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TRAINING PROCESS CONTROL SKILLS

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This paper discusses issues associated with operator training including emphasizing the importance of designing for human factors in general to provide a sensible context for training as well as discussing training methods themselves. The benefits of an analytical approach to identifying, designing for, and integrating these various training solutions is emphasised as this can lead to training which is effective whilst avoiding unnecessary expense. The paper emphasises the need to return to principles of learning to support practical training design.

Keywords: process control skills; training; simulation, human factors; task analysis

INTRODUCTION

Training is well established in the process industries. While much of this is well done there is scope for improvement, especially as new technologies offer new opportunities. An aim of this paper is to argue that training practice in these industries will be enhanced by training theory. Before turning to the nature of such theory, I shall first consider the different forms of training method currently in practice. Broadly, there are four main types of training commonly observed in the process industries, knowledge training, on-job instruction, simulator training and experience.

Teaching process knowledge

Teaching basic knowledge about plant, for example its structure and function, and about elementary physics and chemistry has long been regarded as an essential component of operator training. It can certainly help in teaching the names of parts of plant and equipment, justifying certain procedures and safety measures and is motivating if done well.

There is a danger that this form of training is over-emphasized because, firstly, it is relatively easy to generate content by presenting a diluted version of the chemistry and physics underlying the plant's design. Secondly, it is relatively easy to administer — all of the knowledge to be taught can be assembled and presented in a classroom session or in a computer-based learning package. Unfortunately the relationship between knowledge and skill is not so straightforward and administrative expedients often prevent training from fulfilling the real needs of learners.

On-job instruction

A second common form of training is on-job instruction, where a trainee watches activities on a real plant and is introduced to certain tasks under the scrutiny and control of an experienced colleague. There are some genuine benefits to be had from this sort of training. Firstly, it provides a very real opportunity for the trainee to see work paced as it is required to be, to see the actual signals which must be responded to and to gain a proper feel of controls. But there are negative aspects which are particularly pertinent to hazardous process industries. One implication of hazard is that the consequences of action by unskilled people cannot be risked. A second implication of process work is that crucial events occur intermittently, offering little or no opportunity for practice.

On-job instruction has its place as an essential component of a well thought out training strategy, but the tendency to use it, on its own, as a cheap method of skills training is not justified in hazardous industries. Where a management's motivation is towards economizing, this is often reflected in a failure to train and support instructors. For instruction to be effective, the instructor should be trained, should have an instruction programme to guide which areas are to be trained and the standards to be attained, and should have some kind of instruction manual to prompt any crucial key operating points and provide any training aids that might be useful. In addition, the instruction process must be managed properly by the plant manager responsible. This is particularly important where instruction is just one duty of a senior operator or supervisor since the manager should make sure that the instructor is relieved of operating duties to give the trainee full attention when required. Failure to do this can severely limit the potential benefits of instruction. Creating full-time instructors is rarely the answer, since the process instructor will be in danger of losing up to date knowledge of the process. Nor are full time instructors usually justifiable on process plant, where labour turn-over is low — compare this with the vast machine shop in a manufacturing industry where dozens of operatives are working on dozens of identical machines, accompanied by a steady labour turn-over.

Simulator training

Simulator training is used widely where a company is able to afford a simulator or is otherwise obliged to use one. Simulation training means using some kind of representation of the task to be learned to provide a trainee with the opportunity to practise aspects of operating skill safely within a training programme. It is the *task* rather than the *equipment* that should be simulated. Simulators need not be close physical representations of control consoles and control panels. It may be that such fidelity is required for some purposes, but it is only through analysing the task that precise simulation requirements can be established. Moreover, training simulators must be designed not merely to simulate, but also to train. This apparently obvious fact is frequently ignored in simulator design.

Experience

Reliance is often placed on training through experience. There is, undoubtedly a role for experience, as it is necessary for an operator to learn to work independently, but experience alone is unsatisfactory as suitable opportunities for learning will not be forthcoming, and proper conditions for learning will not be available.

The common forms of training described above are all acceptable in the right context and provided they have been developed according to sound principles. In particular, it is important that they are treated in conjunction with each other to build up an effective level of operator skill. The necessary interaction between these various forms of training are best understood by considering the theoretical notions underlying training practice.

THEORETICAL IDEAS IN TRAINING

Industrial practitioners are primarily interested in the practical applications of training, especially as applied to their own industrial context, and less interested in theoretical aspects. However, because simple training practices do not always translate well to similar but different industrial contexts, and partly because failing to understand the key features which help people learn, often means that training

is ineffective or unnecessarily expensive, a theoretical perspective is important to the training practitioner if training is to be effective and efficient. This paper will set out some theoretical perspectives on training and illustrate their practical importance. For a full account of issues concerned with training research see Patrick (7).

Human learning constitutes a vast research field, in which many ideas are of largely theoretical interest only, applying to limited laboratory tasks. However, many ideas about aspects of human learning have direct implications for the manner in which practical training is conducted.

Skill and Skill Acquisition

Input, Action and Feedback: The essence of skill is contained in a simple model of *input*, *action* and *feedback*, where the operator must know which information to monitor in order to recognize system states in need of change (input), must be able to select actions to affect the necessary change (action) and must then monitor the changes that have been affected to determine whether the action needs modification or whether the action can be terminated. This conception obviously fits well with the responsibilities of process work. Apart from the input and feedback intrinsic to a specific task, it is also useful to provide additional input and feedback to the trainee during learning. Such *extrinsic* information includes cues to prompt the trainee what to do, help for the trainee, and feedback to tell the trainee how he or she is progressing. Extrinsic feedback is necessary to help the learner start to perform effectively. As training progresses sources of extrinsic information must be removed to ensure that the trainee learns to cope with only those features that will remain present during real operations. In slow response systems, such as industrial processes, confirmation that a selected action is appropriate will only emerge when the system starts to respond — possibly several hours later. This means that trainees must be helped to select actions based on interpreting current cues, rather than waiting for their consequences to become manifest.

Knowledge, Skill and Practice: While knowledge and skill have long been regarded as essential components of operator training, their interaction with practice has recently been emphasized in cognitive theories of learning such as that described by Anderson (1). A practical implication of these ideas is that skill is acquired as a learner applies knowledge to deal with practical problems. Formal knowledge as presented to the trainee is in a form which can be communicated verbally or through a computer program or a book or remembered through previous educational encounters or previous experiences. The challenge to the trainee is to establish skills to guide his or her actions in practical situations. Thus, practical skill emerges through practice. Knowledge serves to help the trainee fashion the response.

The practical implication of this is that the knowledge to be taught and the practice that should be provided to enable the trainee to develop skill should be considered by the training designer at the same time. It is unsatisfactory to present a classroom based course of knowledge then expect trainees to use this material later in a concentrated practice session on a simulator or on the real plant. Knowledge must complement practice. This has implications for the scheduling of knowledge training and practice.

Stages in Learning: A long established notion in learning research is that learning develops through a series of stages. A typical example, which will be used as a basis for discussion in this paper, is Fitts' model (5). This describes an initial 'cognitive' phase where the learner attempts to generate an appropriate set of actions, often from a verbal analysis based on knowledge, an 'fixation' phase, where the correct response patterns are laid down by practice with appropriate training support, and an 'automation' phase, where practice continues to consolidate the response patterns. Other researchers have discussed similar phases emphasizing the transition from conscious responding, often entailing reasoning using knowledge about the system, through to practice to consolidate automated responses.

Criteria of Learning

In addition to ideas concerning learning processes it is essential to be clear about the criterion to which each aspect of the task should be learned. These will substantially affect the training conditions for the task. The options to consider include whether the trainee is required to reproduce a set of actions precisely on subsequent occasions or whether the trainee is required to modify responses according to circumstances. In fault diagnosis, for example, we are rarely able to anticipate precisely the situations which may occur, therefore, operators must acquire skills which are adaptive to different circumstances. These factors affect decisions concerning training conditions and the manner in which the trainee's competence should be assessed. A particular aspect of this relates to the learning phases. If training is to meet a criterion where the trainee is able to reproduce a set of actions precisely, then practice during the 'fixation' stage would be aimed at carrying out repetitive drills. Some craft skills would fit here. On the other hand, if training is to meet a criterion where the trainee must adjust actions to cope with varying circumstances, then training must aim at establishing a capability to recognize the differences between presented circumstances and develop a set of rules for selecting appropriate actions to cope with these circumstances. These options match ideas by Rasmussen (8) concerning 'skill-' and 'rule-based' behaviour, whereas the selection of action based on application of process knowledge alone, such as may apply during the 'cognitive' phase, relates most closely with Rasmussen's 'knowledge-based' behaviour.

A Training Design Framework

The foregoing discussion on learning issues must be reflected in the design of training. Training is, in essence, the manipulation of conditions to promote learning. The discussion suggests four main phases of learning needing support— ensuring appropriate knowledge, then helping the trainee through each of the three learning phases. These four learning stages suggest the training framework set out in Table 1.

For Stage 1, we need to ensure that the trainee has the knowledge necessary to accomplish the task. A good training system will keep records of what people already know, or test them to see whether knowledge training is necessary. Stage 2 requires appropriate opportunity for practice to be provided along with various practical training strategies to help the trainee accomplish the task and relate knowledge to the task. The role of guidance and help as well as feedback *extrinsic* to the task is necessary to help the trainee accomplish this. The context for practice could be the real workplace, but this may be unsatisfactory for a number of reasons. One reason is safety; the consequences of unskilled action are usually unacceptable in hazardous situations. Moreover, ideal conditions for practice are rarely available in the real workplace. Some form of task representation, or *simulation*, is often warranted. But often, simulators are built without paying adequate attention to the training facilities they provide.

In Stage 3 the trainee organizes the skill. It is essential to ensure that an appropriate strategy is emerging that will ultimately meet the criteria set for the task. An effective training system monitors the trainee's developing performance in order to adjust training conditions according to progress. It is necessary to monitor progress both in terms of how successfully the trainee accomplishes the tasks set in training (the *product* measure) and the manner in which the trainee accomplishes these tasks (the *process* measure). In fault diagnosis, for example, it is important to ensure that the trainee is carrying out the task using a strategy which entails some kind of analysis of the problem — probably a rule-based approach — rather than simply interpreting patterns, since the analytical approach will lead to transfer of skill to non-routine situations, whereas pattern recognition will not.

Stage 4, the automation phase, requires that the trainee be given a realistic context in which to practice. Full task simulation comes into its own as the means of providing practice without risk,

although practice in the real situation may be an acceptable alternative, thereby avoiding the costs of full simulation.

1.	**Ensure the trainee has knowledge appropriate to the task to be learned**
1.1.	look up in training records
1.2.	test the trainee
1.3.	teach missing knowledge
2.	**Help/guide the trainee to carry out the task ('cognitive' phase)**
2.1.	demonstrate the task
2.2.	relate appropriate knowledge to execution of the task
2.3.	provide advanced organizers/operating 'rules-of-thumb'
2.4.	provide opportunity for practice
2.5.	monitor performance
2.6.	give guidance as necessary
2.7.	give extrinsic feedback to aid learning
3.	**Help/guide the trainee to carry out the task ('associative phase)**
3.1.	provide opportunity for practice
3.2.	monitor performance
3.3.	manipulate events to enable the right things to be practised
3.4.	give extrinsic feedback to aid learning
4.	**Help/guide the trainee to carry out the task ('automation phase)**
4.1.	provide opportunity for practice
4.2.	monitor performance
4.3.	manipulate events to enable the right things to be practised

Table 1: A Framework of Training Stages.

The Applicability of the Training Model to Traditional Training Methods

The training elements listed above are quite general and should apply to all practical training of tasks in all media. I shall now consider how these should be manifested in the training methods commonly encountered in the process industries.

Knowledge training methods: The discussion above on learning methods has justified the importance of knowledge teaching but has emphasized the importance of relating it more closely to the practice necessary for acquiring skills. Knowledge teaching in the classroom is, in principle, satisfactory, but it embodies a number of weaknesses. One weakness of classroom teaching, well understood from studies of programmed instruction methods in the 1960s and 1970s, is that classroom teaching is often not as well prepared as it might be. A lecturer may undertake to teach a topic without a detailed specification of subject matter or without the rigour necessary to keep to the subject or include all necessary detail. Another weakness of classroom teaching is that there is no guarantee that all members of the group have understood all of the lesson. A third weakness is administration — it is most convenient to arrange classroom teaching in blocks and schedule all knowledge teaching for a continuous period so that lecture rooms can be reserved.

An increasingly popular alternative to classroom teaching, which overcomes many of its weaknesses, is computer-based training (CBT). In CBT programs students are, typically, tested as the lesson proceeds, repeating parts of the program or modifying its presentation according to trainee progress. Moreover, individual CBT can take place in smaller rooms than classrooms, or even in the work-place, and be used intermittently as skills are practised. The content can be assured and the effectiveness of the content formally tested. A problem with CBT is that it can be costly to produce. A good 'knowledge' course would mix classroom teaching with other methods. Classroom teaching can be motivating and help build social interaction between course members, but CBT methods will help ensure that material has been properly mastered.

On-job instruction: If we wish to train solely using on-job instruction then instructors should follow the stages suggested in the framework in Table 1. The instructor should ensure that the trainee has necessary knowledge; trainees should be guided through the introductory 'cognitive' phase where they are shown what to do and helped to understand why they are doing it; they should then be given opportunity to establish a sound method of performance by appropriate manipulation of guidance and feedback in order to meet desired performance criteria; then they should be given opportunity to practice and consolidate the skill to ensure they are competent and confident. The major problem with on-job instruction is that it often cannot provide adequate conditions for practice in safety or provide the instructor with control over the events that occur to enable the trainee to be given suitable practice. Other criticisms include the fact that human instructors, especially in an on-job instruction role, are not necessarily equipped to teach knowledge and component skills most effectively. On-job instruction should be supplemented by other methods.

Simulation training: A solution to some of the weaknesses of on-job training is simulation training, where the trainee is given a representation of real plant in order to practice tasks in safety and with the facility to manipulate events with which the trainee is required to practise. Again, simulation training should follow the general pattern of stages listed in the model above. The trainee needs appropriate knowledge of the task; the trainee needs to be taken through the task; the trainee needs to fashion an appropriate performance; and then an opportunity to consolidate the skill. Weaknesses here are that simulation training does not address the issues of teaching knowledge effectively. Nor do many simulators encountered in industrial training provide adequate facilities for dealing with the cognitive or fixation phases of training. Most simulators in use merely attempt to provide a replication of the real operating conditions. This is important for helping the trainee develop through the automation phase. For them to be effective also during the knowledge and cognitive phases, they would need to provide, for example, facilities for more careful monitoring of the manner in which trainees accomplish tasks, as well as their attainment of goals and sub-goals, and facilities to provide more useful feedback to the trainee. Such feedback facilities would include freeze-frame and re-run facilities. Some commercial simulators include training facilities to support these other phases of learning, but many do not.

Another weakness of simulators for training is that they are expensive. This means that a company will rarely purchase more than one. Adding this to the fact that simulators become useful tools for engineers and operational management to explore various operational consequences of different conditions, we find that little opportunity for practice is provided for each trainee. Typically, we see trainees given classroom learning plus some plant familiarity — which, hopefully, takes care of the knowledge phase of the training, followed by a short time on the simulator. This simulator experience has to try to build up competence through the different phases of learning. Often simulation training is not nearly as effective as it promises to be.

Part-task trainers: A solution to overcome many of the deficiencies of full simulator training is to utilize part-task trainers. Part-task trainers have long been established in military contexts and many industrial contexts, but they tend not to be used in process control training as often as they should. A part-task trainer will focus upon a specific type of sub-task to provide concentrated practice for the operator in a closely defined set of activities in a supportive environment. A part-task trainer might be deployed, for example, to focus on fault-diagnosis training. In this case the trainer would provide a knowledge

input concerning the nature of the plant, information and product flows and diagnostic rules. Then the trainee would be given a set of fault scenarios to practice with. The fault scenarios would consist of representations of fault conditions; the practice should be aimed at helping the trainee to identify faults using an appropriate strategy. The representation need not be completely faithful to the real plant, but it should be sufficient to enable practice of relevant skills. An obvious concession is to present static representations of symptoms of particular faults. This enables trainee's to practice the skills of applying diagnostic logic but the symptoms would not be presented in the time pattern that would be encountered in real plant.

The trainee's performance would be monitored to determine whether or not he or she was correct and to determine the manner in which diagnosis was undertaken. The next item for practice would be determined according to the progress the trainee had made to date. This general approach will be exemplified more fully shortly. Important to note now, however, is that training is focused upon a sub-task and practised until the trainee demonstrates that the skill has been acquired. In this way, the trainee can be said to have developed through the cognitive and fixation stages of learning. It may be possible to practice the skills further in order to automate them, but if the part-task trainer has made a concession to fidelity, for example the static simulation suggested above, then some practice using a more faithful representation of symptoms would be necessary, with fault scenarios generated by a mathematical model, for example. This would justify the use of a full simulator. Using part-task trainers in conjunction with a full simulator is a sensible training option. It provides an affordable and effective means of developing the trainee's skills most fully, such that the limited time available for full simulator training can be put to best use.

Mixing approaches in a fault diagnosis training programme

The case of fault diagnosis has been discussed as a typical process control sub-task and it is to this I shall turn to pull together various threads to illustrate how such a sub-task might be treated in practical training to comply with the learning ideas discussed above. The general approach is adapted from that described by Marshall et al. (6).

In Marshall et al.'s paper, which describes an approach to diagnostic training based on research into diagnostic methods, diagnosis is shown to be a skill that is best accomplished by the application of diagnostic 'rules-of-thumb'. These 'rules-of-thumb' are statements linking observed symptoms to types of fault that can occur on plant. By systematically applying a small set of rules, usually 5 to 10 rules, the operator is directed towards focusing onto the area at fault and, eventually, identifying the source of an operating problem. Marshall et al.'s paper shows how this can be applied to a real large continuous process plant. Developing the accompanying training programme entails considerable analysis and design effort. For the present purpose, however, I shall simply describe its components.

The first part of the training approach described is concerned with teaching appropriate knowledge. This knowledge includes information concerning how a control loop works, information concerning the unit operations in the plant and how these unit operations link to form a plant. This provides a language with which to communicate with the trainee and it provides the trainee with basics concerning how problems may be manifested in control loops and in process dynamics.

Knowledge training includes the introduction of diagnostic rules. A typical diagnostic rule is the *location* rule, namely, 'scan the display to see where the disturbance is likely to occur'. This could only be interpreted by a trainee who understands how product and information flows around the system. For example, non-pressurized systems will see a flow forward of symptoms if there are no physical recycle loops in the systems, therefore the site of the disturbance will be in the vicinity of the symptoms furthest upstream — so this is where the trainee must concentrate attention. A second rule is the *control* rule, namely, 'look to see if the plant in the 'disturbed' vicinity is being controlled properly. This will be interpreted if the trainee has understood how to recognize the correct functioning of control loops. The best way of achieving this is to explain the principles of different control loops and then practice categorising different configurations as acceptable or unacceptable. This is sensibly done with CBT as different trainees may practice until they feel confident and have demonstrated competence. A third rule might be concerned with recognising blockages to flow, for example, 'a high level in a vessel, combined with a low flow in a take-off line (where the control of the unit has been judged to be functioning correctly) indicates an obstruction in the line". The teaching of a rule is an aspect of the knowledge phase. As each rule is taught, the trainee is required to deal with problems consistent with the rules presented so far. So, after the 'location' rule the trainee practices locating the source of difficulty; after being presented with the 'control' rule, the trainee is presented with problems where the problem is first located, then the adequacy of the control in that area is judged. Subsequent rules are added as the trainee demonstrates mastery of the previous rule set.

Practice is provided using a static plant simulation. Marshall et al. (6) describe an approach using panel displays, created on magnetic instruments with indicators adjusted according to symptoms, projected on a back-projection screen for operators to inspect as they would a real control panel. In a subsequent exercise, a hypermedia authoring program, running on an IBM PC compatible was used to produce a very realistic representation of a hierarchically organized plant supervisory system (mimicking Honeywell TDC 3000 displays) in order to teach diagnostic rules. This application is described by Shepherd (11). It is important during the fixation phase that the trainee learns to carry out the task using a strategy that will transfer in a suitable fashion to the real situation. An important performance criterion in this respect is that the trainee can transfer skill to deal with events not previously encountered. Such transfer of training is obtained if trainees are encouraged to follow the rule-based strategy, rather than being allowed to adopt a less analytical approach, for example, using pattern recognition. In order to ensure that a rule based approach is followed, it is not sufficient simply to give practice at diagnosis. A technique called 'withheld' information training is used, where all information is withheld from the trainee until it is specifically requested. In this way, the trainer may discern whether or not the trainee is diagnosing using the rule-based strategy and can give the trainee feedback accordingly. This withheld training method can be carried out by an instructor or it can be carried out automatically in a CBT program. This requirement to ensure compliance with a transferable rule-base strategy for diagnosis provides a good illustration of the kind of instructional control necessary during the fixation phase of training.

Following the acquisition of the rule-based skill, the trainee then needs to practice diagnosis with a more realistic task representation. Here, it would be appropriate for the trainee to be confronted with a full simulation. In this way, the training programme has laid solid foundations of a transferable skill. When the opportunity to use the full simulation is presented, the trainee is already a long way down the line and the time permitted on the full simulator can now be used to best effect. Thus training is more efficient and effective.

The broad principles of training development illustrated by the example of fault diagnosis can be applied to all types of task. The important central point to be emphasized is that the best training will rely on different methods to cope with the different phases of learning.

TASK ANALYSIS AS A MEANS OF SUPPORTING TRAINING

A precursor to any training design and development is a proper task analysis. Task analysis is necessary first to establish whether training is a proper solution to the supposed training problem. Then it is used to carry out the training design itself.

Task analysis methods examine the goals that people are set at work and the problems they must overcome to attain these goals. The hierarchical approach to task analysis proposed by Annett et al. (2) and further developed by Duncan (4, 3) and Shepherd (9) is particularly suited to the analysis of process control jobs. Hierarchical task analysis commences by describing the job or task in terms of

an operation —an instruction to achieve a goal, such as 'run plant', 'operate desalination plant' or 'operate compressor'. The analyst then redescribes the operation in terms of a set of sub-ordinate operations and a plan which governs the conditions under which each of the sub-ordinate operations are carried out. Any operation is therefore equivalent to the set of its sub-ordinate operations as carried out according to their plan. Each of the sub-ordinate operations can be redescribed further if the analyst requires, again in terms of sub-ordinate operations and a plan. The plan is an essential component of hierarchical task analysis, since it describes the cues the operator must attend to in order to signal the need for various activities. It also integrates the various parts of the task or job and ensures that the analysis is thorough.

Non-Training Issues

The issue of whether training is, on its own, a suitable solution to the performance problem is fundamental to human factors work. Often, performance problems arise, not because the operators' skills are inadequate, but because the task has not been designed sensibly. If people have too many things to do at once, or if displays are poorly designed, for example, they will make mistakes. Training may not be able to overcome these problems. This issue is discussed by Shepherd (10). This is a particular problem where training decisions are left till late in the design and development of a plant or process. Often, training decisions are not considered until the plant is built and approaching the time when operational staff are to be recruited. If task analysis for training then reveals a problem for which a modification to a display system or a reorganization of jobs is advised, then it will be extremely costly to overcome such problems. Good training systems need to consider training requirements as early as possible in the life cycle of a system, in order to eradicate all potential human factors solutions for which training will not provide an adequate solution. Task analysis is the key to identifying which aspects of the task should be dealt with by training and which aspects should not.

Task Analysis and Training Design

As an aid to the training design process, task analysis serves a number of important ends. (1) It specifies each task element which the operator must accomplish. (2) It provides a context in which training design choices can be made. A particular operation may be trained in a number of different ways. The most appropriate method will depend on a number of contextual feature. (3) The task analysis shows how the task is structured and, therefore, how the various training elements can be put together to ensure competence at the whole task.

Identifying Task Elements

To illustrate how hierarchical task analysis can be applied in the process industries to identify the different task elements requiring training, it is worth describing how analysis of a continuous process control task might be started. Briefly, operation of a continuous process plant is characterised by the need for the operator to bring the plant to designed operating conditions as rapidly as possible, then monitor its performance and do what ever is required to keep it at its design specification for as long as is necessary. In continuous processing one expects to see the operator monitoring a steady state and, hopefully, having little to do. Process operator jobs are diverse, ranging from routine activities for which a prescribed series of actions is required to non-routine tasks which require the operator to select a course of action to deal with the circumstances that prevail at a particular time. The start of analysis of any continuous process control task invariably looks like a list of the general duties the operator has to carry out, for example: start-up from cold; start-up from standby; run plant; shut-down to cold; shut-down to standby; clean out plant. All of the operator's activities and decision making would fall within these operations. The plan governing these general operations would state the conditions when each has to be carried out. The plan would be in terms of cues from instruments, or from samples, or instructions from managers or supervisors. Figure 1 shows how such an analysis might commence and how some of its parts might be developed. Hierarchical task analysis can be applied to all sorts of task including, batch processing and maintenance tasks.

Through the task analysis we have identified that trainees need to acquire a set of concepts about the nature of continuous process plant operation. Moving a plant, economically and safely from a cold and empty state to a steady state of production, then trying to keep it there by a variety of means, encapsulates a range of concepts such as economy, control, heat exchange, and unit operation, that most trainees simply will not be familiar with. As attempts are made to train less qualified people the problem becomes more acute.

As task analysis progresses the analyst frequently encounters procedures that have to be carried out. Sometimes the procedure will only be required infrequently or when the operator is under stress, so the likelihood of error will increase. Sometimes the procedure is so long that it cannot be remembered reliably. Sometimes the procedure has to be carried out in conditions where a job aid cannot be used or is otherwise unavailable. Sometimes it is clear that operators would not use a job-aid even if they were provided with one. All of these factors must be borne in mind when deciding whether or not to rely on job aids or unaided performance.

Flexible operation is often a key requirement of the process operator. A prominent activity of this kind is 'dealing with faults' and an examination of this area highlights the major training issues in other variable activities. While dealing with faults is vital in process operation, in order to minimise plant downtime and avoid hazards which will affect plant, personnel and the environment, it is important to be clear exactly what sort of skill is required. Several different activities can fall within this general classification, many involving different skills and requiring different conditions for improving performance. These skills include: 'detection'; 'diagnosis'; 'compensation'; 'rectification'; and 'recovery'. The diagnosis phase has been discussed extensively above. The other phases need similar attention

Context and Training Choices

When making decisions concerning training media, it is necessary to consider the context in which each operation is carried out. Four major contextual features will substantially affect the training choice made. These are *criticality*, *difficulty*, *recoverability* and *frequency*. By 'critical' we mean the consequences that may arise if the operation is carried out incorrectly. Some operations may done badly but the overall system is not significantly affected. By 'difficult' we mean how easy it is for the skilled operator to carry out the task element successfully. Diagnostic tasks are often difficult; procedural tasks are often easy. By 'recoverable' we mean the extent to which, having made a mistake, it is possible to recover from the situation that then arises. In hazardous contexts it may be impossible to recover. 'Frequency' reflects the extent to which the operator may have opportunities to practice the task during the normal course of operations. Frequent tasks offer opportunity for practice and therefore training may be less intense.

The effect of context on training decisions can be quite subtle. There are no hard and fast rules, but consideration of some alternative combinations of contextual features illustrates the subtleties. If a task is critical, difficult, provides no opportunity for recovery and is infrequent, then simulation training is necessary and considerable expense may be justified. If, however a critical and difficult task is both frequent and recoverable, then expensive simulation may not be necessary, but conscientious instruction and supervision is necessary to ensure that proper recovery takes place and that proper

instruction is given when relevant events occur. If a difficult task is non-critical, infrequent, yet recoverable, again the costs of expensive simulation will probably not be justified. In considering these contextual effects it is best to rely on the training model discussed earlier in this paper. The training designer needs to judge whether a particular set of circumstances enable learning to take place.

The Sequencing of Training

An important feature of any training programme is how its various elements are put together to enable overall competence to emerge. The hierarchical task analysis serves to provide an overall structure in that it shows how subordinate goals link together to enable higher order goals to be met. So, we may train people to monitor plant, carry out diagnosis, rectification and recovery, using appropriate modules combining knowledge teaching, part-task training and general task practice, then they must learn how to carry these out in conjunction with one another. This is important to enable the trainee to integrate, say, monitoring skills with diagnostic skills, and so on. Within the training of each of the individual task elements, as has been emphasized throughout this paper, training should be directed towards helping the trainee through individual stages of learning in an effective way. This means, above all else, that administrative expedients, such as lumping all classroom teaching together are not taken without fully considering their consequences.

CONCLUDING REMARKS

A prominent feature of industrial training in the 1980s and early 1990s has been the development of educational technology. Educational technology offers opportunities for adaptive individualised learning, ever more realistic simulation at an ever more affordable prices and the control of instruction through 'intelligent' or 'adaptive' tutoring systems. However, we still have some way to go before such technology fully meets the needs of industrial training. A main motivation for this paper has been to re-emphasize the importance of training designers having a theoretical perspective on training such that training, by what ever medium, is best suited to the needs of people who have to learn complex tasks. Training research has developed over the years in a way that does have relevance to practice. This perspective, it is hoped, will improve the use made of existing methods as well as prompting a more discerning demand for novel technological approaches.

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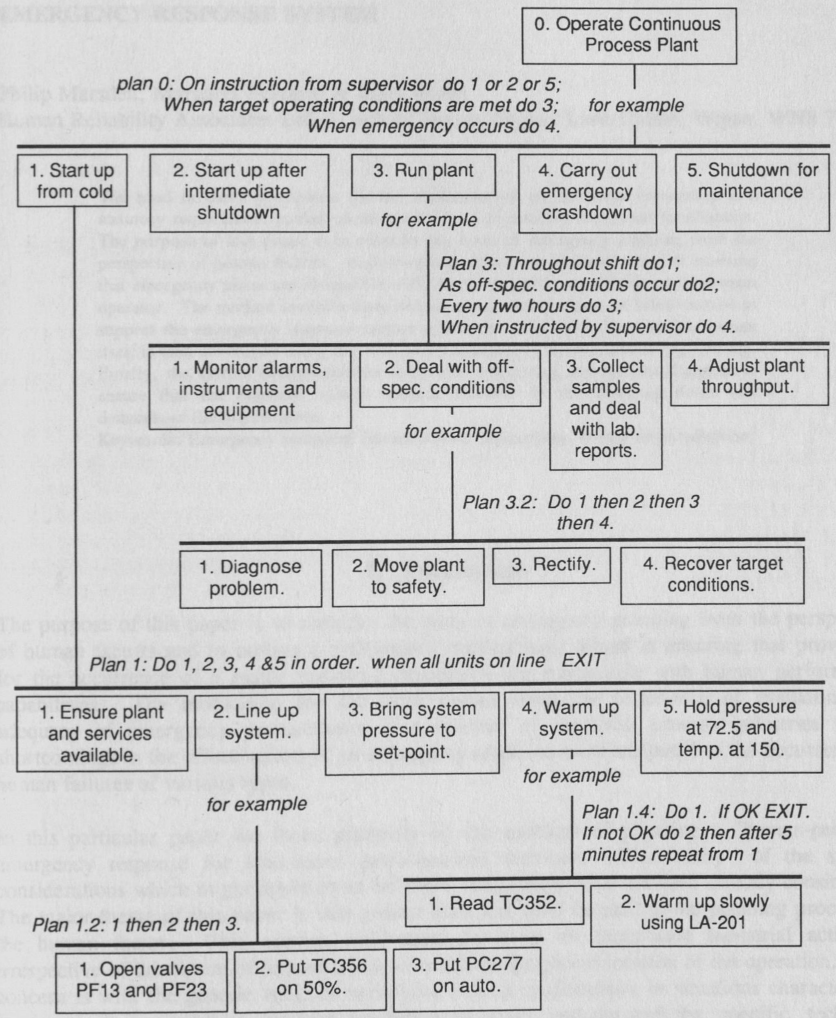

Figure 1: Representative hierarchical task analysis of a continuous process task.