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A STUDY OF MENTAL PROCEDURES IN ELECTRONIC TROUBLE SHOOTING

by

JENS RASMUSSEN AND AAGE JENSEN

February 1973
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Abstract The mental procedures used by skilled electronics repair men in their normal working environment have been studied by analysis of verbalized records.

The aim of the experiment was to identify and isolate typical heuristic subroutines used by the repair men, and to have a qualitative description of the typical features of the subroutines and their role in the search procedures.

The procedures found are organized as a search through a system which is viewed as a hierarchy of subunits. The general structure of the search can be broken down into a sequence of recurrent search routines. Basically different types of such routines are found with great differences in respect of the number of observations needed and the complexity of the mental data processing involved. They also differ greatly with respect to the depth of knowledge of the internal functioning of the system used by the repair men.

The records demonstrate a great ability in the men to conduct the search by general routines mostly depending upon their general professional background, and a preference for rapid streams of simple decisions as good/bad judgements regardless of whether observations are informationally redundant or not.

Seen from the viewpoint of information economy, the procedures are inefficient, but if the men are supposed to minimize the time spent on the task and the mental load involved, the procedures are very rational.

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1. INTRODUCTION

The work reported in the present paper was initiated by a discussion within a group of system engineers concerned with the problem: How do we efficiently utilize the variety of ways to present information to a human operator - ways now offered by the computer controlled display systems that are used in many complex technical systems?

The task of the human operator in any such system is to select, from the information presented to him by the system, the data relevant to his current goal and to transform this information into a set of manipulations appropriate to his goal. This transformation is based upon a "mental model" and a set of data handling procedures acquired by the operator from his education and operational experience.

In order to be able to display the information to the operator in a way compatible with his "mental models" of the system, the system engineer quite naturally puts forward the question to psychologists: What is the structure of these models and how are the data handling procedures of the operators organized under real life conditions?

The mental model of a car available to the everyday car driver is completely different from the model available to the car designer, and somewhere between these extremes in technical detail the model as conceived by the repairman may be found. Thus the mental model of the system designer is not the most appropriate basis for the design of information display to be used by system operators or repair staff.

The psychological literature does not give system designers much support in their effort to solve this coding problem. The body of knowledge resulting from psychological experiments in clear-cut laboratory conditions dealing with well-defined and isolated aspects of human behaviour should be supplemented by studies of real life working conditions and of the mental procedures used by human system operators to make the laboratory results really useful.

The results of such studies are as important for the design of data displays to support the system operation as for the layout of the system itself and of the maintenance procedures and manuals to facilitate system repair.

2. STUDY OF MENTAL PROCEDURES IN REAL LIFE TASKS

An important aim of a study of such procedures is (a) to clarify to what an extent a man is able to base his procedures upon the large data handling capacity underlying subconscious recognitions and routines, and (b) to identify those working conditions which force him to use sequential procedures related to his basic understanding of the system function and anatomy.

This implies that one has to carry out such studies in the actual working conditions of a group of trained operators. To generalize from clear-cut laboratory experiments where the task has been stripped of seemingly secondary factors is an unreliable procedure, even where trained operators are involved. The choice between different procedures available to an operator may depend heavily upon his subjective formulation of the task and performance criteria, both being very likely to change in the artificial atmosphere of a laboratory experiment.

A further complication is that a behaviouristic study based upon a recording of the information selected by the man and of his external responses is not reliable since the data gained may be related to several basically different procedures.

We have found that the only way to separate the different data handling procedures and to relate them to the actual working conditions is in some way to ask the operator what he is doing. This means, however, that reliable quantitative information is difficult to obtain, and the analysis is time-consuming and requires much subjective judgement.

3. EXPERIMENTAL CONDITIONS

How to ask the man depends upon the nature of the task. As part of our experimental programme to formulate the data handling procedures under real life conditions, we have carried out a study of the procedures used by electronic maintenance technicians performing normal tasks of repairing the variety of electronic instruments used by a nuclear research establishment.

In this case, we found it appropriate to do the study by asking the technician to verbalize his procedures during a repair work, i.e. to take a tape recording while he was thinking aloud.

An important advantage during this study was the close personal contact and working relationship between the people conducting the exper-

iments and the repair men, and the natural interest of the maintenance group of a scientific institute to be directly involved in a research programme related to its own professional methodology.

In order to get a qualitative formulation of the basic features of the diagnostic procedure rather than quantitative data from standardized experiments, records were taken of several individuals locating different faults in the instruments. This fact also enhanced the confidence of the group in the stated aim of the study since it removed the possibility of a comparison of the efficiency shown in the different cases.

In order to enable the men to familiarize themselves with the experimental procedure and the tape recorder, the instruments used for the initial cases were selected by the technicians themselves when they found it convenient to make a recording.

It soon turned out that stereotyped procedures were used for the more simple instruments, such as amplifiers, power supplies, etc., and the cases to be recorded were then selected by the planners of the experiment.

More complex systems were then chosen, i.e. systems of a greater variety in the external display of features related to the internal operational state. These included multichannel analyzers, oscilloscopes, TV-receivers and digital voltmeters. It turned out from the analysis that information contained in the external system response was not used to any great extent, and the tendency to use "short-cut" methods based upon such information was only slight, even when the planners of the experiments found such methods to be clearly indicated by the system response. Therefore, in later phases of the experiment, simulated faults were introduced in order to have a reasonable number of cases in which the fault looked for could be located rather exactly by short-cut methods if the information available from the external response was taken into careful consideration. The simulated faults were not artificial, however, but normal or probable component faults in carefully selected parts of the system.

During the experiments, such instruments were chosen for the individual man the use of which, and their overall design, were familiar to him. At no time was chosen a highly trained expert in the specific type of instrument involved, with such a person's ability to go directly to the fault by a simple recognition of the faulty response pattern.

A total of 45 cases were recorded, comprising 6 individuals performing fault-finding in 8 different types of instruments, each case having its particular fault. The experiment thus covered a small number of cases and a very large number of parameters influencing the performance during the

task, and reliable quantitative information was not to be expected.

All records were preliminarily analyzed, and some of them were rejected from further analysis. Cases from the initial training of the recording were omitted, as well as cases with faults in system parts for which the group had no equipment, such as high-frequency parts of TV-receivers, and cases of intermittent or multiple faults, etc. The final, detailed analysis covers 30 recordings.

4. ANALYSIS OF RECORDS

The task of finding the structure of nearly 50 verbal records made by several persons trying to locate individual faults in different types of systems, makes one realize how colourful real life working conditions are and how much work is needed to carry through the analysis.

An almost immediate experience is the danger that the analyst himself develops fixed routines in the analysis in order to be able to manage the classification of the multitude of situations. It proves imperative to have long breaks in the analyzing effort, to be able to relax from fixations and to return to the original material with an open mind. It also seems important to have several analysts criticizing each others' models of the structure in order to break fixations and to decide which differences in the classifications made by the different analysts result from weaknesses in the definition of the classes and which are due to differences in the interpretation of the records.

The men were asked to relax and tell what they were thinking, feeling and doing, and to express themselves in everyday terms including short hints in fast work sequences. A record was immediately typed out and the man was asked to read it in the actual working position in front of the instrument to correct mistakes and supply supplementary information when he felt something was missing. At the same time the analyst had the first review of the record and a short talk with the man to clarify weak passages in the verbalization.

The initial systematic analysis was based upon the definition of a set of elementary events describing the microstructure of the sequences (Appendix A). The records were coded and a computer print-out made, giving a graphical picture of the sequence as well as a connectivity matrix describing each case. The graphical read-out turned out to be a convenient support in the effort to locate and identify recurrent routines. Owing to the large number of parameters, the connectivity matrices gave only a very few hints about the general pattern.

Based upon the graphic read-out, sequences identified as recurrent routines were re-analyzed from the original records and classified according to the characteristics of the data handling taking place.

The analyses started by extracting the most obvious and frequent routines, leaving for later analysis the complicated and more individual parts of the records. Contributing greatly to the amount of work was the necessity for a highly iterative classification; each new class of routines which was introduced made it necessary to review all classes already used. For each subroutine a graphic symbol was chosen, with a set of codes indicating important features. The records were finally coded as a graphical pattern showing the interconnection of the subroutines and with comments to facilitate later reviews (Appendix B).

In formulating the generalized subroutines in the man's data handling, one has to cut away most of the details related to the individual case. To be able to find why a specific routine is chosen, one must, however, return to the details in the original record and to the features of the specific instrument.

It is important for the analysts to have a background in engineering in order to be able to imagine themselves in the task situation, and thus have a clear understanding of the meaning of the manipulations and measurements. They can then formulate <u>what</u> the man is doing, and thus find the structure of the information handling. On the other hand, some knowledge of psychology is needed to explain <u>why</u> the man has chosen that particular approach and to formulate the goal and motivation which control the sequences found. The present report mainly considers the structure of his information handling procedures.

Our experience confirms the statement by Bainbridge et al. (1968) that a very formalized analysis in which the procedure of the man is compared to a model covering all possible strategies is impracticable for real life conditions, although it is a very effective tool in laboratory experiments with a smaller number of decisive parameters, as reported by Alan Newell (1966).

During our analysis we found that the following cases of interference from the verbalizing task may cause uncertainty during classifications of subroutines:

It may be more attractive for the man to do something physically, to manipulate, than to use mental activities such as reasoning because action is more readily explained in the records and goes better with the pace of speech.

Sometimes we get the impression that activities reported sequentially

would normally be part of a parallel data processing, i.e. a set of automated routines; thus a routine may be disturbed because it is forced into consciousness, and therefore it may be erroneous and incomplete.

Some of the records indicate that the men subconsciously collect information concurrently with the reported activities and that such information supports "bright ideas", which are difficult to explain later in the sequence.

However, careful discussion with the men after the analysis of the records does not indicate any serious misinterpretation of the general structure of the procedures. After becoming accustomed to the recorder, the men consider the execution of the task as well as the time spent in locating the faults normal.

5. BASIC FEATURES OF THE PROCEDURES

5.1 An Example

A discussion of the results of the analysis of our records may benefit from a simplified example based upon the main features of one of the actual cases.

We consider a case where a digital scaler displays two digits simultaneously in one decade, but otherwise functions normally. The task is now to obtain from the response of the system and by appropriate measurements, a reference to the location of the faulty component.

In the present case, there is a close relation between the faulty parameter of the system response - i.e. the fault in display of the second decade - and a well-defined part of the system. The man's interest will then quite naturally be limited to the circuitry connected with the second decade.

Further reference to the location of the fault may now be obtained in different ways. It may be based upon detailed observations of the actual faulty response and consideration of the internal anatomy and functioning of the system. In the case under consideration, a design engineer localized the the fault to a specific resistor in the decoder directly from the response, using his knowledge of the digital code and a diagram of the circuitry of the decoder. This method can, of course, also be chosen by a trained maintenance man and, judging from textbooks for the training of maintenance technicians, some authors of such books consider it to be the "intelligent" method: i.e. to take few, carefully chosen measurements and use the observations in careful reasoning based upon functional understanding of the system.

Our records indicate that a trained technician is most likely to choose another method, viz. that of scanning through the faulty decade by a rapid

sequence of good/bad checks of the actual signals against normal signals which are measured in one of the other decades, or which are found on the circuit diagram.

In this way, the fault may be localized to the decoding circuit. In the circuit diagram this circuit is seen to contain less than half a dozen resistors. Therefore, rather than evaluate their function, it may be preferred to scan through the resistors by good/bad checks with an Ω-meter. Thus, an open circuit resistor is found.

5.2. General Features of the Procedure

Although very simplified, this example illustrates some of the general features of the procedures found in our records:

- The basic feature of the routines used may vary greatly in several respects. In the example given above, the designer used only a few observations, but employed a complex data handling in his decision procedure. His procedure is very specific and related to the system anatomy and internal functioning and to the actual faulty condition. He treats several observations simultaneously, and his procedure is informationally economic.

  The trained technician uses many observations in a sequence of simple decisions. His method is a general search procedure which is not dependent upon the actual system or specific fault. He treats the observations individually in a stream of good/bad judgements which is informationally uneconomic, but fast.
- The man defines his task primarily as a search to find where the faulty component is located in the system. He does not consider his task a problem-solving one, which is to explain why the system has the observed faulty response and from which an understanding of the actual functioning of the failed system can be arrived at.
- The procedures are organized as a search through a system which is viewed as a hierarchy of units. The system is composed of a number of subsystems: amplifiers, scalers, deflection generators, etc. Each subsystem has easily identifiable units such as amplifier stages, flip-flops, and oscillators, and these units have components, e.g. transistors, capacitors, and resistors.
- The general structure of the search can be broken down into a sequence of search routines, which are used to identify the appropriate subsystem, stage, or component. The structure illustrates how the man attempts to sequentially limit his current field of attention. He is all the time asking the question about where to look next and thus tries to extract topographic refer-

ences from his observations.

- A topographic reference from the observations is typically obtained in three different ways depending on very different depths in the consideration of the internal anatomy and functioning of the system.

5.3. Derivation of Topographic Reference to the Fault

The topographic reference may be derived merely from the location in which the observation or measurement is made. Having traced the signal stage-wise through an amplifier with no output, the next field for search is the stage in which the signal disappears.

In some cases, a topographic reference may be drawn from an observation by considering the normal functioning of the system. When an abnormal vertical geometry of a TV-picture leads the man to the vertical deflection generator, he considers only the normal role of each subsystem in overall system performance.

In these two modes of obtaining topographic reference, very little information is drawn from the observation itself. Only one bit - good or bad - and the topographic reference is taken either from the location of the measuring point or from the function as related to the relevant state parameter.

Generally, a more specific topographic reference may be obtained if the observation is not judged merely good or bad, but the actual mode of faulty functioning is evaluated. If a digital scaler has an erroneous indication in one digit, simple good/bad judgements of the function refer only to the related decade circuitry. If, however, the way the indications are faulty is carefully evaluated, the fault may be closely located, as shown in the example given above. However, this is only possible if the detailed functioning of the circuitry is considered.

The procedures found in our records are composed of types of subroutines related to these different ways of deriving a topographic reference from the observations. The different subroutines have also different roles in the overall procedure.

5.4. Typical Subroutines

Faced with a faulty instrument or system, the man will limit the field that has to be covered by a detailed search by means of a functional search. In this search different typical parameters in the system response, e.g. features of a TV-picture, known to be related to the functions of clearly defined subsystems, are scanned and judged individually. If an abnormal

parameter is found, the search is carried on in the related subsystem.

However, if no clear indication is found in the external system response, the initial limitation of the field to be covered by a detailed search may also be determined by a number of individually chosen check-measurements, i.e. simple good/bad judgements of signals at strategically important points in the system, which are to indicate in which subsystem the fault originates. In its ideal form this routine is the classical "half-split" method.

The interest of the man is now focused upon a subsystem which very often has a rather clear-cut main signal or information path through a number of familiar subunits or "stages". This structure invites the use of another frequently used routine: the system is scanned along the main signal path by a rapid sequence of good/bad judgements. This routine is called the topographic search routine, since a reference to the next search field will be chosen around the topographic location where the decisive judgement is made.

A more efficient (informationally speaking) topographic reference can be obtained if the information describing the actual mode of function failure is considered. Such subprocedures are here called fault evaluations. Quite naturally, their appearences are more individual than those of the search routines. The complexity varies from simple recognitions and statements based upon general electronics background or experience to complicated deductions based upon understanding of the internal functioning of the specific system.

The typical functional and topographic search sequences are based upon one bit of information from the observations - good or bad - and this search can therefore only give topographic references which point to where to look next. The fault evaluations, however, deal with the actual functioning of the system, and the available information can therefore be used more efficiently. Searches by evaluation of the mode of failure are also able to point to what to look for and they may thus be important to support planning of the search procedures, e.g. in the choosing of the relevant state parameter (DC-bias voltages, signal parameters, etc.) to be used during a search routine.

Before the more general features of the procedure are discussed further, the subroutines will be discussed in somewhat more detail.

6. THE TYPICAL SEARCH ROUTINES

6.1. The Topographic Search

In the topographic search, reference to the location of the fault is

obtained from the topographic location of a measuring point. The system or some part of it is scanned by a sequence of measurements, and the observations are subject to simple, individual good/bad judgements.

The search is normally a test of the performance along a main signal path in the relevant subsystem. The circuitry along the route is seen as a row of familiar units, e.g. amplifier stages, and by a sequence of rapid judgements the stage is localized in which the signal disappears or a faulty signal appears or an abnormal bias voltage is found.

In the 30 records, which are analyzed in detail, the total number of sequences identified as topographic search sequences is 82.

The way in which a reference is obtained to the field in which a topographic search should be performed is illustrated by table 1 to 3. In order of their relative importance, the decisions have been:

- The search is a repetition of a previous topographic search in the same field, either a different or the same (i.e. - be more careful!) parameter or signal being used.
- A functional search has indicated the field.
- The search is a local topographic search initiated from a good/bad judgement in another topographic search.
- Reference to the field is derived from the evaluation of the fault mode in a previous sequence.
- The field is found from an overall search by check-measurements.

6.1.1. Choice of Parameter or Signal to be Used in the Search

When turning to a subsystem to perform a topographic search, normally very little information from previous observations (e.g. the nature of the fault) is carried over to assist the man in planning the search. The choice of the parameter to be used in the search is very dependent upon those norms for judgement which are immediately available.

In some cases, the parameters chosen for the search cannot lead to the location of the fault, and information clearly indicating this may actually have been recorded by the man prior to the decision to start the search. However, the decision about where to look is often the only connection with the previous search.

This may seem very inefficient, but still it should be remembered that a simple search of typically 5 to 10 measurements is a very rapid sequence, which may very often prove successful. Therefore, in the long run it may pay to take a chance and not consider every decision carefully.

In our records, the parameter to be used for the topographic search is

chosen in different ways in analog and digital systems. This is partly caused by the basic difference between the signals, but the main reason is that suitable reference data were available in most diagrams for the analog systems, but not for the digital systems.

The choice of parameter is illustrated by tables 1 to 3. In analog systems the parameters used for search in about half the sequences have been DC-bias voltages or AC-wave forms for which the diagram indicates convenient norm values. As far as the remainder is concerned, the choice of parameter is spread fairly equally among the following:

- A signal convenient for judgement by the man's general experience.
- A parameter found from the evaluation of the fault mode in a previous sequence.
- Another parameter with which a previous unsuccessful topographic search can be repeated (e.g. a search by DC-measurement is followed by a search by AC-measurements).

In the digital systems more than half of the topographic sequences are based upon a parameter judged from general experience. In the remaining sequences, the parameters chosen are fairly equally divided between parameters found from evaluation of the fault mode and parameters for which convenient norms are available from the diagram or by measurements in another system.

6.1.2. The Route for Search

The main signal path through the system, which is used as the route for search, is normally clearly indicated by the graphical layout of the circuit diagram or the physical layout of the circuitry. In the same way, a convenient subdivision is normally indicated along the route in units or "stages" in each of which a measurement should be taken.

In our records, the selection of the route and the steps of the search sequence are generally based upon the wiring diagram of the system. For this application, the diagram is not viewed as a functional description of the system, but solely as a topographical map, showing the information highways. Measuring points are chosen along the route of search at locations where convenient norms for judgements are available (e.g. points for which the diagram gives reference data such as bias voltages or signal wave forms).

In some cases, the layout of diagrams is not immediately usable as a topographic map and some "topographic evaluation" is necessary. The man then tries to identify familiar units and to find the interconnections. This can also be done by using the graphic layout of the diagram without considering the functional aspects.

In simple and familiar systems such as straight amplifiers, the steps of the route are selected from the man's general experience of the physical layout of the system, the latter being a row of directly identifiable transistor or vacuum tube stages.

In other cases, no consideration is paid to the signal path, which may not be too clearly defined, and the search will be controlled solely by the use of reference data in the diagram and thus be restricted to a systematic test at corresponding measuring points in the system.

The search is performed as a rapid scan along the route chosen and no judgements as to whether some of the steps will be informationally redundant seem to be made.

In yet other cases, the circuit diagrams do not directly indicate convenient routes for search because the information path is not a simple one-way route as it is in an amplifier. This may be the case in digital circuitry, especially if logical operations are performed which combine or modify signals and result in several information routes with common cross - roads. The route must then be planned step by step by a careful consideration of the functioning of the system, normally supported by the wiring diagram, which is then used as a functional description of the system, a role which is clearly different from being a topographic map in the "straight" search.

In such cases, the overall performance and speed is significantly influenced by the mental load from this activity and the effort to find good reference data for the judgements may be very limited. Mere hints may be used, such as "this wave form looks reasonable".

If the route disappears for the man during the search or is difficult to trace in the more complex systems, there is a preference to jump to a search along another route rather than to establish a better basis for control of the original route by functional reasoning.

In the attempt to locate the measuring points physically along the route in the system, the faulty component may be found visually, e.g. short circuits in the wiring and mechanically damaged components.

The control of the search route is illustrated in tables 1 to 3. The differences in analog and digital systems are not great. 70% of the sequences are based upon the diagram used as a topographic map; the remaining ones are based upon general experience of the physical layout of familiar systems such as amplifiers and similar circuits. Only in a few cases the search route is based upon functional reasoning.

Table No. 1.

Summary of Topographic Search Analog Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Topographic Search Routines	60	
Field for Search Found from:		
- functional search	15	
- topographic search	8	
- extension of search in a connected field	2	
- evaluation of faulty response data	9	
- repetition of search in the same field	18	
- overall search by check meas. etc.	6	
Choice of Search Parameter due to:		
- convenient norm is available	30	
- convenient signal to trace	10	
- another parameter needed for repetition	8	
- ref. from evaluation of faulty response	11	
Route for Search Controlled by:		
- diagram topography	46	
- diagram data	2	
- experience, familiar layout of system	10	
- route prepared by functional reasoning	1	
Source of Norm Data for Judgement:		
- diagram data, wave forms and voltage	35	
- experience, familiar signals	22	
- deduction from functional understanding	1	
- measurement in other systems	1	

Table No. 2.

Summary of Topographic Search Digital Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Topographic Search Routines	22	
Field for Search Found from:		
- functional search	4	
- topographic search	8	
- extension of search in a connected field	1	
- evaluation of faulty response data	2	
- repetition of search in the same field	3	
- overall search by check meas., etc.	4	
Choice of Search Parameter due to:		
- convenient norm is avaible	5	
- convenient signal to trace	12	
- another parameter needed for repetition	o	
- ref. from evaluation of faulty response	5	
Route for Search Controlled by:		
- diagram topography	14	
- diagram data	o	
- experience, familiar layout of system	7	
- route prepared by functional reasoning	1	
Source of Norm Data for Judgement:		
- diagram data, wave forms and voltages	2	
- experience, familiar signals	16	
- deduction from functional understanding	o	
- measurement in other systems	4	

Table No. 3.

Summary of Topographic Search — Total

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Topographic Search Routines	82	
Field for Search Found from:		
- functional search	19	
- topographic search	16	
- extension of search in a connected field	3	
- evaluation of faulty response data	11	
- repetition of search in the same field	21	
- overall search by check meas.,etc.	1o	
Choice of Search Parameter due to:		
- convenient norm is available	35	
- convenient signal to trace	22	
- another parameter needed for repetition	8	
- ref. from evaluation of faulty response	16	
Route for Search Controlled by:		
- diagram topography	6o	
- diagram data	2	
- experience, familiar layout of system	17	
- route prepared by functional reasoning	2	
Source of Norm Data for Judgement:		
- diagram data, wave forms and voltages	37	
- experience, familiar signals	38	
- deduction from functional understanding	1	
- measurement in other systems	5	

6.1.3. Judgement of Observations, Source of Reference Data

Literally speaking, all data collected during the search sequence are immediately judged good or bad individually. For these judgements the man needs some model or description of the normal state of the system which supplies him with reference norms for each observation. The presence of a set of convenient reference norms is often directly stated in the record as the reason for the choice of the route and parameter used for the search.

Reference norms given in circuit diagrams as DC-bias voltages or AC-signal amplitudes or wave forms allow a fast and convenient stream of judgements and typically these are used whenever available. If reference data are not given in the diagram, the judgements are often based upon experience of a general electronic nature, e.g. typical magnitudes of bias voltages for tubes or transistors, typical wave forms of multivibrators, etc.

If reference standards for the judgements are not otherwise available, the man has to work them out himself by deduction from an understanding of the normal function of the circuitry, a task which is normally supported by the wiring diagram. If the man also has to plan the route for search from a functional understanding of the circuit, he has to maintain simultaneously mental models at two different functional levels, which is a considerable task.

A model at one level is necessary to control the route of search; this model has to be related to the signal or information flow and thus to the function of the entire subsystem under consideration. Models at the other level are needed to supply reference norms for the individual judgements and thus have to be related to the detailed functioning of the sub-units along the search route. In that case the procedure is slow and hesitating, probably owing to the considerable difficulty in simultaneously maintaining models at different levels. The situation appears in connection with digital circuitry - especially circuits performing logical operations.

In such circuits, the signals may be present having normal wave forms if judged individually, but coding may be faulty or signals may be present in faulty combinations, and therefore the normal search routine may break down and be unsuccessful.

To circumvent this difficulty without at the same time having to rely on functional evaluation of more data, the men typically prefer to utilize another feature of many digital systems, viz. the presence of the same type of circuits in several subsystems, e.g. identical circuits in different decades of a scaler, and they simply use another circuit as the source of reference

data or they just interchange printed circuit cards.

The same tendency to avoid the mental load from functional reasoning may explain why DC-bias measurements are invariably preferred to AC-wave forms in analog signal systems when no reference data are given in the wiring diagram. Judgement of DC-bias voltages may be based upon general experience of tube or transistor parameters whereas judgement of wave forms has to be based upon experience or understanding related to the specific type of circuit.

If the necessary reference data for the judgements are hard to find, the measuring point or even the route may be discarded. Switching of attention to another route or field of search is often preferred to the effort needed to establish reference norms by functional reasoning.

The source of norm data is shown in tables 1 to 3.

In analog systems, the main source of norm data is the diagram and general experience, i.e. familiar signals and bias voltage. In digital systems, diagram data play a minor role, and general experience is the most important source followed by measurements in other systems. Reference data deduced by functional reasoning is only found in a single case.

6.1.4. Exit from Topographic Search

The results obtained by topographic search is illustrated in tables 4 to 6.

If the topographic search is successful, the interest of the man is focused upon the field around the measuring point which indicates an abnormal bias voltage, a disappearing signal or similar strategic judgement. The most frequent exit from the topographic search routines in our records is the initiation of such a local topographic search from the result of a single good/bad judgement.

In some cases, however, information related to the actual faulty mode of functioning is also observed and used by the man. Generally, he does not seem to be looking for such information, but suddenly "something shows up". Often, important information is merely mentioned in passing in the main routine, but sometimes it catches the interest of the man and causes him to switch to another procedure in which he derives topographic references or hints about what to look for obtained from such functional information. In less than half of the topographic sequences initiating local search, the mode of failure is used to indicate what to use as parameter in the local search and only in a few cases the observed fault mode is used to give a further location of the fault by evaluation.

Table No. 4.

Summary of Topographic Search Analog Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Topographic Search Routines	6o	
Topographic ref. from one Observation:		
- judgement initiates local search	17	
- eval. of fault data gives top. ref.	3	
- eval. of fault indicates "what to look for"	7	
Search Unsuccessful, Next Activity:		
- repeat same field by other parameter	11	
- repeat same field-by same parameter	1	
- continue search into a connected field	4	
- return to previous, less significant ref.	4	
- repeat previous activity	4	
- return to previous, interrupted activity	1	
- return to overall search (func. or checks)	7	
- take a break, wait for good ideas	4	
- evaluate summary of observations		
- to have topographic ref.	1	
- to support "what to look for"	3	
- concluding judgement later recalled for use in overall search	6	

Table No. 5.

Summary of Topographic Search Digital Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Topographic Search Routines	22	
Topographic ref. from one Observation:		
- judgement initiates local search	14	
- eval. of fault data gives top. ref.	o	
- eval. of fault indicates "what to look for"	6	
Search Unsuccessful, Next Activity:		
- repeat same field by other parameter	o	
- repeat same field by same parameter	2	
- continue search into a connected field	1	
- return to previous, less significant ref.	o	
- repeat previous activity	2	
- return to previous, interrupted activity	o	
- return to overall search (func. or checks)	1	
- take a break, wait for good ideas	o	
- evaluate summary of observations		
- to have topographic ref.	1	
- to support "what to look for"	4	
- concluding judgement later recalled for use in overall search	1	

Table No. 6.

Summary of Topographic Search Total

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Topographic Search Routines	82	
Topographic ref. from one Observation:		
- judgement initiates local search	31	
- eval. of fault data gives top. ref.	3	
- eval. of fault indicates "what to look for"	13	
Search Unsuccessful, Next Activity:		
- repeat same field by other parameter	11	
- repeat same field by same parameter	3	
- continue search into a connected field	5	
- return to previous, less significant ref.	4	
- repeat previous activity	6	
- return to previous, interrupted activity	1	
- return to overall search (func. or checks)	8	
- take a break, wait for good ideas	4	
- evaluate summary of observations		
- to have topographic ref.	2	
- to support "what to look for"	7	
- concluding judgement later recalled for use in overall search	7	

If the search through the current field of interest is completed without any clear topographic reference to control the next search, the exit from the search may lead to a concluding summary. Mostly this is a simple statement summarizing the judgements that have been made such as "all voltages ok" or "the subsystem seems to be all right". Normally, the original observations are not mentioned, either as reviews of the accuracy of the judgements or as attempts to judge the relationships between several observations. This is even true when a comparison between the information from observed system response and the data recorded during search would clearly indicate that judgements have been made too hastily. Sometimes the concluding judgement refers to a previous hypothesis inferred from the functional search or the evaluation which initiated the search.

More than half of the topographic sequences end unsuccessfully and a number of possibilities are then open for the choice of the next activity. The only clear preference is found in analog systems where the same field is repeated, another parameter being used. Typically, an unsuccessful search by DC-voltages is followed by an AC-sequence and vice versa.

The experiments do not give any basis for other rules of choice. What is done depends upon the phase of the overall search, the outcome of preceding search routines and, possibly, the fields not yet treated but offering convenient search routines and having some relation to the failed function, etc. A list of the choices found in the records may be illustrating:

- Repeat the search more carefully, typically if both AC- and DC-searches have been unsuccessful and the field has a well-defined relation to the failed function.
- Extend the search into the topographically connected field or subsystem, even against evidence mentioned during initial functional search.
- Make a functional search through parameters of a display of the output voltage wave form from the field (by oscilloscope).
- Return to the initial functional search. Typically, this is merely a repetition, not a more thorough treatment of the available information in order to get a more specific reference to a detailed field for search. At most, a somewhat more careful selection of the parameter to be used in the next search is considered.
- Return to a previous, less significant reference, or to a previous activity which was interrupted by a reference to another routine.

- Evaluate more carefully the information found during the search to derive a topographic reference.

In some cases, an unsuccessful sequence results in a period of confusion and doubt, a break for a "smoke" or a sequence of spurious activity. During such periods, "good ideas" normally emerge.

These schemes for planning and carrying out the search often prove successful in the end, but cause difficulties in some types of systems and faults. Typical cases are faults within a closed feedback loop in which a topographic search is not directly possible. Difficulties are also found if spurious signals propagate along other routes than do the normal signals, e.g. some types of mains ripple faults which influence several functions in different ways.

A comment on the tables may be useful here. It is not possible to cross-check the figures given in the table. A few examples may illustrate the reasons for this: Some of the classes shown are not mutually exclusive, e.g. the same observations may be used several times for different purposes. The classes used do not cover all the situations found in the records, e.g. in table 6 is shown that in 14 cases a repetition is chosen after an unsuccessful search, whereas table 3 indicates that in 21 cases it has been decided to repeat a search. The reason for this discrepancy is that in 7 cases other activities have been tried before the decision was made to repeat the search.

Similarly table 15 indicates that 26 cases are found, where a check is used to confirm a hypothesis "what to look for" obtained by evaluation, whereas table 21 states that only 12 such hypotheses are tested by checks. The reason for this is that a number of hypotheses "what to look for" are stated by the user as his complaint when he calls for the repair. The hypotheses are checked by the repair man, and the checks are included in table 15, but the user's evaluation is not included in table 21.

6.2. The Functional Search

In the functional search, the topographic reference is obtained from the normal functional relation between a feature in the system response and a specific part of the system.

A good example is trouble shooting in a TV-receiver. The man will scan the features of the picture in a stream of good/bad judgements and turn his interest to the subsystem related to the faulty feature. If the picture is too low, he will perform a search in the vertical deflection generator. The functional search is quite naturally the opening move in complex systems

having subsystems with specific functions which are individually recognizable in the overall system response. However, the routine may also be used later in the procedure when the man is faced with more complex data patterns such as wave forms on oscilloscopes.

The search used shows similarities to the topographic search. The information pattern is scanned and familiar features are judged individually in a stream of good/bad judgements, and only the results of the judgements are normally used to control the next activity. If a response feature is judged faulty, attention is typically turned immediately towards the subsystem related to that function and a routine search is then performed in the subsystem. Information related to the observed mode of failure of the function is used very cursorily and mainly to indicate the parameter to be used in the next search (what to look for).

In practically all cases the functional search gives some reference to the topographic location of the fault. In two thirds of the cases, the function judged as faulty directly refers to a field for which a convenient search routine is available. In the remaining - typically digital cases - the function is not related to a topographically well-defined field and a further limitation is then obtained by evaluation of the fault mode or by an overall search by check measurements. These last-mentioned two methods are equally frequent in our records.

The use of the functional search is reviewed in tables 7 to 9.

The way the man scans through the parameters of the response pattern is very individual. In some cases, the reference to a subsystem is like a pattern recognition; in other cases, the man judges a sequence of parameters systematically. Sometimes, a careful manipulation of the system is needed to obtain a clear reference to a specific subsystem.

In not few cases, the man studies the faulty response in great detail, but the information is not used to any large extent to control the search which follows. Sometimes the information is recalled later in the record to confirm a hypothesis found by routine search, and perhaps accompanied by a remark indicating an "eureka-feeling" when the hypothesis appears.

Faced with a multiparameter pattern of information, the man normally has a good opportunity not only to deduce rather precisely what is the cause of the faulty response and where the fault is to be found, but also what sort of search procedure will be most efficient. However, one of the clear indications of our experiments is that the information available is not used efficiently by the man in that way, even when faults were simulated to invite the use of short-cut methods by functional reasoning and evaluation.

Table No. 7.

Summary of Functional Search Analog Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Functional Search Routines	19	
Reference to Location of Fault:		
- where to look next -		
- obtained from failed function only	17	
- further ref. by evaluation of faulty response	1	
- further ref. by subseq. check measurements	1	
Reference to Nature of Fault:		
- what to look for -		
- by evaluation of faulty response	7	
Evaluation Based Upon One Observation	3	
Faulty Response Studied in More Detail:	8	
- data from more observations used for evaluation, give ref. where or what	5	
- observations recalled later, used to derive hyp. where or what	2	
used to test hyp. found in other ways	1	
- observations repeated later	2	
- observations not used	3	

Table No. 8.

Summary of Functional Search Digital Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Functional Search Routines	12	
Reference to Location of Fault:		
- where to look next -		
- obtained from failed function only	3	
- further ref. by evaluation of faulty response	3	
- further ref. by subseq. check measurements	3	
Reference to Nature of Fault:		
- what to look for -		
- by evaluation of faulty response	2	
Evaluation Based Upon One Observation	0	
Faulty Response Studied in More Detail:	8	
- data from more observations used for evaluation, give ref. where or what	5	
- observations recalled later, used to derive hyp. where or what	0	
used to test hyp. found in other ways	2	
- observations repeated later	2	
- observations not used	5	

Table No. 9.

Summary of Functional Search **Total**

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Functional Search Routines	31	
Reference to Location of Fault:		
- where to look next -		
- obtained from failed function only	2o	
- further ref. by evaluation of faulty response	4	
- further ref. by subseq. check measurements	4	
Reference to Nature of Fault:		
- what to look for -		
- by evaluation of faulty response	9	
Evaluations Based Upon One Observation	3	
Faulty Response Studied in More Detail	2o	
- data from more observations used for evaluation, give ref. where or what	1o	
- observations recalled later, used to derive hyp. where or what	2	
used to test hyp. found in other ways	3	
- observations repeated later	4	
- observations not used	8	

6.3. The Data Collection Sequence

The typical topographic and functional search routines may be viewed as sequences of judgements rather than sequences of observations of data. In some cases, however, the attention of the man is caught by features of the system response, thus initiating a sequence of two or more detailed observations which are not judged good or bad, but instead result in a "study" of the actual functioning of the system.

Such situations are classified as "data collection sequences". Informationally speaking, the observations are generally not used efficiently; in many cases, only the information from one of the observations in the sequence is used to derive a topographic reference, to indicate which parameter is to be used in the next search sequence or to test a hypothesis. In some cases, the information is recorded but apparently not used.

The data collection sequences are often closely connected to the functional search, and the use of the information when the fault is studied in detail as part of a functional search is shown on tables 7 to 9. A summary of all data collection sequences is given on tables 10 to 12.

6.4. Check Measurements

Among the sequential routines in the records, a number of single measurements are dispersed at locations which are chosen individually in the system. Since such measurements typically are followed immediately by good/bad judgements, they are classified as check measurements. These play an important role in the overall search procedure; they are used either to confirm a hypothesis or as part of an overall topographic limitation of the field as in a "half-split" procedure. In our records, general electronic experience is most frequently used as a basis of judgements which indicate that locations of check measurements are preferably chosen where norm data are immediately available.

In our 30 records, a total of 75 check measurements were found.

The most frequent application of these measurements is typically check measurements to confirm a hypothesis "what to look for" obtained by evaluation of the fault.

Frequently check measurements are used to confirm a hypothesis regarding the location of the fault obtained by evaluation of the fault, and to confirm a topographic reference found by a topographic search.

Check measurements are also used as part of an overall topographic search, such as half-split search. However, a measuring point is not normally chosen according to a formulated plan but is rather chosen between

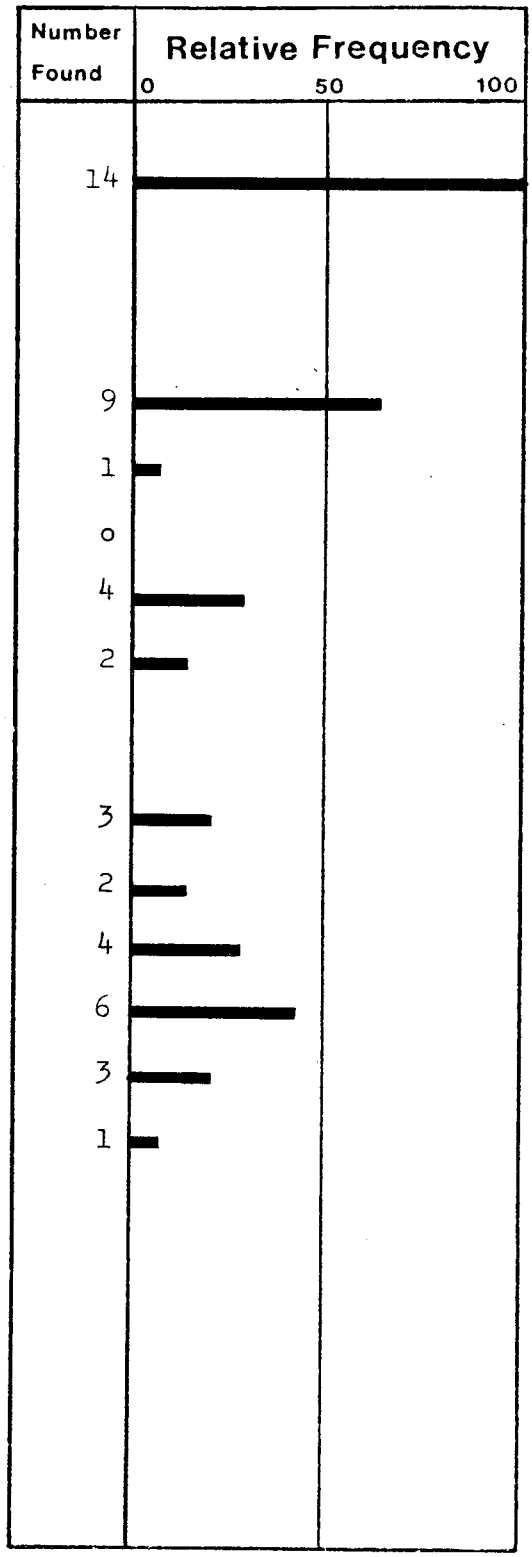
Table No. 1o.

Summary of Data Collection Sequences — Analog Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Sequences	17	
Collection Initiated Observation		
during:		
- functional search	1o	
- topographic search	2	
- check measurement	2	
- sequence is repetition of prev. coll.	2	
- evaluation of fault	o	
Use of Information		
- evaluate, hyp. "where to look"	5	
- evaluate, hyp. "what to look for"	12	
- evaluate, to test hyp. found in other ways	1	
- data recorded only	3	
- data recalled later	1	
- observations repeated later	1	

Table No. 11.

Summary of Data Collection Sequences — Digital Systems



	Number Found
Number of Sequences	14
Collection Initiated by Observation	
during:	
- functional search	9
- topographic search	1
- check measurement	0
- sequence is repetition of prev. coll.	4
- evaluation of fault	2
Use of Information	
- evaluate, hyp. "where to look"	3
- evaluate, hyp. "what to look for"	2
- evaluate, to test hyp. found in other ways	4
- data recorded only	6
- data recalled later	3
- observations repeated later	1

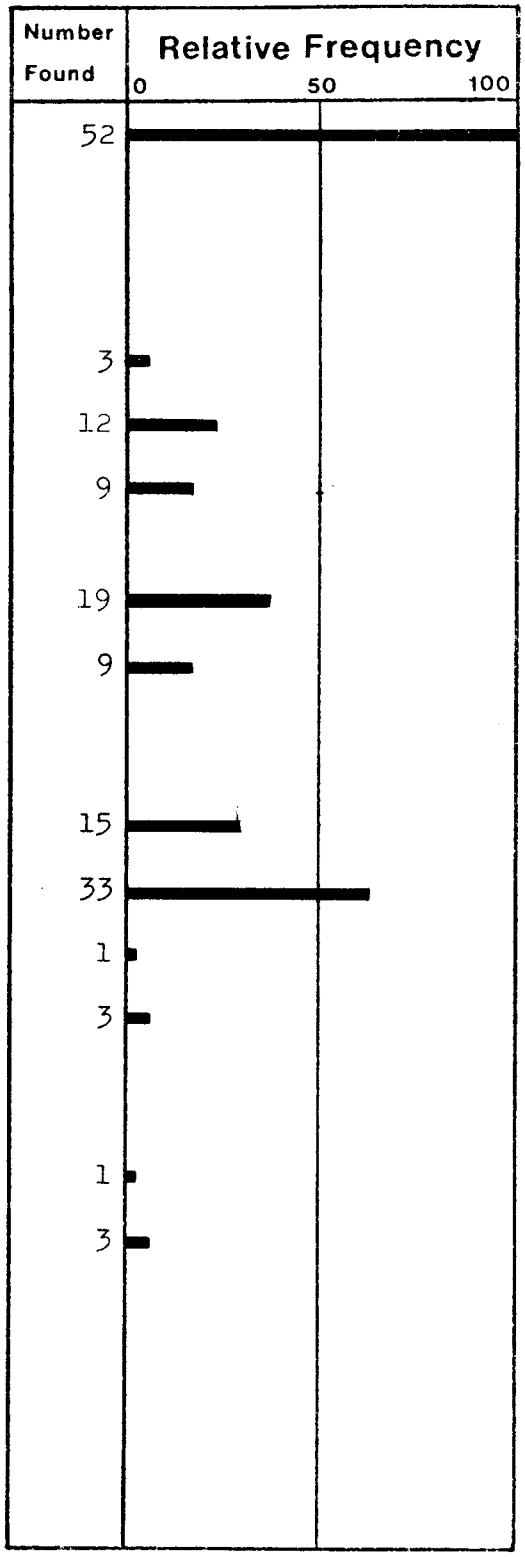
Table No. 12.

Summary of Data Collection Sequences — Total

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Sequences	31	
Collection Initiated by Observation		
during:		
- functional search	19	
- topographic search	3	
- check measurement	2	
- sequence is repetition of prev. coll.	6	
- evaluation of fault	2	
Use of Information		
- evaluate, hyp. "where to look"	8	
- evaluate, hyp. "what to look for"	14	
- evaluate, to test hyp. found in other ways	5	
- data recorded only	9	
- data recalled later	4	
- observations repeated later	2	

Table No. 13.

Summary of Check Measurements Analog Systems



	Number Found
Number of Check Measurements	52
Check Measurements Used to:	
- confirm topographic reference found by	
- functional search	3
- topographic search	12
- eval. of faulty response	9
- confirm hypothesis "what to look for" from evaluation of faulty response	19
- perform overall topographic search	9
Source of Norm Data for Judgement	
- data from diagram (wave forms or voltages)	15
- experience, familiar wave forms or voltages	33
- deduced from functional understanding	1
- normal data measured in other system	3
Observation of Mode of Failure Used	
- to derive hyp. "where to look" next	1
- to derive hyp. "what to look for"	3

Table No. 14.

Summary of Check Measurements Digital Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Check Measurements	23	
Check Measurements Used to:		
- confirm topographic reference found by		
- functional search	0	
- topographic search	4	
- eval. of faulty response	7	
- confirm hypothesis "what to look for" from evaluation of faulty response	7	
- perform overall topographic search	5	
Source of Norm Data for Judgement		
- data from diagram (wave forms or voltages)	3	
- experience, familiar wave forms or voltages	14	
- deduced from functional understanding	1	
- normal data measured in other system	5	
Observation of Mode of Failure Used		
- to derive hyp. "where to look" next	1	
- to derive hyp. "what to look for"	2	

Table No. 15.

Summary of Check Measurements — Total

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Check Measurements	75	
Check Measurements Used to:		
- confirm topographic reference found by		
- functional search	3	
- topographic search	16	
- eval. of faulty response	16	
- confirm hypothesis "what to look for" from evaluation of faulty response	26	
- perform overall topographic search	14	
Source of Norm Data for Judgement		
- data from diagram (wave forms or voltages)	18	
- experience, familiar wave forms or voltages	47	
- deduced from functional understanding	2	
- normal data measured in other system	8	
Observation of Mode of Failure Used		
- to derive hyp. "where to look" next	2	
- to derive hyp. "what to look for"	5	

topographically well-defined system parts, as determined from the graphical layout of the diagram or the mechanical layout of the system.

Only in a few cases a check is used to confirm the topographic reference obtained from a functional search.

The most frequent source of reference norm data is general electronic experience of familiar wave forms and bias voltages. Next in frequency are data from the circuit diagram. Again, only few samples are found where reference data have been deduced by functional reasoning.

In only a smaller part of the check measurements, the information observed describing the failure mode is used to derive reference to location (where) or nature (what) of the fault.

In their pure forms, topographic and functional searches and check measurements depend merely upon good/bad judgements of the data observed. Clearly a more specific determination of the fault from the observations will be possible if the information describing the actual mode of failure is taken into consideration.

6.5. Search by Evaluation

Search by evaluation of fault is used when the man derives the topographic reference from the actual faulty response. This derivation implies an analysis of the information observed with respect to the specific instrument and its actual state of operation. This transformation may be illustrated as:

Observation (i.e. data observed describing failed state) ⟶ Cause (i.e. what is changed in internal signals or functions) ⟶ Location (i.e. where is the faulty component resulting in the specific malfunction).

To be able to make such conversions, the man has to use mental models of the system relating changes in internal signals, parts, or components to the changes observed in system response.

Clearly such conversions will be much more varied in their individual appearance than are the routine search procedures. Also the complexity of the conversions varies greatly from rapid statements based upon recognitions from previous cases to more complex deductions based upon several parameters and careful consideration of the internal system functioning and anatomy.

6.5.1. Mental Model and Procedure used for Evaluation

Most of the conversions found in our records are rapid statements based upon general professional experience. For illustrative purposes a few examples are given below. The experience is classified here in three types related to (a) the specific type of system, (b) the general behaviour of electronic circuitry, and (c) the typical failure mode of components.

a. Experience of specific systems plays a less important role in our records than would be expected from "old boys in the trade", because the choice of systems during the experiments was such that it would not allow the man to go directly to the fault by mere recognition. This choice was made to study general features of the search procedures and thus avoid too much influence from experience characterizing a specific man - instrument relationship.

b. General electronic experience independent of the specific type of system. Typical samples are: Observation: Woolly or fuzzy wave form by oscilloscope measurement ⟶ what: mains ripple. Observation: signal compressed ⟶ what: short circuit. Observation: unstable wave form from flip-flop circuit ⟶ what: faulty trigger signal, etc.

c. Experience of component fault rate or mode, which is also independent of the specific system. Samples are: What: short circuit ⟶ where: cable connector. What: faulty triggering of flip-flop ⟶ where: trigger diode "blown". Observation: low bias voltage ⟶ where: short circuit in transistor.

Such statements are generally expressed as recognitions. The transformations based upon conscious reasoning related to internal functioning of the system are complex and difficult to keep pace with during verbalization, and the records only indicate the surface of the activity.

This fact, combined with the low number of cases, allows only very general and subjective attempts at classifying behaviour, but at least two groups of procedures seem to be used.

In one type the man seems to be working from inside the system outwards to the response in a way which could be illustrated as: Establish, by examination of diagrams or by memorizing, a mental model of the normal system anatomy, its signals and functioning. Then make a guess as to which signal or component might be involved in the faulty response. Modify the model accordingly and evaluate the resulting response pattern. Compare with the data observed to judge the relevance of the guess. The procedure may be called a mental functional search.

This sort of procedure is most clearly expressed when the hypothesis it not a guess, but when the fault is found by another search procedure and the result is tested against system response by functional reasoning.

In other cases, the man is working from response data into the interior of the system. The procedure looks like a mental topographic search: From the response pattern and an understanding of the system, the absence or presence of a normal signal or system state along a chosen search route is deduced by functional reasoning. The main difference from the normal topographic search is that the data, which are subject to individual judgement, are not measured directly, but deduced from the system response.

The functional and the topographic search routines in their stereotyped form are only able to give a topographic reference - to indicate where to look next. The search by evaluation of the fault is dealing with the actual internal functioning of the system and can therefore, in addition to a topographic reference, give information about what to look for (i. e. which signal to use for further search), or it may be used to confirm a topographic reference found by other means.

In our records we find that all the data observed by the men as part of a search sequence or a check measurement are almost immediately judged to be good or bad. However, derivation of a reference as to where to look next or what to look for from the data describing the actual mode of failure plays an important role in the decisions which link the more stereotyped search sequences together into a complete procedure. In an analysis of 35 records, a total of 110 instances have been found, which have been classified as evaluations of the fault mode to find reference to "where to look" or "what to look for". Nearly 80% of these evaluations are expressed as rapid statements based upon a single observation and upon general professional experience. Only about 20% indicates careful reasoning related to the internal functioning of the specific system.

30 of the records have been analysed in detail, and these records contain 87 evaluations, which are illustrated in tables 16 to 21.

As it is seen from tables 16 to 18 most of the evaluations in these records are expressed as rapid statements, based upon general electronic experience. The decisions are usually taken very rapidly, like recognitions, and only a single feature from the information obtained by a single measurement or observation normally supports the statements.

A smaller part of the evaluations is found to be more complex ones based upon a functional understanding of system function. In our cases the

Table No. 16.

Summary of Search by Evaluation of Faults — Analog Systems

		Number Found	Relative Frequency (0 – 50 – 100)
Number of Evaluating Routines		54	
Source of Data			
	- observations during functional search	15	
	- observations during topographic search	14	
	- observations during check measurements	8	
	- recall of observations	7	
	- repetition of observations	4	
	- result of a previous evaluation	6	
Amount of Observations Used			
	- data from only one observation	32	
	- data from more observations	15	
Procedure and Mental Model Used			
Recognitions	experience with circuit perform	19	
	experience with component perform	3	
	experience with specific system	12	
Functional reasoning	evaluation by mental top. search	2	
	evaluation by mental func. search	8	
	top. search by recalled judgements	4	

Table No. 17.

Summary of Search by Evaluation of Faults — Digital Systems

		Number Found	Relative Frequency (0 – 50 – 100)
Number of Evaluating Routines		33	
Source of Data			
	- observations during functional search	8	
	- observations during topographic search	11	
	- observations during check measurements	3	
	- recall of observations	4	
	- repetition of observations	4	
	- result of a previous evaluation	6	
Amount of Observations Used			
	- data from only one observation	16	
	- data from more observations	12	
Procedure and Mental Model Used			
Recognitions	experience with circuit perform	16	
	experience with component perform	2	
	experience with specific system	3	
Functional reasoning	evaluation by mental top. search	2	
	evaluation by mental func. search	8	
	top. search by recalled judgements	2	

Table No. 18.

Summary of Search by Evaluation of Faults — Total

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Evaluating Routines	87	
Source of Data		
- observations during functional search	23	
- observations during topographic search	25	
- observations during check measurements	11	
- recall of observations	11	
- repetition of observations	8	
- result of a previous evaluation	12	
Amount of Observations Used		
- data from only one observation	48	
- data from more observations	27	
Procedure and Mental Model Used		
Recognitions: experience with circuit perform	35	
Recognitions: experience with component perform	5	
Recognitions: experience with specific system	15	
Functional reasoning: evaluation by mental top. search	4	
Functional reasoning: evaluation by mental func. search	16	
Functional reasoning: top. search by recalled judgements	6	

Table No. 19.

Summary of Search by Evaluation of Faults Analog Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Evaluating Routines	54	
Result of Evaluations:		
- Hypothesis "where to look" Next	17	
- hypothesis tested by check	1o	
- component found by this check	6	
- reference used for top. search	1o	
- hypothesis followed by further eval.	o	
- Hypothesis "what to look for"	27	
- hypothesis tested by check	8	
- indicates parameter for other check	6	
- indicates parameter for top. search	1o	
- hyp. followed by further eval.	6	
- Test of Hypothesis Found in other Ways	5	
- Hypothesis Found Rejected by Check		
- return to previous activity	4	
- return to previous reference or hyp.	2	
- repeat previous activity	o	
- take a break, wait for ideas	1	
- Result of Evaluations Not Used	3	

Table No. 2o.

Summary of Search by Evaluation of Faults Digital Systems

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Evaluating Routines	33	
Result of Evaluations:		
- Hypothesis "where to look" Next	9	
- hypothesis tested by check	5	
- component found by this check	2	
- reference used for top. search	4	
- hypothesis followed by further eval.	1	
- Hypothesis "what to look for"	16	
- hypothesis tested by check	4	
- indicates parameter for other check	5	
- indicates parameter for top. search	3	
- hyp. followed by further eval.	7	
- Test of Hypothesis Found in other Ways	6	
- Hypothesis Found Rejected by Check		
- return to previous activity	1	
- return to previous reference or hyp.	1	
- repeat previous activity	2	
- take a break, wait for ideas	o	
- Result of Evaluations Not Used	2	

Table No. 21.

Summary of Search by Evaluation of Faults Total

	Number Found	Relative Frequency (0 – 50 – 100)
Number of Evaluating Routines	87	
Result of Evaluations:		
- Hypothesis "where to look" Next	26	
- hypothesis tested by check	15	
- component found by this check	8	
- reference used for top. search	14	
- hypothesis followed by further eval.	1	
- Hypothesis "what to look for"	43	
- hypothesis tested by check	12	
- indicates parameter for other check	11	
- indicates parameter for top. search	13	
- hyp. followed by further eval.	13	
- Test of Hypothesis Found in other Ways	11	
- Hypothesis Found Rejected by Check		
- return to previous activity	5	
- return to previous reference or hyp.	3	
- repeat previous activity	2	
- take a break, wait for ideas	1	
- Result of Evaluations Not Used	5	

"mental functional search" was used more frequently than "mental topographic search". These evaluations are based upon the original information observed. In some cases another form of "mental search" is explicitly mentioned: By recalling concluding judgements from previous search sequences, the man decides where to seek next by the exclusion of "good" fields or parts of the system. Such good/bad mapping of the system in a more subconscious form may control the search in even more cases.

6.5.2. Source of Data for Evaluations

The source of data used for search by evaluation of the fault can be observations made during topographical and functional search or measurements planned individually to give such information.

The most important source found in our records is observations which are also used for good/bad judgements during routine search, and in most cases the evaluation follows immediately after the observation.

A smaller part is based upon observations made during a previous stage of the procedure, and in such cases a repetition of the observations is as frequent as a recall of the data. In some cases the evaluation is followed by a further evaluation, e.g. a hypothesis of "what to look for" can be followed immediately by an evaluation and a hypothesis about "where to look".

6.5.3. Use of the Evaluations in the Procedures

Nearly half of the evaluations result in a hypothesis about what to look for. The use of this hypothesis seems equally likely to lead to: a) a further evaluation of where to look, b) a reference to the parameter for use in a topographic search or c) a reference to the parameter for a check measurement at a location determined by other means. Only the results of a smaller part of these hypotheses are tested directly by check-measurements.

Less frequent are evaluations resulting in a hypothesis "where to look next", and more than half of these are tested directly by check measurements. The hypothesis results in a) a topographic search. b) a reference directly to the faulty component as the final search in a local "stage", or c) in a single case to further evaluation to limit the possible location.

Of minor importance is the use of evaluations to confirm a hypothesis found by other means; e.g. the result of a topographic search is confirmed by evaluation of recalled or re-observed system response.

In some cases the resulting hypothesis from an evaluation is not used or is rejected by a check. In such cases the man is most likely to return to his previous activity, which was interrupted by the evaluation. If he is in difficulties, he may repeat previous activities or "take a break", waiting for "good ideas".

7. GENERAL ASPECTS OF SEARCH ROUTINES

The analysis of our records shows that, although the complete procedure used in a specific case depends strongly upon the type of instrument and upon the actual fault, the procedures can be broken down into a sequence of subroutines, which can be grouped into typical classes. The frequency of the different subroutines in our records is shown in figs. 1 to 3.

As already illustrated by the example previously discussed, the subroutines available to the men differ greatly along several characteristic dimensions, such as their generality, the complexity of the data handling procedure and the depth of system knowledge needed for support as well as the amount of observations used. In our context it is interesting to discuss these features in somewhat more detail.

7.1. Generality of Procedures and Depth of Supporting System Knowledge

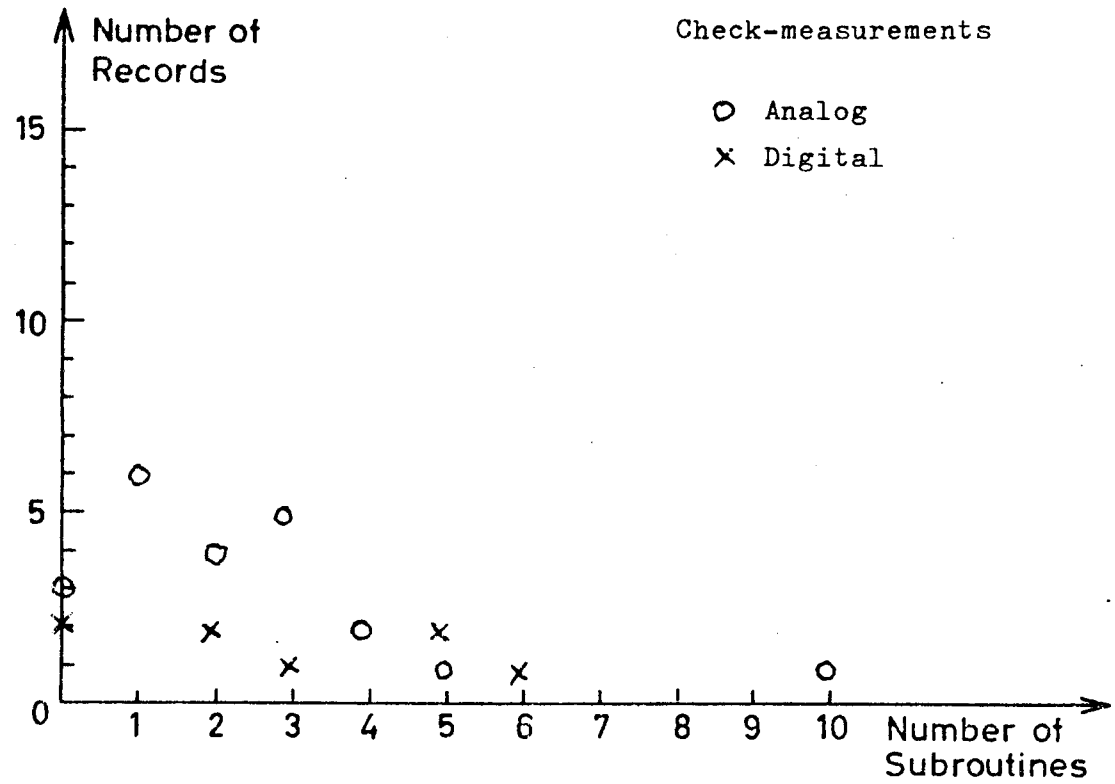
The mental data handling necessary in a co-operative man - machine endeavour implies that the man has available some sort of mental model of the system and a procedure to make this model operate upon the data observed. The mental model as well as the procedure may be supported by external means such as diagrams, drawings, instructions, and rules.

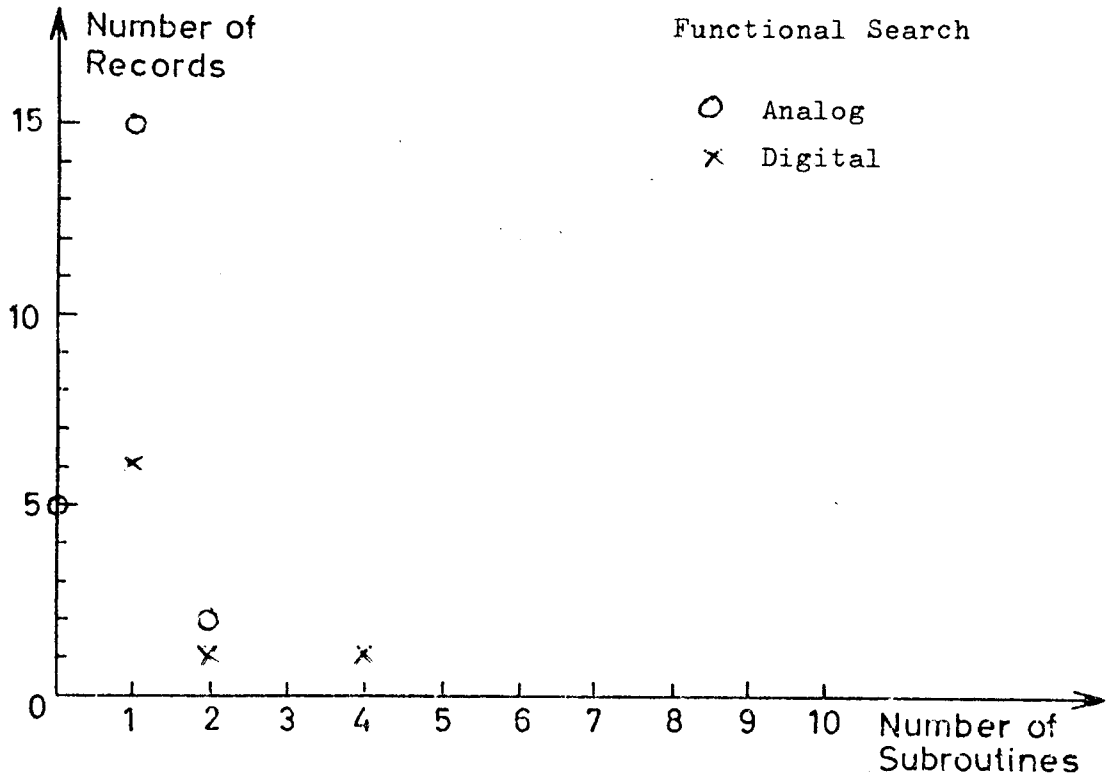
The previous discussion indicates that the mental procedures used in trouble shooting vary greatly in respect of the depth of system knowledge needed as support. At one extreme, the man has procedures which are based only upon very general professional training and experience; at the other, he has procedures available which call for very detailed knowledge of the specific system and the laws controlling its internal functioning.

In our experiments, the records demonstrate the men's great ability to get around their search problem by means of a sequence of general procedures mostly depending upon their general professional experience and background.

In a topographic search, the search procedure consisting of a sequence of good/bad judgements is very general. The model of the system

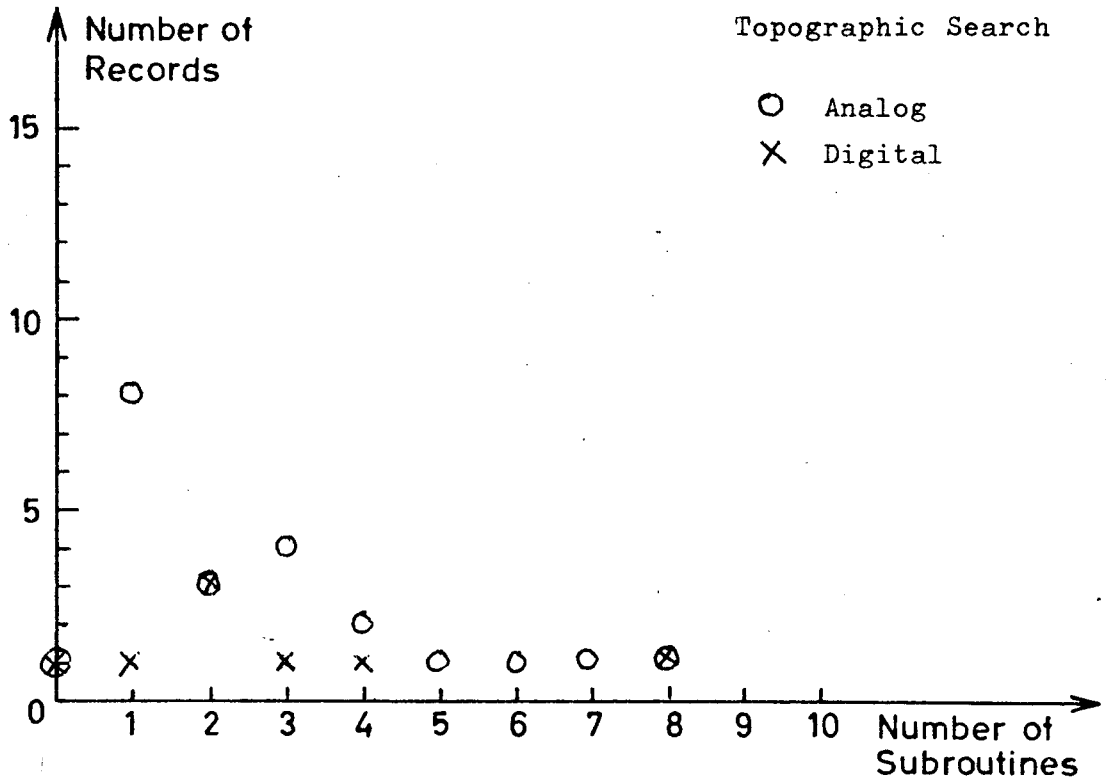
Fig. 1

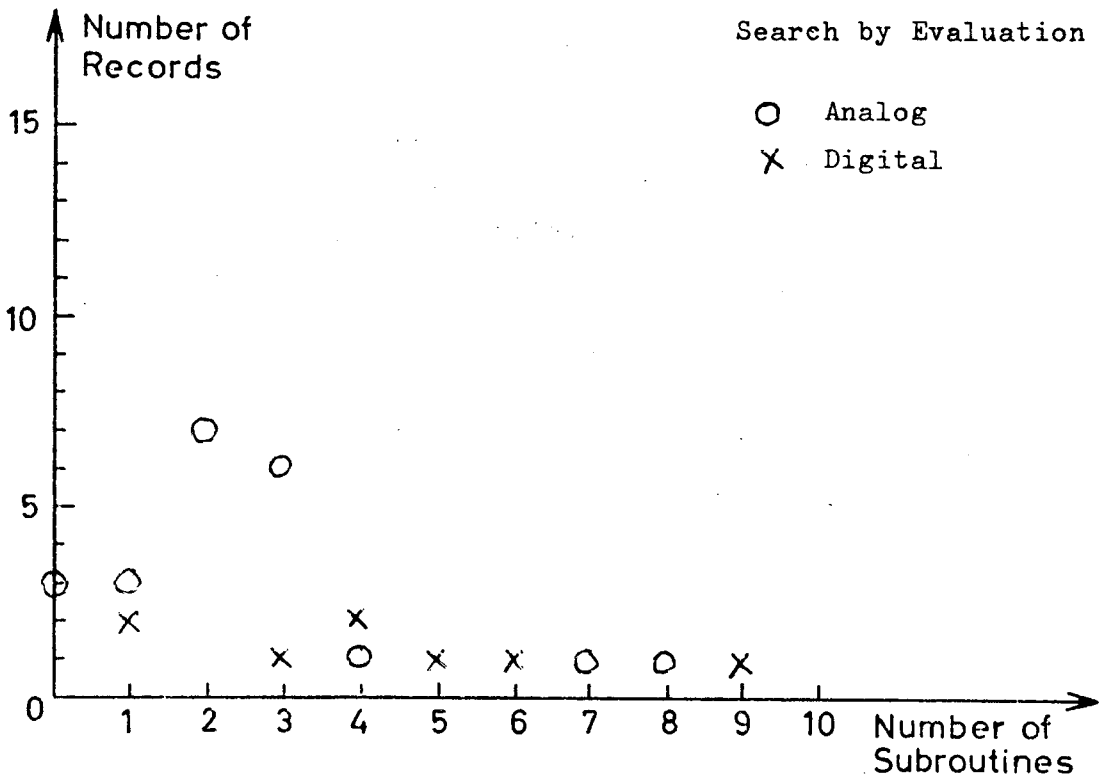




Histogram illustrating the distribution of search routines found in 3o records, which were analyzed in detail. The analysis covers 8 digital and 22 analog systems.

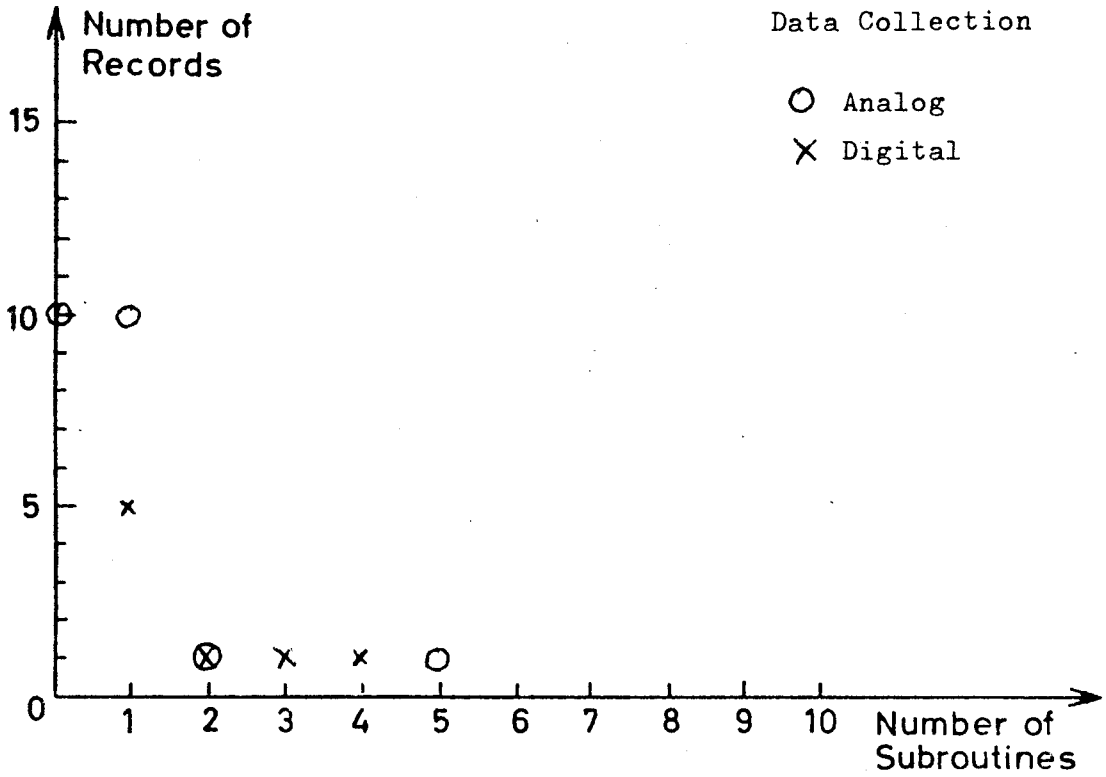
Fig. 2





Histogram illustrating the distribution of search routines found in 3o records, which were analyzed in detail. The analysis covers 8 digital and 22 analog systems.

Fig. 3



Histogram illustrating the distribution of search routines found in 3o records, which were analyzed in detail. The analysis covers 8 digital and 22 analog systems.

used for the search has to supply the man with an appropriate route for search and reference data for his judgements. If a circuit diagram is available which clearly indicates the main signal path and gives sufficient data for normal bias voltages and signals, the mental model needed by the man has only to support him in the topographic correlation between the diagram and the system. His mental model need only be based upon his professional experience with the visual appearance of typical components and circuits and with the normal layout of the circuitry. This is the case in practically all the topographic search routines found in our records. In 70% of the routines, the route is supported by the circuit diagram, which is viewed as a topographic map.

Appropriate routes for search or reference data for judgements may not always be immediately available in this way.

In such cases other types of search must be used, or the route and the reference data for topographic search must be planned or deduced from an understanding of the internal functioning of the system by employing a mental model of the specific system anatomy and functioning. This model is also normally supported by the circuit diagram, which is now seen as a functional description. Topographic search supported in this way is found only in very few of our cases.

Our records also show a clear ability in the man to base his functional search upon very general mental models of the system. The man will scan familiar features in the response by a sequence of good/bad judgements. If he meets a faulty response feature, a general "block-diagram understanding" of the system can refer the man to the related subsystem. If this is a topographically well-defined part of the system, his attention will immediately switch to this system in order to perform a routine search. Even when such faults were simulated so that the system response to the planners of the experiments clearly indicated possible short-cut methods if the internal functioning of the system was considered, the men normally used their general search routines.

Also in the search by evaluation of the actual fault mode, the records show a pronounced preference for the use of transformation models which are not closely related to the specific system, but based upon general experience.

Nearly 80% of the instances of fault evaluations found in our records are expressed as rapid statements and classified as a recognition based upon general professional background or experience. Only about 20% of the evaluations indicate more careful reasoning based upon a mental model

related to the internal functioning of the specific system.

Thus an interesting feature of the procedures found in our records is the pronounced ability demonstrated by the men to produce overall procedures based on general search routines which are not closely related to the specific instrument.

Scanning a high number of observations by simple procedures is clearly preferred to the preparation of specific procedures worked out by studying or memorizing the internal functioning of the system.

7.2. Redundant Observations and Impulsive Decisions

Other fundamental aspects of the procedures quite naturally follow the preference of the men for general methods not closely related to the specific system or its actual fault.

A general procedure cannot, of course, be based upon very detailed information found in the observations or measurements. In particular general methods cannot take advantage of information contained in the specific relations between several observations. This is clearly indicated by the general features of the procedures found in our records.

The functional and the topographic searches appear as functional or topographic good/bad mappings of the system.

Practically speaking, all observations are immediately judged to be good or bad, and only the results of the judgements normally control the next activity. In some cases, the parameters chosen for a topographic search cannot locate the fault, and information clearly indicating this may be recorded by the man prior to his decision to turn to that particular search. Often only the decision about where to look connects the routine to the previous search. During the search routines, no attention is paid to whether a measuring point will be informationally redundant or not.

When specific information related to the actual mode of the faulty function is used by the man, he seems generally not to have been looking for such information; instead, "something shows up".

Often, important information is merely mentioned "in passing" in a search routine, but sometimes it catches the attention of the man and causes him to switch to another procedure giving him a topographic reference as to "where to look" or hints about what to look for.

The dependence of the procedures upon individual observations and judgements corresponds to a general tendency found in the records. Instead of making overall plans for the search, the tendency is to make rapid or

impulsive decisions all along the search based only upon the information observed at the moment. This, of course, gives a very individual pattern to the different overall procedures found in our cases.

A main rule for the structuring of the procedures seems to be that as soon as an observation is found to give a topographic reference to a more restricted field for which a familiar search routine is at hand, a decision is taken to switch to that field, to follow the "way of least resistance".

There seems to be a "point of no return" in the attention of the man the moment he takes such a decision, as discussed by Bartlett (1958). Although more information indicating possible short-cut methods or important hints for the next search, is clearly available from the observation and is recorded by the man the decision prevents any influence from such information; hence the next search is a routine, starting from scratch.

The basic difference in the amount of data needed for the different procedures and in the complexity of the mental data handling task these procedures impose upon the man constitute important features of the various search procedures available to the men. There is a complementary relation between these aspects of the routines

The very general procedures are based upon a rapid stream of good/bad judgements, and call for a large number of observations which are treated individually and then left behind. The system is mapped in a rather systematic way by such judgements, and this seems to be a convenient way of remembering the results of past activities. A general impression is that during his search the man is well aware of his previous judgements.

However, the originally observed data are discarded without subsequent recall, but, in some cases, they seem to build up - unconsciously to the man - a sort of feeling in him; and later in the procedure this feeling can initiate hypotheses appearing as good ideas.

The very specific procedures based upon system anatomy and functioning require only a few observations, but the information handling is complex, and simultaneous treatment of several observations and a considerable carry-over of information may be needed in the short-term memory between the individual steps of the procedure.

7.3. Mental Load from the Procedures

This discussion focuses the attention upon mental load on the man during the task.

As discussed thoroughly by Bruner et al. (1967), the mental procedures chosen by the man may be strongly influenced by the constraints

he meets in his limited capacity for short-term memory and inference. The multiple-task nature of trouble shooting may make this an important constraint. On a time-sharing basis, the man has to formulate his route for search through the system by use of a diagram or by reasoning; he has to locate the route in the real system, to manipulate measuring devices, to establish norms for his judgements from diagrams, experience, or functional reasoning, and he has to keep track of his overall search.

Several indications of high cognitive strain are found in the records. A good example is a topographic search in a digital system performing logic operations when the man has to plan the route and produce reference standards for judgements by deduction from an understanding of the functioning of the circuitry. As discussed earlier he then has to maintain simultaneously, mental models at two different functional levels, and this is a considerable task. In this case, the procedure becomes slow and hesitating, and the man seems to be very insensitive to hints in the observations which would normally be familiar to him.

The records give several indications that difficulties in one of the subtasks tend to cause simpler procedures to be used in others. This should be taken into careful consideration when generalizing from clear-cut laboratory experiments with special equipment which eliminates all secondary subtasks.

7.4 Fixations in Routine Search Procedures

The records indicate that the men place a great deal of confidence in the experience showing that the general search routines will ultimately lead them to the fault.

If therefore a topographic search turns out to be unsuccessful and fails to result in a local search, which occurs in more than half of the attempts, the decision preferred is to repeat the search by another parameter. Typically, an unsuccessful search by DC-Voltage measurements is followed by an AC-sequence and vice versa.

If this search, too, proves unsuccessful there is a pronounced tendency to return to a search performed earlier. This, however, seems to be a repetition with more careful judgements of the observations rather than a more careful evaluation of the actual faulty function. This is especially true if the man repeats the initial functional search; even then there is little tendency to use specific short-cut methods based upon functional reasoning.

It should be stated that the choice of these methods is not due to any lack of ability to carry out functional reasoning, but more likely to the fact

that these methods are inherently attractive as they consist of fast sequences, which are normally successful in the end. The behaviour may be compared to that of most car drivers who prefer, when moving around in a big city, to drive along familiar main streets rather than preparing individual short-cut routes by means of a city map.

If the general search routines in special cases ultimately turn out to be unsuccessful, the man often seems to "be in trouble". When in trouble, there is a tendency to rely on good ideas which admittedly seem to appear in most cases after a break or a period of confusion, removing fixations.

Good ideas are difficult to trace. Sometimes, the man returns to deviations met in a previous search, but passed over without further consideration; sometimes he expresses "a feeling that something is wrong around here " - a feeling which has grown from slight indications during earlier search sequences. In some cases important information has been recorded several times during routine search without triggering his attention until a period of confusion sets in.

When in trouble, there seems to be no tendency to consider it worth - while studying by means of manuals or diagrams the functioning of the circuitry in greater detail.

During a discussion of the procedures found in the experiment, the technicians stated that as a rule they found the general search routines successful. Apart from a "block-diagram understanding" of the system - which supports the functional search - it was not considered worth-while studying the internal functioning of the circuitry. If you run into trouble, better take a break, wait until next day, or discuss the problem with a colleague.

Asked if they could suggest types of cases for which they would find it worth-while studying the internal functioning of the system in detail, the technicians said that would be the case if measurements of manipulations could have serious consequences, as in live warning systems - "when a siren is at the end of the wire" or if the working conditions on site are unpleasant, e.g. owing to bad smells as in chemical plants. A test case in connection with the level control system in a radioactive waste tank system resulted in a very "rational" procedure based upon a careful functional evaluation of the system response in advance and very few measurements on site.

We also suggested to the technicians that they use functional reasoning when in trouble in the normal repair shop environment. This, however,

did not cause any significant changes in the procedures used in the records made thereafter. The procedures seem to be so highly trained that they are difficult to change by suggestion of "better procedures". When a trouble shooting task is running, the man seems to be completely occupied by the task, and he does not "remember" the suggestion when difficulties arise. The test case with the waste tank system may indicate that, to change a procedure, the man has to consider the task in advance as one calling for special treatment.

7.5. Subjective Formulation of Task and Performance Criteria

We now turn to the role of the subjective formulation of the task and the performance criteria in the choice among the various search procedures available to the man.. This aspect is especially important since the formulation of the trained repair man may be basically different from that of a design engineer, who is after all very often responsible for preparing the working conditions for the repair man in the form of layouts of systems, instructions, and operating manuals and diagrams.

Our records clearly indicate that the task is defined by the men primarily as a search to find where the fault originates in the system.

He is faced with a system which he supposes has been working properly, and he is searching for the location of the discrepancy between normal and defective states.

He does not see his task as a more general problem-solving one in order to understand the actual functioning of the failed system and thus to explain why the system has the observed faulty response.

On the other hand, the design engineer does not in his normal work in a development laboratory think in terms of standards for normal operation, but considers it his task to understand the basic functioning of the system and to test observations, made during his experiment, against his conceptual intentions.

Are the procedures found in our records rational? What is rational depends upon the performance criteria adopted by the men. Normally a reasonable criterion for a maintenance technician is to locate the fault as quickly as possible, and only in special circumstances his criterion will be that of minimizing the number of measurements as discussed above. From this point of view, the procedures found in our records are rational since in most cases the faults were found within very reasonable times.

The system designer with his theoretical background may quite naturally value as rational the "elegant" deductive procedure which is infor-

mationally very efficient and based upon few observations, but this criterion is not the appropriate one on the basis of which performances in real life maintenance work can be judged.

It is important that system designers preparing working conditions and involved in the training of maintenance personnel become aware of these different possible task formulations and performance criteria and have some knowledge of the procedures available to trained repair men.

8. CONCLUDING REMARKS

In the present paper the mental procedures used by trouble shooters in their normal working conditions and studied by analysis of verbalized records are reported. A major result has been that procedures found unsystematic in a behaviouristic study may turn out to be rational and systematic in the light of the man's verbalizations.

The study shows that several different mental data handling procedures may be used by a man for the same real life task, and that verbalized records may be an appropriate tool for the formulation and separation of the procedures.

The nature of the procedures found in our records, being simple mental procedures related to a sequence of observations, may be especially suited for verbalization. We have indications that great difficulties will appear when verbalization is used to study highly trained tasks implying parallel processing of information by pattern recognition and subconscious routines as well as tasks calling for complex reasoning.

However, rapid sequences of simple decisions based upon informationally redundant observations may be more characteristic of human problem solving than one would suspect from psychologists' great interest in complex, rational problem solving.

The interest and co-operation of the electronics maintenance group in the trouble shooting experiments are greatly appreciated, as well as the contribution of P. Videriksen of the Institute of Applied Psychology, Directorate of Labour, to the planning of the experiment.

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APPENDIX A

Initial Analysis of the Microstructure

The initial analysis of the records was based upon a list of elementary operations. No great effort was spent in making a conceptually consistent list, but a list of events found to be typical of the procedures, judged from a review of some of the records, was prepared.

The records were then coded as a sequence of the elementary events, and a graphic computer print-out was made to facilitate a visual recognition of recurrent patterns of events. An attempt to analyze the sequences by print-outs of connectivity matrices gave only few results. Most important was the strong indication that all the observed data were immediately judged individually.

Categories of elementary operations

0 Manipulations (except measurements)

01 Prepare, turn on or open the faulty system.

02 Adjust the system to fit the model supplying norms for judgements.

03 Manipulate the system for a response test.

04 The system initiates manipulations, it offers tempting possibilities.

05 Replace a component.

06 Test of an isolated component.

1 Statement of the problem

11 Users' complaint is mentioned initially.

12 Users' complaint recalled later in procedure.

2 Planning

21 A procedure is planned and formulated.

22 A procedure is stated directly.

23 Judgement of the current procedure.

24 Decision to repeat a measurement or a procedure.

3 Model of the system is prepared

31	Memory,	support the formulation of a "model"
32	Measurements,	describing the normal functioning
33	Diagram or Manual	of the system.
34	Memory,	support the formulation of a "model"
35	Measurements,	describing the actual failed functioning
36	Diagram or Manual	of the system.

4 Conjectures and hypotheses are mentioned

41 Regarding normal functioning.

42 Regarding actual failed functioning.

43 Regarding general type or nature of fault.

44 Location of fault in system.

5 Measurements and observations

51 Data observed. Choice initiated by system.

52 Data observed or measured. Choice initiated by "model" of system.

53 Data observed or measured. Choice initiated by plan.

54 Data taken from diagram.

55 Data recalled from previous measurements.

56 Summary of measured data.

6 Topographic evaluation

61 Search in the system to find measuring points or components.

62 Topographic evaluation of the diagram.

63 Recall of familiar circuitry or components to support the orientation

7 Judgements

71 Individual test of data against norm data.

72 Set of data, response pattern tested as against "model" of system.

73 Direct judgement of response pattern; recognition.

74 Hypotheses, conjectures tested as against system by measurements.

75 Hypotheses, conjectures tested as against "model" of system by reasoning.

76 Visual inspection of circuitry.

8 Abstract mental operations

81 Counting.

82 Algebraic calculations.

83 Abstract logic reasoning.

9 Situations

91 Intervals, breaks.

92 Hesitation, memory weak, model insufficient.

93 Hesitation, inconsistency, that's odd!

94 Hesitation, what next?

95 Idea appears, information offered by diagram.

96 Idea appears, information offered by system.

97 Idea just appears. Eureka.

98 Confusion, cursing.

00 Special, individual events

"Models" of system controlling procedures and judgements:

T: Trained routines, pattern recognitions

E: Experience System knowledge obtained from previous cases

1. Related to general behaviour of components.
2. Related to general behaviour of systems and circuits.
3. Related to behaviour of specific type of system.

U: Functional understanding

1. Fundamental electronic knowledge.
2. Knowledge and understanding related to functioning of specific system.

R: External system "models" or descriptions

1. Diagrams, manuals.
2. Other similar system.

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↑G

.GO
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1L
CONT?
1M
OUT-T
/ SYMBOLTAPE. NR. 9.
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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
	30	-5	14	-2	24	-4	12	12	61	19	15	19	-9	-6	--	24	-4	27	27	34	60	-2	53
A	-6	--	--	--	-2	--	-1	-1	-6	-3	--	--	-1	--	--	-1	-1	-4	-4	--	--	--	--
B	--	--	-1	--	-1	--	--	--	-2	--	--	--	--	-1	--	--	--	--	--	--	--	--	--
C	--	--	--	--	--	--	-1	--	10	--	-1	--	--	--	--	-1	--	--	-1	--	--	--	--
D	--	--	--	--	--	--	--	--	-1	--	--	--	--	--	--	--	--	-1	--	--	--	--	--
E	-2	--	-1	--	--	--	--	-1	-7	-1	--	--	--	--	--	-4	--	-8	--	-3	10	-1	-7
F	--	--	--	--	-1	--	--	--	-1	--	--	--	--	--	--	-1	--	-1	--	--	-3	--	-1
G	--	-1	-1	--	-2	--	-1	--	-2	--	--	-1	--	--	--	--	-1	-1	-2	--	-8	--	-3
H	--	-1	-2	--	--	--	-1	--	-1	-1	--	--	--	--	--	-1	--	-2	-3	--	-9	-1	--
I	-1	-1	-3	-1	-1	-1	-2	-2	-3	-5	12	17	-5	-2	--	-4	-1	--	--	16	14	--	21
J	-2	-1	--	--	--	--	-1	-1	-6	-3	--	--	--	--	--	-3	--	-1	-1	--	-1	--	-4
K	-1	--	-3	--	--	-1	-1	--	-2	--	-1	--	-1	-1	--	-1	--	--	-3	-6	-4	--	-5
L	-1	-1	-2	--	-1	--	-2	-1	-1	--	--	--	--	-1	--	-3	--	--	-6	--	-9	--	10
M	-1	--	--	--	-1	--	--	-1	-2	--	--	--	--	--	--	--	--	-1	-3	-5	-1	--	-2
N	--	--	--	--	--	--	--	--	-2	--	--	--	-1	--	--	-1	--	--	-1	-4	-1	--	--
O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
P	-3	--	-1	--	-3	-1	--	-2	-7	-1	-1	-1	--	--	--	--	--	-4	--	--	--	--	--
Q	--	--	--	--	-2	--	-1	--	--	--	--	--	--	--	--	--	--	-1	--	--	--	--	--
R	-8	--	--	--	-6	-1	--	--	-5	-5	--	--	-1	--	--	-1	--	--	--	--	--	--	--
S	-5	--	--	--	-4	--	-1	-3	-3	--	--	--	--	-1	--	-3	-1	-3	-3	--	--	--	--

*

Fig. 4. Example illustrating the connectivity matrix used. Codes used are related to the elementary operations as shown in the list next page.

Codes in the connectivity matrix are related to the elementary operations as follows:

A:	01, 05, 06, 07	Manipulations, general
B:	02	Adjust system to model with norm data
C:	03	Response test
D:	1	Users' complaint mentioned
E:	21, 22	Procedure mentioned
F:	23, 24	Judgement of procedure
G:	3	Model of the system is prepared
H:	4	Hypothesis is mentioned
I:	5	Measurements taken
J:	6	Topographic orientation in system or diagram
K:	71+	Individual observation judged good
L:	71-	Individual observation judged bad
M:	72, 73, 74, 75, 76+	Set of observations judged good
N:	72, 73, 74, 75, 76-	Set of observations judged bad
O:	8	Abstract calculation
P:	91, 92, 93, 94, 98	Hesitation, doubt
Q:	95, 96, 97	Ideas Appear
R:		Subroutine starts
S:		Subroutine stops

T:	T	Procedure is trained routine
U:	E	Procedure controlled by general experience
V:	U	Procedure controlled by functional understanding
W:	R	Procedure controlled by diagram or manual

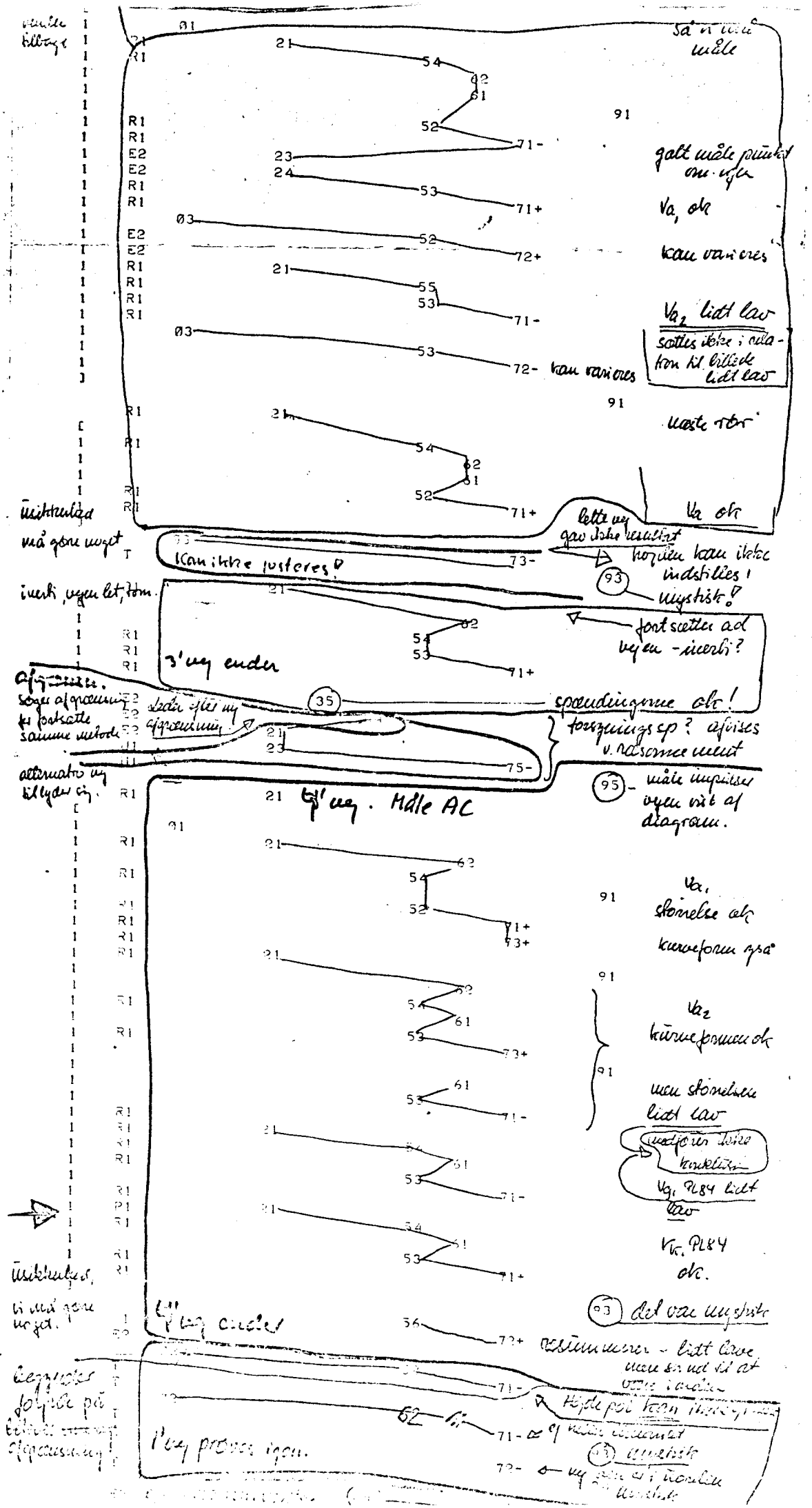


Fig. 5. Sample of a computer print-out of the sequence of elementary operations, used for identification of characteristic recurrent patterns to formulate subroutines.

APPENDIX B

Coding of the Records into Sequences of Subroutines

In order to have a convenient shorthand notation of the procedures, we have used a number of graphic symbols to illustrate the pattern of the individual records. Different codes are used to identify characteristic features of the individual subroutines. The graphic symbols and codes used are as follows:

Classification symbols:

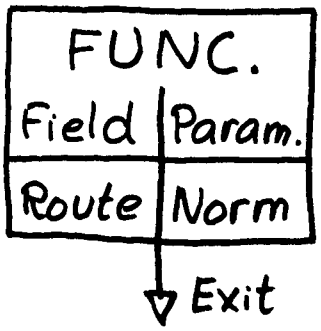
Functional search

Field: Indicates how the search field is chosen.
Empty space indicates that the field - as usually - is offered by system. Other references should be stated.
Parameter: Indicates the reference to the parameter used. Reference is only stated if parameter is not offered directly by system, e.g. external display.
Route: Indicates information used to support the sequence in which information is scanned. Only stated if not in the order of the visually most significant.
Norm: Indicates the source of norm data for judgements.

Codes: Di-da: Data from diagram, etc.
Exp: General experience
Fu: Deduction from understanding
Syst: Data from other system

Codes for exits:

Func: Reference to next activity from function
Fault: Data describing fault mode used
Jdg: Judgements used in subsequent activity



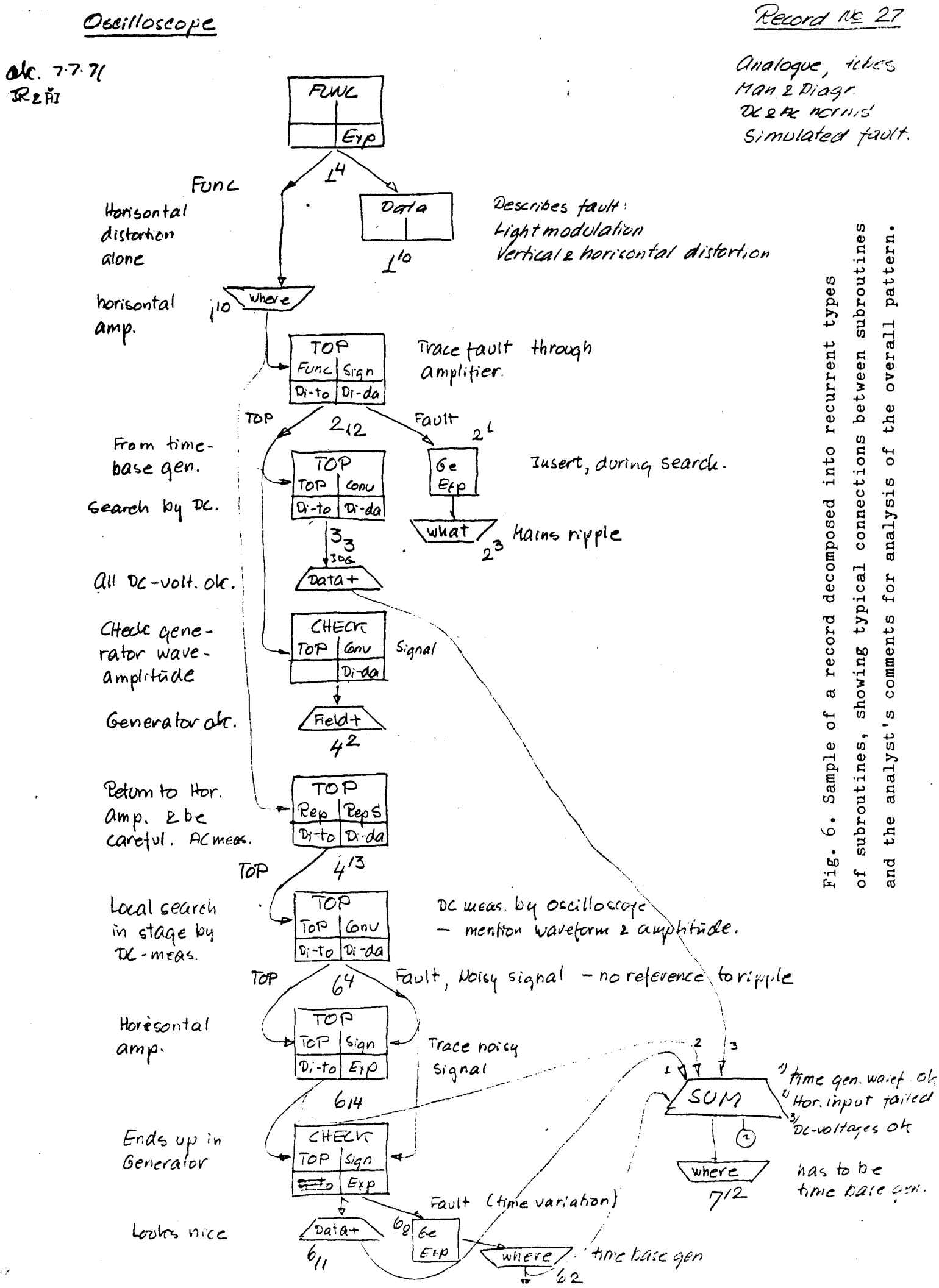
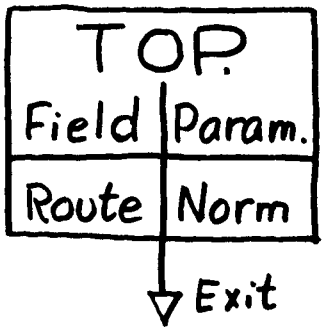


Fig. 6. Sample of a record decomposed into recurrent types of subroutines, showing typical connections between subroutines and the analyst's comments for analysis of the overall pattern.

Topographic search



Field: Indicates how reference to the search is obtained.

Codes:

Func:	Reference from function failed
Fault:	Reference from eval. of fault
Top:	Topographic reference
Plan:	Chosen from plan
Rep:	Repetition of prev. search

Parameter: Indicates how the parameter used is chosen.

Codes:

Sig:	Decision to trace signal
Conv:	Convenient norm available
Eval:	Chosen from evaluation
Rep S:	Decision to repete by same par.
Rep O:	Decision to repete by other par.

Route: Indicates information used to support the route of search

Codes:

Di-to:	Diagram topography
Di-da:	Diagram data
Exp:	General experience
FU:	Planned from functional understanding

Norm: Indicates source of norm data for judgements.

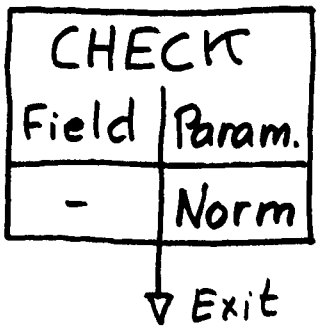
Codes:

Di-da:	Data from diagram etc.
Exp:	General experience
Fu:	Deduction from functional understanding
Syst:	Other system

Codes for exits:

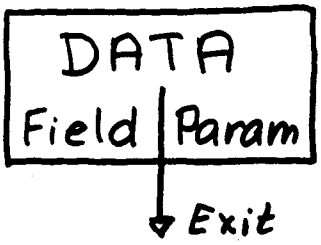
Top:	Reference to the field for the next activity found topographically
Jdg:	Judgements used in subsequent activity
Fault:	Observations describing fault, used later

Check measurements



Codes are the codes used for topographic search. Except that Route is not used.

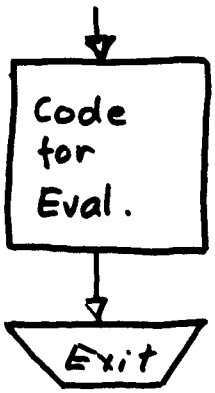
Data collection



Field: Data collection is normally observations supplementing current activity if not the reference to the field should be stated.
Parameter: Normally offered by the system; if not the reference should be stated.

Exit is only fault data

Search by evaluation of fault



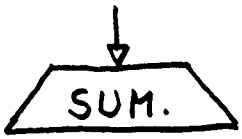
The procedure and system information used is stated by the code:

Ge Exp:	General electronic experience
Comp Exp:	Exp. with comp. fault mode and rate
Syst Exp:	Exp. with specific system
FU-Eval:	Mental functional search
Top-eval:	Mental topographic search

Codes for exits:

Where:	Hypothesis where is the fault; where to look next
What:	What to look for
How:	Plan for subsequent activity

Summary, concluding judgements



All subroutines can be followed by a summary, a review or concluding judgements.
Codes:

Sum:	Simple recapitulation

Field $\pm$ Data $\pm$ System $\pm$	Concluding judgements regarding the field, the data or the system. Result of judgement indicated by + or -
Proe $\pm$:	Judgement of current procedure
Hyp $\pm$:	Judgement of previous hypothesis

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