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SIMULATOR TRAINING ANALYSIS

A PROPOSAL FOR COMBINED TRAINEE DEBRIEFING AND PERFORMANCE DATA COLLECTION

E. Hollnagel
J. Rasmussen

Abstract. This paper presents a suggestion for systematic collection of data during the normal use of training simulators, with the double purpose of supporting trainee debriefing and providing data for further theoretical studies of operator performance. The method is based on previously described models of operator performance and decision-making, and is a specific instance of the general method for analysis of operator performance data. The method combines a detailed transient-specific description of the expected performance with transient-independent tools for observation of critical activities.

INIS Descriptors BEHAVIOUR; DATA ACQUISITION; EDUCATION; MAN-MACHINE SYSTEM; PERFORMANCE; REACTOR OPERATORS; REACTOR SIMULATORS

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INTRODUCTION

In the last couple of years there has, for obvious reasons, been a growing interest in the nuclear industry for the use of training simulators. The primary purpose of this has been to improve the education and training of nuclear reactor operating personnel. An additional purpose has been the wish to establish a vehicle for licensing and for renewing the license of operating personel. The desire has generally been to extend the repertoire of training simulators, both to increase the degree of fidelity and to permit the testing of of--normal situations. This desire has been matched by a development in hardware which has made the construction of larger and better simulators feasible. This, by the way, is not restricted to the nuclear industry. A similar trend may be found in other professions where simulators have traditionally been used, e.g. in aviation. Still, a simulator is considered to be a very expensive piece of equipment. This is so although the costs of establishing and using a simulator are only a fraction of what it costs to build and run a nuclear plant, and although a simulator may lead to substantial savings in the running expenses of a plant. Therefore the number of simulator hours available is clearly inadequate to meet the demand.

In this situation it may not seem very sensible to suggest that training simulators be used for other purposes besides training and licensing. But there are good reasons for doing so. First of all the growing interest in the use of training simulators has been parallelled by an interest in the design of a safe working environment, particularly the computer systems used for process control and disturbance analysis and the interface between the man and the machine. It is obvious for anyone who has studied e.g. the Licensee Event Reports from U.S. Nuclear Power Plants (cf. Rasmussen, 1980) that the behaviour of the operator is no less important for the shaping of events than the quality of the computer system is. The need for at better design of control rooms therefore makes it necessary that we get a better understanding of human performance - of the cognitive processes, of their nature and their structure - which form the basis for the operator's activities.

Secondly, the limited training simulator capacity makes it evident that any improvement of the efficiency of training simulators is of value. And since the primary purpose of a training simulator is training, anything which can improve the training should be given serious consideration. The suggestion put forward here is that the need for a better understanding of operator performance may be combined with the need for using the training simulators more efficiently. This is because the detailed psychological study of operator performance brings with it a repertoire of methods of servation and analysis, which may improve the daily use of a training simulator, without interfering with is. The following sections of this report will describe the details of this suggestion. It will be evident that the suggestion represents an integration of knowledge and experience from the study of real-life incidents, research simulator experiments, research on operator performance in a variety of situations, and cognitive psychology. The result is a guideline for a methodology which can easily be implemented in a concrete training simulator. The report concludes with a description of how such an implementation can be made.

THE PURPOSE OF USING TRAINING SIMULATORS FOR RESEARCH

In the investigation of operator performance there is no one type of situation, no one type of data, or no one aspect of performance which is logically more important than another. Some researchers may emphasize the influence of stress, some the choice of strategies, some the effect of the organization, etc. As long as it is remembered that these are aspects of the performance rather than the performance, all is well. Otherwise one might be tempted to conclude that if the operator is relieved of e.g. stress, then all problems will be solved; but this is obviously an unjustified simplification. Not even the assumption that human performance can be explained in terms of cognitive functions warrants the exclusion of any means of gathering information. Particularly in research, it is important to avoid the trap of premature conclusions and concep-conceptualizations.

Data Sources

Several different sources of data are at hand, each of them with particular features with respect to problems of data collection and the quality of data which it is practically feasible to collect. The data sources may belong either of two categories: nuclear power plants or just plants, and simulators of nuclear reactors. Within each of these categories one may distinguish several different types. It is, however, generally sufficient to make a distinction between the following four sources of data.

1. Routine event reports or plant events (PE). Examples of these are the U.S. Licencee Event Reports (LER) which are standardized reports about incidents in US nuclear power plants (cf. Rasmussen 1980). The raw data in plant reports are normally checklists and free text comments and concerned only with the incident in question. The plant event reports are, of course, only concerned with abnormal events or off-normal situations.

2. Special human factors post incident studies of events or plant interviews (PI). These represent a more thoroughgoing analysis of an incident by human factors (HF) specialists and technical specialists (cf. Pew et al., 1981). The raw data include, in addition to the raw data from the plant event, interviews with plant personnel, expert assessment

of critical parts of the incident, special checklists, computer logs and time line printouts, etc. The plant interviews are, similarly to the plant events, only concerned with abnormal events or off-normal situations.

3. Training simulators (TS). Training simulators are designed to train operators in a high-fidelity simulation of a work situation. It is the source of data which we shall be most concerned with here. They normally include a detailed replica of the control room in the corresponding nuclear plant as well as a faithful computer simulation of the plant functions. The raw data available from training simulators are normally computer logs and various automatically generated recordings of the operator's performance, as well as the instructor's evaluation thereof. This may be supplemented by checklists (for the instructor), debriefing interviews and discussions based on replays of critical situations, and possibly the operator's self-evaluation. Since training simulators are aimed at simulating work situations, they provide data about normal situations as well as abnormal situations. The operator must be trained to run the plant during normal production, but also to be able to handle various typical faults.

4. Research simulators (RS). Research simulators are designed for the study of operator performance during simulated real-life scenarios (cf. e.g. Hollnagel, 1981). A research simulator may be a modified training simulator or may be a specially constructed simulator. A research simulator normally simulates a typical plant rather than a particular plant, and the control room need not be a replica of any particular control room. Research simulators are quite often used to study experimental control rooms. The raw data available from a research simulator include the raw data available in a training simulator, but the recording of the data is normally more flexible, to honour the requirements of various special purpose investigations. In addition to this, research simulators may provide data

about operator verbalizations and comments including operator-experimenter dialogues tape recorded during the experiment, as well as data from self-confrontations, i.e. the operator's retrospective comments made during a replay of the experiment. Research simulators obviously provide data about normal as well as abnormal situations, although they normally use experimental sessions which are shorter than the training sessions in the training simulator. A considerable advantage of research simulators is that they may be used to study particularly important incidents, which either have happened or may happen.

In addition to this, the raw data in both research simulators and training simulators may include various other types of performance recording such as physiological measurements (EKG, GS, EMG, etc.), video-tape recordings, eye movement recordings, etc. This cannot be done for plant events and plant interviews. The reason for this is simply that in the latter cases one does not know in advance neither when to record something nor what to record. The convenient feature of simulators is that the instructor or experimenter knows in advance the nature of the disturbance the operators have to control and will be able to prepare for observations and interviews.

The relation between the various data sources and data types can be illustrated as shown in Figure 1. It is evident that training simulators in this way provide a sort of link between the real-life situations and the pure research simulators. It is the fortunate combination of a realistic task and working environment with a high degree of control, not only of what data will be observed but also of the disturbances that will occur.

TYPES OF DATA \ SITUATIONAL CONTEXT	PLANT EVENTS	PLANT INTERVIEWS	TRAINING SIMULATORS	RESEARCH SIMULATORS
CHECKLIST	■	■		
FREE TEXT COMMENT	■	■		
INTERVIEW		■		
EXPERT ASSESSMENT		■		
SPECIAL CHECKLIST		■	■	
COMPUTER LOG		■	■	■
TIME LINE		■	■	■
PERFORMANCE MEASUREMENT			■	■
INSTRUCTOR EVALUATION			■	■
DEBRIEFING INTERVIEW			■	■
"THINK ALOUD" & DIALOGUE				■
SELF-CONFRONTATION				■

TYPICAL RELATION BETWEEN DATA TYPES
AND DATA SOURCES (SITUATIONAL CONTEXT)

Figure 1.

THE IMPLEMENTATION OF RESEARCH IN THE NORMAL USE OF TRAINING SIMULATORS

The general purpose of a training simulator is, of course, to train the operators, i.e. to provide them with the knowledge and skills necessary for controlling the plant. The specification of what these skills shall be, the degree or extent of them, and the criteria by which they shall be evaluated are issues which may be quite problematic (cf. Wirstad & Andersson, 1980). We need, however, not be bothered by them here. We shall simply assume that we have available a sufficiently precise description or definition of what is required of the operator when he has finished the training, and instead be concerned with some essential aspects of the training and the use of TS. This means that we shall have to look at the role of the instructor as a <u>teacher</u> and the role of the operator as a <u>student</u> or <u>learner</u>.

As it was mentioned in the introduction, the general purpose of a training simulator may be supplemented by the purpose of <u>investigating operator performance in detail</u>. There is a practical need for a more detailed knowledge of operator behaviour and especially the psychological "mechanisms" which are assumed to lie behind the observed behaviour. It is important to note here that the <u>typical</u> psychological mechanisms are the objects of research, rather than the performance of individual operators. Among other things this knowledge is needed for the <u>analysis and explanation of so-called human errors</u>, as well as for the <u>planning and design</u> of new control and display systems. The primary sources for this knowledge have hitherto been reports from plant events and plant interviews (i.e. detailed investigations of a specific incident), and a few experiments using research simulators. The former provide a large number of cases of off-normal behaviour but with only a limited number of observations made in each case. The latter provide a small number of cases of normal behaviour with very detailed and comprehensive observations. The training simulators would be able to provide a considerable number of cases of both normal and abnormal behaviour in realistic environments with the possibility for detailed observations. This would obviously constitute an important source of knowledge. It will be argued in this presentation that the purpose of investigating operator performance, i.e. making a theoretical study, may be combined with the normal use of the training simulator without interfering with it. And further, that the inclusion of the theoretical study may be valuable for the normal use of the training simulator, because it puts more sophisticated means of analysis at the disposal of the instructor.

Training and feedback

The role of the instructor as a teacher and the role of the operator as a learner implies that the operator is informed by the instructor about his progress. The operator is in other words given feedback about his performance, and the quality of this feedback is crucial for his learning. If the operator does not get any feedback, he will not learn anything at all. This is a basic psychological fact which has been demonstrated in a large number of experiments (cf. Annett, 1969), and which also corresponds with common-sense knowledge -- a source of data which should not be disregarded. The better the feedback (sometimes also called KR or Knowledge of Results) is, i.e. the more detailed the knowledge of the result is, the easier it will be for the operator to assimilate it and to change or modify his performance. Accordingly, anything which increases the quality of the feedback will also contribute to the efficiency of the learning.

The feedback, or KR, may of course be provided from various sources, being either internal, i.e. from the person himself (for instance from his own judgement of the responses of the system), or external, i.e. from another person which has observed and evaluated the performance. In the case of a training simulator it is the task of the instructor to provide this feedback. The operator may, of course, to a limited extent be able to evaluate his performance himself and to learn something. That does, however, require that he is provided with information about a goal state and this must obviously be given by someone else. Therefore, even in this case the instructor is needed. Normally the instructor provides the description of the goal state together with the feedback. He does this based on his experience as an instructor, i.e. in his capacity as an expert with regard to the system, as well as based on the tools and methods he is supplied with. In all this he can, however, never guarantee that the operator learns anything but only that he is provided with an appropriate feedback. This is nothing peculiar to training , simulators, but something which is universally true for any kind of teaching.

Feedback and Faults

One important aspect of the role of feedback in teaching/learning is that feedback can only be given when there is a discrepancy between what happened and what was expected to happen, i.e. between what the operator did and what he should have done. In other words, the important situations are the ones where the operator does something wrong or incorrect. (Strictly speaking, one may also give the operator a feedback when there is no discrepancy, informing him that his performance was perfect. But since there was no discrepancy there can, by definition, be no learning, and we may therefore exclude this situation from our considerations here. But it certainly has influence on the operator's motivation to learn.) Whenever the operator does something which is wrong, i.e. whenever he makes a fault, he may be informed about this. The feedback may specify the nature and the extent of the fault, and the operator may use this to change his performance so that the discrepancy is reduced. It is therefore the faults the operator makes which acquire special interest in the training since these provide the best opportunities for improving his skills and knowledge. (In addition to this they are, of course, also very valuable for the theoretical study of performance.)

It is consequently of the utmost importance to provide a detailed feedback in the situations where the operator makes a mistake. This feedback must, however, be of a qualitative rather than a quantitative nature, i.e. it must describe and explain the mistake to the operator rather than simply measure it or point it out to him, The feedback must not only inform him that he did something wrong, but also provide him with knowledge of what he did wrong.

In this discussion, the terms of human error and mistakes have been used in the normally accepted meaning that the operator performs some inappropriate action on the system seen in reference to the normal, or expected or instructed action. Seen as "errors" they supply important information for training - which is related to feedback in the specific situation to the individual person.However, the errors can also be viewed as misfits between man and machine, operator and console. From this point of view, errors give important clues for improvements of the system, for new designs, since it from analysis of a number of cases, removing all individual features, will be possible to relate "errors" to general psychological mechanisms and aspects of the design of the system. From this general analysis guides to better designs of interface, as well as guides to better training systems can be derived.

Measurement and description

Measurement is basically an appraisal of a selected and predefined set of aspects of the performance by means of a quantified description. Normally, the aspects chosen are inherently measurable in the sense that they can be registered by a kind of measuring instrument, e.g. a computer or a questionnaire. If that is not the case, a set of procedures and criteria must be provided by means of which a value can be assigned to the aspect in question, which thus is made measurable. This is particularly relevant in the case of behavioural science, since behaviour is only rarely inherently measurable. Much of the traditional methodology in behavioural science is therefore concerned with providing methods, preferably automatic, for measuring various aspects of behaviour, e.g. in learning, communication, social interaction, knowledge, beliefs, etc.

Measurement is, however, not something which can be employed out of a context, and it is in particular dependent upon a proper description and classification. The measurement, in fact, cannot be better than the description and classification on which is is based. It is therefore logical that one should pay attention to the description rather than to the measurement. This is particularly so when one is concerned with operator mistakes (but also operator performance in general). Operator mistakes are, by definition, unique, hence heterogeneous rather than homogeneous and alike. They are peculiar to the individual situation in which they actually occur, although one may find common features when a theoretically based description of the formal and prototypical performance is given; that is precisely one of the aims of the theoretical study. But for the operator the mistake is unique and it should therefore be treated as such by the instructor. Operators are individual persons who want to learn, rather than a set of subjects whose behaviour must be shaped in a common mold. Quantitative measurements or rankings are therefore of a very limited value. Ideally, the mistake can only be understood in terms of the operator's strategies and mental models of the system. These may, however, be quite laborious to identify and describe, and will certainly influence, if not directly interfere with, the normal use of the training simulator. It is a task which is better accomplished by means of a research simulator. Instead one can give a "detached", i.e. non-evaluative description of the operator's performance, based on the theoretical concepts used in the more elaborate forms of analysis.

Performance descriptions and TS

Such a detailed performance description is, however, not something which is parts of the normal functions of the instructor in training simulators. Not that a good instructor may not be able to provide such a description, but it is not included in the procedures explicitly described and rather something the instructor does because he has the knack for it. In contrast to this the detailed analysis and description of the performance is something which directly is a part of a theoretical study, i.e. the detailed investigation of operator performance. It is because of this that the theoretically based analysis may supplement the normal work of a instructor. The theoretical study is aimed at the description of the prototypical performance, i.e. what an operator typically would do in a given situation as well as why he would do it. And this description of the prototypical performance is of course based on a description of the actual performance, i.e. what the operator did in the situation.

<u>In such a performance description it is not of interest simply to measure operator performance or to rate or compare performances</u>, let alone compute averages or other indicators of the operators as a group. That would completely miss the point of giving the description, which is to provide the operator with a detailed feedback about his performance, specifically the mistakes he made. It is clearly not the average performance of the group which is of interest. It is rather the formally described performance of an operator based on the observations made during the training. Thus the purpose of the theoretical study is in correspondence with the purpose of the practical use of the training simulator in the sense that <u>neither puts any emphasis on quantitative measurement, but rather aims at providing a detailed description of the performance</u>. In this respect the theoretical study posseses in advance a repertoire of methods and techniques, which may be used by the instructor and assist him in his function as a teacher.

THE GENERAL METHODOLOGY IN DESCRIBING AND ANALYSING OPERATOR PERFORMANCE

We have in the first sections considered the place of training simulators in relation to the various sources and types of data, and also discussed some general but essential aspects of providing a description of simulator performance. In this section we shall take a closer look at the common steps in the analysis of human performance data, before going over to the special case of training simulators.

Just as the types of raw data may vary from one context to another, so may the purpose of the analysis of the raw data depend on the context. In event reports, plant events, the purpose is to identify the characteristics of the situation and of the event which adequately account for what occurred, to identify possible needs for improvement of work planning or instructions. In plant interviews, the purpose is to identify the critical decision sequence which led to the observed performance. This is not radically different from the purpose of plant event analysis, although training simulators the emphasis may be put on an understanding of human performance rather than the correction of specific work conditions. In training simulators the purpose is normally to improve the training by improving the feedback the instructor can give to the operator. And in research simulators the purpose is either to gather data about a particular problem or piece of equipment, or to evaluate a specific hypothesis or assumption. This means that the way in which the raw data are analysed depends upon their type as well as the purpose. A recent paper (Hollnagel et al., 1981) has described how one may derive the various modes of analysis from a common description, which can be characterized as follows:

- Raw data. This is the basis from which the analysis is made. Some examples of various types of raw data have been mentioned previously and were summarized in fig. 1. The raw data may be regarded as performance fragments, in the sense that they do not provide a coherent description of the performance, but rather the necessary building blocks or fragments for such a description.

- Intermediate data format. This represents the first stage of processing of the raw data. In this stage the data are combined and ordered along a time line, to provide a coherent description of what actually occurred. It is thus a description of the actual performance but given in the original terms, i.e. as a professional rather than an expert description. The language used is the language from the raw data, rather than a refined, theoretically oriented language.

  The step from the raw data to the intermediate data formats is relatively simple, since it basically involves a re-arrangement rather than an interpretation of the raw data. Hence special translation aids are not required.

- Analysed event data. In this stage the data in the intermediate format, resp. the raw data, have been transformed into a description of the task or performance using formal terms and concepts. These concepts reflect the theoretical background of the analysis, typically a combination of an information processing theory and a theory for decision making. The description of the performance is still ordered along a time line which is specific to the situation in question. The transformation has, however, changed the description of the actual performance to a formal description of the performance during the specific event.

  The step from the intermediate data format to the analysed event data may be quite elaborate, since it implies a theoretical analysis of the actual performance. The translation is one from operator task terms to formal terms. The emphasis is also changed from providing a description to providing an explanation as well. Special translation aids (tools, methods, and concepts) are therefore required. In the normal use of a training simulator, i.e. as a training tool, the analysis will normally be carried no further, since this is the level where a feedback may best be given.

- Conceptual descriptions. At this stage of the analysis, the description is no longer specific to a particular event but rather aimed at presenting the common features from a number of events. By combining formal descriptions of performances one may end up with a description of the generic or prototypical performance. The prototypical performance may still be described as a sequence of activities ordered along some time line, but this is rather a time axis than a time line referring to an actual situation. On the other hand, a description of the performance in a specific event may be seen as an example or a variation of the prototypical performance. Thus generic descriptions of human error mechanisms are, in fact, descriptions of typical deviations from the prototypical performance. Therefore the validity of the prototypical performance may be tested either by determining whether a given formal description of an actual performance, i.e. a given case, can be subsumed under the prototypical performance, or by testing predictions of typical performances made from the prototypical performance.

  The step from the formal to the prototypical performance is again one which is quite elaborate involving a many-to-one comparison and translation. It therefore requires not only a number of special translation aids but also a considerable experience with the analyst. He has to provide a description, based on generalizations from specific events, which permits the prediction of the typical performance in specific tasks.

- Competence descriptions. This is the final stage of the analysis which combines the conceptual description with the theoretical background. The description of competence is concerned with the basic concepts, such as mental models, decision strategies, performance criteria, preferences, problem solving strategies, etc. which in a given situation are combined to produce the performance. The description of competence is context-free; it is a description of the behavioural repertoire of the operator independent of any particular situation - though, of course, still restricted to a certain class of situations. As soon as a context is provided, the description of the competence can become a description of the prototypical performance and, pending further information, a description of the typical performance. The competence description is thus essentially the basis for identification of the content of the training required for a given interface as well as an important guide for design of new systems.

As before, the step from the conceptual description to the competence description may be quite elaborate and require that the analyst has a considerable knowledge of the relevant theoretical areas as well as a considerable experience in using that knowledge. It is not so much a question of knowing particular tricks and tools, as of being able to consider the conceptual description in a broad theoretical context. He has to provide a description in task-independent terms of the generic strategies, models and performance criteria which lie behind the performance.

The various steps in this common analysis are shown in Figure 2. As mentioned, the particular mode of analysis which is used in a particular context will be derived from this common description. (In terms of its own categories, it is therefore a prototypical description of the analysis.) In the case of training simulators the analysis of interest for the instructors will normally stop when the level of formal performance has been reached. This is because the benefit of a continued analysis, in terms of the improved quality of the feedback, will not outweigh the costs. For the purpose of the theoretical study, however, the analysis must be continued. This will typically be done by the HF specialist and not by the instructor. It does furthermore not have to be done in connection with the training but may take place off-line, so to

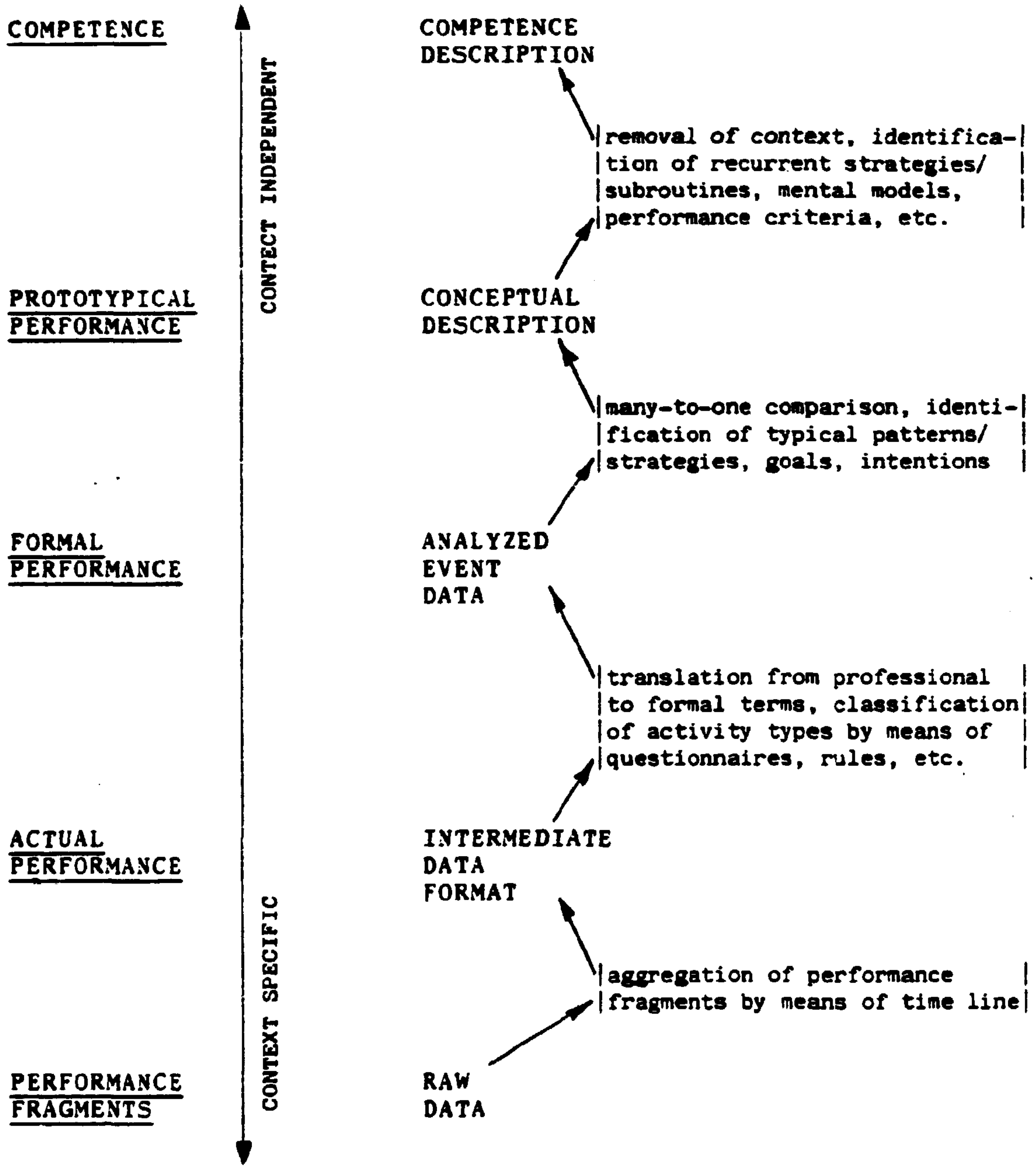

ILLUSTRATION OF THE STEPS
IN THE COMMON ANALYSIS OF DATA

Figure 2.

speak. But it does, of course, rely upon the data obtained in the training session and the preliminary analysis. However, in this analysis any reference to the individual operators can be removed. The analysis for the training is, in other words, a subset of the analysis for the theoretical study. This is an important reason why the theoretical analysis does not interfer with the normal use of the training simulator. It rather takes over where the former ends.

THE SPECIFIC ANALYSIS OF TRAINING SIMULATOR PERFORMANCE

In this section a detailed description of the various steps in the analysis of training simulator performance will be given up to and including the level of formal performance. The further steps in the analysis used in the theoretical study need not be considered here (but cf. Hollnagel et al., 1981, for a description). The steps presented here are a combination of the method used by Pew et al. (1981) and the method developed and used in the Scandinavian NKA/KRU Project (Hollnagel, 1979, 1980 and 1981).

The method

The method is divided into two principal parts, the preliminaries to a simulator session and the actual session. The method as a whole may be described as consisting of several steps, cf. the descriptions in the above mentioned sources. From the work of Pew et al. only the first parts concerned with data collection and analysis are considered. The last parts dealing with the multi-attribute analysis based on expert judgment are excluded since they are irrelevant for the present purpose.

1. Selection of the events to study

The event sequences to be studied are selected from the set of transients and disturbances which are available for training of operators. To develop the method, it is recommended that one simple and one more complex event are selected for pilot experiments in cooperation with interested training instructors.

The events chosen need of course not be from the training program, but may include events which are interesting for other reasons. Simple events are naturally more easy to analyse than complex events, but in principle there is no difference in the way in which the analysis is performed.

Examples of such events are the following, which were suggested for use in the Browns Ferry nuclear plant training simulator (Bockhold & Roth, 1978).

1. Achieving reactor criticality from a shutdown.
2. Reactor Scram from 50% power.
3. Plant startup from hot stand-by.
4. Main steam isolation valve closure, following a generator trip and reactor scram.

For comparative study at several simulators, EPRI has considered the following list:

1. Loss of Main Feed.
2. Steam generator tube rupture with loss of condensor.
3. Charging line break inside containment.
4. Steamline break inside containment.
5. Feedline break inside containment.
6. Pressurizer Level Master controller failure low.
7. Feedline break with failed SG safety, failed motor driven auxilliary feed pumps.
8. Turbine trip with stuck open steam dump valve.
9. Small LOCA with failed rad. monitors.
10. Stuck open pressurizer spray valve.
11. Feedline break with failed pressurizer PORV on repressurization.
12. Steam generator tube rupture with failed rad monitors and loss of offsite power.

13. Pressurizer level control failure - high charging flow.
14. Spurious SI followed by LOCA.
15. Steam generator level control failure.
16. Steam generator tube rupture with stuck open steam generator safety valve.
17. Loss of main feed, loss of all auxilliary feed.
18. Turbine trip, no reactor trip (auto or manual).

2. Description of transient and related operator procedures

A time line description of the transient, i.e., the chain of events in the technical system and the proper operator actions, is prepared from a training simulator print-out of a normal or successful sequence. The time line should include characteristic equipment responses, operator actions together with information available on the display console.

Together with experienced training instructors, typical erroneous operator actions should be identified from prior training sessions. For each of these actions or mistakes the related response of the (simulated) plant should be determined. That will make it possible to construct the sequence of actions which typically will occur for a given type of mistake. If possible, this may be expressed in the form of a generic decision tree which thereby provides a description of the predicted prototypical performance.

Properly speaking the description of the state of the (simulated) plant should be done according to the principles for cause-consequence analysis (cf. Nielsen, 1974). This would yield a detailed statement of how a fault can develop, what consequences it may have and what influence previous and/or extraneous conditions may make. A complete cause-consequence analysis would be a very useful supplement to the description of the procedures, since in a sense it would make it possible to give two parallel descriptions: One of the operator's activities, and one of the status of the system corresponding to the activities. It is, however, a rather complicated and extensive undertaking and therefore out of the question for the normal use of a simulator; and apart from that, all the data needed may not be available. Fortunately, it is not strictly necessary. Instead, one may take advantage of the simulator as a controllable system. Rather than making a paper-and-pencil cause-consequence analysis one may simple run the simulator through the specific faults, and observe what happens. This is obviously feasible in the cases where one can specify the expected formal performance or the generic decision tree for the prototypical performance. In those cases one can also try them out in advance, hence know what the responses of the simulator will be.

Although one must forego the cause-consequence analysis it will still be possible to identify the critical decision points and to explicate the corresponding responses of the simulated plant. This information should then be used to prepare computer recording and replay/debriefing, together with forms to facilitate instructor observations and comments during the transients.

This phase of the preparations is quite important since it lays the ground for the feedback the instructor must give. Formally, the feedback is the deviation of the actual performance from the expected performance. In reality there is probably not a detailed moment-by-moment description of the expected (formal) performance. That might also tend to narrow the instructors point of view. The purpose of this phase is rather to prepare the instructor for the critical parts and critical decisions of the performance so that he may better pay attention to them. His descriptions will certainly also be improved if he has access to a structured scheme of reporting his observations. A systematic description of the performance will also facilitate the following translation from the raw data to the analysed data, hence improve the simulator as a training tool.

3. Training Session

During the training session a computer log is recorded with relevant details related to the critical decision points, cf.

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        OPETUSJAKSON YHTEENVETORAPORTTI                                            80-12-03 KLO 10.00    SIVU  3
        *******************************

                                             08.37.09 * SD32P001      LAUHDUTIN     P  BAR      <  0.1500E-
                                             08.37.40 * RL10L002     SYOTTOVESISAILIO RL10  L >    2.700
                                             09.00.21 * SP10E002     GENERAATTORI SP10     EP >    235 0
                                             09.03.32   SD32P001      LAUHDUTIN     P  BAR      <  0.1500E-
                                             09 06.10   YX13X001     REAKTORIN PROSENTTITEHO  <    70.00
                                             09.06.22 * YX13X001     REAKTORIN PROSENTTITEHO  <    70.00
                                             09.06.32   YX13X001     REAKTORIN PROSENTTITEHO  <    70.00
09 06.59      HAIRION 012 AKTIV HF00              0.0
09.08.26      HAIRION 012 PASSIVOINTI HF00   09.07.29   RL10L002     SYOTTOVESISAILIO RL10  L >    2.700

                                             09.09.12   YP10L002     PAINEENTASAAJA         L <    3.500
                                             09.10.22 * YX13X001     REAKTORIN PROSENTTITEHO  <    70.00
                                             09.12.31   RL50L002     SYOTTOVESISAILIO RL50  L <    2.300
                                             09.12.40   SP10E002     GENERAATTORI SP10     EP >    235 0
                                             09.13.02 * YP10L002     PAINEENTASAAJA         L <    3 500
                                             09.14.01   YX13X001     REAKTORIN PROSENTTITEHO  <    70.00
                                             09.15.09   YP10L002     PAINEENTASAAJA         L <    3.500
                                             09.23.51 * YX13X001     REAKTORIN PROSENTTITEHO  <    70.00
                                             09.23.59   YX13X001     REAKTORIN PROSENTTITEHO  <    70.00
09.20.34         JAADYTYS
            AJASSA SIIRTYMINEN
09 20.03    KAYNNISTYS
09.20.22         JAADYTYS
09.20.22    KAYNNISTYS
09.20.54         JAADYTYS
            AJASSA SIIRTYMINEN
09 15.04    KAYNNISTYS
                                             09.10.04 * RL50L002     SYOTTOVESISAILIO RL50  L <    2.300
                                             09.10.04 * SP10E002     GENERAATTORI SP10     EP >    235 0
                                             09.10.19 * YX13X001     REAKTORIN PROSENTTITEHO  <    70.00
                                             09.12.33   RL50L002     SYOTTOVESISAILIO RL50  L <    2.300
                                             09.12.45   SP10E002     GENERAATTORI SP10     EP >    235 0
                                             09.14.26 * SP10E002     GENERAATTORI SP10     EP >    235.0
                                             09.14.40   YX13X001     REAKTORIN PROSENTTITEHO  <    70.00
09 15.39         JAADYTYS
```

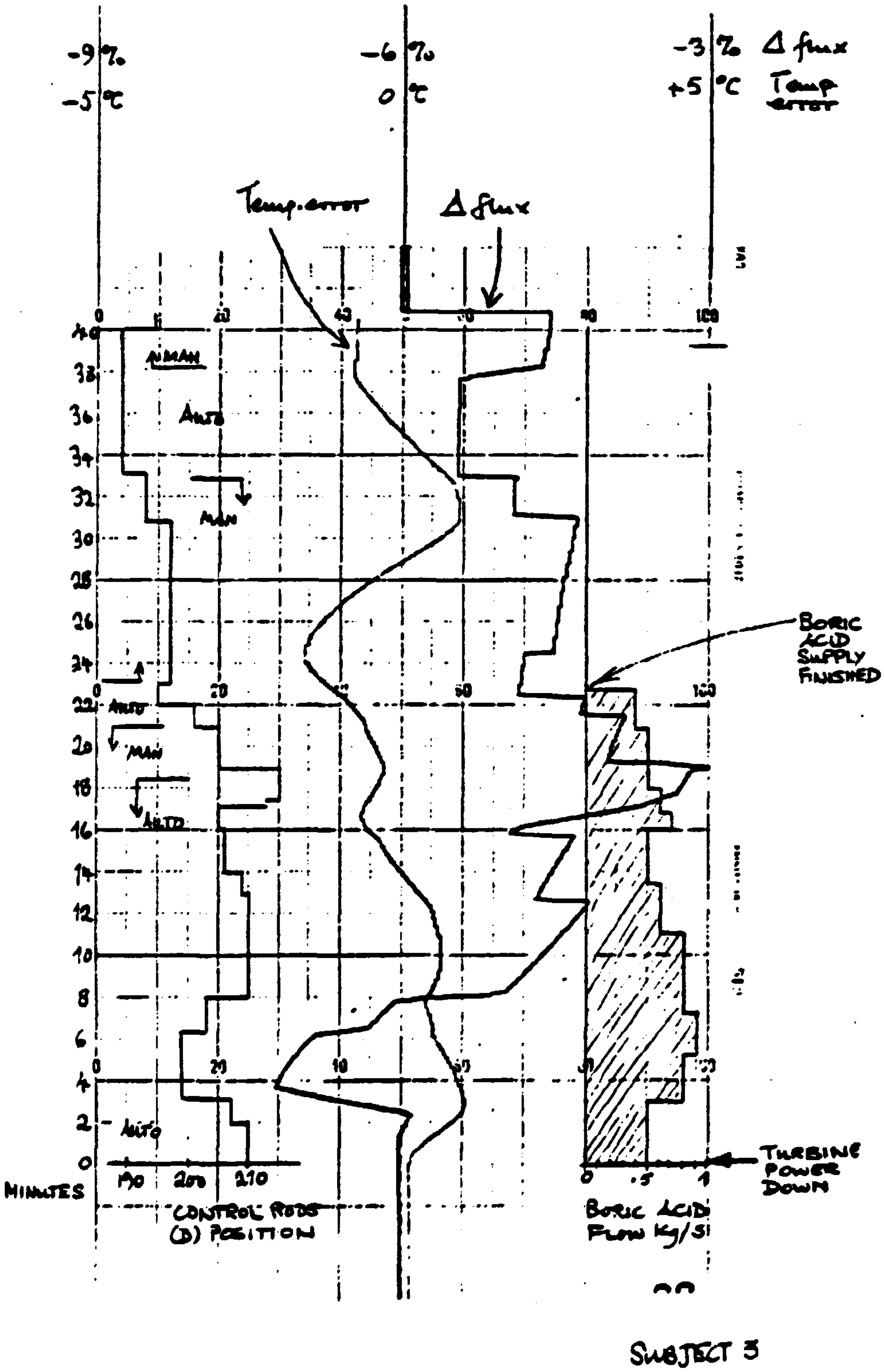
OPETUSJAKSON YHTEENVETORAPORTTI — 80-12-03 KLO 11.12 — SIVU 1

****

OPETUSJAKSO	PCPIN PYSAYTYS JA KAYNNISTYS
ALKUTILANNE	AT19 TEHOAJO 440 MW 3.12
SIMULOINTIAIKA	KLO 10.03.30 - KLO 11.12.04
PARAMETRIT	VA01T001 MERIVEDEN LAMPOTILA T ° 10.0 °C
	ZZ61A001 REAKTORIN PALAMA 0-100% 0.0 %

SEURANTASUUREET		YLARAJA	ALARAJA	MAKSIMI	MINIMI	YLITYKSIA	ALITUKSIA
YX13X001	REAKTORIN PROSENTTITEHO	100.0	70.00	97.89	40.14	0	3
YA15T901	JAAHDYTTEEN KESKI-T	290.0	250.0	280.2	267.9	0	0
YP10L002	PAINEENTASAAJA L	4.800	3.500	4.400	3.193	0	1
YB13L005	HOYRYNKEHITIN YB13 L	2.200	1.960	2.007	2.025	0	0
YB54L005	HOYRYNKEHITIN YB54 L	2.200	1.960	2.007	2.026	0	0
YB13L001	HOYRYNKEHITIN YB13 L	2.200	1.960	2.131	2.053	0	0
YA30T009	OUTLET THERMOCOUPLES	312.0	260.0	289.0	271.4	0	0
RA00P901	HOYRYTUKKI P	48.00	41.00	48.49	42.66	1	0
RL30T004	SYVE KP-ESILAMM. JALK	240 0	164.0	223.3	211 6	0	0
RL10L002	SYOTTOVESISAILIO RL10 L	2.700	2.300	2.776	2.412	1	0
RL50L002	SYOTTOVESISAILIO RL50 L	2.700	2.300	2.551	2.050	0	1
TK50L001	BOORISAATOKAASPO TK50	2 900	2.000	2.666	2.456	0	0
SP10E002	GENERAATTORI SP10 EP	235.0	207.0	240.0	192.9	1	1
SP50E002	GENERAATTORI SP50 EP	230.0	185 0	232.4	-1.094	3	1
SD12L001	LAUHDUTTIMEN PINNANKORKE	1.200	0 5000	1.018	0.7752	0	0
SD52L001	LAUHDUTTIMEN PINNANKORKE	1.200	0 5000	0.8511	0.5550	0	0
SD12P001	LAUHDUTIN P BAR	0 3000	0 1500E-01	0.4211E-01	0.2692E-01	0	0
SD52P001	LAUHDUTIN P BAR	0.3000	0.1500E-01	0.3711E-01	0.1204E-01	0	1
YD13F001	INJEKTIOVESI TULO F	0.4000	0.1900	0.2867	0.2743	0	0
YD13T004	INJEKTIOVESI BRATE VUOTO	65 00	25.00	42.83	42.01	0	0
BA04E001	KYTKINL BA EV	6.500	4 000	6.364	6.233	0	0

Figure 3.



-9 %
-5 °C
-6 %
0 °C
-3 %
+5 °C
Δ flux
Temp error
Temp. error
Δ flux
MAN
AUTO
MAN
AUTO
MAN
AUTO
AUTO
BORIC ACID SUPPLY FINISHED
TURBINE POWER DOWN
MINUTES
190
200
210
CONTROL RODS (D) POSITION
0
.5
1
BORIC ACID FLOW Kg/S
SUBJECT 3

Figure 4.

the example in Figure 3. In some installations it may also be possible to make analog recordings, such as the strip-chart record shown in Figure 4. The instructor observes the performance and adds comment on a review format or scheme derived from the time line (described in the following) and on the generic decision tree related to the predicted "prototypical" critical decisions. A suitable format for this may be Pew's "Murphy" diagrams, Figure 17. The observations may be assisted by a tape-recorder, which either records interactions between the operators (if it is a team), the operator(s) and the instructor, or the instructors own comments. In the case where operators are trained as a team, it is particularly important to observe and record their interaction, since that may be essential for providing a feedback to the individual operator.

4. Replay and debriefing

During debriefing the critical parts of the performance are repeated with the operator/team of operators, and the discussions recorded. The debriefing may utilize the facility of playback build into the simulator, or just be based on the various records and observations which were made during the task.Preformatted guides are employed to structure the discussions and interviews to collect information related to the columns of the time line forms recording operator intentions, expectations, and data sources used. The terms used for the time line forms and interviews must be from a terminology familiar to the operating staff, as discussed above. The description is thus still on the level of raw data or performance fragments. The main purpose of this phase is to extend the basis for the instructor's feedback by elucidating points of doubt. This will also be of great value for the following analysis. During debriefing the instructor supplements and corrects the comments he made on the time line and decision tree formats during the performance.

5. Analysis

From all the performance fragments gathered during phases 3 and

4, a complete time line description is developed as the formal description of the performance. Not all parts of this are, of course, equally interesting, and special attention should therefore be given to the sequences indicated by the predicted critical decisions. The inappropriate operator decisions should be characterized with respect to the related causes, error mechanisms and performance shaping factors. Guides for analysis in terms of checklists or decision diagrams should be prepared, for instance as proposed for routine event analysis (cf. Hollnagel, et al, 1981).

Since this analysis is a part of the daily use of the training simulator, leading from the intermediate data format to the analysed event data, it is of some importance that the instructor is able to do this on his own. In connection with a theoretical study there will of course always be a HF specialist present during the training, who can assist the instructor with the analysis. (The HF specialist needs to be present during the session, because his own impression of the development is important. No amount of data, regardless of how detailed or comprehensive they are, can replace the subjective experience from the situation.) But as the instructor is going to be on his own later on, it is important that he learns to make this kind of analysis. It does not mean that the instructor must also become a HF specialist. It simply means that he should learn to use the methodological tools which are supplied by the theoretical study, and understand the idea behind them. Since the instructor is already an expert in the use of the simulator it should be very easy for him to do this.

6. Feedback

The result of the analysis must, of course, be provided as a feedback to the team of operators which participated in the session, and their comments and conclusions should be recorded. Note, that this is in addition to the feedback given during debriefing.

In addition to this the result of the analysis should be regarded as a general feedback from the performance which may assist the instructor in his job of supervising the training of the operators. To repeat a previously given argument, the purpose of using the training simulator in general is to give the operators a high degree of proficiency in handling the plant, especially in off-normal situations, Hence, anything which can improve the learning is of value. An essential factor in any kind of learning is the knowledge of results, i.e. the trainee's knowledge of how his performance was evaluated, what he did that was right and what he did that was wrong. The role of the instructor is precisely to provide his knowledge of results. It follows that the more he will be able to produce a detailed and coherent analysis of the performance, and the faster that he is able to do so, the larger will the influence of it on the training be. The advantage of offering the instructor a sophisticated method for the analysis of training simulator performance should therefore be obvious, the more so as this methodology is designed not to interfere with the normal procedures.

7. Concluding Analysis

Based on a sample of reasonable size, and without reference to individual operators, a more comprehensive study of the formal descriptions of the recorded cases may be performed. This may employ any methodology which is deemed appropriate, e.g. multivariate analysis. The description of the events is necessarily a multidimensional one, and if a more formal indication of the connection between the various dimensions is possible, it should naturally be included. In addition to this, the successful prototypical performance should be identified as a frame of reference for variants in actual performance and for observed "errors".

This, however, is something which need not be done in direct connection with the training sessions. It is rather a part of the theoretical study as such. It may, however, be of value for the normal use of the training simulator, since it may improve the tools used for observation and analysis. Making an analysis of operator performance is of course not something which can be designed once for all. It would certainly be short-sighted not to take advantage of the results of the analysis and redesign the procedure and the tools if necessary.

Comments

The relation between data collection and data analysis

The present material may appear to put an unduly weight on the methods for data collection, and almost neglect the methods for the analysis of data. This is, however, deliberate and at the present stage of the project almost unavoidable. We shall try to explain why in the following.

First of all, the methods for data analysis are already in existence. The phenomena which we want to investigate are known from work in experimental and cognitive psychology, and particularly from the research in man-machine systems. An important contribution comes from the research which during the last decade has taken place at Risø and similar institutions. The various methods for analysis have thus been tested on many occasions and the results are well documented.

This does not mean, however, that there is a fixed set of methods where one simply has to choose the appropriate one. There is rather a repertoire of methods, developed in different contexts, which is continuously modified and extended on the practical as well as the theoretical level. An example of this is the "Notes on Human Error Analysis", which tries to describe the relations between various methods of observation and analysis which have been used in connection with Nuclear Reactors.

The development of the methods for data collection may thus depart from the repertoire of methods for analysis which is alreday present. On the other hand, the development of the specific method of analysis which is going to be used in this project can only be made when the details of the data collection are known.

This is even more so in the present case, where the data must be collected in a real-life rather than in an experimental setting. The purpose of the IEOP project requires that a considerable amount of data is collected in a standardized way which does not interfere with the normal use of Training Simulators.

It has been argued at length in the previous sections of this paper that the data collected may serve a double purpose: (1) that of improving the use of the training simulator and the training of the operators, and (2) that of the theoretical study. Because of this the methods for data collection must be easy to understand and use. They must not demand information or observations which are not naturally a part of the training, nor require an advanced HF background.

The Comparison Between Simulators

One part of the analysis which has not been mentioned in the preceding is the final comparison and evaluation of the data from various training simulators. In a sense this is something new. We have, of course, in our earlier work used data from various sources; that is one of the foundations for the set of concepts which lie behind e.g. the "Notes ..." report. But a strictly systematic comparison and evaluation on the level which the IEOP project requires has not yet been tried in practice.

The basis for this comparison will be the conceptual description of the performance, i.e. the prototypical performance. If we take as an example the conceptual description for a given transient in a given simulator, this will provide us with the essential performance characteristics. That will naturally include the various errors made by the operators, described as variations or deviations from the prototypical performance as well as the prototypical performance as such. Since the prior expectation must be that the performances for the same transient in various simulators must be equivalent (see below), it will be the characterization of the errors which will be most informative about the simulator as a training device. If, for instance, we assume it is found that the results for a specific transient are the same for all training simulators under investigation, then it must be concluded that they do not differ as training devices.

To put it more formally, we have three sets of independent variables, the operators, the simulators, and the transients. (The list may have to be increases with a fourth set of variables, i.e. the training, although that is better considered to be included in the simulator variables.) We have one set of dependent variables, the performance of the operators, We may, however, reduce the number of independent variables by assuming that the operators have a negligible influence on the result, in the sense that the variability within a group of operators is greater than the variability between groups of operators. Or in other words that the operators are more or less the same everywhere, at least as far as the sample of training simulators goes.

This leaves us with two major sets of independent variables, those of the transients and those of the simulators (including the training). It must be assumed that both of these may influence the performance, hence the independent variable. If we look at the transients as a variable, this is more or less fixed beforehand. The set of transients is selected in advance and is assumed to result in the same development in the simulators. In this sense the simulators are functional equivalents, clones, so to speak, of the same "generic" PWR. This assumption may easily be tested (and should indeed be tested if any suspicion to the contrary arises). Naturally the various transients will result in different performances. Considered as a variable, the transients are discrete rather than continuous, and there would be no point in trying to make a gradual description of the transients, using some more or less arbitrary dimensions (although it certainly is possible, e.g. by means of factor analysis). It is more useful to consider the prototypical performance, which corresponds to each transient, by itself, and use that as a basis for a comparison of the results.

That means that the variation of the results, taken for each transient, may be assumed to arise from the set of variables related to the simulator. In contrast to the transient-variable, the simulator-variable may be modified in various ways. One obvious choice for this is the training, both in the sense of the individual training session and in the sense of the training program as such. The prior assumption is that there will be differences among the performances found in the various simulators for the same transient. And furthermore that one may find similarities in the prototypical performances for the various transients within each simulator. As it was mentioned above, if there are no differences between the results for a transient across the simulators, then we may conclude that they do not differ as training devices or that they are functionally equivalent. (To be sure, this conclusion must be qualified by noting that it only holds for the given categories of observation or set of concepts for description. There may be differences which are not captured in this investigation.) It would seem, that it is precisely this result which is the ideal. Conversely, it is the differences in the performance which may be used to characterize the simulators as training devices, not in an absolute sense but relative to each other -- unless some appropriate standard can be found.

This means that the comparison and evaluation of the results from the investigation will take place between the various prototypical performances for a fixed transient, i.e. the simulator specific prototypical performances. This is entirely possible with the repertoire of methods which is already available. It may be convenient to supplement this by methods of a statistical nature if proper measurements can be found. It is yet too early to say anything about the possibility for this, but it should be taken up as a point in the further planning and development of the project.

The preceding section describes how the tools for data collection may be developed. This description is based partly on theoretical considerations and the practical experience of the authors (J. Rasmussen and E. Hollnagel), and partly on preliminary discussions with instructors from two training simulators -- the AKU Simulator in Sweden, and the Loviisa Simulator in Finland. These discussions have made it quite clear, that the experience of the instructors is a valuable and necessary contribution to the continued work. It is furthermore the only way of ensuring that the methods for data collection are usable in practice.

Both in the "Notes on Human Performance Analysis" and in the present paper it has been described how the analysis of performance data may be developed through several steps going from a description of the actual performance to a competence description, cf. Figure 5. In addition to this Figure 5 also shows how the various types of performance description are related to the project.

The descriptions of the actual and formal performance are produced by means of the various tools, i.e. methods of data collection, which are developed, e.g. the Error Analysis Diagram. These descriptions serve a double purpose. In terms of the project they provide the data for the further analysis. And in terms of the training simulators they present the instructor with an improved basis for debriefing and feedback, i.e. for the purpose of training as such.

The description of the prototypical performance (the conceptual description) is produced by an analysis of the data collected during the training sessions. Since this analysis involves a many-to-one comparison it must necessarily take place after a period of data collection, cf. the overview given in Figure 2. (But note, that the data collection also involves a data analysis.) The theoretical background for this analysis is described e.g. in Pew et al., and in the "Notes ...".

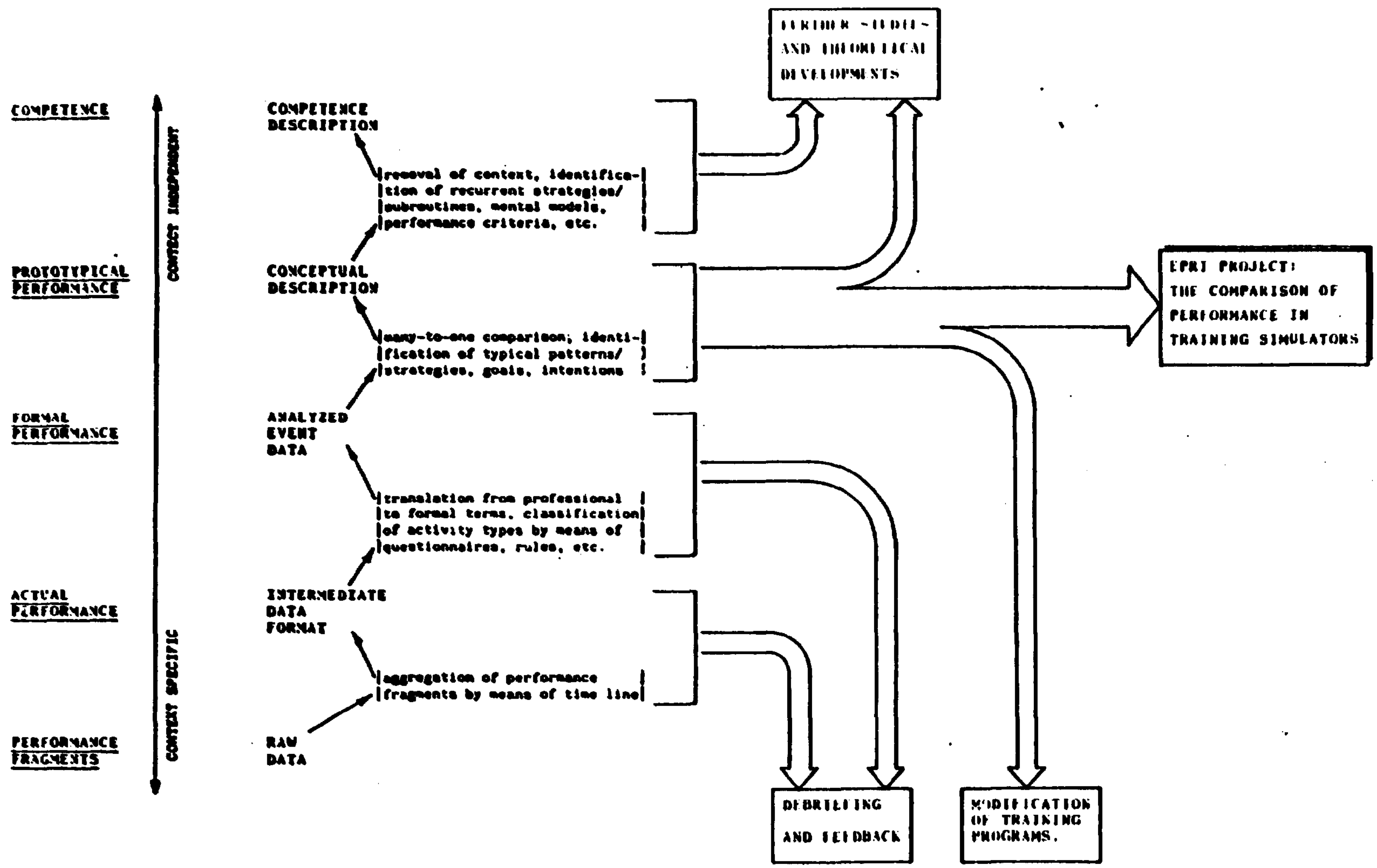

COMPETENCE
PROTOTYPICAL PERFORMANCE
FORMAL PERFORMANCE
ACTUAL PERFORMANCE
PERFORMANCE FRAGMENTS
CONTEXT INDEPENDENT
CONTEXT SPECIFIC
COMPETENCE DESCRIPTION
removal of context, identification of recurrent strategies/ subroutines, mental models, performance criteria, etc.
CONCEPTUAL DESCRIPTION
many-to-one comparison; identification of typical patterns/ strategies, goals, intentions
ANALYZED EVENT DATA
translation from professional to formal terms, classification of activity types by means of questionnaires, rules, etc.
INTERMEDIATE DATA FORMAT
aggregation of performance fragments by means of time line
RAW DATA
EPRI PROJECT: THE COMPARISON OF PERFORMANCE IN TRAINING SIMULATORS
DEBRIEFING AND FEEDBACK
MODIFICATION OF TRAINING PROGRAMS.

Figure 5

The conceptual description is primarily going to be used in the IEOP project. This involves a comparison of the prototypical performances from the various simulators involved in the project. It must also include an evaluation of the prototypical performances in relation to the characteristics of the training simulator and the tasks. A further elaboration of this must, however, await a more detailed description of the purpose of the project.

As Figure 5 indicates, the description of the prototypical performance may also be used by the training simulator as such. This systematic description will make it possible for the training simulator, i.e. the institution running it, to monitor the training as such, and to modify the training program as the need arises. Just as the systematism which yields the description of the formal performance may be used to adapt the training to the requirements of the operator, so the systematism which lies behind the conceptual description may be used to adapt the training program to the requirements of e.g. the authorities. The results from the analyses may furthermore be used to document that the requirements are fulfilled.

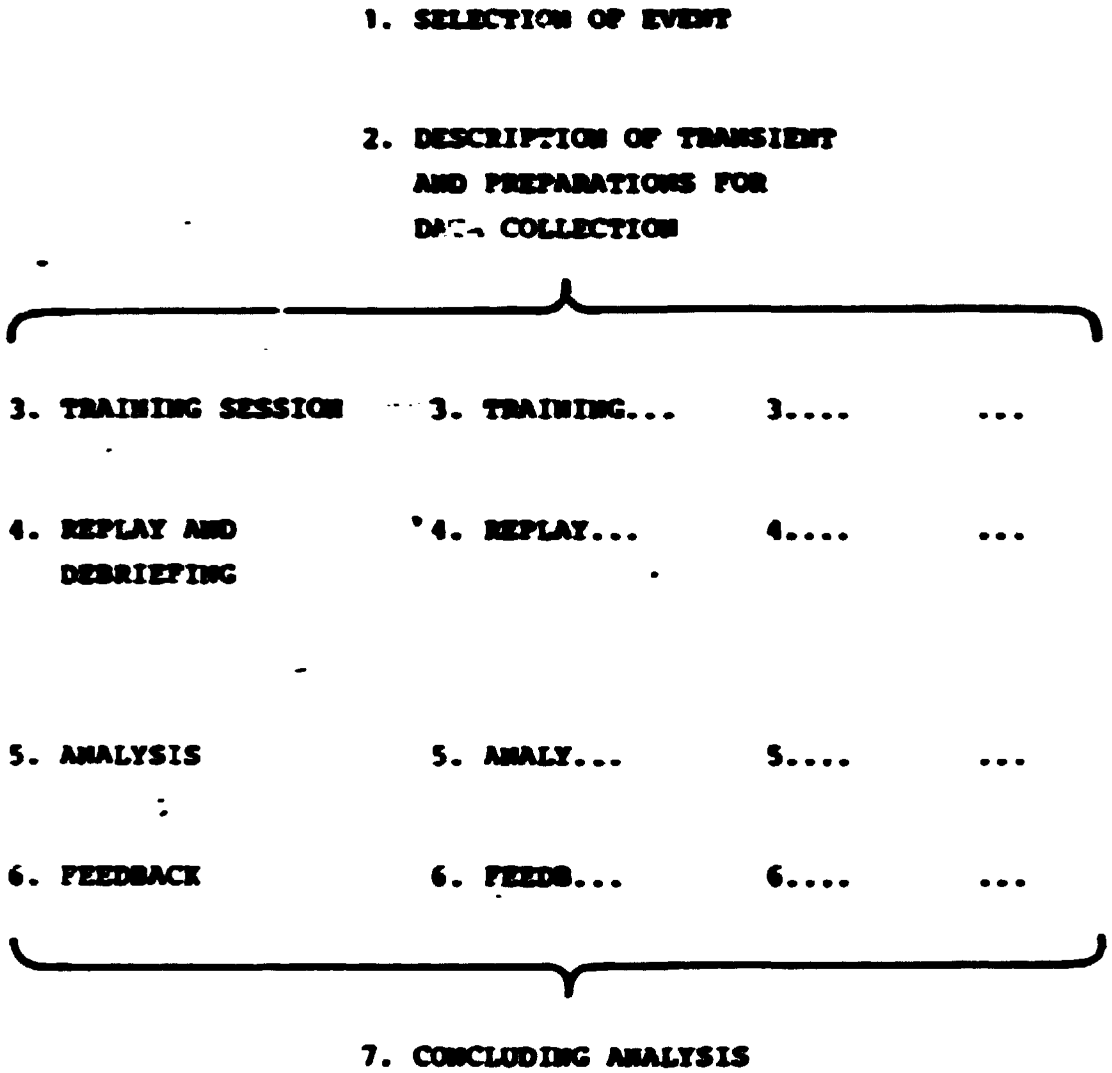
A final use of the description of the prototypical performance, also indicated in Figure 5 , is for the further theoretical study and development. This makes use also of the competence description. The continued development of the theoretical background is rarely an explicit purpose, but rather something which takes place by virtue of using the theories at all. One need hardly point out, that this continued theoretical development is necessary both for this project and for the study of human performance in general.

Comments

We have now given a description of how the analysis of training simulator performance may be implemented, and have identified seven steps in this analysis. The description is summarized in Figure 6, which perhaps gives a more clear impression of how the various steps are related. The first two steps are the preparations for the investigation and are only carried out once for each incident. The following four steps constitute the actual session, including the feedback, and are therefore carried out as many times as required. That will normally depend on the number of operators or teams of operators which are available. The final step is common to the individual training sessions, since it aims at providing a generalization of the results from each session. It is therefore carried out only once.

The description given in Figure 6 is, of course, idealized and prototypical. Thus depending on the number of sessions, the last step may be carried out after a number of sessions and again after all the sessions, rather than only once. The realization of the steps may also be influenced by the type of transient which is investigated. If it is a relatively simple one where the actual performance deviates little from the predicted performance, the analysis may correspond well to Figure 6. But if the actual performance is very much different from the expected performance -- possibly because the transient is complex or unusual -- then it may be necessary to deviate from the prototypical analysis in order to optimize the result of the investigation.

The description given of the analysis of training simulator performance has, so far, been unrelated to any specific simulator. It has been in the nature of a guideline, a basis from which a specific procedure for analysis can be produced as soon as the details of a simulator are known. Although all training simulators share the same purpose, there are obviously differences, not only in the details of the plant they simulate, but also in the possibilities for gathering, storing, and retrieving data. Thus a playback facility may be present as a continuous or frequent automatic recording of the status of the simulator, as a limited amount of manually triggered snapshots, or not be there at all. An example of a specific and detailed procedure can therefore not be given until a "pilot" simulator has been designated. We may, however, show how the tools for



DESCRIPTION OF THE STEPS IN THE ANALYSIS OF PERFORMANCE IN TRAINING SIMULATORS.

Figure 6.

data collection can be developed with a generic simulator as a basis.

THE DEVELOPMENT OF TOOLS FOR DATA COLLECTION

The following is a short description of how the various tools which may facilitate the observations made during a training session are developed, and how they are related. It is an elaboration of the second step in the "prototypical" analysis presented in the previous section.

The basis for the observations is found in the Emergency Instructions, since they describe the steps which an operator must go through to diagnose a situation as well as the actions which are required to bring the system to a safe state. An example of such generic instructions is shown in Figure 7.

For the purpose of describing the expected performance of the operator, the Emergency Instructions should be represented in the form of an Instruction Flowsheet. This is shown in Figure 8 which covers the same parts of the instructions as Figure 7. The advantage of the Flowsheet is that it becomes easier to identify the individual steps in the instruction, as well as the relation between parallel parts of the instruction.

The Instruction Flowsheet may, of course, be made with a varying degree of detail. Since its purpose is to provide an overall view of the expected performance, it should only contain the main steps which the operator must go through. The Instruction Flowsheet should be elaborated in cooperation with the instructors at the Training Simulator, and based on their experience with the instructions. The instructors will know which parts of the instructions are easy to carry out, and which are difficult. The difficult parts are those where the

B. IMMEDIATE ACTIONS

Refer to section on Immediate Actions of E-0, Immediate Actions and Diagnostics, if not already performed.

C. SUBSEQUENT ACTIONS

CAUTION: The diesels should not be operated at idle or minimum load for more than (insert plant specific time period of allowed diesel operation at minimum load). If the diesels are shut down, they should be prepared for restart.

NOTE: Make arrangements to sample containment atmosphere and steam generators to identify presence of abnormal radioactivity.

NOTE: The process variables referred to in this instruction are typically monitored by more than one instrumentation channel. The redundant channels should be checked for consistency while performing the steps of this instruction.

NOTE: Reactor coolant system isolation valves (LIVS) are optional equipment on the Westinghouse Standard Plants. If a plant is so equipped, the use of LIV's is not currently recommended during the course of this instruction. Any use of LIV's must be justified on a plant specific basis.

NOTE: The pressurizer water level indication should always be used in conjunction with other specified reactor coolant system indications to evaluate system conditions and to initiate actual operator actions.

1. Identify the faulted steam generator by one or more of the following methods:

   a) An unexpected rise in one steam generator water level with auxiliary feedwater flow reduced or stopped.

   b) High radiation from any one steam generator blowdown line radiation monitor.

   c) High radiation from any one steam generator, as determined by analysis of a sample.

   d) High radiation from any one steam generator main steam line.

NOTE: While identifying and isolating the faulted steam generator according to Steps 1 and 2, continue with subsequent Steps 3 through 6.

2. When the faulted steam generator has been positively identified, then:

   a) Stop all feedwater flow to the faulted steam generator.

   b) Close the main steam isolation valve and bypass valves associated with the faulted steam generator.

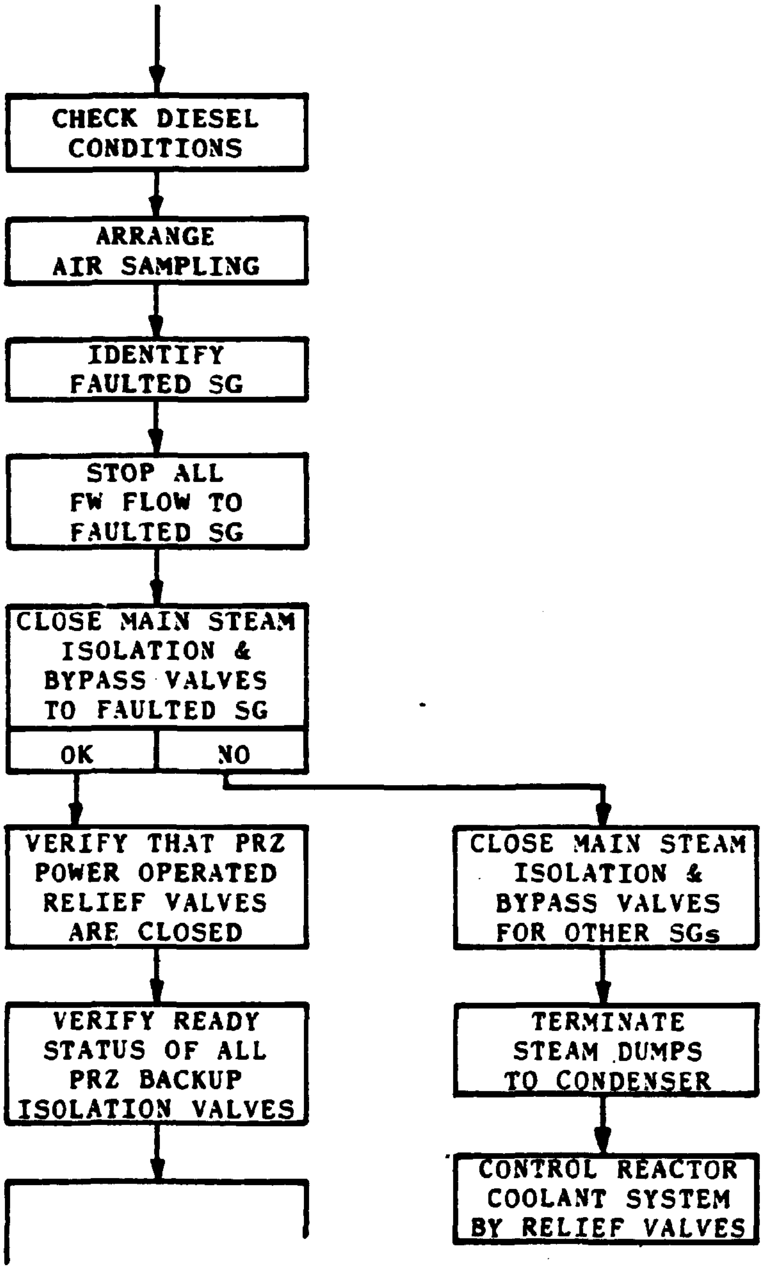
NOTE: If the main steam isolation valve or bypass valve associated with the faulted steam generator will not close, then close the main steam isolation valves and bypass valves associated with the non-faulted steam generators and terminate all steam dumps to the condenser. Utilize the non-faulted steam generators' power operated relief valves to maintain the reactor coolant system at approximately no-load conditions.

   c) Verify the closure of all power operated relief valves associated with the faulted steam generator.

   d) Close the isolation valve in the steam line to the auxiliary feedwater pump associated with the faulted steam generator.

3. Verify that all pressurizer power operated relief valves are closed. Verify the open status and availability of power to all pressurizer power operated relief valve block isolation valves.

Figure 7



INSTRUCTION FLOWSHEET (SAMPLE)

Figure 8.

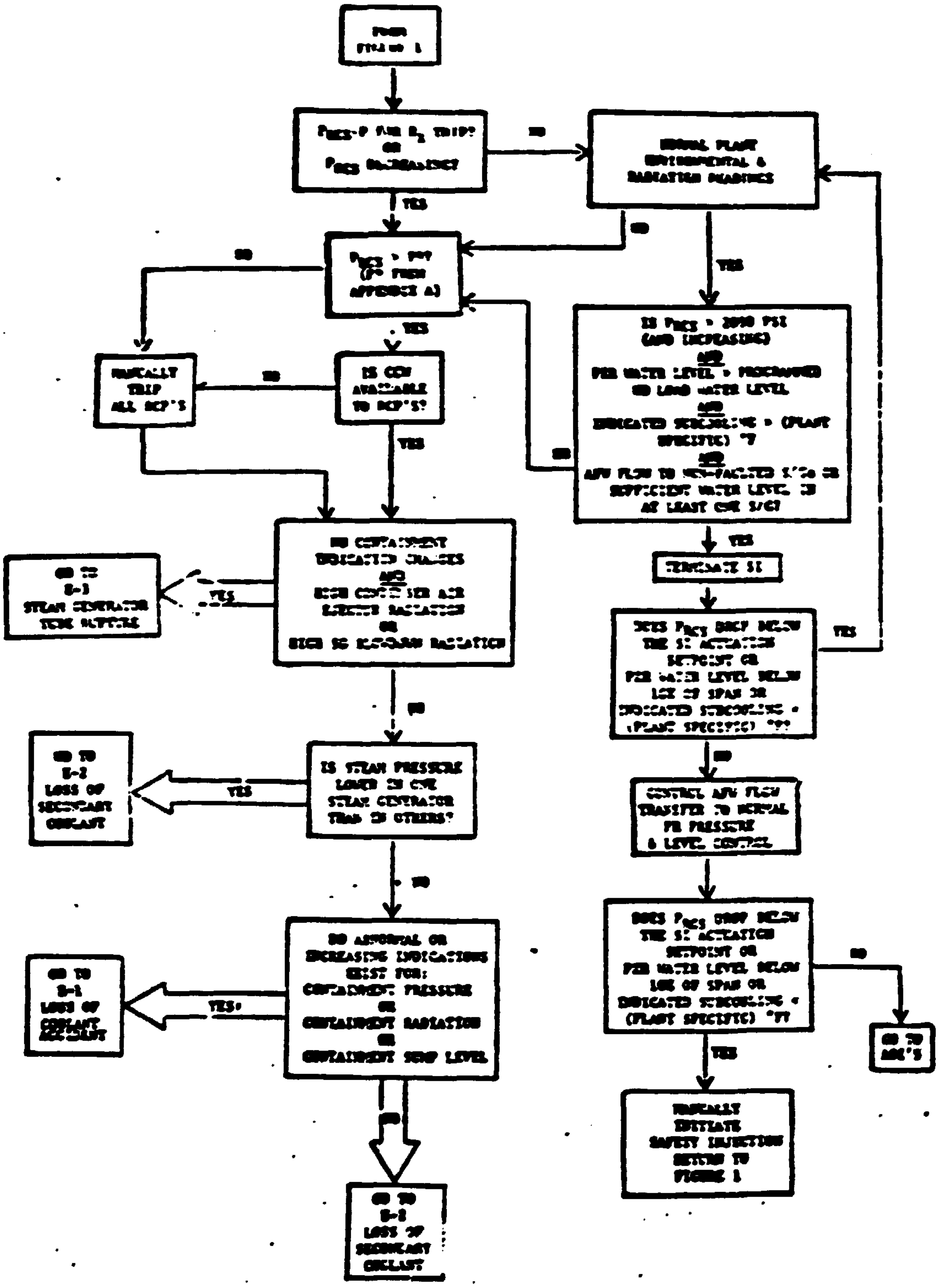
operator is most likely to make a mistake, hence those where detailed and accurate observations are required.

Similarly, a Diagnostic Flowsheet may be prepared. This is often quite easy to do since the Emergency Instructions may supply a flow diagram for the accident diagnostics (cf. Figure 9). As the correct diagnosis is known beforehand, the flow diagram may be pruned (cf. Figure 10), and then supplied with the necessary details and represented as a Diagnostic Flowsheet (cf. Figure 11).

There is, of course, no substantial difference between the structure of an Instruction Flowsheet and a Diagnostic Flowsheet, so we shall look only at the former.

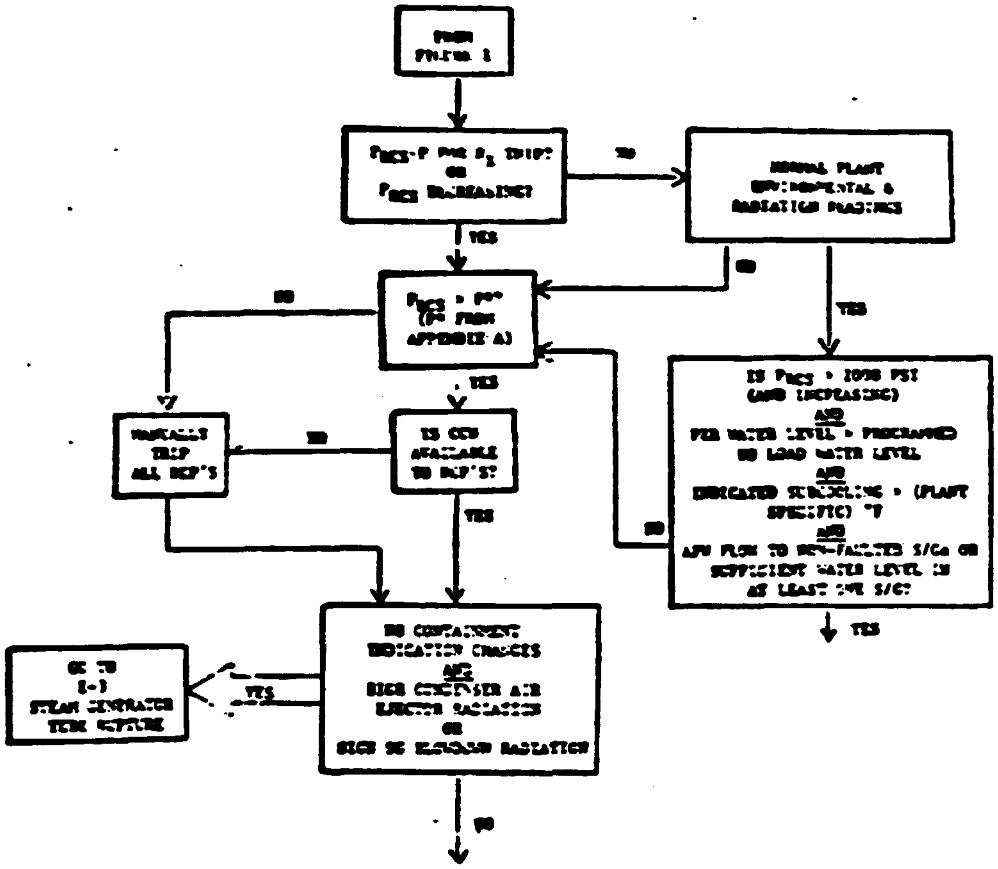
As mentioned above, the Instruction Flowsheet must be elaborated on the points where the instructor knows by experience that difficulties may arise. Ideally, the Instruction Flowsheet should be supplemented by a cause-consequence chart (CCC) which would describe the system states corresponding to each step in the instructions. We have already seen how this may be a difficult requirement to fulfil. And it is generally not necessary in the case of a training simulator since the system responses resulting from operator errors may be collected empirically in the simulator, rather than having to be derived analytically. Furthermore, the system responses need only be described at the points where the instruction flowsheet is elaborated.

Figure 12 shows how this elaboration may be described. Corresponding to the instruction-step "Stop all FW flows to the faulted Steam Generator", we have the expected system response that the FW flow is stopped. If that occurs, the situation is normal and the operator may continue the task. If, however, the response does not occur, then we have an off-normal situation which requires further analysis. As Figure 12 shows, the cause for the failure of the system response to appear may be either a simulated error or an operator error. Since we are dealing with a planned event in a training simulator, the presence of



COMPLETE ACCIDENT DIAGNOSTICS

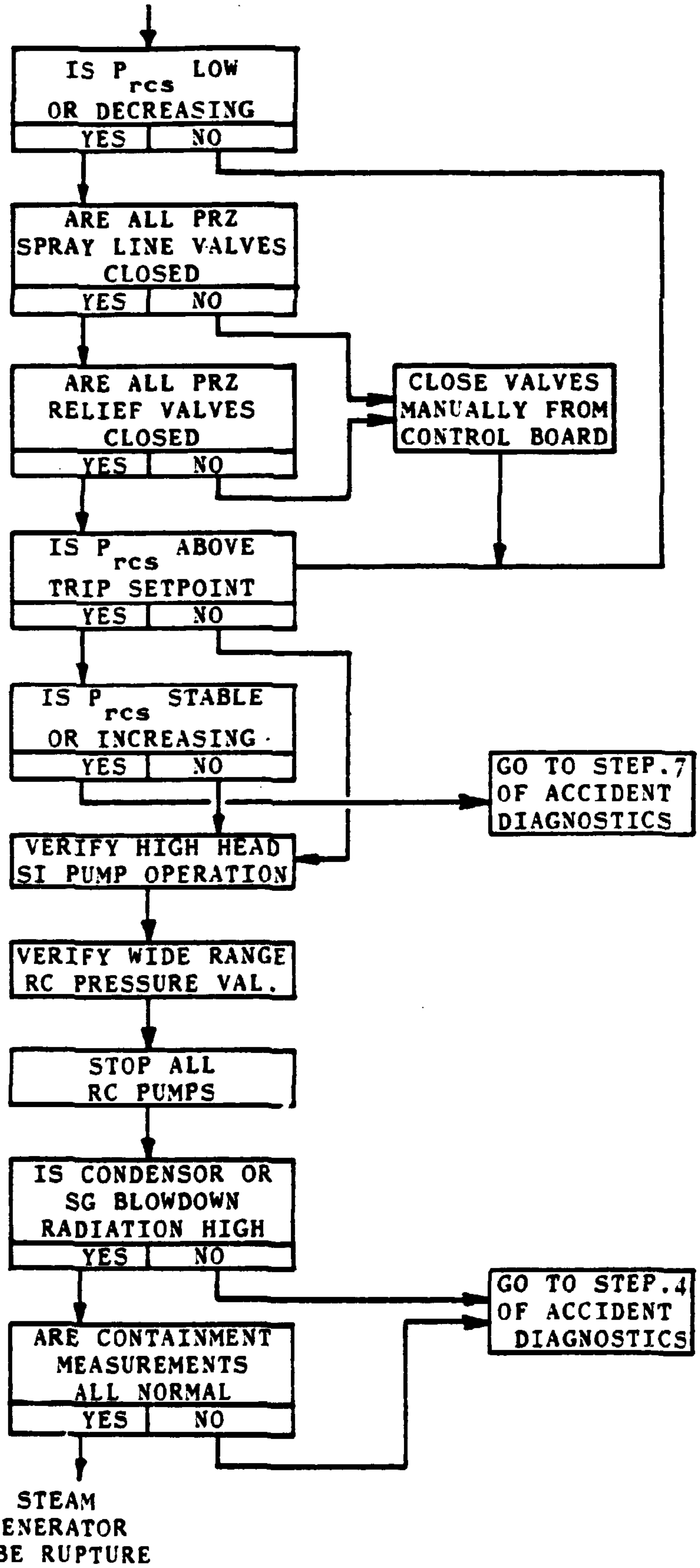
Figure 9.



PRUNED ACCIDENT DIAGNOSTICS

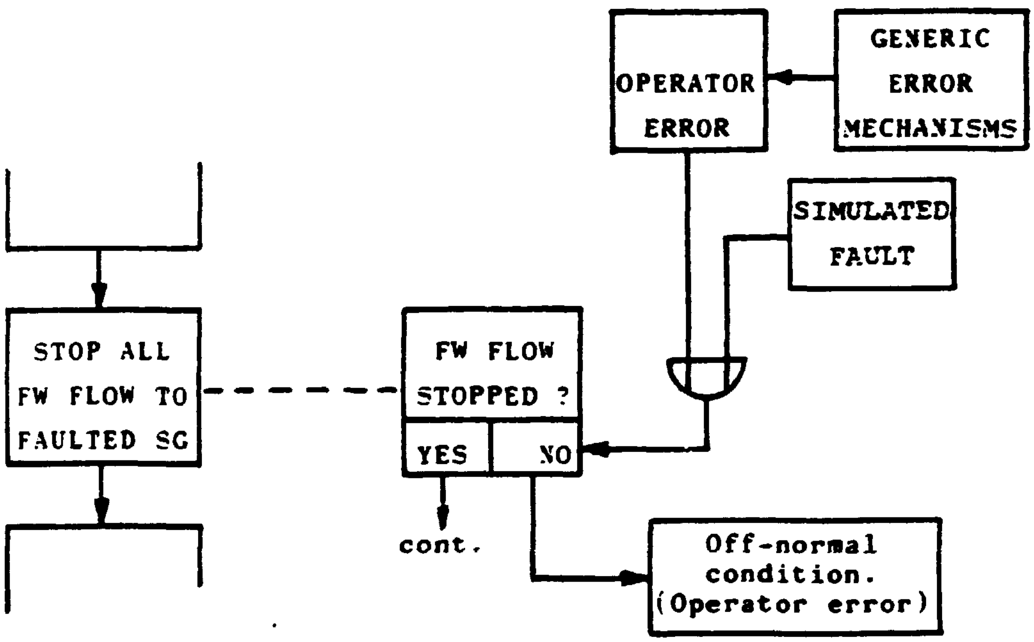
FOR STEAM GENERATOR TUBE RUPTURE

Figure 10



DIAGNOSTIC FLOWSHEET (SAMPLE)

Figure 11.



INSTRUCTION FLOWSHEET
(Detailed Analysis of Critical Point)

Figure 12.

technical faults will always be known. Hence we need consider only the possibility of an operator error. In this case the situation must be described in further detail by means of the Error Analysis Diagram. As Figure 12 indicates, it is assumed that the operator's error may be explained by means of a set of generic error mechanisms.

Although it has not been included in Figure 12, there are frequent cases where a recovery from the off-normal situation is possible. In case a Recovery Path exists and is used so frequently by the operators that it can be described just as any other part of the instructions, this should naturally be done. The instructor may then use this description as a basis for an analysis of how the operator accomplishes the recovery from the error.

It is of course possible that the operator does not follow the sequence of activities outlined in the instruction flowsheet. There may be a number of reasons for this. To begin with the flowsheet may have been in error. Or the operator may for various reasons deviate from the expected sequences. In that case it is of course very important to record the point at which the deviation started and to obtain full information about that during the replay/debriefing. But the operator may also have made an incorrect diagnosis, reacted to it by following the apparently correct but factually incorrect emergency procedure, then have discovered the mistake and made the correct diagnosis. Yet because the operator as a consequence of the incorrect diagnosis has intervened in the system, it may no longer respond as originally expected, even though he now follows the procedure. There are probably several other conceivable situations where the flowsheet can become inadequate as an instrument for following the operator's activities. As the present stage of development there are no ready made answers to this problem, although it is not believed to become a serious obstacle. It should nevertheless be considered whether appropriate measures can be taken to reduce this possibility.

The Error Analysis Diagram is shown in Figure 13. It consists basically of the Generic Error Mechanism Checklist, augmented by some possibilities for describing in further detail the operator's reasons and intentions in the situation, and of a short checklist to be used for the system's responses and the operator's reactions to them. The diagram in Figure 13 is merely a first draft, which tries to put together those categories of observation which it is essential to make.

The intention is that the Error Analysis Diagram should be filled out as far as possible by the instructor whenever the operator makes a mistake. It is assumed that the instructor follows the operator's performance by means of the Instruction Flowsheet, where he may easily check the steps which have been performed correctly. If the operator makes an error, this should be indicated in the Instruction Flowsheet (or the Detailed Instruction Flowsheet), and the instructor should then use the Error Analysis Diagram to provide further information about the error. It is this information which is going to be used afterwards, in the debriefing and the feedback, as well as in the further analyses. Very probably, the information recorded by means of Fig. 13, will be obtained mostly from discussions during debriefing.

The Generic Error Mechanism Checklist is shown in full scale in Figure 14. It is derived from the Generic Error Mechanisms shown in Figure 15. The error mechanisms named in the upper half of the figure are those described by O. M. Pedersen & J. Rasmussen (1980), cf. also Figure 5 and Figure 9 in "Notes on Human Performance Analysis" (Hollnagel et al., 1981). In the lower half of the figure is shown the types of activity which are also found in the step-ladder model (cf. Figures 6, 7 & 16 in the "Notes ..."). In Figure 15 (here) all possible combinations between error mechanisms and activities are shown. Some of these are, of course, irrelevant. The Generic Error Mechanism Checklist in Figure 14 shows the result when the irrelevant combinations have been removed and the categories rearranged. The intention is that the instructor may use this as

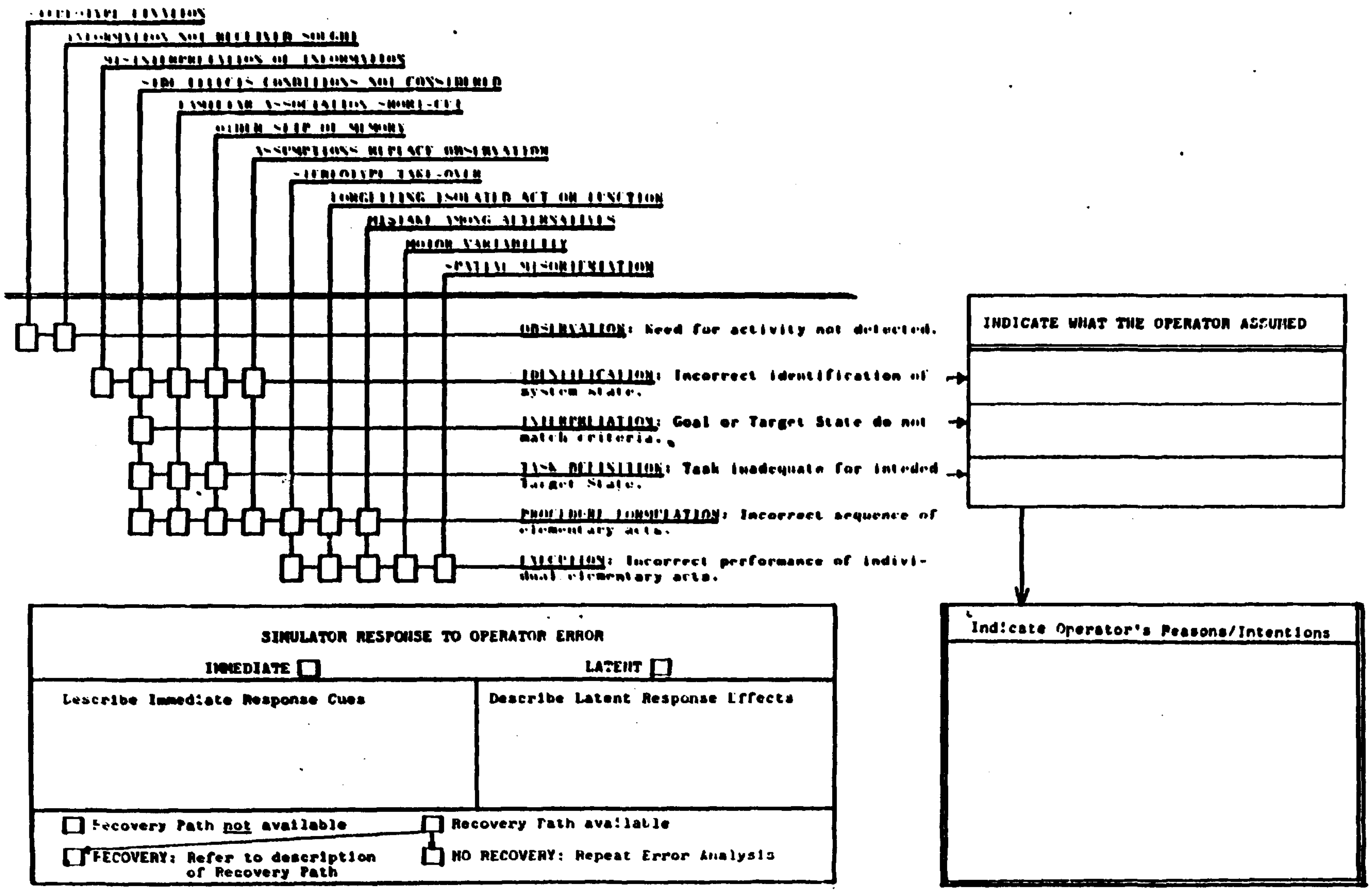

OBSERVATION: Need for activity not detected.
IDENTIFICATION: Incorrect identification of system state.
INTERPRETATION: Goal or Target State do not match criteria.
TASK DEFINITION: Task inadequate for inteded Target State.
PROCEDURE FORMULATION: Incorrect sequence of elementary acts.
EXECUTION: Incorrect performance of individual elementary acts.
INDICATE WHAT THE OPERATOR ASSUMED
Indicate Operator's Reasons/Intentions
SIMULATOR RESPONSE TO OPERATOR ERROR
IMMEDIATE
LATENT
Describe Immediate Response Cues
Describe Latent Response Effects
Recovery Path not available
Recovery Path available
RECOVERY: Refer to description of Recovery Path
NO RECOVERY: Repeat Error Analysis

Figure 13.

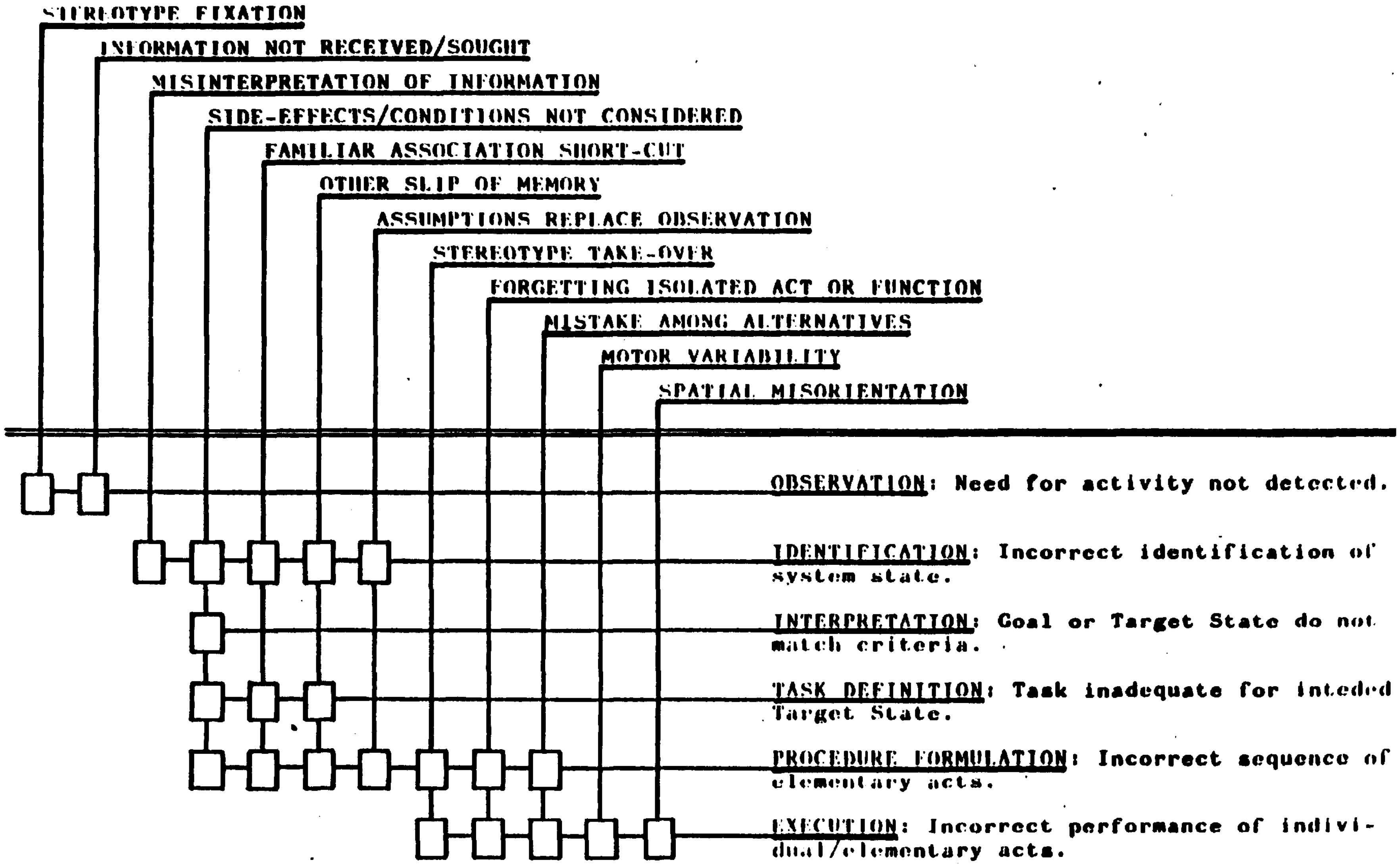
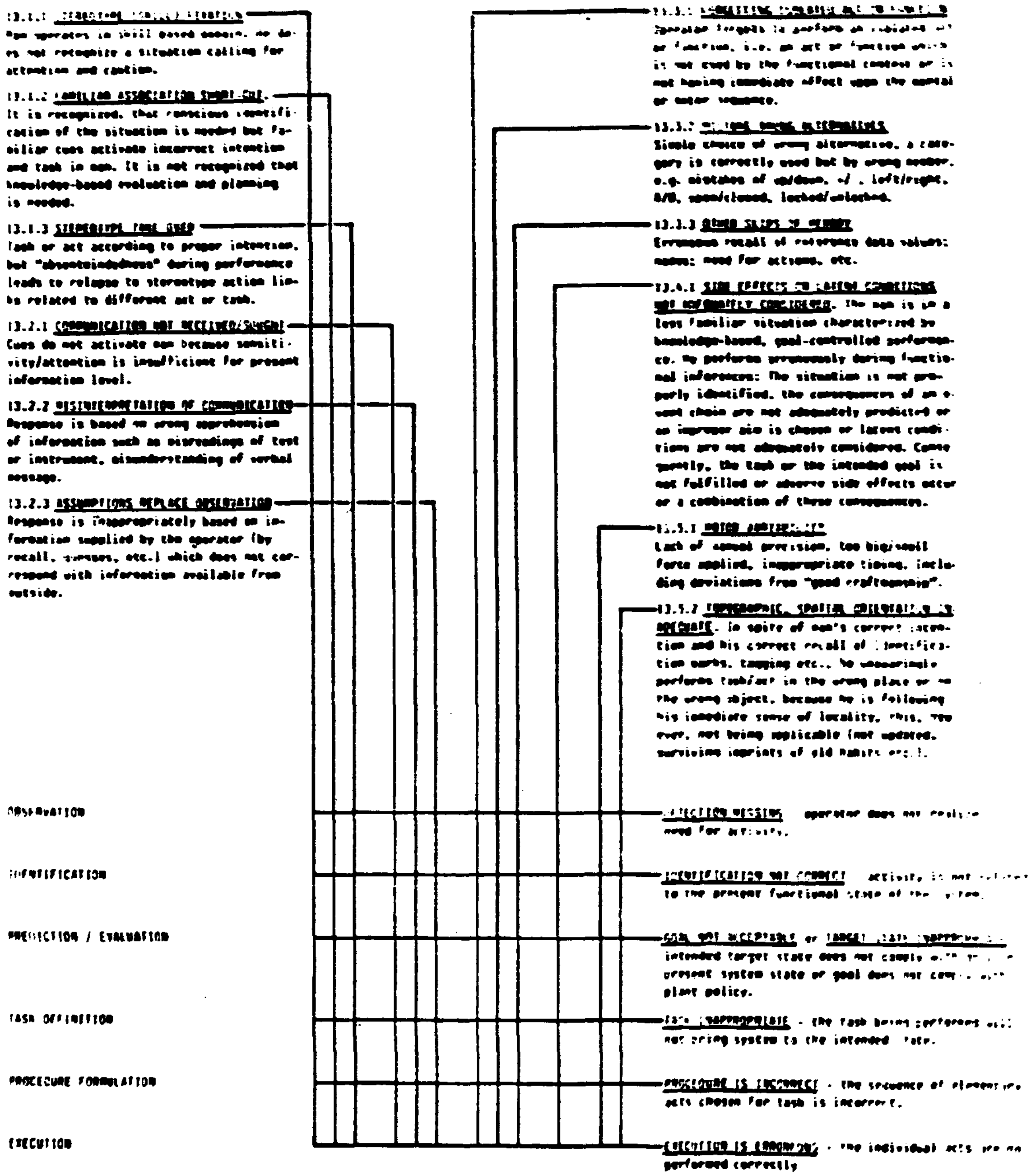

STEREOTYPE FIXATION
INFORMATION NOT RECEIVED/SOUGHT
MISINTERPRETATION OF INFORMATION
SIDE-EFFECTS/CONDITIONS NOT CONSIDERED
FAMILIAR ASSOCIATION SHORT-CUT
OTHER SLIP OF MEMORY
ASSUMPTIONS REPLACE OBSERVATION
STEREOTYPE TAKE-OVER
FORGETTING ISOLATED ACT OR FUNCTION
MISTAKE AMONG ALTERNATIVES
MOTOR VARIABILITY
SPATIAL MISORIENTATION
OBSERVATION: Need for activity not detected.
IDENTIFICATION: Incorrect identification of system state.
INTERPRETATION: Goal or Target State do not match criteria.
TASK DEFINITION: Task inadequate for inteded Target State.
PROCEDURE FORMULATION: Incorrect sequence of elementary acts.
EXECUTION: Incorrect performance of individual/elementary acts.

Figure 14



attention and caution.
13.1.2
It is recognized, that conscious identification of the situation is needed but familiar cues activate incorrect intention and task in man. It is not recognized that knowledge-based evaluation and planning is needed.
13.1.3
Task or act according to proper intention, but "absentmindedness" during performance leads to relapse to stereotype action links related to different act or task.
13.2.1
Cues do not activate man because sensitivity/attention is insufficient for present information level.
13.2.2
Response is based on wrong apprehension of information such as misreadings of text or instrument, misunderstanding of verbal message.
13.2.3
Response is inappropriately based on information supplied by the operator (by recall, guesses, etc.) which does not correspond with information available from outside.
13.3.2
Simple choice of wrong alternative, a category is correctly used but by wrong number, e.g. mistakes of up/down, left/right, open/closed, locked/unlocked.
13.3.3
Erroneous recall of reference data values; names; need for actions, etc.
13.4.1
The man is in a less familiar situation characterized by knowledge-based, goal-controlled performance. He performs erroneously during functional inference: The situation is not properly identified, the consequences of an event chain are not adequately predicted or an improper aim is chosen or latent conditions are not adequately considered. Consequently, the task or the intended goal is not fulfilled or adverse side effects occur or a combination of these consequences.
13.5.1
Lack of manual precision, too big/small force applied, inappropriate timing, including deviations from "good craftsmanship".
13.5.2
In spite of man's correct intention and his correct recall of identification marks, tagging etc., he unconsciously performs task/act in the wrong place or on the wrong object, because he is following his immediate sense of locality, this, however, not being applicable (not updated, surviving imprints of old habits etc.).
OBSERVATION
IDENTIFICATION
PREDICTION / EVALUATION
TASK DEFINITION
PROCEDURE FORMULATION
EXECUTION
operator does not realize need for activity.
to the present functional state of the system.
intended target state does not comply with present system state or goal does not comply with plant policy.
the task being performed will not bring system to the intended state.
PROCEDURE IS INCORRECT - the sequence of elementary acts chosen for task is incorrect.
performed correctly

Figure 15.

an easy way of recording details of the operator's error. If, for instance, the operator made an error in the identification of the system state, the instructor may mark that during the session, and then indicate which error mechanism he considered to be the cause of it based on the bebriefing interview.

In the Error Analysis Diagram (Fig. 13), the instructor may further note the consequences of the operator's error, e.g. which state he thought the system was in, or which goal he chose. This may be supplemented by some information about the operator's reasons and intentions, i.e. <u>why</u> he acted in a specific way and <u>what</u> he hoped to accomplish. This information corresponds to the categories of "Knowledge and/or Belief State Components", "Intention" and "Expectation" in the Operator Decision Summary developed by Pew et al. 1981 (cf. Figure 13 in the "Notes ..."). The information may again be supplied either during the training session or during the debriefing.

The part concerned with the simulator's response points to the <u>type</u> of the simulator's response (whether it was immediate or latent), the <u>cues</u> which the operator used to recognize the immediate response, the <u>effects</u> (if any) of the latent response, and whether a <u>Recovery Path</u> was available and used by the operator.

The observations recorded in the Error Analysis Diagram may be further analysed into <u>Reasons for Actions</u> and <u>Reasons for Intentions</u>. The former describes the details of the errors in an Action Sequence, as shown in Figure 16 (from Rasmussen, 1981). In addition to describing the mechanisms of error or malfunction pertaining to actions, it also describes the Causes of Malfunction and the External Mode of Malfunction, cf. Figures 5 and 10 in the "Notes ...". The latter describes the details of the errors in intention by means of the <u>Murphy Diagram</u> developed by Pew et al. This is shown in Figure 17 (cf. also Figure 17 in the "Notes ...").

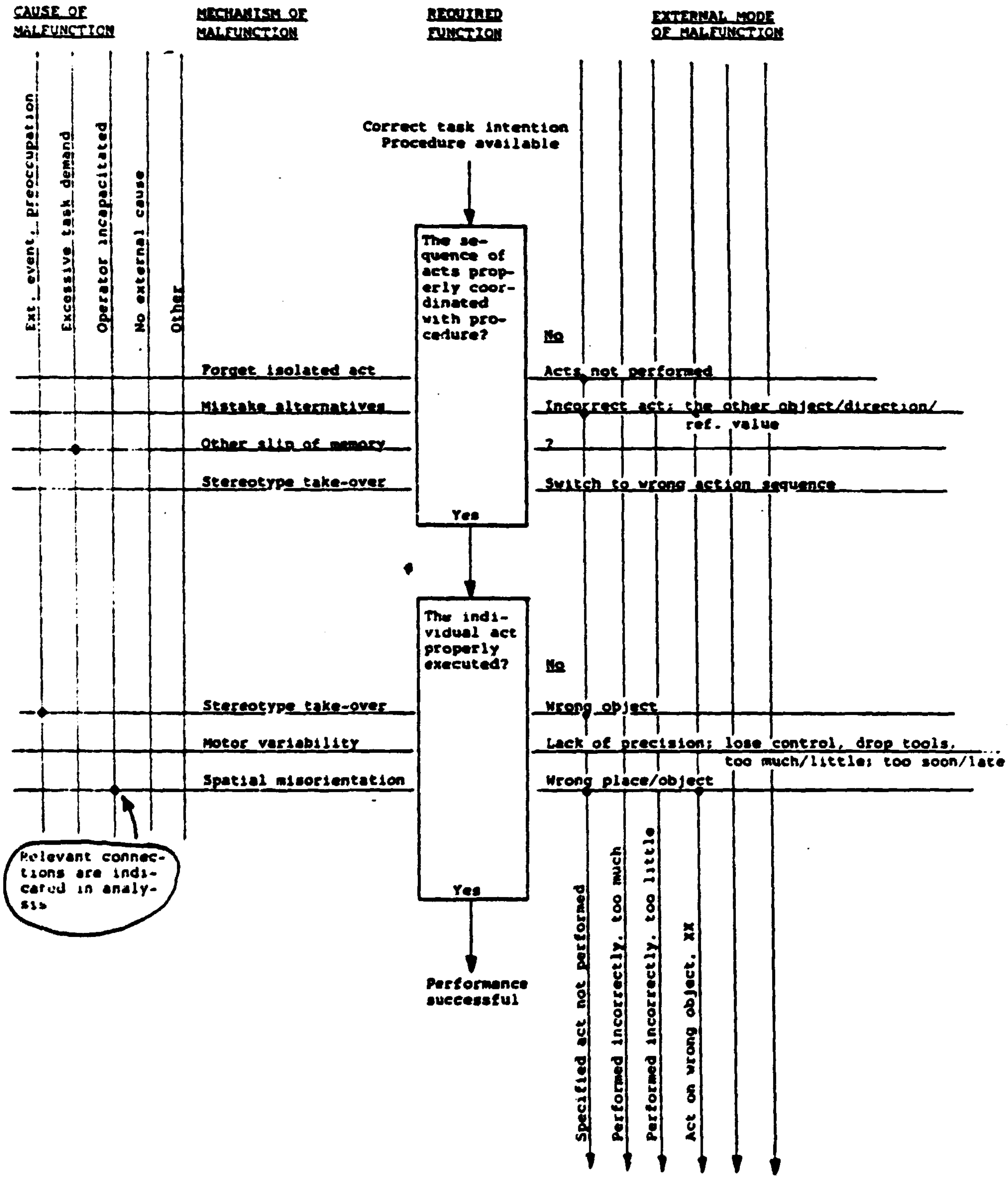


Figure 16.

Schematic format for prediction of error in action sequence. Will serve to generate fault trees in a failure mode and effect analysis. For illustrative purpose, only limited number of items in the different categories are included.

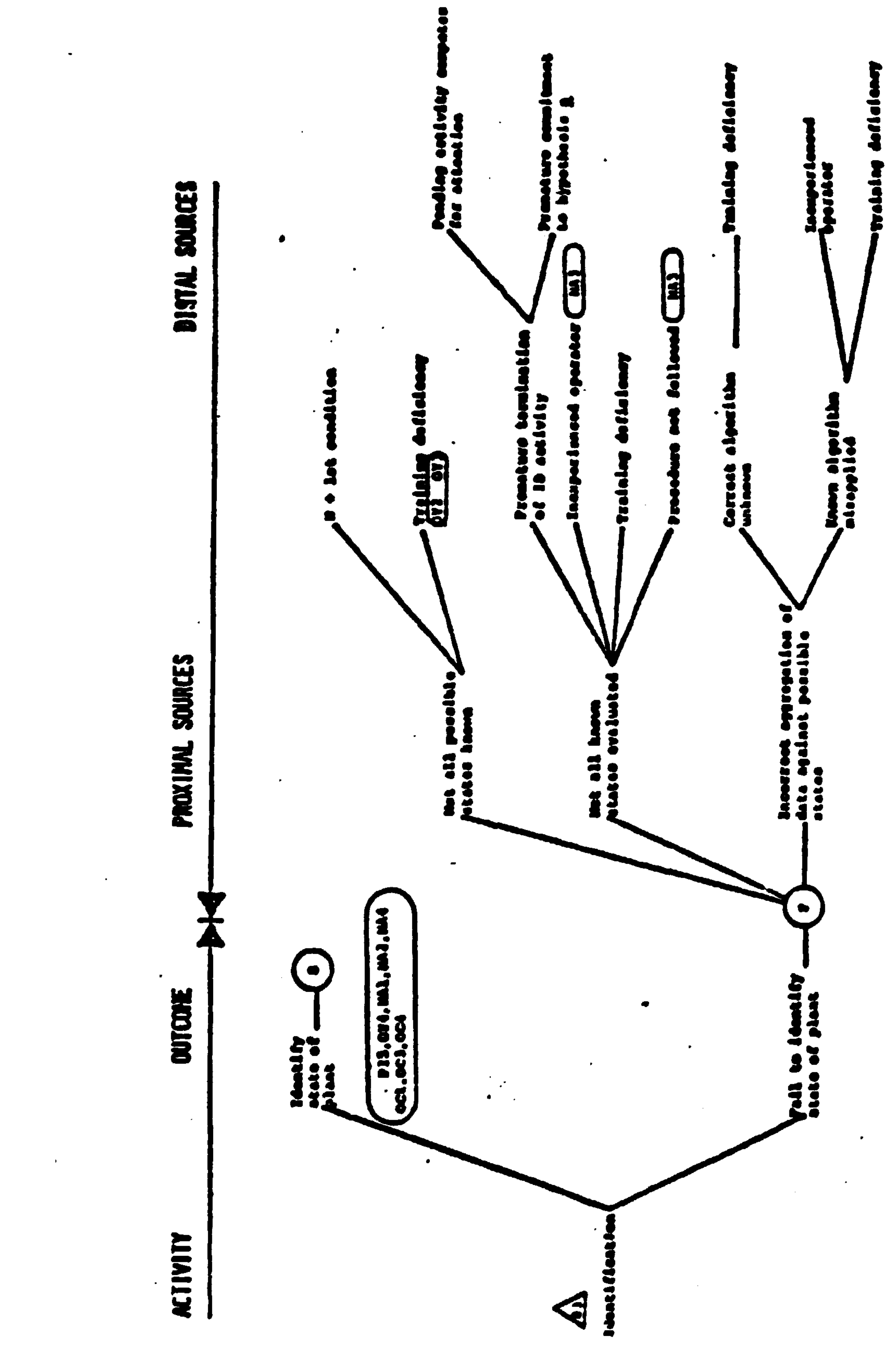


Fig. 17. Murphy diagram for identification.

The essential points in the description given here have been summarized by means of Figure 18. The important points [illegible] are the following:

1. An Instruction Flowsheet is generated from the Emergency Instructions and critical parts are identified by means of the instructor's experience.

2. The instructor uses the Instruction Flowsheet to check the operator's execution of the task.

3. When the operator makes an error, this is indicated in the Instruction Flowsheet and further observations are made by means of the Error Analysis Diagram.

4. The observations in the Error Analysis Diagram may be analysed further by means of the Action Error Diagram or the Murphy Diagram.

The presentation given here has tried to describe the major points of the methods for data collection, but is far from complete. Its main purpose is to be the basis for further discussions and developments, within the project-group and with the instructors at the training simulators.

The method for systematic observations during normal use of training simulators outlined here, has been developed as Risø's contribution to an international project called IEOP: International Evaluation of Operational Practices. In order to assess the practical feasibility of the method, it is going to be tested in a pilot-project which will take place in the last half of 1981. Since this probably will involve substantial revisions of the actual tools (diagrams and schemes) which are going to be used, the reader should not be too concerned about apparent deficiencies in the tools presented here. The function of this report is to provide the necessary background for beginning the pilot-project. It thus represents the stage of development of our ideas by June 1981.

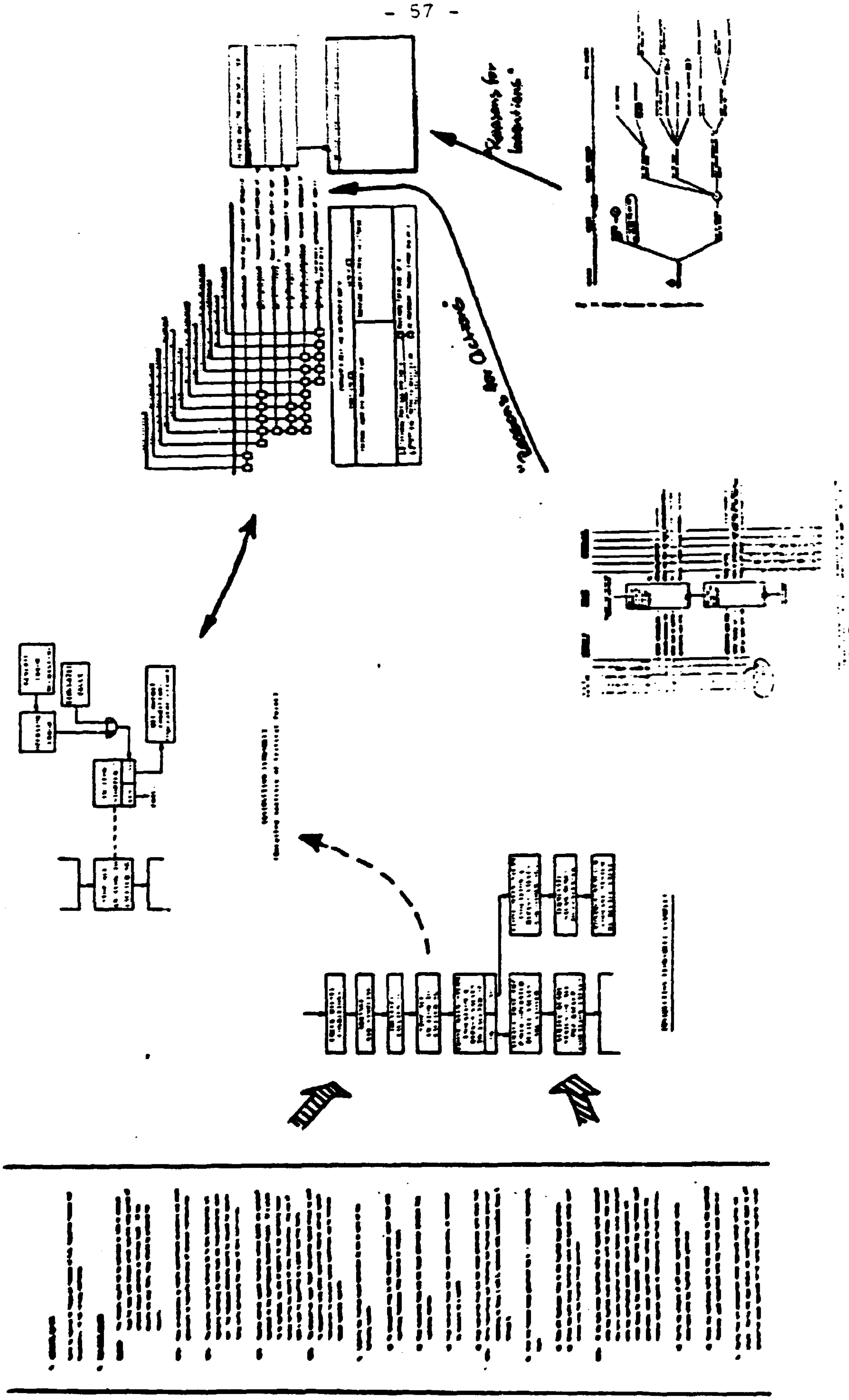


Figure 18.

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SIMULATOR TRAINING ANALYSIS

A PROPOSAL FOR COMBINED TRAINEE DEBRIEFING AND PERFORMANCE DATA COLLECTION

E. Hollnagel and J. Rasmussen

39 pages + tables + illustrations

Date August 1981

Department or group

Electronics Dept.

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Abstract

This paper presents a suggestion for making systematic observations of performance in training simulators, in a way which can serve both trainee debriefing and further theoretical studies. The method is developed from a general method for analysis of data from various sources: (1) Plant Events, (2) Plant Incidents, (3) Training Simulators, and (4) Research Simulators, described in RISØ-M-2285.

A discussion is made of the way in which systematic observations developed from a theoretical context can be integrated into the normal use of training simulators. It is argued that this may provide a detailed qualitative description of operator performance which resembles the implicit assessment made by the experienced instructor. By making the assessment explicit the task of the instructor may be eased, and valuable data for analysis of e.g. decision-making may be obtained. The results, in the form of descriptions of prototypical performance, may furthermore be used to evaluate the training program as such, including training methods and materials.

The first step of the method is a detailed analysis of the transient and the typical operator responses. This is used to develop a flowsheet which is used during training to record the steps in operator performance. In addition to that special transient-independent diagrams are developed which are used to make detailed observations where the actual performance deviates from the expected performance. An example is given of how such diagrams may be developed, based on the generally accepted models of operator performance and decision-making developed at RISØ and elsewhere.

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