the paper cover a synopsis of the evolution from analogue to digital equipment in photogrammetry, a structured generalised list of the AP system attributes and their inter-relations, a summary of the pertinent items of information for evaluation of the variants, an outline of the evaluation procedure itself, and finally some concluding remarks.

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2. From analogue to digital equipment

The following outline of a gradual integration of digital components in photogrammetric restitution systems tends to present a functional rather than a chronological view. The aim of this review is to illuminate a broader area, of which the analytical plotters (AP's) form an essential part. The evolution from 'analogue' to 'digital' has been affected by the following main factors:

- technological progress in- and availability of- the digital computers and their standard peripherals
- development of the high performing control electronics and servo-mechanisms
- decreasing cost of electronic equipment
- improved equipment intrinsic properties
- new operational and support characteristics
- established technology and available know how of the photogrammetric equipment manufacturers
- the users' willingness and ability to change to a new style of equipment and operation.

In the following diagrams the different stages of the evolution are reviewed. For easy interpretation these diagrams are presented in a simplified form.

Fig. 2 represents the simplest version, i.e. an analogue instrument with digital recording facility.

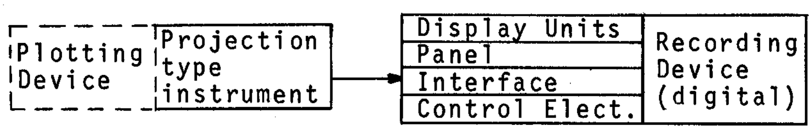

Fig. 2

A computer supported analogue stereoplotter with a uni-(or bi-) directional flow of information, and with extra peripheral units, is represented in fig. 3.

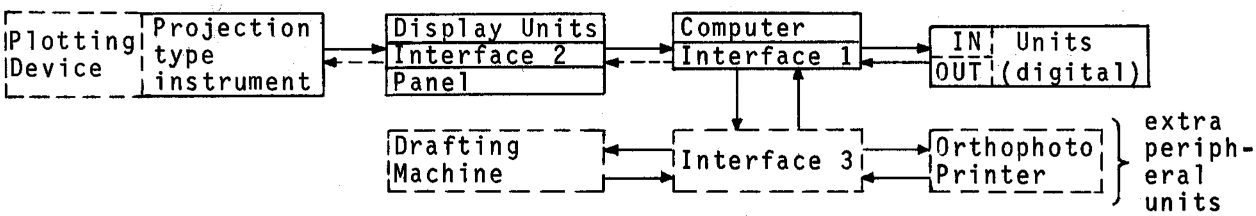

Fig. 3

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Fig. 4 is a symbolic representation of a typical hybrid system (i.e. embodying an incomplete projection system) with extra peripheral units.

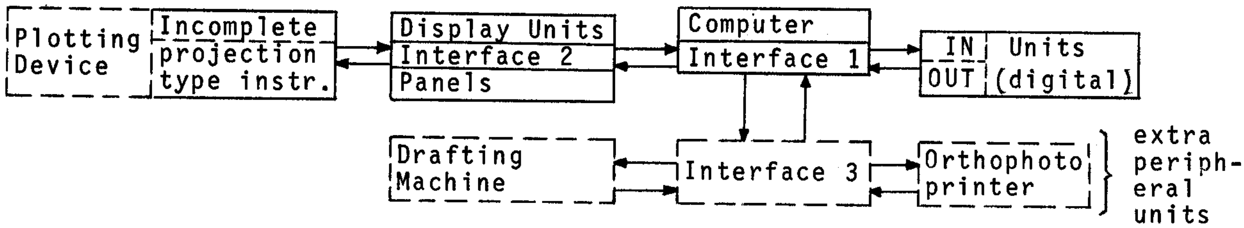

Fig. 4

In this version the computer supplements the function of the incomplete projection system.

The next diagram (fig. 5) represents a fully digital system, i.e., an up-to-date analytical plotter.

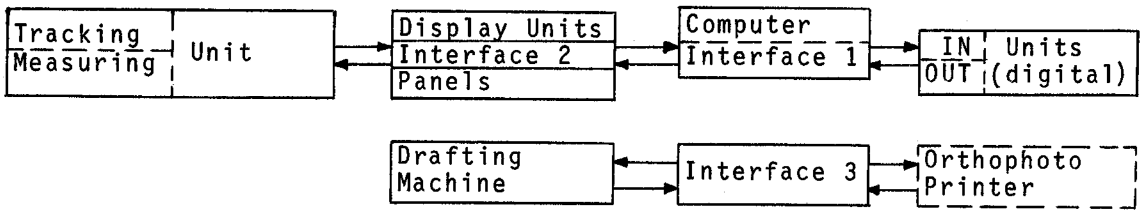

Fig. 5

In figures 4 and 5 the interfaces 2 and 3 can be physically combined.

A "digital projector" type of analytical plotter (under development), linked to a larger external computer (with its own peripherals), is represented in fig. 6.

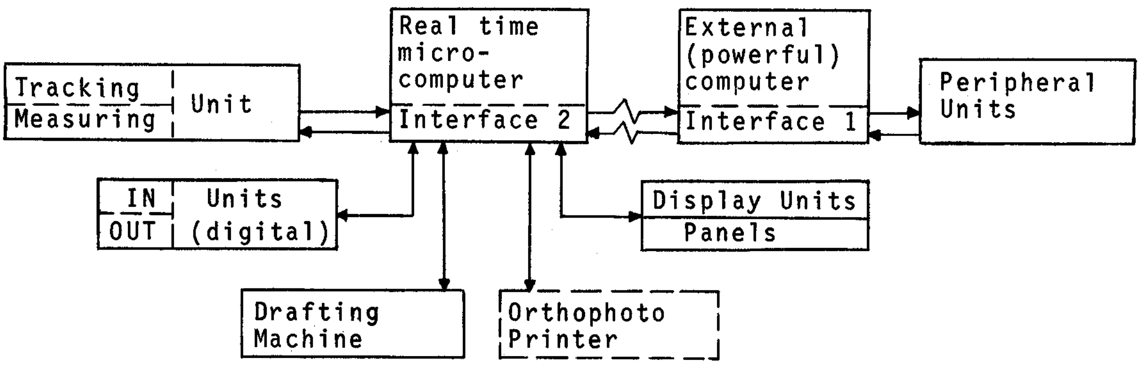

Fig. 6

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Fig. 7 illustrates an analytical plotter supplemented with analogue components for image processing.

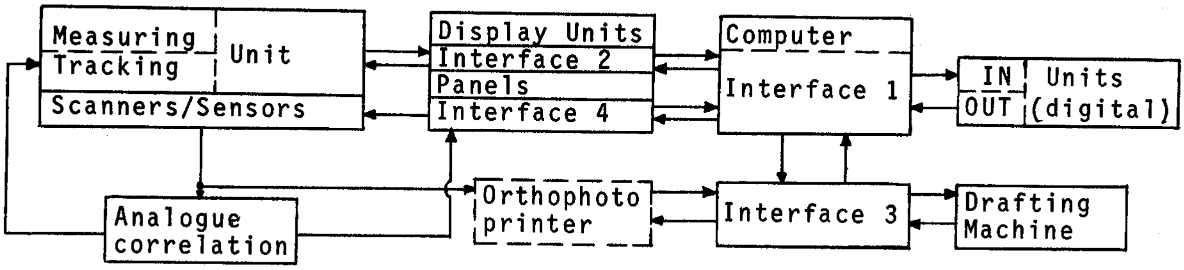

Fig. 7

An analytical plotter with digital image processing capability is represented in fig. 8. In figures 7 and 8 the interfaces 2 and 3 can be physically combined.

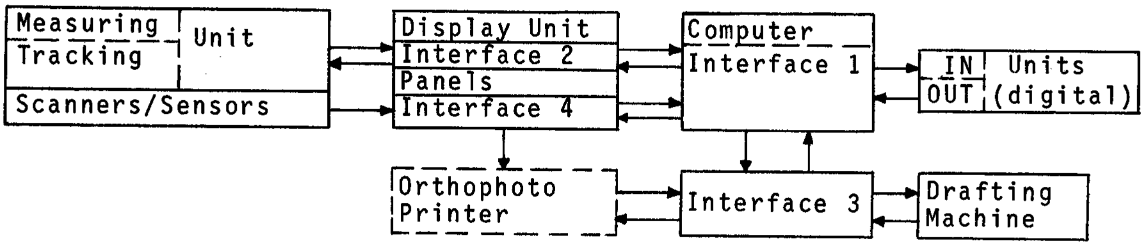

Fig. 8

All the equipment reviewed so far may operate either as single or as multiple systems.

Fig. 9 illustrates a photogrammetric/cartographic entity in which, amongst others, the analytical plotter capability is integrated.

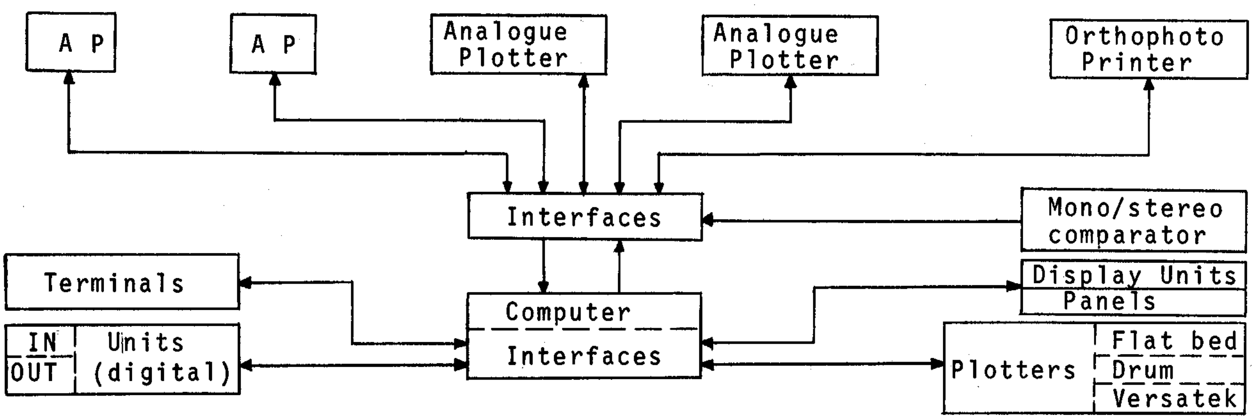

Fig. 9

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By examining the reviewed stages of evolution, the following trends can be extracted:

- increasing impact of digital techniques
- growing complexity of the systems
- gradual transition from small-size autonomous equipment to larger integrated systems
- increasing degree of automation

This development is inevitably leading to significant qualitative changes in the profession. A photogrammetrist is becoming increasingly involved in adapting and expanding his tools to the changing needs, and environments. This, however, has also serious consequences on the professional training and education.

Our further consideration will be restricted to the present analytical plotters. For the purpose of their evaluation it is appropriate to first review the different AP system attributes and to identify the significant influencing factors.

3. System attributes and influencing factors

The three basic categories of the system attributes, (i.e., hardware, software and procedures; fig. 10), are strongly interdependent, as are the three basic categories of the influencing factors, (i.e., intrinsic properties, operational and support characteristics, and managerial attributes). The 'attributes' and 'factors' are also mutually related.

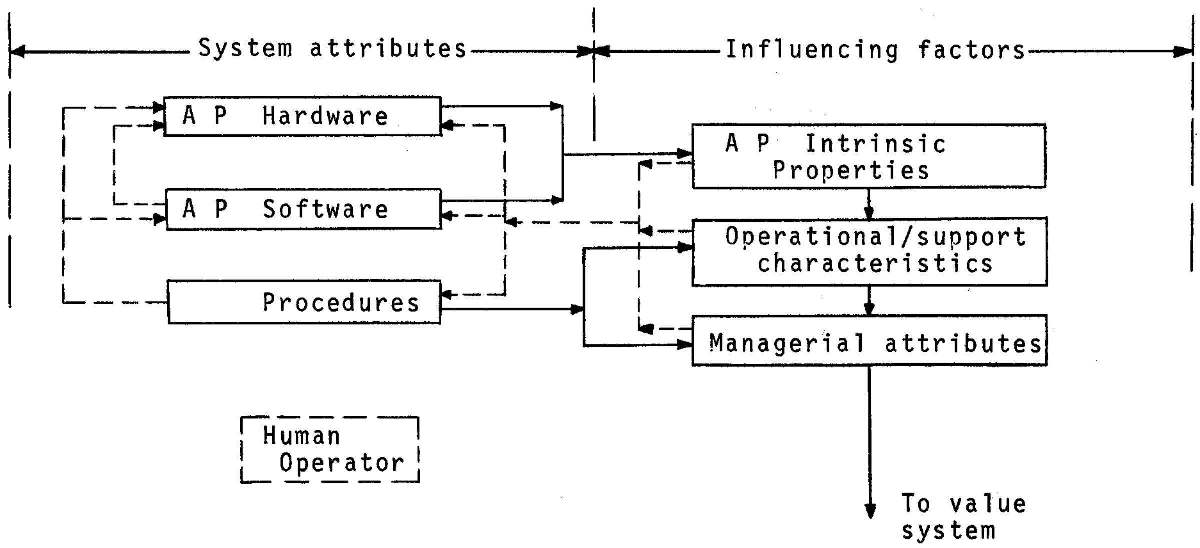

Fig. 10

Interrelations between 'attributes' and 'factors'

The solid lines indicate the casual relations in systems after being developed, whereas the dashed lines represent the feed back effects during the development stage. Thus, the software depends on the hardware, and the procedures are determined by both the hardware and software. The influencing factors are strongly affected by the system attributes. The operational and support characteristics are affected by the system intrinsic properties, and the managerial attributes depend on, both the intrinsic properties and the operational and support characteristics. The boxes in fig. 10 indicate the kind of information concerned and the solid lines show the (forward) sequence of identifying the different items of information. The resulting information represents the input for evaluation.

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As the representation in fig. 10 is very general and is, therefore, abstract, it seems appropriate to review the lists of the main attributes and the influencing factors.

1. List of system attributes

i. - Hardware

- Mechanical photogrammetric devices (photo stages, plotting device, other)
- Observation System (basic and auxiliary units)
- Electrical analogue devices
- Digital computer(s) (CPU, storage, special hardware)
- Interfaces (standard, dedicated)
- Control panels (standard, dedicated)
- Display units (alpha-numerical, graphical; standard, dedicated)
- I/O devices (standard, dedicated)

ii. - Software

- Operating system (monitor, utility programs)
- Photogrammetric basic software (calibration, orientation, correction programs; real-time manual operation-support programs; support programs for automatic operation)
- Photogrammetric application software (general service programs, support programs for nearly real-time operation, off-line programs)
- Unconventional (dedicated) application software (for non-conventional and short range images)

iii. - Procedures (operational)

- Preparation (of data, materials, equipment)
- Restitution (real-time, nearly real-time)
- Post-processing (off-line routines)

2. List of influencing factors

i. - Intrinsic properties

- Versatility (with regard to data, materials, ranges, capacity, etc.)
- Flexibility (concerning modularity, compatibility, and operational procedures)
- Performance (precision, resolution, time cycles, time responses, image quality, algorithms, etc.)
- Reliability (failure sources, protection, failure checking, etc.)
- Mobility (assembly/disassembly, packing, weight/size, transport)

ii. - Operational and support characteristics

- Ease in :
  - handling devices (i.e. equipment)
  - implementing procedures (in each operation, interactivity, operational instruction manuals)
- Support in :
  - maintenance (of hardware and software)
  - training (for operation and maintenance)

iii. - Managerial attributes

- Overall factors :
  - cost (of purchase, operation, support)
  - time (of operations, training, maintenance, life)
  - personnel (required for operation and support)
- Specific factors (emerging from internal organizational environment):
  - needs (current, anticipated, internal and external commitments)
  - financial state (budget, conditions of financing, specific circumstances)

- internal compatibility (established techniques and state of the equipment, etc.)
- personnel (existing, potential)
- support facilities (for hardware, software and training)

The above lists, in conjunction with the diagram presented in figure 10, provide a frame of reference, both for establishing the criteria for evaluation, and for on orderly collection of the pertinent information. The collection of information may proceed in the reverse sequence, i.e., from the managerial attributes backward, towards the software and hardware. This permits a more rational selection of the pertinent information.

4. Information for evaluation

According to the source of information a distinction can be made between the check lists, check-out processes, and the testing processes; the limits being fluid.

The check lists are supposed to cover all the pertinent information for the evaluation. In principle an evaluation could be based merely on information contained in the check lists.

The 'pertinence' of an information item is defined by its importance and tangibility (i.e., ability to quantify its merit) and by its sensitivity to the differences between the AP variants. I.e., if an item affects equally the values of all AP variants under consideration, it is not pertinent.

The sources of information for the check lists are the data supplied by the AP manufacturers and those reported by others, e.g., users, researchers, professional working groups, etc. As the total amount of information is extensive, the corresponding effort can be reduced by:

- identifying the contraints and excluding accordingly some of the AP variants,
- evaluating coarsely the remaining AP variants and excluding those which are evidently inferior.

Hence, only a few variants need be considered further for more detailed collection of information and subsequent fine evaluation. For practical application, however, it is convenient to subdivide the check lists into the 'overall' and 'specific' categories of factors. The following lists are presented in a generalised form.

1. Overall factors

- versatility (data, materials, ranges, means, capacity)
- flexibility (modularity, compatibility, operational procedures)
- cost (purchase, operation, support)
- performance (algorithms, precision, time, observation, displays)
- reliability (failure sources, failure checking, protection)
- software (OS, photogrammetric basic and application programs, unconventional application programs)
- ease and comfort (in using devices and implement procedures)
- support requirement (training, maintenance, mobility)

2. Specific (internal) factors

- needs (for projects and programs; present, anticipated)
- financial state (budget, conditions of financing, specific circumstances)
- compatibility (established technology, equipment, physical environment, etc.)
- personnel (for operation, support, supervision; available, potential)
- support facilities (training, maintenance)

The check-out procedures are needed for the extraction of only that information which should be physically verified. This is the case when the available documents are insufficient or/and when the potential user considers it necessary for some other rational reason. In principle the check-out procedures are intended for qualitative assessment only, i.e., to answer whether a function can be performed, or a certain property is met. In some cases the merit of the factor under consideration may be ranked into few discrete levels - which is a limiting case between check out and testing.

The check-out procedures can be classified similar to the check lists, into the 'overall' and 'specific' categories. The functions and properties to be included can be identified by critical inspection of the check lists. The choice is, obviously, a subjective one and is rather tentative. In due time, as knowledge increases, some of the items, initially covered by the check-out procedures, can be gradually transferred to the check lists. In order to make this review short the following list of the items are presented in generalised form.

1. Overall factors

- flexibility : modularity, compatibility
- performance : algorithms, time, displays
- reliability : protection
- ease : of using devices and of interactive operation
- support : maintenance, mobility

2. Specific factors

- internal compatibility : equipment, software, physical environment

The testing procedures (for evaluation prior to purchase) are meant for quantitative assessment of those important items of information which cannot be satisfactorily covered by the check lists and the check-out procedures.

When considering the conduct of a certain test, the following two questions should be answered first:

i. - What is the importance of information to be gained by the test?

ii. - What is the complexity and/or the effort of the test?

A trade-off between the two properties is often required.
The tests, providing information on the selected items, should be ranked according to their importance. Some of the tests of lower priority can be transferred to the list of the check-out procedures, or even to the plain check lists.

In the following some general guide lines are listed for the conduct of tests:

i. Differentiate between:

- testing of the devices (by means of artificial inputs) : performance, reliability and ease of handling.
- testing of the procedures (by using real inputs) : performance and operating ease.

ii. Distinguish, according to the scope, between:

- overall (integral) tests
- specific (partial) tests

From the users' viewpoint overall tests are of primary interest. Specific test may be restricted to the critical devices and procedures only.

iii. Reliability test should be mainly restricted to the devices; the computer and its standard peripherals can be excluded.

iv. Test of procedures should be combined with those of software, ease of operation and performance.

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Moreover, it seems purposeful to classify the tests into three levels according to their importance.

LIST OF TESTING PROCEDURES

LEVEL 1:

Overall tests:

- Devices: Stationary performance:
  overall accuracy: {without / with} corrections for deterministic errors
- Processes: Performance: overall accuracy, operating speed
  Human factors: operating simplicity, interactions and strain
  } aerial triangulation, planimetric map compilation, contouring, continuous profiling, sampling DTM's

LEVEL 2:

Specific tests:

- Devices: Stationary performance: positioning resolution (repeatibility)
  tracking and reversal errors
  image (& measuring mark) geometry and definition
  Reliability: measuring and positioning devices
  special panels, keys and display units
  special control units
- Processes: Performance: accuracy
  operating speed
  Human factors: operating simplicity
  interactions and strain
  } Preparation: calibrations, orientations
  Restitution: manuscript, labelling, annotation, display / record
  Pre-editing: various

LEVEL 3:

i Overall tests:

- Devices: Dynamic performance: in positioning carriages
- Processes: Reliability (processes are listed under "Level 1")

ii Specific tests:

- Devices: Dynamic performance: image definition
  slewing rates
- Processes:
  Performance: accuracy
  operating speed
  Human factors: operating simplicity
  interactions and strain
  } Preparation: loading programs, data and materials
  Restitution: basic image/model/map transformations for unconventional images, correction routines
  Postprocessing: editing & upgrading information, general (application) routines, off-line plotting and off-line orthophoto printing

Obviously, these lists have also been generalized.

A treatment of the technicalities of the testing itself is beyond the scope of this paper. However, most of the listed tests have already been conducted in conjunction with other photogrammetric equipment or for research. The entire information on the AP variants, resulting from the check lists, check-out procedures and the testing procedures, forms the input for the process of evaluation.

5. Procedure of evaluation

The aim of the evaluation is a qualitative ranking of the AP variants in the light of the overall user's environment. The procedure may either be improvised (with a minimum of effort) or it can be methodologically supported. A possible way is to start with a crude evaluation and proceed towards an increasingly detailed evaluation, and rejecting after each iteration the least favourable variants.

A suitable methodologically supported approach is the s.c. multiple factor method, which covers the following main steps:

- inquiry and preparation of information
- identification and formulation of the value model (i.e. rules and procedure of evaluation)
- estimation of partial and composite (total) values
- analysis of results

Such a procedure makes the evaluation transparent and more objective. The basic prerequisites for evaluation are thus sufficient information on the variants to be evaluated and a suitable value model. The quality of the model needs not be better, but should not be worse, than the accuracy and comprehensiveness of the information to be handled. However, both should reflect the objective(s) of the evaluation (fig. 11). As the information and its quality increase in due time and the objectives may be up-graded, the value model should be flexible enough to accommodate such changes.

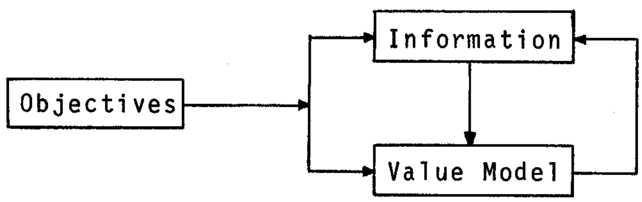

Fig. 11

Adaption of the value model

The procedure of conceiving a value model is shown schematically in figure 12. The value related information is divided into the general part, which is valid for any man-made system, and the specific part, which is typical for the kind of system under consideration. Thus, the value model is basically system independent, though the influencing factors involved may to some extent differ from one kind of system to another. Specific for each system kind is the importance of the factors involved. By introducing the corresponding weights the value model is calibrated. The weights should preferably be assessed by several experts independently and then averaged. The unpoundable factors should be excluded from evaluation as they do not affect ranking of the alternatives.

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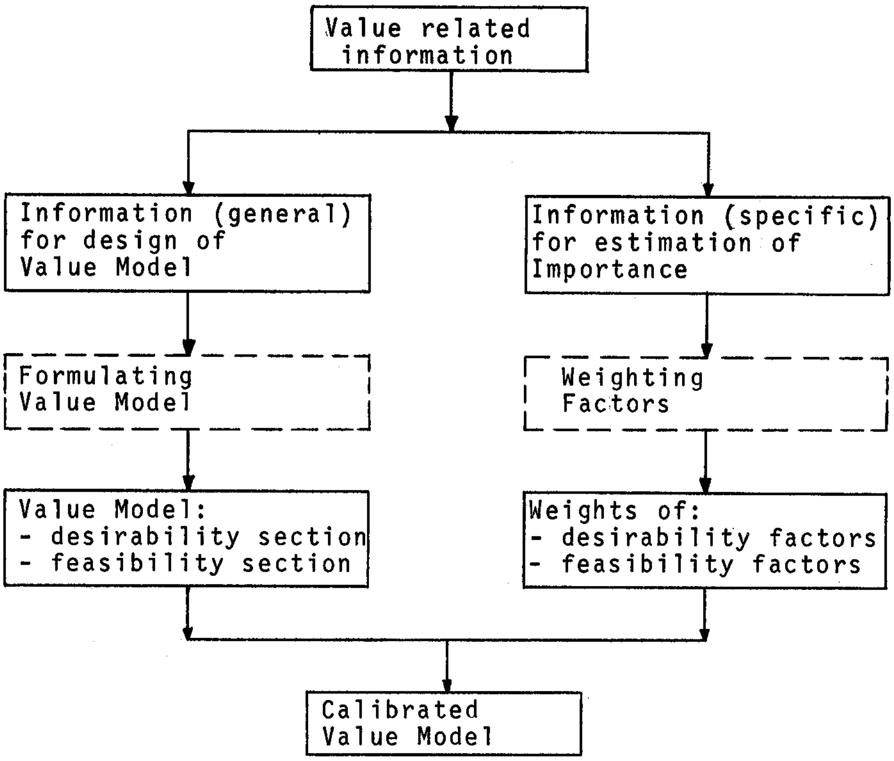

Fig. 12

Formulation of value model

A general procedure of evaluation is illustrated schematically in figure 13. The diagram shows, in addition to the procedure, also the corresponding categories of the criteria, and the algorithms for quantitative assessment of values. The entire procedure is subdivided into preparation, policy making, and feasibility judgement.

In the evaluation a multitude of influencing factors is involved which are grouped into the 'desirability' (i.e. policy making) and the 'feasibility' (technical and economic) sections. To the first section belong the following global factors: needs, economy, compatibility with changing environment, security/safety, reputation and moral. As in our case these global factors equally affect the values of all AP variants, the desirability judgement will be bypassed.

The second section of the influencing factors has been differentiated according to the overall state-of-the-art and the specific organisational environment. The former class covers : versatility, flexibility, performance, cost, reliability, software, ease (and comfort), and support requirements. The second class includes : internal needs and external commitments, financial state, internal compatibility, personnel, and specific support facilities.

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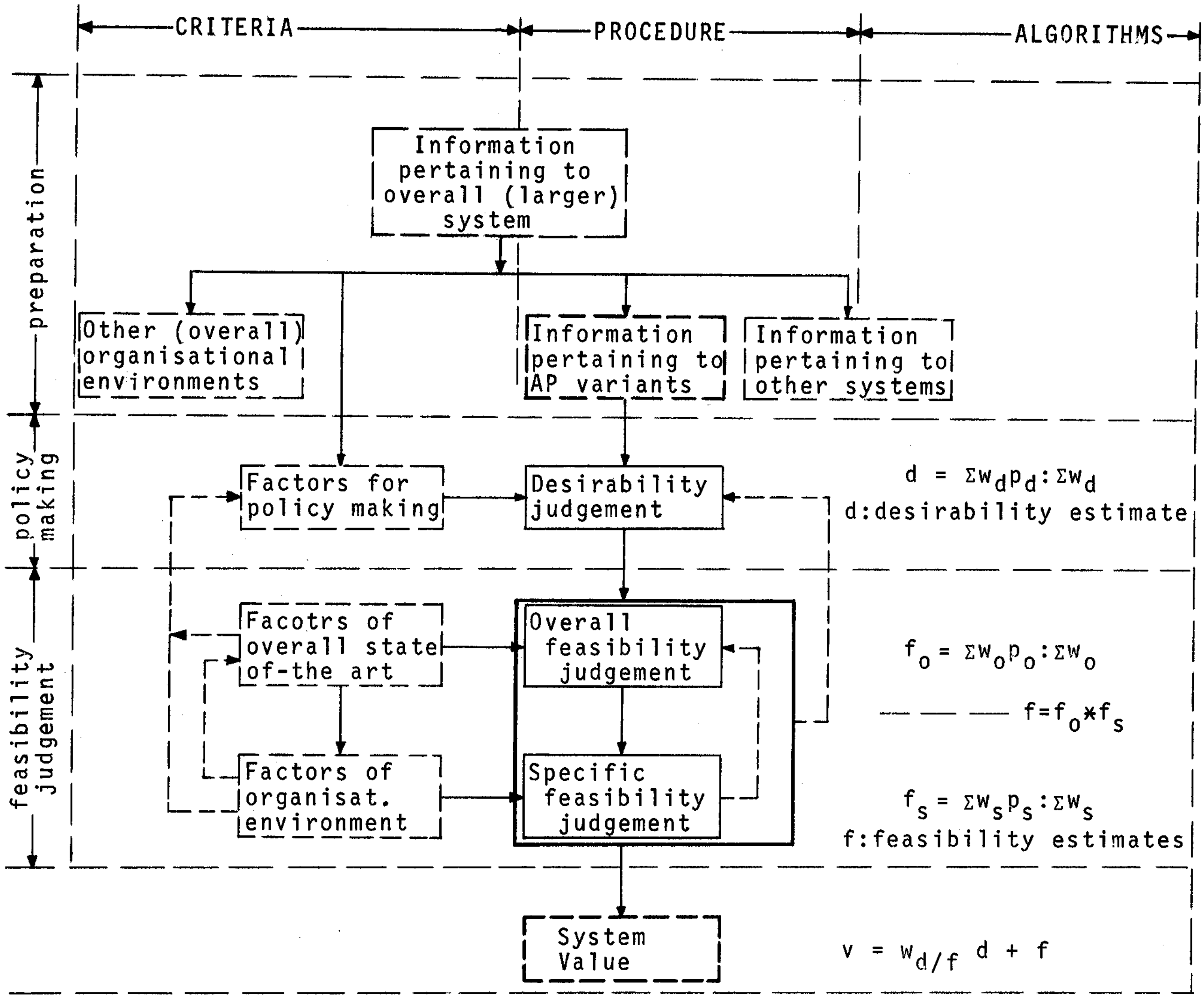

Fig. 13

Evaluation procedure

where v : value

$w_{d/f}$: relative weight of d with respect to f

w, p : weights and figures of merit of factors

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The multiple factor method uses an evaluation matrix, consisting of the variants and the influencing factors which determine its dimensions (fig. 14). In general the matrix is formed by the 'desirability' and 'feasibility' submatrices. However, in the case under consideration the former submatrix d can be bypassed, while the latter one, f, is subdivided into the 'overall', f_o, and the 'specific', f_s, parts.

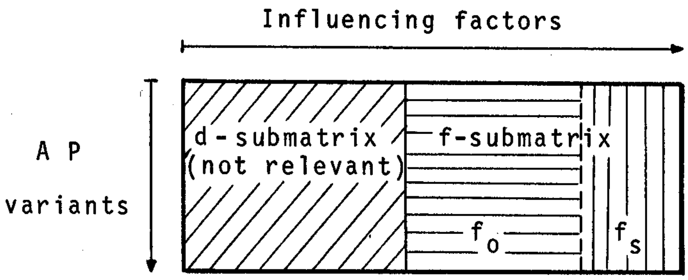

Fig. 14

Structure of evaluation matrix

Figure 15, illustrates symbolically a submatrix in detail.

A P variants \ Influencing factors / weights	A_1 / w_1	A_2 / w_2	A_3 / w_3	... / ...	Partial Values
B_1	p_{11}	p_{12}	p_{13}	...	$\Sigma w_j p_{1j} : \Sigma w_j$
B_2	p_{21}	p_{22}	p_{23}	...	$\Sigma w_j p_{2j} : \Sigma w_j$
B_3	p_{31}	p_{32}	p_{33}	...	$\Sigma w_j p_{3j} : \Sigma w_j$
⋮	.	.	.	...	...

Fig. 15

Submatrix

The input for evaluation is, as stated before, the information contained in the check lists and gained by the check-out and testing processes. During evaluation this information has to be converted into figures of merit, p, for all influencing factors included in the value model. These figures should preferably be assessed, similar to the weights, by several experts independently, and then averaged.

As overlaps and interrelations of some influencing factors cannot be entirely avoided, it is convenient to group such factors together, and subsequently to encounter their common issues only once, i.e., the first time the issue occurs in evaluation. This prevents an overemphasis of those issues which are inherent in more than one influencing factor.

In matrix notation, the partial values can be expressed by

$$V^T = P\ W^T$$

where W is the vector of weights, P is the matrix of figures of merit (both W and P being assessed by a group of experts), and V is the vector of partial values. For the 'overall' and 'specific' feasibilities it follows

$$F_o^{\ T} = P_o W_o^{\ T} \quad \text{and} \quad F_s^{\ T} = P_s W_s^{\ T}$$

subsequently the composit feasibilities F can be defined by

$$F^T = F_o F_s^{\ T}$$

The AP-variants can be ranked according to their feasibility F. However, prior to ranking it is appropriate to:

- check the evaluation matrix and related computation for gross errors
- apply sensitivity analysis to the weights and figures of merit, i.e. vary them within acceptable limits and observe the effect
- verify, e.g. by means of the law of error propagation, whether the F-values of the variants differ significantly.

The multiple factor method has, obviously also some limitations, i.e.

- interdependency of the influencing factors;
- subjectivity in weighting the factors and assessing the figures of merit;
- accumulation of errors if the number of influencing factors is great (it should be ≤ 10 to 20)
- possibility to manipulate the results by giving bias estimates of w and p.

Nevertheless, most of these shortcomings can be omitted if the method is applied with sufficient care and professional honesty.

6. Conclusion

High investment and the desire for an optimal integration in the existing and anticipated environment of photogrammetric organisations, call for a careful selection of the AP variants prior to the purchase. The decision should be preceded by a comprehensive evaluation, based on all the pertinent information and an adequate value model, and by involving sufficient expertise. The value model should meet the following two somewhat contradictory requirements:

- it should be detailed enough - to respond to the changes in all significant influencing factors
- it should be easy to handle and not too elaborate - in order to be accepted by the potential users.

Moreover, the evaluation system should be flexible - to permit adaption to different environments and upgrading in due time.
A suitable approach to evaluation is the multiple factor method, applied iteratively from 'coarse' to 'fine'. After each iteration the least feasible variants can be excluded from further consideration, which reduces the effort involved.

Although the multiple factor method seems to be the most adequate approach to the ranking of variants, it has - as any other approach - some limitations. These can be summarized as follows:

- prediction of the future technological and organizational environments
- identification of the influencing factors and their structuring
- availability of the pertinent information
- inaccurate and biased assessment of the importance and merits for the influencing factors.

By increasing the thoroughness of evaluation the process becomes more involved, and thus less feasible for implementation by the users. Therefore, a compromise should be sought.

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Abstract

The aim of the paper is to outline an orderly approach to the evaluation of Analytical Plotters, which would be carried out by the potential users prior to purchase.

As the investment is high and the consequences of an inappropriate decision might be serious, a profound procedure of evaluation - and subsequent decision - is essential.

The proposed approach covers two basic issues, i.e. an orderly collection of the information, covering various facets of Analytical Plotters, and a well structured evaluation procedure. The latter should be flexible and dynamic in order to permit adaption to the circumstances and eventual upgrading.

The many facets involved tend to make the evaluation procedure very complex and thus less practicable. Therefore carefully controlled simplifications are required.

Benutzer-Aspekte analytischer Auswertegeräte

Zusammenfassung

Der Vortrag möchte einen systematischen Bewertungsschlüssel für analytische Auswertegeräte skizzieren, nach dem sich der potentielle Erwerber richten kann. Ein umfassendes Bewertungsverfahren ist wesentlich, da die Investitionskosten derartiger Geräte hoch sind und unzweckmäßige Entwicklungen einschneidende Folgen haben können.

Der vorgeschlagene Ansatz folgt zwei Hauptgesichtspunkten: eine geordnete Informationssammlung der verschiedenen System-Aspekte und ein gut strukturiertes Bewertungsverfahren. Letzteres sollte flexibel und beweglich sein, um sich an Umstände und Entwicklung anpassen zu können.

Die vielen Aspekte des Problems machen das Bewertungsverfahren sehr komplex und daher nicht direkt praktisch anwendbar. Deshalb sind sorgfältig abgestimmte Vereinfachungen erforderlich.

Les restituteurs analytiques du point de vue de l'utilisateur

Résumé

Le but de la conférence est d'esquisser des critères d'appréciation utiles pouvant être pris en considération par les intéressés au moment de l'acquisition de restituteurs analytiques.
L'investissement étant important et une erreur dans la décision qui a été prise pouvant avoir de sérieuses conséquences, il est absolument indispensable de procéder à une évaluation scrupuleuse du matériel sur laquelle pourra se baser la décision ultérieure.

La manière de procéder exposée ici englobe deux problèmes fondamentaux, l'acquisition d'un maximum d'informations sur les différents aspects des restituteurs analytiques et une méthode d'évaluation judicieuse. Cette dernière doit également être flexible et dynamique afin de laisser suffisamment de jeu pour l'adaptation aux données respectives et une extension éventuelle du matériel.

La diversité des aspects à considérer complique l'évaluation et porte préjudice à sa réalisation. Il convient donc de procéder à une simplification contrôlée soigneusement.

Photogrammmetrische Woche 1979
Institut für Photogrammetrie
Schriftenreihe, Heft 6, 1980

Restituidores analíticos desde la perspectiva del usuario

Resumen

El objeto de la conferencia es bosquejar criterios adecuados de evaluación para restituidores analíticos que pueden ser consultados por los interesados antes de hacer una compra. Por tratarse de una gran inversión en la que una decisión falsa podría tener consecuencias graves, es indispensable un procedimiento minucioso al hacer la evaluación y, más tarde, al tomar una decisión.

El método sugerido comprende dos problemas básicos, es decir, la obtención de informaciones amplias sobre los distintos aspectos de restituidores analíticos, así como un método de evaluación bien pensado. Este último debería ser flexible y dinámico para permitir una adaptación a las condiciones del caso y una ampliación ulterior del instrumento.

Los numerosos aspectos a considerar complican considerablemente la evaluación y afectan su ejecución. Por tal razón, es indispensable una simplificación controlada cuidadosamente.

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