AN EVALUATION OF TASK ANALYSIS TECHNIQUES FOR INDUSTRIAL PROCESS CONTROL

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The concept of a task is fundamental to the discipline of ergonomics. Approaches to the analysis of tasks began in the early 1900s. These approaches have evolved and developed to the present day, when there is a vast array of methods available. Some of these methods are specific to particular contexts or applications, others more general. However, whilst many of these analyses allow tasks to be examined in detail, they do not act as tools to aid the design process or the designer. The present thesis examines the use of task analysis in a process control context, and in particular the use of task analysis to specify operator information and display requirements in such systems.

The first part of the thesis examines the theoretical aspects of task analysis and presents a review of the methods, issues and concepts relating to task analysis. A review of over 80 methods of task analysis was carried out to form a basis for the development of a task analysis method to specify operator information requirements in industrial process control contexts. Of the methods reviewed, Hierarchical Task Analysis was selected to provide such a basis and developed to meet the criteria outlined for such a method of task analysis.

The second section outlines the practical application and evolution of the developed task analysis method. Four case studies were used to examine the method in an empirical context. The case studies represent a range of plant contexts and types, both complex and more simple, batch and continuous and high risk and low risk processes. The theoretical and empirical issues are drawn together and a method developed to provide a task analysis technique to specify operator information requirements and to provide the first stages of a tool to aid the design of VDU displays for process control.

KEY WORDS

Process control
Ergonomics
Task Analysis

DEDICATION

To my mother and grandmother who taught me most of what I know about life,
and to Rob who taught me most of what I know about Ergonomics.

"If nothing is too hard for thee,
All things are possible for me."

John Wesley

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CHAPTER 1
INTRODUCTION TO THE THESIS

1.1 THE AIMS AND OBJECTIVES OF THE THESIS

The thesis is concerned with the evaluation of task analysis techniques for industrial process control, and in particular with the study of task analysis for determining operator information needs.

The initial aim of the research was to evaluate existing task analysis methods for use in industrial process control, in terms of both theoretical background and practical application. Based on this review, the objective was to consider methods of task analysis that were particularly relevant to display design and more specifically CRT displays. The aim is the production of a method of task analysis that would analyse operator information needs. The information needs of a process control operator determine the displays that are required to perform the task optimally. The method to be developed would be required to meet theoretical guidelines and to show empirical effectiveness when applied to plant situations.

The aim was to consider task analysis in a general way in a process control context, providing general theoretical guidelines for the selection of methods and of issues to consider in task analysis. The aim of the case studies was to provide a complementary input into the study, evaluating the task analysis methods over a variety of process situations including batch and continuous plants, high risk and complex control situations, the design of new plants and upgrading of existing ones.

The objectives of the research are summarised below:

- A review of task analysis techniques relevant to an industrial process context.
- Consideration of the theory of tasks and definition of the concepts used in task analysis.
- The provision of criteria for a theoretically 'optimal' method of task analysis for analysing operator information needs.
- A comparative analysis of existing methods of task analysis, both in

relation to the criteria and to each other, for the analysis of operator information needs.

- The development of a new method, or modification of an existing method of task analysis to analyse operator information needs, based on these theoretical criteria.
- Extensive empirical testing of the task analysis method on a wide range of process plants, and continued development of the method in line with the results of the studies.
- The extension of the task analysis method to provide a tool as an aid for display design in process control situations (this was included as an additional aim, following the development of the task analysis method).

The nature of task analysis is such that it was felt to be most appropriate to study it in an applied context. Whilst experimental laboratory studies could be used to study specific aspects of the task, it was felt that within the timespan and scope of the project empirical studies would allow consideration of a wider scope of task analysis issues for several reasons:

- No two process control environments provide the same task content or work situation (this is true even on plants where the processes are the same).
- The range of problems that arise in using a task analysis technique often only become evident when the method is used in anger. Therefore to allow a realistic comparison of methods, and to allow a method to be fully developed, it must be tested for robustness, validity and consistency in an empirical context.
- Areas for useful study in the laboratory would be more readily highlighted as a result of an empirical application.

The case studies provide two main inputs into the research:

- They offer an 'applied' context for the study of the methods to compliment the theoretical considerations of analysis.
- They provide a process by which the method can be evolved to meets the demands of empirical applications to plants and design.

In response to these aims the primary outputs of the research are :

- Criteria for the selection of a method of task analysis for operator

information needs in industrial process control.
- A method of task analysis for identifying operator information needs based on an extended version of Hierarchical Task Analysis (HTA).
- Studies to assess the reliability and consistency of use of HTA.
- Empirical evaluation of the task analysis method in a number of different process situations.
- A tool for translating the task analysis information into guidelines for the selection of process control display formats.

1.2 ORGANISATION OF THE THESIS

The thesis is divided into three sections. The first two sections examine the theoretical bases of task analysis and the development of methods, the final section describes the case studies and empirical evaluation of task analysis methods.

The initial section comprises chapters 2 and 3 and considers the theory and concepts underlying tasks and task analysis and traces the evolution of task analysis in the context of human factors engineering. The second section consists of chapters 4 to 5. These chapters outline the role of task analysis in a process control situation, both in the design life cycle and in the applications it can have within process control. Chapter 5 relates directly to the case studies and outlines the development of the method of task analysis for operator information needs.

In contrast, chapters 7 to 10 describe the case studies, with chapters 11 and 12 forming the final discussion of the thesis, outlining the conclusions reached and recommendations made. Chapter 11 draws together the theoretical and empirical strands of the thesis to provide the outline of a task analysis tool for process control display design. Chapter 6 provides an introduction to the case studies. The case studies are reported in chronological order, with some of the studies overlapping temporally. The recommendations of the case studies relate to chapters 5 and 11 and the evolution of the task analysis method. Finally the appendices provide details of the task analysis methods reviewed and, where the plant information was not considered confidential, copies of the task analyses carried out.

CHAPTER 2
THE THEORY AND EVOLUTION OF TASKS AND TASK ANALYSIS

OVERVIEW

This chapter aims to define the concept of a task and the evolution of task analysis methods in the context of the evolution of "human factors engineering". The concept of a task is considered in relation to the need to document human task performance against a background of increases in the size and complexity of systems and growth in automation. The development of task analysis methods is traced from Taylor's work and time and motion studies, through Miller and Gagné's work, to the wide variety of task analysis methods that are currently in use. Given this large repertoire of task analysis techniques, the different dimensions of a task analysis which need to be considered when selecting and developing task analysis methods are outlined. Finally the justifications for carrying out a task analysis within a system are considered.

I. ERGONOMICS AND TASK ANALYSIS

2.1. INTRODUCTION

Ergonomics emerged as a technology during World War II, when the need to optimise human performance in military systems, especially aviation systems, became evident. Following the war, a new breed of scientist was established who specialised in research and applications in the field of ergonomics and applications in human machine systems engineering. Military systems and industrial technology have developed a long way since then, and so have the ergonomics and human factors technologies that accompany them. Human factors technology is now applied to many areas of human activity and makes a positive contribution to the quality of life and the working environment.

In advanced industrial and commercial systems the need for human factors has always existed. Indeed the need was there with the very first systems where men used tools and needed to make plans. With the industrial revolution, and as machines and tools became more complex, there came the need to make people function more efficiently in their relationship with machines. To facilitate this relationship behavioural sciences were employed, in the first place engaged mainly with "fitting the man to the job" (Roger, 1952). This approach was characterised by training, personnel selection and skills development. It was only during World War II that the importance of helping the person use the machines effectively by "fitting the job to the man" was recognised. In the first place this effort was focused on the overt physical activities of the person. The effort then moved towards consideration of cognitive capabilities and their relation to the task. As industrial systems have become more automated so much more attention has become focused not only on the cognitive abilities of the person but also in the way knowledge, skill and expertise is attained and used in task performance.

2.2. THE EVOLUTION OF TASKS

Tasks have existed as long as people have made use of tools or carried out activities with the aim of achieving a particular goal. Moreover tasks have always had both a manual and cognitive component, even if the latter was in the form of a simple planning activity in order to reach the desired task goal. Prior to the industrial revolution the emphasis was on one individual who had responsibility for the total production of goods or services. With the industrial revolution the emphasis of the task changed and continued to change as human tasks became part of a larger system function.

The focus of the task shifted as industry progressed in technological development. People were no longer working on a one to one basis with machines, but were involved in operating and managing 'systems'. Tasks involved not only the physical operation of a system, manual dexterity and skill, but also the psychological element of human performance became recognised as a part of the task that was now being explored and beginning to be understood. Methods now attempted to allow for analysis of both physical and cognitive task processes. As automation increased further, manual tasks were still present, but the operation of a complex system by a team of operators was increasingly in evidence. Task analysis would no longer focus only on physical actions and the problems of training the person to fit the job. A whole range of different tasks needed to be assessed; communication, the use of the interface, workload assessment and the measurement of human performance. Methods were developed to address these issues, mostly in the context of specific needs on specialised projects. This is one of the reasons so many of the methods available are directed at a very specific and often small range of task situations.

Tasks and Automation

The evolution of tasks, especially in a process control environment, cannot be achieved without due consideration being given to the impact of automation on the operator's role. Changes that have occurred in the functions of the operator in a system over the last twenty years or so have moulded the role and tasks of the human operator in modern systems. Automation is often viewed as desirable and a means of improving system efficiency and, often, quality of the product or service. However, rather than aiding and enhancing the operator's task, automation may present a different set of task-related problems than existed prior to automation.

Even in automated systems the human is a necessary component, at the very least for supervising, maintaining and for the improvement of the system. The human is still important to the total system functioning and must therefore be considered in design. Indeed as Bainbridge (1983) notes one of the ironies of automation is that:

> "The more advanced a control system is, so the more crucial may be the contribution of the human operator."

So the tasks of the operator in such cases need to be given careful consideration. Often the operator is required to carry out those tasks which it is not yet possible to automate and a consequence of this may be an odd assortment of tasks that have no coherent structure.

Task design is all the more important, therefore, in systems where there is a high level of automation. Whilst it may be desirable to automate those tasks which human operators do not perform effectively, they cannot then be expected to perform these tasks to a high level of manual control in situations where an automatic component fails. Furthermore, the implications of automation for wider task issues such as motivation and job satisfaction cannot be ignored. Whilst it is often viewed as desirable to allocate the monitoring aspects of a task to the machine (Hopkin, 1984) the operator may feel that he or she is no longer involved in the process (Brouwers, 1984).

It should not be assumed that the operator will be a major source of error or inefficiency in a system. Sources of error can equally occur in the design stage of the system. Control, therefore should not be removed from the human purely on this justification. There may be exceptions where human error is extremely probable and an automatic sequence can help maintain the integrity and safety of the plant. That is, where the risk or consequence of any human error is unacceptable on the grounds of plant efficiency or safety.

Task analysis, at an early stage of design, can help in the human factors aspects of these tasks. It will have the aim of maximising operating effectiveness and feelings of achievement and motivation. This would be by looking at the allocation of function issue, then looking at the design of the tasks themselves and finally at the way in which the tasks are implemented and trained. For good ergonomic design, the human factors specialist needs to be aware of the problems that can arise in highly automated systems and to examine in detail the overall structure and design of the human's tasks under both normal and abnormal operating conditions.

2.3 THE EVOLUTION OF TASK ANALYSIS TECHNIQUES

The need for ergonomics and ergonomic design exists whenever a human has a task to perform. If one takes Singleton's (1974) definition of a task as "A piece of work to be done by a human operator", then almost all human actions can be construed as tasks.

The study of tasks began in the early 1900s well before ergonomics was established as a science. Taylor's (1911) work on 'scientific management' became the precursor of what we now recognise as time and motion study. In his "Principles of Scientific Management", Taylor states:

> " Perhaps the most prominent single element is the task idea...This task specifies not only what is to be done, but how it is to be done and the exact time allowed for doing it".

From this, task analysis developed as a technique alongside the evolution of ergonomics. Its origins were very much embedded in the observance of physical actions and on the stimulus-response idea which was the preoccupation of the early psychologists who specialised in human factors. Early methods of task analysis such as activity analysis (Christensen, 1948) reflect this thinking.

Later in the 1960s came work by Miller, Galanter and Pribram (1960). Their method was based on an idea of TOTE units for the sequence of task elements; TOTE representing <u>T</u>est, <u>O</u>perate, <u>T</u>est, <u>E</u>xit. The current task state is tested against the current task goal of the operator. If a mismatch exists, then the task is operated on until the task goals are reached, a match is obtained and the operator can exit from the task. This method also gave consideration to the cognitive elements of the task. An example of the representation of TOTE units is given in figure 2.1.

In the late 1950s and early 1960s many of the methods of task analysis were directed towards the analysis of learning tasks and training (For example Miller, 1967; Gagné, 1972; and HTA, Annett et al., 1971). Again many of the methods were

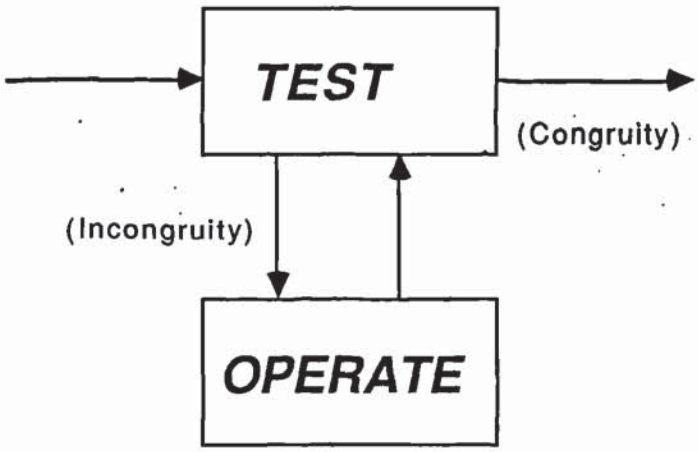


Figure 2.1 A TOTE Unit (Miller, Galanter and Pribram, 1960)

developed in a military context. Cotterman (1959) proposed a task classification to order information on human learning. Perhaps one of the best known methods of task analysis of this period is that of Miller (1962, 1967, 1975). His 1967 paper entitled "Task Taxonomy: Science or Technology ?", described tasks for training and their breakdown. The technique was directed primarily towards training applications and learning tasks, deriving a taxonomy of eight classificatory terms which could be applied to procedure design and training and part task training.

Miller's work was followed by a form of analysis, also directed at learning tasks, proposed by Gagné (1972). Gagné's task classification is shown in figure 2.2. The taxonomy focused on the processes of learning rather than on the content of the subject matter to be learnt or on the identification of the stages that occur in a learning task. Hierarchical Task Analysis (HTA) a method described by Annett, Duncan and their co-workers (Annett and Duncan, 1967; Annett et al., 1971) was also applied to training tasks. A different approach was proposed to the classification schemes of Miller and Gagné, an approach of breaking the task down into increasingly detailed task elements by means of a hierarchical analysis.

Sensing requirements **Identifying requirements** **Filtering conditions** **Shunting conditions** **Memorial inputs (long term and short term)**

Figure 2.2 Gagné's task classification

During the 1960s and 1970s many methods began to emerge that used task analysis as a tool or technique for aiding design. Miller's method had been successfully applied and other methods that were applied successfully included those of Berliner, Angel and Shearer (1964), a method developed for training and applied by Rabideau (1964) to evaluate performance. There was also Brooks (1960), whose operational sequence diagrams aimed at providing documentation of the interactions at the Human Machine Interface (HMI) over time, with the objective of providing input into design.

Also during this era, as the discipline of human factors engineering broadened, methods of task analysis became more diverse. They became more applicable to specific areas of human factors specialisation with general techniques being less common. Examples of some of the methods arising from other areas of ergonomics include Job Process Charts (Tainsh, 1982, 1985) for Human Machine Dialogue design, N^2 charts (Lano, 1977) for showing communication and information flows within a task, Critical Incident Technique (Flanagan, 1954) for examining human error and its causes and Cognitive Task Analysis (Rasmussen, 1974, 1979, 1985) which focuses on the cognitive aspects of complex control tasks.

As the range of methods broadened, two primary and distinct approaches began to become evident, those of decomposition methods and those of hierarchies. Decomposition methods analyse a task by breaking it down into a series of categories, usually in the form of a table. Hierarchical methods approach analysis by breaking down the tasks into increasingly detailed elements. There are various reviews of task taxonomies available (eg, Fleishman and Quaintance, 1984; Wheaton, 1973) which outline the diversity of methods using this framework, other reviews (eg, Drury, 1983) have examined methods available for task analysis in general. These frameworks are by no means all encompassing, other means of breakdown have emerged as task analysis has developed, for example the net form and more formal task grammars (eg, Payne, 1984). However, the majority of methods include either a hierarchical or decompositional approach or both.

2.4. DIMENSIONS OF A TASK ANALYSIS

Task analysis is now firmly established in the ergonomist's repertoire of tools and techniques. However, the choice is such that the average ergonomist can be somewhat daunted by the selection of methods available. Experience suggests that ergonomists tend to favour the use of one or two tried and tested methods or they develop or adapt a method to suit their own specific needs and applications.

One reason for this narrow approach is that the possible applications of task analysis are so wide that no one method could cover them all. However, when the dimensions of a task that may need to be analysed are studied (irrespective of application) it becomes evident that many methods are lacking task information in one or more dimensions.

This is not necessarily to the detriment of the method, which may serve its purpose well. However, if a general method of task analysis is to be developed, then these dimensions need to be documented within the analysis. It may be argued that the resulting analysis and representation would be too complex. However, when one considers the complexity of the tasks that are being documented, it becomes evident that this is unavoidable for all but the simplest of tasks.

In many systems, such a detailed analysis would not be needed. In others, such an analysis would provide a source document for design and evaluation. This would provide much general task information on which to base in depth and detailed task studies, where more detail would be appropriate. If such a model of task analytic dimensions is given, then it is easier to identify what information a task analysis method will not give and so help selection of a method. Outlined below are six dimensions that should be considered for any task analysis that aims to have some general application, they are,**where, what, when, how, why and who.**

What - This dimension specifies what equipment is to be used in carrying out the task. Equipment is used in the broadest sense of the word and can mean controls and displays at a specific level, or knowledge or information. When combined with the **how** dimension of the task it specifies what the human is expected to achieve with the task and by what means.

When - The temporal dimension; in some tasks absolute timing is important, in others it is the relative timing or sequence of events. Often with tasks, some element of time needs to be specified either for performance measurement or to show the boundaries of the task.

Where - This is the place within the system where the task is to be performed, it can refer, at a high level, to buildings and at a low level to specific displays and control panels. **Where** will also include details of assumptions made about the physical working environment.

How - This is the content of the task itself, what is to be achieved. In terms of both physical and cognitive actions, it is the procedures and operations of the task.

Why - This dimension sets the task in the overall context of the system. The goals of the task are outlined, as are initiating events for a particular task. The dimension shows why a particular task or task element is necessary in the system and what it aims to achieve.

Who - This is the dimension that considers functional allocation within the system. In a task analysis context, this is the allocation of function between humans and machines and between humans within a system.

An analysis cannot document all things within system performance that may influence task performance. These dimensions encompass the primary factors which relate to task performance. Assumptions that are made about an analysis need to be stated in the documentation which accompanies that analysis, for example assumptions about the characteristics of the user population. The analysis would also assume effective human factors design of associated factors which may affect task performance, this may include the social environment, and factors such as the motivation of personnel and a well designed physical environment.

Increasingly, the human is being accepted as being part of total system functionality and not an adjunct that is designed for separately. However, with this acceptance come demands for the human to be treated in design the same way as other system elements such as the hardware and software. This requires the system to be documented and design decisions based on analyses. Failure rates and reliabilities are required to be quantified and the capacities and capabilities of the human are weighed against those of machines. This and the complexity of such systems means that task analysis is no longer seen as being a luxury in system design, but more of a necessity to help sort out the complexity of the system. It is essential to give the team of designers a basis for their design decisions. The following sections outline some of the justifications for carrying out a task analysis and consider the issues in the selection and application of task analysis methods.

II. TASKS AND THEORY

2.5 THE CONCEPT AND DEFINITIONS OF A TASK

The concept of a task is central to the field of human factors. The study of human activity and involvement within systems invariably requires the study of the tasks that will be carried out by humans in the system. Tasks as an entity have existed as long as humans have carried out work. However, awareness of the need for terminology and concepts relating to the idea of tasks arose as man-machine systems became increasingly complex and industry more advanced.

This need is more evident as systems become more complex and advanced. Reliability and quality are major issues not just from a hardware point of view but also for the human. Humans are a major limiting factor in system performance and so there is a need to ensure the reliable functioning and effectiveness of the human systems component. This will be achieved by means such as task design and the design of the human computer interface.

However, despite the centrality and pervasiveness of tasks in human engineering, there is no theory or body of theory surrounding the idea of a task. Although the concept is fundamental and widely used there are few cases in which it is rigorously defined. It is often assumed that the same concept of task is known and understood by all. However, an examination of the literature indicates that there can be huge discrepancies in the scope of what a 'task' is assumed to be. For example Miller (1967) defined a task as:

> "Any set of activities occurring about the same time, sharing some common purpose that is recognised by a task performer."

This is a definition which focuses on a task as being a goal orientated activity, with the emphasis on 'overt' and observable task activities. An alternative definition is offered by Bennett (1971):

"Generally speaking any kind of behaviour which can reasonably be labelled with a verb can be called a task."

This forms a very general definition which views a task as encompassing all aspects of human activity when an action is involved.

Teichner and Whitehead (1973) see the task as being a more abstract activity and not directly concerned with concrete human behaviour. A task is defined as:

"A transfer of information between components *(within a system)* "

Other definitions follow from the application for which they have been used, rather than preceding it and forming a basis of theory for the application. Fine et al. (1974) and Folley (1964) both define a task in a way which directly relates to the methods of task analysis they propose.

Folley :

Task : A collection of activities that are:
i) Performed by one person
ii) Bounded by two events
iii) Described within the bounds of Folley's method.

Fine :

"A task is an action or action sequence grouped through time designed to contribute a specified end result to the accomplishment of an objective and for which functional levels and orientations can be reliably assigned"

This wide discrepancy and failure to agree on a common definition would appear to arise from the range of contexts in which a task can occur. The definitions focus on only one particular aspect of a general task model rather than defining a task in a way that would be applicable to all task contexts. For example, the task definitions that focus on physical and observable activity fail to account for tasks that are purely cognitive and may not produce any overt physical task elements.

Task definitions in the literature fall into five broad categories which show the types of approach most commonly adopted. The broad categories and the type of task definition they cover are outlined below:

1. PERFORMANCE ACHIEVEMENT

The definition focuses on the overt, physical and mechanistic aspects of task performance.

2. TOTALITY OF THE TASK SITUATION

Some definitions aim to encompass all the possible influences on task performance, including the physical and social environmental factors affecting task performance.

3. GOAL ORIENTATED ACTIVITY

The task is carried out to achieve a goal. The goal can be self generated or imposed externally.

4. INFORMATION PROCESSING DEFINITIONS

Such definitions focus on the flow and exchange of communications and information, where the task is defined in terms of information processing theory. The definition of tasks often constitutes three phases: an input, a transformation of some nature and an output.

5. GENERAL AND ALL ENCOMPASSING THEORY

A task is defined as almost any human activity that is dynamic and involves an action of some nature.

None of these definitions are entirely satisfactory. A general model of task performance will include some aspects of all these; more specific definitions of task can then be applied to situations where they are required. Eason and Harker (1979) put forward a more general model of a task:

> "A task involves a causal agent, usually man, who has a goal (state B) who will attempt to find a means of transforming the stimulus (state A) to match the requirements of a goal."

In this definition the transition from A to B is the task (Figure 2.3).

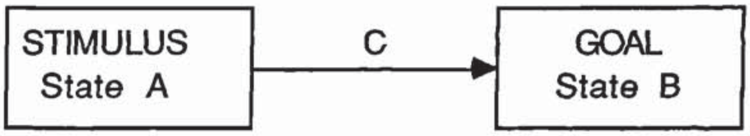


Figure 2.3 Task definition : Eason and Harker (1979)

2.6 MODELS OF TASK PERFORMANCE

In recent years much work has been carried out on the modelling of task performance and the way in which humans carry out tasks. This emphasis on modelling has grown alongside the increased recognition of the importance of the cognitive as well as physical components of tasks. In order to be able to completely analyse and document this cognitive task component, the way in which humans process task information needs to be considered and understood.

Information processing theory provides an important input into any consideration of display design and task analysis. For any task, information flows are needed and the human operator is involved in transforming information from a variety of sources (including his or her own knowledge and models of the system) into a task output. This output moves the operator and the system nearer to a goal.

There are a variety of models that have been put forward to analyse complex cognitive control tasks. Some are appropriate to consider as alternative approaches to defining the concept of a task. The field of cognitive modelling is closely allied to that of task analysis. Sometimes the two overlap and a task analysis can function as a task model. Alternatively a model may require a task analysis to enable it to be formed or to provide task information as an input to the model.

Whilst a model will aim to represent how a task is performed, usually aiming to represent the dynamic aspects of the task situation in some way, a task analysis will often extract other information, documenting specific aspects of the task. For example, it may describe the controls and displays that may be required, thus imposing a framework on the structure of the way in which the task is described or represented. Task analysis may be used to identify where there are gaps in the information concerning a task, and can provide a framework in which a new task can be developed. For a model to function, all the task elements must be there in some form. Whilst a model could help to test a newly designed task and to provide information for the iterative cycle of task analysis, a model could not be used to develop a task.

Williges (1987) identifies two basic types of human performance model, conceptual and quantitative. In the information collection stages of task analysis, both can be used to generate information about a task or about user behaviour that will feed into analysis. Likewise the output of an analysis can give information that can be used by models to simulate tasks (for example SAINT, Chubb, 1981) or can be used to input into tools for modelling the work situation (for example SAMMIE, Case and Porter, 1980). This is in addition to providing the basic task information needed as a basis for many models.

In modern complex control systems the task of the human is likely to have a large cognitive component, especially in the areas of problem solving, decision making and planning. There are a variety of approaches that have been taken to modelling the cognitive performance of the human operator, some formal and others more informal.

Quantitative Models

Many models are concerned with Human Computer Interaction and related tasks. The GOMS model (Card et al., 1983) looks at human information processing. Card et al. also aimed to quantify performance developing a model of a keying task, the Keystroke Model. However, the model is not without its problems as it is based on the assumption of error free performance. With such models that aim to quantify performance, the question is, how accurate does a model need to be to give useful information on which to base design decisions. Even if such models do not accurately quantify performance, the estimates they give may be a useful design aid. Other approaches that aim to quantify performance include amongst others, mathematical modelling (Johanssen and Rouse, 1979), fuzzy set theory and analytical methods (for example, Queuing Theory).

Formal methods and models

Formal methods that are used to develop task models (Payne, 1984; Johnson et al., 1984, 1985; Moran, 1981) are often also task analysis methods. Some are in the form of task action grammars, using a task analysis to derive generic information to model user performance within a system. Such models aim to address issues such as specifying the knowledge elements of the human and the sources of knowledge, the goals towards which the human aims, the elements of human information processing and the user's model of the system.

Conceptually based models

Conceptually based models are more common, these are often focused on aspects of human information processing. Rasmussen (1985) distinguishes between models at three levels of behaviour, skill-based, rule-based and knowledge-based. Rasmussen (1976) proposes a hybrid model of the operator, comprising a variety of models to represent the variety of sub-tasks and information processing mechanisms that an operator must call into play when performing a task. Models that are included in this hybrid are physical models, functional models, state models and behaviour models. Other methods focus more directly on an information processing approach, modelling the task in terms of its input and output and the transformation function that links them.

As with task analysis it is doubtful whether any single approach would be sufficiently general to model all task performance that was to be studied for a particular application. The approach advocated by Rasmussen would appear to give the most comprehensive coverage of a task, using various types of model to represent the different aspects of performance, thus forming a hybrid model of the task. In some situations, where it is appropriate, it may be useful to use a hybrid mixture of task analysis and cognitive or task performance models to give all the task information relevant to design.

2.7. A MODEL AND DEFINITION OF A TASK

It is necessary to state the task model which has been used as a basis for the analyses and work on tasks within the context of this research. It is evident that different interpretations of the definition of a task have influenced work on tasks and the analysis of tasks to date. This definition aims to be general within a process control environment (which forms the context of this research) and to complex cognitive control tasks. It is based on the ideas of Eason and Harker and also on models of system behaviour derived from computer science (for example, petri-nets and state transition diagrams, Petri, 1976).

A task is seen as a goal directed activity. The operator at any given point in time has a physical and mental state within the task context. From this a goal state will be formulated. As task activity is generally purposive, a goal state (or desired state) is formulated along with a plan of how to achieve that goal, this may include contingencies and alternatives. The different routes to the goal are assessed and evaluated in the light of the operator's current state. Task performance is then the formulation of the goal and the executing of the plan in order to achieve it. The task is complete when the human recognises that the goal has been achieved. Task performance can be further confounded by the changes or modifications of the goal or the means of achieving it during task performance or both. Here the operator must reassess or reformulate the plans and criteria for successful task completion. Figure 2.4 presents a simplified diagram of the task definition.

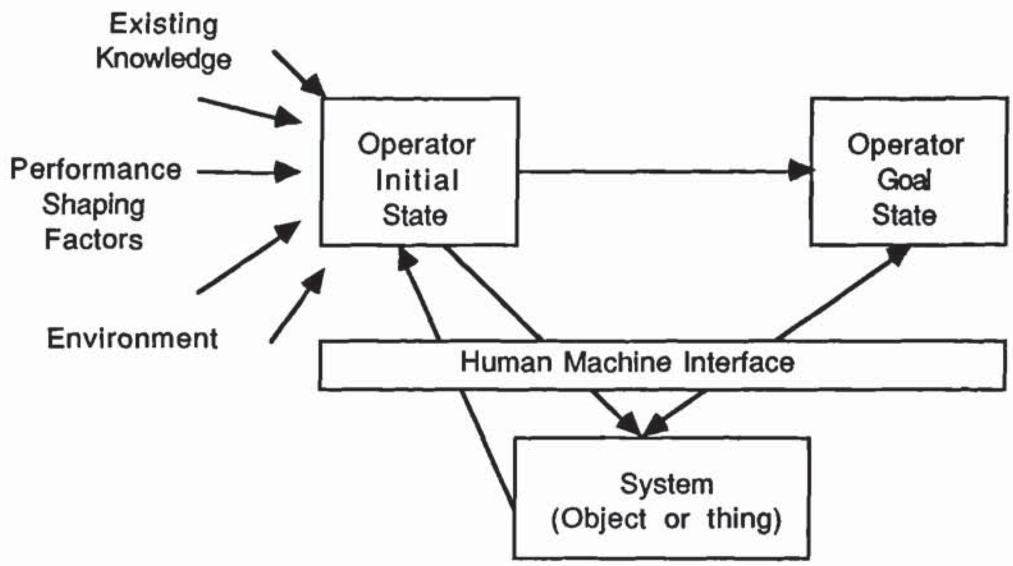


Figure 2.4 A task definition for process control

Levels of task performance - the hierarchical approach

Task performance can take place at several levels. Tasks can be viewed as hierarchical in nature (Card et al., 1983). Within the hierarchy of task elements at the top level are the overall task goals, which can in turn be broken into further task goals, this continues until eventually, at the lowest level the hierarchy, is formed a set of very simple task elements and goals which are easily achievable by the operator.

Rasmussen (1976) identifies three levels of task performance; skills, rules and knowledge. Skill based task performance is low level task performance based on sensory-motor activity. Here achievement of the task goals occurs without conscious effort or control and the behaviour is automated. Human activity, at a higher level, consists of sequences of such skilled performance related to the ability to be able to form sets of what Rasmussen labels 'subroutines' (ie the low level tasks) into a goal directed activity. At the next level of the hierarchy is 'rule based' behaviour. Here the performance of a task is goal orientated and consists of series of these subroutines formed together by "stored" rules, these are rules in the operator's repertoire.

Knowledge based activity is the highest level of task performance, and occurs in situations where no rules are available or developed from previous experience. Task performance is controlled by goals, and at this level the goals are explicitly formulated in contrast to other levels where they occur almost automatically. A plan is developed and its effects estimated and predicted and the task carried out.

These levels reflect the different levels of task performance and illustrate that in order to completely analyse a task, the analysis needs to occur at several different levels of task performance.

Whilst cognitive modelling has a large influence on how the concept and definition of a task has developed, there are other approaches which are relevant to the development of a definition. Theories relating to information processing are closely related to cognitive modelling, but the ideas of an input stimulus, followed by a transformation function, in turn followed by an output, is reflected in a range of task analysis methods (for example, Miller, 1967). Other influences include control theory and problem solving models such as those of Simon and Simon (1962). Control theory has also been applied within a task context. It is based on the concept that it is important to be able to predict total human machine performance and consequently to predict human task performance. In this approach the human operator is viewed as part of a closed loop system (the cybernetic approach) where feedback and information processing are all important components of the human loop. This model also provides a hierarchical approach to analysing tasks where the human is seen as part of this hierarchy.

2.8 TASK ANALYSIS AND ITS RELATION WITH JOB ANALYSIS AND TASK DESCRIPTION

As there are so many definitions relating to the concept of task and so many methods of task analysis available, it is important to draw some distinctions between the concepts that are used in this area. There are 3 broad categories which illustrate different approaches to breaking down task information:

Job analysis
Task description
Task analysis.

There are also the additional and related concepts of task synthesis and task modelling.

There is often confusion between these terms and methods are sometimes wrongly classified into one category or another, for example as being a task analytic technique when they are in fact a task descriptive or job analysis technique.

Job analysis versus task analysis

Job analysis addresses issues concerning the overall occupation of an individual. It involves looking at overall duties and responsibilities within the work context. Task analysis, however, addresses more specific work issues (or categories of individuals) specifically in the work environment. It looks at how individuals work and interact with the system and its interfaces. Many job analysis methods use a task analysis technique at a lower level of detail. However, whilst a job will often comprise several tasks, any individual is unlikely to perform a single task in isolation. With a job analysis, tasks are not defined at the same level of detail that a task analysis of the same situation would provide.

Task analysis versus task description

In the same way that no central concept surrounding the idea of a task exists, interpretations as to what constitutes a task analysis are loose and varied. The terms task analysis and task description are often confused and not clearly defined. In fact they are closely related but different entities.

A task description is a statement of task criteria, it documents the simple elements of observable behaviour. No quantitative or qualitative judgments are drawn from the task. The task description usually concentrates on the physical level of the task only. It is a recording of the operator's observable units of behaviour and the simple flow between these. No inferences are made as to the nature of the internal processing or to the transformation that takes place between stimulus and response. In general the description centres on the interaction occurring at the Human Machine Interface rather than on the human as a systems component.

Task description, whilst focusing at a physical task level, does form an essential element and sub-process of task analysis. The nature of a task description means that its content is less open to subjective interpretation. One positive result of this is that a higher degree of consistency is likely amongst analysts than with a task analysis. Task description can be used as a task definition in its own right but it is more commonly used as a preliminary step in task analysis.

A task analysis is both descriptive and prescriptive, taking a task description and adding quantitative or qualitative elements or both, forming a statement of human performance requirements, which help to specify the human subsystem. However, in science most analyses are rigorous and task analysis cannot always be so. In some situations this is a failing, in others an advantage. Whether or not the highly subjective content of task analysis is problematic depends on the context in which it is applied. Task analysis not only describes the task it analyses, it also evaluates, specifies, synthesises and interprets the task information.

2.9. THEORETICAL AND FORMAL JUSTIFICATION FOR TASK ANALYSIS

Within any human machine system, extensive documentation will be available outlining the parameters, expected performance, functioning and specifications for the human-machine components. As technology advances and machines become more sophisticated and reliable, the human element has become the limiting factor in system performance. In order to be able to assess and predict the functioning of humans in the system, the task which they will perform needs to be assessed.

Analysis of the human as part of the total system is important for a variety of decisions that will be made in the design and evaluation of a system. At the early stages of design, it is important to ensure the human will be allocated those functions they can perform effectively and which reflect the abilities of the personnel employed. Those decisions relate closely to the automation decisions within a system. Some tasks still cannot be automated and require the flexibility and knowledge of a human operator, others are better carried out by machines; either to relieve the operator of monotonous, boring and repetitive tasks, or else to alleviate workload. A balance needs to be found and decisions can only be made if enough is known about the human's task contribution to system's performance and functioning.

At later stages in design, specifications are needed to feed into both the human engineering design and design work carried out by other disciplines, a task analysis acts as a source document and as a record of why design decisions were taken. So the different aspects of design which include consideration of the human will be working from a common basis and, hopefully, common assumptions. This should lead to consistency and harmony in the human factors aspects of the system design.

This specification also allows some of the phases in design to be considered in parallel, stages which without a task analysis would be contingent upon one another. For example in a complex control room design, interface design would normally precede training. With an effective task analysis some of the development of a training programmes could occur in parallel.

A task analysis also provides a means of evaluation and quality control. It can be used to evaluate how well a system meets the acceptance standards during commissioning or to evaluate an existing system for retrofitting or for new system design. The analysis can be used to set a standard or to form a specification against which expected system performance and quality of human performance can be checked. This means that if tradeoffs are made or compromises reached, then these have to be justified explicitly.

A task analysis does not have to be extensive, if specific information is required a task analysis can be used to give this. The vast range of methods available mean that often one can be selected or modified to suit particular analysis requirements. The analysis can then be carried out at a level of thoroughness and detail appropriate to the application.

At a more theoretical level, practical uses of task analysis help to further ergonomics knowledge and theory in this area. Through practical use, problems or deficiencies in methods will be highlighted, methods can then be progressed and theory extended or both.

2.10. DISCUSSION

To summarise, there are a vast range of definitions of task and task analysis expounded in the literature, the variation probably being due to the lack of any central body of theory concerning tasks. Following from this, a definition that is general to process control is suggested and definitions of the different terminologies in this area outlined along with the distinctions between them. This definition is used as a basis for considerations of task analysis methods within a process control context throughout the thesis. The discussion of the evolution of tasks and task analysis provides a background into which the case studies and consideration of task analysis in process control can be set, and a context for more detailed consideration of task analysis issues. Finally the principal justifications for carrying out a task analysis are summarised below:

- As with any component within a system, the role and functioning of the human subsystem needs to be documented.

- Documentation of a task provides information on how design decisions were arrived at and shows the basis for design. This can help reduce future design effort and help in modifying and updating current systems.
- Different aspects of the human factors design can be carried out in parallel, whilst otherwise they would be contingent upon one another.
- Work in the task analysis field helps to advance techniques and to develop methods more appropriate to modern technologies and related tasks.

CHAPTER 3
ISSUES IN TASK ANALYSIS

OVERVIEW

Chapter 3 considers the issues involved in the selection of task analysis methods and the individual stages that comprise a task analysis. The first stage in carrying out a task analysis is the collection of information for the analysis. Whilst the task analysis technique provides a framework for organising the task information, the quality of the analysis is dependent on the information input to the analysis. It is important to select a method that provides information in a form that can be used by the analysis or to select a method of analysis that can use the data available.

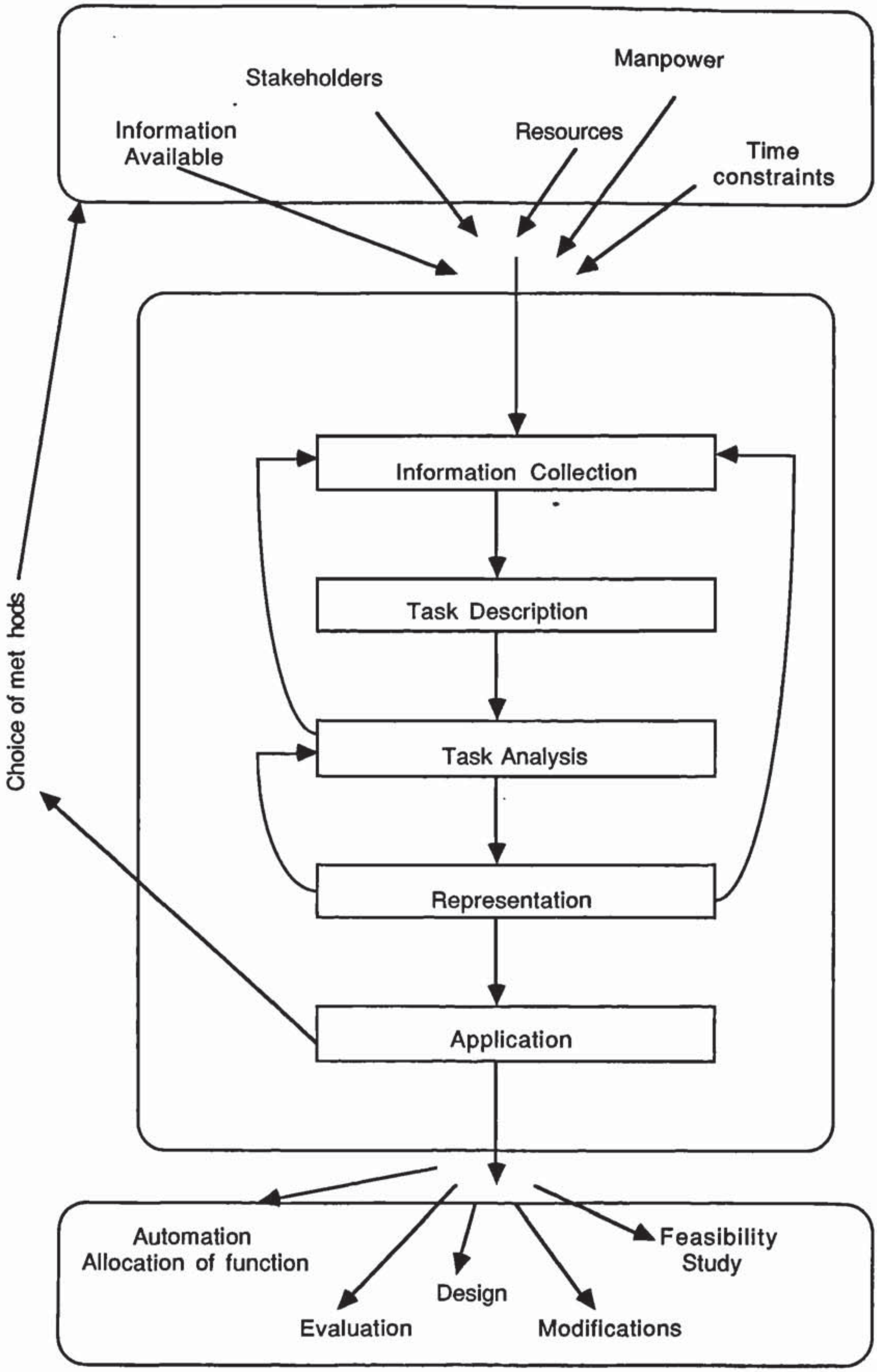
It is often difficult to select task analysis method for a particular application from the vast choice available. In selecting a method, whilst the utility of a method for the specific application is important, general issues such as the validity and reliability of the method form core criteria for selection. Formal validity studies are not always practicable, however, the consistency of analysis produced by several analysts studying the same task, can provide an acceptable indication of the reliability of a method. Finally consideration should also be given to important, but less central issues, such as the use of stopping rules and the level of detail of analysis.

3.1 INTRODUCTION

Task analysis is a process in which information about a task is collected and translated into a format which will represent the task or some aspect of the task for the purposes of design or evaluation. This process occurs in a series of distinct stages which are each contingent upon one another, although in some methods one or more stages may be merged. However, the process is an iterative one, the iterations occurring within and between stages.

All the stages are inter-related, the first is concerned with the information available about the task or information that can be collected. This stage is dependent on the resources available both in terms of manpower and access to information about the task. Carrying out the analysis in terms of task analysis and description is the second stage. The application for the task analysis will help to decide which of the task analysis techniques available will be the most appropriate. If the analysis is to be used for a large scale advanced system, the analytic information may need to feed into a wide range of design areas. In this case, two alternative paths of analysis are open. One is to carry out the analysis using a battery of selected and complementary task analysis methods, the other is to carry out a general task analysis which provides a common source of information to feed into other more specific analyses relevant to the applications required. What the analysis is to be used for is ultimately the deciding factor for which methods are used. Having selected a method, the analysis then takes the form of a series of stages; these may be combined or distinct but they occur sequentially. Figure 3.1 illustrates the stages.

Figure 3.1 Stages in Task Analysis



3.2 STAGES IN TASK ANALYSIS

The process of carrying out a task analysis can be very complex, as, in practice, iteration can occur at any stage of the cycle. This iteration may involve going back one or several stages in the analysis, either to gain more information or to show the analytic information in an alternative form.

The analysis begins with a series of decisions about the nature of the information and its uses. Usually this will involve consideration of the following:

(i.) **Resources** - Decisions on the resources that can be provided (ie, manpower, finance etc) for the analysis.

(ii.) **Choice of methods** - Decisions on the method or group of methods to be used.

(iii.) **Stakeholders** - Consideration of who the people with an interest in the new system are (Harvey, 1988, defines these as "stakeholders") and the level of their interest in the outcome of the task analysis.

(iv.) **Applications** - Consideration of what the final analysis is to be used for and who it will be used by.

3.2.1. INFORMATION COLLECTION

This is followed by an information collection stage. All the task information is gathered together in a form that is usable for the analysis. The information collection that can be carried out may be determined by what is already available in existing systems, or in the case of a new system, on what has been decided to date by the design team. Information that can be gathered in addition to this may be dependent on resources such as, time, manpower and cost, as well as the task information needed to complete the analysis.

Much of the task information will be gathered from people who are already involved in the system or similar systems. This involvement may take the form of design, operation or system management.

One possible approach to deciding who in the system to collect task information from, is suggested by Harvey (1988). Here the approach is one of identifying who the stakeholders are in the system and their relative importance, and using them accordingly as a source of task information. This approach ensures that the different viewpoints of managers, operators and other people in the system are represented. Often the approach taken is to concentrate on one group of people in the system, such as the operators, rather than the views of a range of relevant personnel. The former approach can lead to biases in design and a system that does not adequately consider the needs of all its users.

There is a considerable range of techniques available, providing both qualitative and quantitative methods of collecting information about a task. The methods used will depend not only on the method or methods of task analysis that are to be used, but also on the time and resources available. In addition, the current design or evaluation situation of the system may eliminate the use of certain methods. The methods available can be grouped into four principal kinds of approach to information collection:

Documentation

The documents surrounding a task and its performance can provide a rich source of task information. The task is shown in terms of how it was intended to be performed and documentation can illustrate how the task relates to the wider system purpose. There may also be documentation on the development of the task during design which shows justification for design decisions. Some of the main sources of documented task information are given below.

Existing formal documentation

This technique involves the gathering together and analysing of the formal documentation surrounding a task. It can include job descriptions, standards, specifications etc. However, this method can only render information on how a task or job is 'supposed' to be performed and does not account for the incumbents' informal adaptation to the workplace. There is also the possibility that the information has not been updated as the job has evolved and so may be out of date.

System Specifications

Usually in the situation where a new system is under development a system specification can be a source of information regarding performance requirements and expectations. Specifications help to allow the matching of system demands with user characteristics. They can also help in ensuring the quality of the human engineering within the system by providing a specification to which the task must be designed.

Historical Records

This is similar to a critical incident (Flanagan, 1954) type of approach in the information it renders. Often in a system there are records available documenting such incidents as system failures, operator error, accident reports, down times and so on. These can be an invaluable source of information as to parts of the system that are, or have been, susceptible to human error. Records are also often kept in the form of logs which give information about the day to day tasks of the operators, commonly occurring variations and patterns of tasks.

Operating documentation

Often the operator in any system has a plethora of written instructions regarding the tasks available to them. These can be in the form of manuals, operating procedures, health and safety standards and a variety of other information surrounding the correct conduct and the role of the human in the system. This information can be produced from a variety of sources, for example, system manufacture, company trainers, management and the operator, and can be in both formal and informal forms.

Post job performance information collection

This group of information collection techniques involves the derivation of information about the task, at some point after the task has been performed. This includes methods of recording task performance for later analysis and the use of task experts to perform subjective evaluations of the task.

Video Techniques

Video recording techniques can be used as a means of recording operator activities either in an empirical or a representational task setting. They are useful for two main purposes:

1. Where other observational measures would be considered too obtrusive, for example the presence of an analyst in a control room or electrophysiological measures.
2. Where it is not possible for all the relevant task information to be recorded easily whilst the operator is performing the task. Videos allow the complete task to be recorded and analysed at a later date.

Advantages of the method include possibilities of repeatedly observing the same piece of task performance and being able to speed up and slow down the video tape to give more detailed task information. The disadvantages are that the information can be very time consuming to extract. Another is that ambiguities may not easily be resolved without having someone experienced in the performance of the task to contribute to the process. The analysis can take the form of either an expert providing a commentary of the task or of an analyst extracting relevant task information.

Scenario Diagnosis

Here an operator is given one or more scenarios and asked to perform a diagnosis of the task situation, (for example a process plant, or a computer system). This method relies on the use of experienced operators but may give an insight into the cognitive processes of the operator and their decision making and problem solving strategies. The information gained is very much dependent on the task situational details given to the operator.

Critical Incident Technique

This is based on real and critical events occurring during the performance of the job or task. It renders information on such factors as human error and inadequacies in task design. However, such data looks only at the extremes of task performance and so does not give a complete task description. This makes it useful for only a narrow range of applications. However, it can be particularly useful in the high risk industries or those which are safety critical for identifying potentially hazardous situations.

Unstructured Interview

This is less reliable than other methods in the type of information it produces. This can vary between individual operators and factors such as their personality, verbal ability and so on. Its usefulness lies in providing an overview of the task . It allows the user's framework for task performance to be explained. Such interviews also provide an opportunity for the analyst to collect data which may be unforeseen and therefore not gathered in a more structured context. Its weakness lies in the fact that it is secondhand data, therefore the information may be diluted by subjective opinion and bias.

Structured Interviews

Here the job incumbents are asked predetermined questions and the interviewer guides them along a specific path designed to elicit certain task information. It is more fruitful than the unstructured interview situation as it yields more standardised information which is of direct relevance to the analysis.

Job Product Analysis

This technique looks at the output of the job with the aim of inferring certain information about the process and the tasks which go to make up the task output.

Subject Matter Experts

This can be information gained from a single expert or a group of experts. Relying on one person as a source of task information leads to many biases in the information, not least that the information is likely to be knowledge orientated rather than task orientated. However, it is a good source of clarification for task related information. Alternatively groups of experts can be used to arrive at conclusions about tasks and how they should be carried out. Results can again be heavily biased, dependent on the structure and composition of the panel. Subject matter experts can range from the job incumbents to managers and researchers in the area.

Model Comparison

When a task analysis is required for a task that does not yet exist and a similar task can be found, then the latter can be used as a model for the former. An analysis is made of the model job(s) and the data adjusted by whatever information we have about the job. This is an iterative process and can consist of a series of refinements as knowledge of the task grows and as the task becomes operational.

Task Situation Representation Techniques

This range of techniques is based on the representation, at varying levels of fidelity, of the task situation. The degree of fidelity needed is dependent on both the type of task information needed and the resources available to collect the task information.

Simulation

This involves an accurate representation of the task situation. Usually the aim is for fidelity to the real setting as far as possible. There is a wide variety of uses for simulation and it can be used for collecting most information that cannot be collected in a true operational setting. Its advantages are varied. It allows scenarios to be repeated for a large number of operators with a high degree of accuracy. Events can be represented in real time or manipulated temporally, and error or alarm conditions can be shown. This makes it especially useful for training purposes. However, the cost of developing such a simulation can sometimes be prohibitive.

Mock-ups

Here the task environment in question is represented as a mock-up of the real task situation and operators are requested to "walk through" the task procedure as they would normally perform it. In this way various forms of task data can be collected. Mock-ups give low level fidelity in task situation representation and do not have any dynamic task representation.

Walk throughs

This is a method which can be incorporated into either of the above or for example, in a control room situation where the plant is off line. Information is gained as the operator goes through the operating sequences as he or she would normally perform them usually giving a verbal commentary on their actions as they perform the task.

Physical Models

The representation is based on models of the physical task situation (for example, a control room) with the use of manikins to portray the role of the human operator in task performance. Manikins can only offer a static representation of physical task performance, so the information gained will relate to such issues as the layout of a control room, the positioning of items on an interface and so on.

Computerised Representations

Computing techniques allow a whole range of representational possibilities to be explored, from the mathematical modelling of the task situation as a way of gaining information, to the graphical representation of interfaces. In this context the computer can be used as a tool to represent the task situation as whole; in a modelling sense, or to simulate some part of the human computer interface.

Real Time Techniques

This group of techniques is used for gathering task information in an empirical setting whilst the task in question is being performed.

Observational Techniques

Information gathered in various forms simply by the analyst observing the operators whilst they are performing the task under study. The information can be recorded manually by the observing analyst or by automatic means. It usually only documents the observable physical actions of the operator and can be carried out by the following techniques or similar variations:

1. Continuous behaviour observation - a continuous record of the activities (or a sample of activities) as they occur, for example by keeping a running log of task activity, more commonly known as activity analysis.
2. Time sampling observation - a sampled cross section of the operator's activity, usually at regular time intervals.
3. Use of checklists and behaviour inventories, covering either the full range of

activities or selected elements.

Mental Workload Measures

This can be measured in an empirical or simulated setting. One of the most popular methods of assessing this is by the use of secondary task techniques, where changes are made in either the primary or secondary task and their impact on performance measured. It gives information on the cognitive loading of the operator as he or she performs the task in question.

Physical Task Measures

These are measures of the physical task load of the operator as he/she performs the task in question. They give an indication of the physical demands of the task. Such measures could include information on frequency of control usage, cycle time for repetitive manual tasks and error rates.

Verbal Protocols

This method aims to gain information on the way in which incumbents approach the task, make control decisions and may also give an insight into the way in which they process information and their mental model of the system.

The method involves subjects being asked to "think aloud" whilst performing the task or to account retrospectively for their task actions. It can also be a "post task situation" technique. The method does not give complete or reliable data but is a source of task information that cannot be obtained in other ways. Usually the protocol is recorded and then transcribed and analysed at a later date.

This is just an overview of some of the more commonly used methods. For an analysis of all but a simple task it is likely that several methods will be employed to collect the task data, either independently or in conjunction with one another.

3.2.2 TASK DESCRIPTION

Once collected, the task information may need some initial organisation into a form suitable for task analysis. At this stage no interpretation is made of the information, but it should be structured in a way that allows it to be interpreted and applied. This stage produces a task description and may be formal or informal (for example, in a formal representation that is required as an input into analysis or as informal handwritten notes). Sometimes this will be carried out as the data is collected or used as a means of organising the task data. Alternatively the task description may form a more formal part of the analysis itself.

3.2.3 TASK ANALYSIS

If practical constraints allow, the task analysis technique will have been chosen before the task information or data is collected. Chapter 4 discusses the methods that are most suitable for different applications and stages in the system design life cycle. Some of the practical problems and issues in carrying out a task analysis are outlined in the following sections.

The analysis technique provides a framework for structuring and interpreting the task data. It can be prescriptive as well as descriptive, providing information that can be used for design and evaluation of systems and tasks. However, existing methods of task analysis provide a framework in which to document tasks and task related information. They do not always provide complete tools for design or evaluation. Often a human factors engineer or other appropriately qualified specialist is required to interpret the analysis into information that can usefully be applied to design. The effectiveness of the analysis in communicating the task information is highly dependent on the following stage in task analysis, that of representing the results of the analysis in a usable form.

3.2.4 REPRESENTATION

The representation of the analysis is the final form in which it is communicated to the end user, who will not necessarily be the analyst. Often this is in a graphical, symbolic or textual form, with words used to describe the content of the task elements. The use of natural language to describe and analyse tasks provides a flexibility and accuracy of description not given by any other means. However the very nature of this flexibility is a source of inconsistency amongst analysts (Astley, 1988). Natural language provides the opportunity to describe tasks in a very accurate and detailed way. However, this is very dependent on the analysts, the way in which they approach the task and the exhaustiveness of their approach and attention to detail. A tool is there for description, but that does not mean to say it will be well used. To some extent this variability between analysts can be overcome by providing a more rigid structure to a task analysis technique. However, variability does not necessarily mean that any one analysis is incorrect, it may just be an alternative way of representing the task.

This final phase of representing the task is not a small one. If a task is complex, the analysis of it will reflect this complexity. It should be remembered that humans are intricate and flexible system components, and that much of the way in which humans process information and carry out tasks cannot yet be replicated by machines. So it is reasonable to expect a task analysis to be at least as complicated as some of the engineering and system analyses within the same system. However, as a human factors specialism, task analysis and its representation must aim to follow human factors guidelines. It should aim for comprehensibility, readability, the effective use of symbols and signs and above all it must be usable.

3.2.5 APPLICATION

Once the analysis is complete the final stage is applying the analysis. Task analysis can be used either for the evaluation of an existing or new system or in design. If there is no similar existing system from which task information can be drawn then the process of task analysis is often labelled "task synthesis", as the task is formed without an existing task basis.

The application is the most important factor in the choice of task analysis method. The application determines what information is needed from the analysis and in what form, and so also relates to the information collection stage. One of the important features of the method is that the representation of the analysis is in a format that is suitable for the application and which minimises the chance of misinterpretation. All stages of analysis are controlled by extrinsic factors such as the time, manpower and finance available to carry out the analysis.

The information should also be presented in a form that other analysts and users can understand. If the analysis has to be changed or updated it is essential to allow other analysts and users to be able to relate the documentation of the task to the task analysis method that was used to produce it.

What it is important is that the analysis provides an accurate representation of the task, is without bias and is as detailed and complete as the application requires.

3.3 SELECTING A METHOD

The use of task analysis techniques raises many issues wider than simply how the mechanics of a method work, if it is useful for a particular application and where it can be used in design or evaluation. This section aims to address some of these issues, with particular emphasis being placed on those of selecting a method and its consistency in analysis. The former is important as the method selected determines the ultimate success of the use of task analysis. The latter is important as consistency in a method can help to reduce the effort needed for analysis and to ensure that the resulting task information is valid and reliable.

There is a vast range of task analysis methods available. Some are well known and commonly used, others have been developed for a specific purpose and are more narrow in their approach. Despite the array of techniques, selecting a technique for use in any application can be problematic. This is not only because there are often many choices of method for any one application, but also because there are no standards or criteria to aid the choice of a method and to ensure it will be effective in meeting its aim.

In selecting a technique, the first step is to establish the application or applications the analysis is to be used for, and the stage in the design cycle that it will relate to (chapter 4 offers some guidelines). From this, the requirements of a method can be established. Ultimately the effectiveness of a method will show itself in a practical application. This assessment of effectiveness will be, for the most part, subjective, as few methods take a quantitative approach to task analysis.

In selecting a technique, the methods can be assessed comparatively to find the most useful or effective method in a relative sense. Alternately, methods can be evaluated against a set of criteria which are relevant both to task analysis methods in general and specifically to the application(s) in question. As each application is task specific, much depends on the overall effectiveness of a method and there can be no absolute delineation of what constitutes a good task analysis.

Outlined below are criteria and issues to be considered when selecting a technique. Initially, criteria that are central to all task analysis methods are described, then criteria that are relevant to methods from some of the more common application areas are covered. The criteria are based on information gained from an extensive literature review showing which methods have been extensively applied, are successful empirically and are theoretically clear. Finally, issues which need to be considered in the selection of a technique are discussed. These are situation specific and can have a positive or a negative influence, but are important areas for consideration.

3.4 CORE CRITERIA

The criteria that need to be considered for all task analysis methods are: usability, validity, reliability and to a lesser extent, generality.

Usability

That a technique in the repertoire of a human factors specialist should be usable is a natural assumption. The task analysis method should be usable for the user population it was designed for. This may mean that some methods are exclusively the domain of the human factors specialist, whilst others are employable by engineers, designers and software specialists.

The usability of a method has two facets. Firstly the usability of the end product for design or evaluation, this is how effectively the task information is communicated to the end user. It involves consideration of such factors as the structuring of the information and the extent to which rules can be applied to its interpretation and application.

The second aspect of usability relates to the technique itself. The method should be both clear and well documented so that it can be applied unambiguously by the intended user population. The method should also be well structured with clear and explicit rules, with an indication of the training that is required to be able to carry out the method.

Generality

This is the consideration of the generality of a method across a range of tasks, disciplines and varying degrees of task complexity. This is not to say that methods limited to a very small range of tasks and applications are not effective, however, their range of use may be small and as task situations vary, it may be difficult to judge if a method with a narrow scope is useful to a particular application. Of course at the other extreme a method that is too general may not produce sufficiently detailed task information.

General methods are useful for gaining an overview of a task and can provide a common source of task information for other more detailed methods that are needed for design or evaluation. A more specific method, if its generality is proven, can be selected for an application area with confidence in its validity and without the need for constant "reinvention or adaptation of the wheel" for each new and specific task situation.

Validity

The validity of a method is a difficult concept to define, but again can be considered from 2 approaches. Theoretical validity involves considering the concepts underlying the technique, such as the concept of task, task analysis and ideas about the structuring of the task. These may be expected to have a grounding in psychological theory and also be valid in terms of their approach to psychological theory. Empirical validity concerns assessment of the method in practice, looking at its effectiveness in the real world. In particular the objective should be to ensure that the results of the analysis are successful in their application. From a pragmatic viewpoint this is as essential as theoretical validity. The validity of methods is an issue which has not been addressed in detail in the literature and is discussed further in chapter 12.

Reliability

Task analyses often have a highly subjective content and so it is inevitable that there will be differences in the analyses that are produced. Unlike a mathematical problem there is no "correct answer" to a task analysis, as long as it provides an accurate representation of the task under study. Very few task analysis methods have been tested to assess how consistent the results they produce are. One of the likely reasons for this is the time and effort involved in carrying out a task analysis exercise. However, it is important that for a method to be valid it should produce reliable and consistent results with use by different analysts and on different tasks. One measure of reliability is known as inter-rater reliability and involves assessing the consistency of several analysts independently analysing the task using the same method.

3.5 OTHER CONSIDERATIONS IN ANALYSIS

When embarking on a task analysis there is a series of issues that need to be considered in conjunction with the task situation and the overall aims of the analysis. These are outlined below:

The level of detail required in the analysis

Some methods allow task analysis to take place at only one level of detail, for example flowcharts. Although the level of detail given may vary there is no distinction made between levels. For a large analysis this would mean an overall lack of structure to the analysis and make the analysis difficult to use. Alternatively, for a simple procedural or sequential task such a method may be extremely useful.

Stopping rules

In any analysis there needs to be a set of guidelines or rules to judge when analysis is complete; these are referred to as stopping rules. In some methods there is a finite number of levels of detail to the analysis and so the framework for the completion of the analysis already exists. Other methods are more flexible and need defined guidelines to indicate when the analysis is complete.

Some methods (for example, FAST, Williams, 1988) stop analysis at a level determined by expert judgment. Other methods carry analysis to a level appropriate for each specific application, for example a hierarchical method that is to be used for interface design may stop at a level where individual interactions with the elements of the interface are specified. Other methods have specific stopping rules. For example Hierarchical Task Analysis (HTA) has a rule called the " P times C" rule, this rule takes each individual task element, assesses its importance and determines if the analysis needs to be more detailed. There are also stopping rules put forward for HTA by Shepherd (1981) which can be generally applied to task analysis. Both the stopping rules and "P times C" rule are discussed in more detail in chapter 5.

However, with present analysis methods, much is dependent on the task situation and the analyst's judgment of the needs of the task environment. Overall, in any analysis, it is better to err on the side of caution and to ensure that information that may be required is included. Whilst this may conflict with the recommendations of some stopping rules, in applications such as the analysis of information flows, it is important to provide a thorough analysis. If an analysis has to stop for a reason other than meeting the requirements of one of the stopping rules, this must be noted for anyone using the analysis in the future. For example, this should happen if the analyst was unable to collect sufficiently detailed task information or if there is a gap in the task information.

Task Analysis - Tool or Technique ?

In a systems context, task analysis commonly has two goals, that of input into a design or for evaluation of a system design. However, the extent to which task analysis methods available provide tools for either is limited. Methods currently available provide a framework to structure information about a task, including a task description and interpretations of the task description, rather than providing a tool which gives information that leads directly to design decisions. The analysis itself does not provide a direct input into design, it simply provides information that will be interpreted by a human factors specialist into useful design information.

Some methods produce guidelines as an output of the analysis, but these also need to be interpreted and fitted into a task context. The use of task analysis as a task information gathering technique is one reason why it is of critical importance in selecting a method to consider the information that will be produced by the analysis. It is important to ensure that it is in a form that will be usable for the intended application.

Task analysis of cognitive and physical tasks

The need to document the cognitive elements of task performance as well as the physical and overtly observable elements is well recognised. In modern complex systems, tasks have a high cognitive content compared to the largely manual tasks of early industry. However, the analysis of such tasks can be difficult. First it is difficult to extract information about cognitive skill and knowledge as they are not directly observable. Methods such as interviews and verbal protocols give some task information but it is often difficult for operators or subject matter experts to verbalise how they carry out their task. Also, many aspects of the task performance may have become automated skills and the operator is unable to describe exactly how they are carried out step by step. Some analyses will require information about physical task attributes, for example an analysis to look at the biomechanics of a manual handling task. Others will focus more on cognitive task aspects and need an analysis which helps thorough examination of the task from this viewpoint.

As expert systems technology becomes more in evidence, techniques for knowledge acquisition are being developed and these are closely related to cognitive task analysis methods. Indeed many are similar to the task analytic methods that are used for cognitive task analysis for example.

Evaluation of alternative design options/independency of design

Many task analysis methods rely on existing tasks as a basis for analysis. One major problem with this is that many of the problems of an existing interface may be unwittingly carried forward into the new design. This is especially the case if the current design aim is to introduce ergonomics principles into the design. A method should aim to be independent of the current interface and to consider constraints on design afresh, so that options available can be evaluated in an unbiased manner. If task analysis is to be used for evaluation, then the existing interface will need to be appraised at some time.

Formal versus informal methods

Recently more formal approaches to task analysis have been emerging (for example

Johnson et al., 1985; Payne and Green, 1986) often in the format of task action grammars. Formal methods offer a more rigid approach to task analysis and so result in greater consistency amongst analysts. However, a formal approach does not guarantee greater rigour in the method, methods are still reliant on the thoroughness of the analyst. Indeed some take a "bottom up" approach (Diaper, 1988) to analysis, where task detail moves to increased generality. Here there is an increased risk of lack of completeness of the analysis if the bottom level of analysis is not exhaustive. Also, generalisations to form the higher levels of the analysis may be based on incomplete information. Further, if the analysis is to be revised, extended or updated it will be difficult to see where improvements on the original could be added or made. However, formal methods do help to mitigate the effects of subjective input into analysis.

Many of the formal methods in existence have been directed towards human computer interface design. Jacob (1983) used a formal method of analysis to specify the human computer interface and other methods (Moran, 1981; Card et al., 1983) are aimed at the design of the interface. The user interface and human performance need to be specified in the same way as hardware and software systems are specified if we are to ensure quality in human factors design. If there is a specification which a design must meet, then any deviations from that specification must be justified. Human factors as a relatively new science is often viewed as an area where tradeoffs and cost savings can easily be made. As it is difficult in many cases to demonstrate the tangible benefits of ergonomics, the design contribution of the ergonomists can be seen as a target for compromise. To avoid this, a specification can help in ensuring that human factors standards are met and maintained and that the design is not compromised because a "fitting the man to the job" approach has been imposed.

However, the less formal approaches also have advantages primarily in their flexibility and adaptability. Unlike formal methods, such approaches can be adapted to meet the needs of specific situations. The use of natural language in many of the methods means that tasks can be specified in a way appropriate to the task situation and nuances of meaning can be included that could not be communicated in formal methods. The representations are also structured in a way that allows them to be added to and easily updated; this is often not true of formal methods.

The choice of method depends on the task situation and the approach that the analyst adopts to analysis. Formal methods offer a greater consistency and a more rigorous framework to analysis, they may also be more acceptable to a system where human factors specialists are working primarily with engineers, as formal methods offer documentation more akin to engineering notation. In contrast, more informal methods offer a flexibility and adaptability of approach that formal methods cannot match.

3.6 CONSISTENCY AND RELIABILITY IN ANALYSIS

Task analysis is one of the first steps carried out by an ergonomist in the design or evaluation process. It is therefore essential that this task information is correct as a basis for design decisions.

One problem that is frequently encountered is that of ensuring consistency amongst analysts. Failure to achieve consistency may lead to errors or false assumptions being drawn from the task analysis. Analysis has traditionally been carried out by human factors specialists, but now it is increasingly common for engineers and designers to become involved in the process more directly. This gives rise to a new range of problems coming from the application of techniques. As analysis is a time and person intensive activity, it must be carried out as efficiently as possible. Consistency is important to avoid large discrepancies in the quality and type of analysis produced by the analysts and to avoid the need for repeated reiteration.

The opportunity to assess the consistency of results rarely occurs even in large scale systems where there are several analysts working. The time and effort expended in analysis means that analyses are rarely allowed to overlap significantly. So there is little scope to compare the results of several analysts on one system or part of a system. Consequently the validity of techniques has tended to be shown by the results of their use in the design process rather than by any formal evaluation.

The repeatability of results achieved by any technique is important for the scientific validity of a method. Yet few techniques have been tested in this way and have thus proven their repeatability. Previous successes in practical application are an indicator of effective methods. If a method consistently produces usable results across a variety of applications it can be considered to be fairly robust. Indeed to produce a method that is perfectly reproducible would need a high degree of training and a method with a complex and constraining rule structure. Three small studies were carried out in the context of this thesis to examine the extent to which consistency is achieved when independent analyses are carried out on a common task. The task analysis methods examined were Hierarchical Task Analysis and FAST, selected because they are the two methods which are studied in detail in the present research.

Consistency studies

During the course of the present research three informal studies were carried out with an aim to exploring the factors that influence consistency amongst analysts in carrying out task analysis. The overall findings of these studies are presented in a paper by Astley (1988). As task analysis is a very resource intensive activity, it was not possible to study the full process of analysis, from information collection to the application of the analysis, in an empirical context. However, the opportunity was presented to study, in an informal way, the results of analyses of a common task carried out independently by three different groups of analysts. Few methods have had their consistency assessed. One exception is the Abilities Requirements Approach (for example, Fleishman 1967, 1972; Fleishman and Quaintance, 1984). Here, each of the abilities outlined in the technique has been assessed and developed to give consistent ratings amongst analysts.

The first study involved training a group of final year undergraduate students in the use of Hierarchical Task Analysis (HTA). The students were familiar with the concept of a task analysis but had no previous experience of its application or use. This group of students were trained in carrying out a task analysis over the course of two, two hour sessions. As the final part of the course they were involved in carrying out a HTA (described further in chapter 5), using the hierarchical diagram for representation. As a basis for the analysis all students were given identical descriptions of a hypothetical task and its context. This task involved a variety of different task elements ranging from sensory motor control activities and monitoring to decision making and other cognitive task elements. The analysis was constrained as the only task information available to the students was the task description. Whilst the normal stopping rules could be applied (if the relevant information was given), the students were asked to stop analysis when there was no further information available from the task description. The study examined both the difficulties reported by the students in carrying out the analysis and the results of the analysis in the form of the hierarchical diagrams.

The second study was carried out in the context of a task analysis training course for a group of professional software engineers. The course was given over the period of a day and at the end of the course the group was asked to carry out an identical exercise to the group of students using the same task description. Again, the results of the analyses and the reported problems in carrying out task analysis were examined.

The final study examined the results of analyses produced by a group of engineers and human factors specialists working on the human factors aspects of a large scale process plant and control room design. The methods used were FAST (see chapter 9 for further discussion of the method) and a modified time line analysis. The members of the group had differing backgrounds and experience in the use of task analysis techniques. The analysis was carried out on a common task independently by the members of the group. For this study the analyses were used to examine the consistency in the results produced amongst members of the group.

The studies highlighted some of the problems commonly encountered and identified some of the main issues to be considered in achieving consistency. The main results of the studies are summarised below:

In a method such as HTA which uses natural language to describe the task elements (as opposed to a more formal method which uses a task grammar), inconsistency results from the variety of language that can be used to describe a task. The advantage of natural language over task grammars is the flexibility it affords to describe task elements in a detailed and exact way. However, in examining the analyses it is difficult to judge whether a task operation expressed in one way is the equivalent of a task operation expressed in alternative language. So it is difficult to judge whether, in relative terms, one analysis is the equivalent of another. The use of natural language is a source of inherent inconsistency, and based on this, face validity could never be achieved in the application of HTA. It may be that if the advantages of using natural language are to be retained, then training analysts to approach analysis in a particular way and to emphasise the quality and accuracy of analysis, might offer a partial solution. Another option is to constrain the vocabulary used.

Most task analysis methods provide a framework and approach to structuring the task information. However, many methods fail to provide a detailed step by step guide to carrying out the analysis. Failure to understand the stages involved in a task analysis, or the way in which the information is intended to be structured within the framework, provided another source of inconsistency amongst the analysts. This could be overcome by improved training in the use of methods and more detailed guides to carrying out the analysis.

In these studies the same task information was available to all the analysts analysing the tasks, therefore this did not prove to be a source of inconsistency. However, an analysis can only be as good as the information input into the analysis, and if different analysts have access to different sources of information, then this too may prove to be a source of inconsistency. Guidance could be given alongside a method as to the appropriate methods of information collection to use and sources of different kinds of task information highlighted.

In the use of HTA, the primary inconsistencies resulted from the use of language, but more importantly in the structuring of the task information and allocation of items of information to the different parts of the structure of the analysis (eg. the allocation of information between plans and operations, and distinguishing between the task elements and the conditions under which they were to be carried out). In the FAST analyses, where human functions are analysed alongside system functions, there appeared to be difficulties in some of the group approaching the analysis in a human centred way. In training the group of engineers in the use of task analysis, problems appeared as they tried to apply their knowledge of engineering methods (some of which present a similar structured approach to task analysis) to the analysis. An awareness of this when providing task analysis guides and handbooks would facilitate the use of such methods by engineering personnel.

Overall a high level of consistency can only be achieved if the process of analysis is highly proceduralised and constrained and the analysts are trained in the use of the methods. If the flexibility of methods such as HTA is to be retained then the steps to be taken in applying the method and the intention of each of the steps must be understood by the analyst. As the groups in the study were trained together it was not possible to examine if this common training had a positive effect on the consistency achieved in the analysis. However, it is envisaged that if a common training is given, then analysts will approach the analysis in a similar way (for example, Fine et al, 1974). An alternative approach, for example, in the analysis of a large scale system, is to have personnel dedicated to the auditing of the analyses to identify inconsistencies and to correct them. Finally it may be that the consistency of the analyses can only be truly assessed when it is applied empirically. A study to examine the consistency of results when analyses are applied to a control room design for example, may indicate that a method or approach which does not appear to produce consistency in its analytical results, does produce a high degree of consistency when applied to design. The issue of consistency relates to the validity of a task analysis method, and this is discussed further in chapter 12.

3.7 DISCUSSION

In performing a task analysis, a series of stages are carried out, whether this is explicit or not. If an analysis method does not include all the described stages of information collection, task description, task analysis, representation and application, then it cannot be truly viewed as a task analysis. For example, some methods which are labelled task analysis are in fact simply task descriptions as they do not interpret the task information in any way. Similarly, information collection methods may be construed as task analysis, when in fact they stop short of being an actual technique. As the completeness of a task analysis is dependent on the information input into the analysis, information collection methods have been considered in some detail. When selecting any task analysis method, the available task information should be collected or available in a form that can be used in analysis.

Few task analysis methods have been validated or had studies carried out to ensure reliability in use. Often it is only over a period of time that the empirical reliability of a method becomes evident, for example HTA. However, whilst it was not possible to carry out a formal validation study in the context of this research, 3 studies were carried out with the aim of evaluating inter-rater reliability on HTA and for comparative purposes with HTA for FAST. The purpose was to ensure that a method developed within the context of this project could be demonstrated to be reliable. This discussion of issues such as the use of stopping rules, the analysis of cognitive and physical tasks and the independence of analysis in design are relevant to task analysis in a general sense. It is important now to consider issues in task analysis which relate specifically to the analysis of information needs and the process control context.

CHAPTER 4
TASK ANALYSIS IN INDUSTRIAL PROCESS CONTROL

OVERVIEW

This chapter discusses the evolution of the process operator's task and role in process systems . The impact of changing technology and in particular that of increased automation is considered. Although many of the issues arising from the use of task analysis techniques are generalisable, the characteristics of a process context which may impose limitations on the application of methods are outlined. The applications of task analysis within a process control context are varied. The analysis may provide direct input into the design or evaluation of a system, for example for training or interface design, or it may provide the basis for the application of other techniques such as human reliability assessment. Finally the chapter considers the different analytical approaches that are relevant at different stages of the design cycle, from the feasibility study through to the decommissioning of the system.

4.1 THE EVOLUTION OF THE PROCESS OPERATOR'S TASK

With the advent of industrialisation came changes in the types of jobs and tasks people were expected to perform. Purely manual tasks became replaced by tasks involving the use of more complex machinery. The human operator became part of a human-machine system, no longer was one person responsible for producing a product from start to completion.

Automation had far more impact on the people in these systems than simply increasing their productivity. The whole organisation of labour, the roles of the humans and the location of control were changed. At first the machines held the locus of control, the human fitting in with their pace and working to the machines. This was the epitome of the 'Fitting the man to the job' approach. Gradually these systems became so technologically advanced that the limits on productivity were imposed by human and not by machine capabilities. The tasks that machines could perform well they were already doing better than any equivalent human performance. It was also becoming evident that in some areas machine technology would have to advance considerably to allow all human roles to be automated and the human to be designed out of a system completely. Indeed some human abilities were far superior to any of those that could be replicated by machines. Neither was it desirable to design a human out of a system, it was far more profitable to consider how they would work best together in harmony.

The organisation of systems has tended towards centralisation as automation has increased. Crossman (1960) points out that manufacturing methods in industry pass through three stages as they become more technologically advanced. First there is small batch or unit production, where a skilled operator works in close association with a machine. The second stage involves larger batch production. Here many semi-skilled workers work in close association with machines and often the output of one machine will provide the input to another. The final stage is that of continuous or flow production. This was first achieved in the chemical and oil industries and now has spread further to a variety of industries. In continuous production, the product flows from start to finish without the necessity for an operator to initiate each cycle.

In both automated batch and continuous process industries, control has become centralised into a central control room and the role of the operator has changed accordingly. There are still operators on plant, but these tend to be fewer and fulfil more of a maintenance and preparation role. Some industries are semi-automated and require interaction between humans on the plant operating the machinery and operators in the control room controlling the automated parts of the system.

The case studies

The case studies in this research were selected (within the limitations of the plants that were available and the companies that offered co-operation) to represent a range of process industries in order to assess the full potential of any task analysis method in process control. The plants selected for analysis were all automated or semi-automated for two reasons. First, much of the industry is progressing towards the third phase of technological development, that of highly automated process plants. So it was decided to concentrate on methods that would continue to be of use as process technology progresses. Second, as much of the early work on task analysis was focused on physical task performance, the literature illustrates the validity of many of these methods and where they have been successfully applied. So it was decided to focus the efforts on more complex, and cognitive, control tasks that are characteristic of the highly automated process industries and where methods are still being developed.

The plants studied included continuous, mechanical, semi-automated and more fully automated plants. These comprised a batch plant which had manual processes at the start and end of the automated batch process; a continuous plant, from a high risk industry, that was still undergoing design; a continuous process that was highly mechanised and processed a high bulk, low cost product; and a continuous plant with four identical process units all at different stages of evolution in relation to automation.

This range of plants was felt to be representative of the state of the art in process control and to provide a variety of task situations and plant variations to assess and evaluate task analysis methods.

4.2 THE IMPACT OF AUTOMATION

As levels of automation and technology have changed, so the role of the operator has undergone a similar metamorphosis. Modern plants no longer require the human to carry out short cycle repetitive tasks. Plant operators are more likely to be responsible for maintenance, rectifying process faults and maintaining the plant in a ready state. The locus of control is now usually a centralised control room. Automated plants are often computer controlled, so the role of the operator varies according to the degree of responsibility he or she is accorded in the organisational structure of the plant. In some, the operator's role is one of controlling and ensuring that the quality of the product is maintained. In others, the operator is responsible for planning, monitoring, making complex decisions and solving plant problems.

In all cases the task will have moved away from the physical "hands on" tasks, to tasks where the operator is remote from the plant, often not controlling directly but through the plant data processing system. The task is likely to have a high cognitive content and involve making decisions and solving problems as well as the more monotonous monitoring and procedural tasks. Any study of operator tasks must therefore take account of the complex cognitive skills the operator is expected to develop and use, as well as detailing the more routine tasks which must be performed equally reliably and accurately.

4.3 THE ROLE OF TASK ANALYSIS IN PROCESS CONTROL

The study of the operator's tasks in process control is no more or less important than it ever was. In order to achieve successful design of the system so that the human works effectively and efficiently, human factors principles need to be applied. The most common approach in process control is to rely firstly on the suppliers of the process control systems for the design of the human machine interface. Therefore in modern automated plants, the control room human-machine interface is often the result of suppliers' hardware, and a standard range of displays and display building software.

In order to approach design and evaluation systematically, the tasks of the operator and his or her information needs in relation to the system need to be considered. Information is so important because it provides the link between the human component and the rest of the system. The human's task has already been defined in terms of its goal structure, but a task often uses information from the system which is transformed and processed in some way and which results in information being fed back to the system. Assessing what the operator uses the information for and how it is used can help in the design of the information and its presentation. Easterby (1984) summarises the factors that need consideration.

> "Designers, psychologists and ergonomists are therefore involved in the nature of tasks - what needs to be done; in processes - the psychological mechanisms involved; and in information display design - the nature, content, and form of messages needed to facilitate the performance of the task in hand."

Generally the first step in carrying out this analytic process is to analyse the operator's task. In systems design it is accepted as a matter of course that the design of the mechanical system and the software will be documented, standards for design will be set to allow quality assurance procedures, and the documentation will be used to relate to the design of other parts of the system. Such documentation outlines not only the details of design, but also provides information on the tradeoffs accepted and background as to why certain design decisions might have been taken.

Yet often the human is not regarded in the same light and so fails to merit documentation in the same way. A well chosen task analysis method could provide a common basis for the human factors input not only into the human factors design, but also into areas of the plant outside the auspices of the human factors engineer. This would help to avoid any misconceptions and give consistency, for example to areas such as interface design, training and personnel selection, not to mention the assessment of allocation of function and therefore automation requirements.

A method that is easily updatable would evolve with a system. Although a large cost in terms of manpower and time is involved, often the cost of the equipment needed for a task analysis is negligible, requiring only a pen and paper or tape recorder. Also if time is severely limited, a short task analysis using a method that rendered information in the form needed for a specific application could be used.

In the long term a task analysis can help to reduce design effort. This is because once the information is documented it is there as a design source. If there is no task analysis, design effort may be repeated and the same information gathered by several designers for use in different applications. So the justification for carrying out a task analysis exists, the problem then remains of selecting a method to use that is appropriate for the application and stage in the design cycle reached.

4.4 APPLICATIONS OF TASK ANALYSIS IN PROCESS CONTROL

The overall aim of this research is to study task analysis in a process control context. Although many of the considerations relating task analysis in process control are generalisable, the process control situation has certain characteristics which limit the scope of task analysis methods that will be relevant. The systems that are being dealt with are typically large scale, so the tasks that a human must perform constitute part of the overall function and goals of the system. In addition to fulfilling the criteria such as validity and usability (as outlined in chapter 3) there are others particular to the selection, use and application of a method in process control, these include some of the following considerations:

1. The process operator's role typically includes both monotonous routine tasks and also highly complex problem solving tasks. The task analysis method selected should be able to cope with analysing both aspects.

2. One of the most important roles of the operator is that of a troubleshooter when the automatic system fails, or cannot process particular plant information. However, many task analysis methods deal only with "normal" task performance, that is, the operation of the system when it is functioning correctly and without any faults. A method that is used in process control must document task behaviour that relates to abnormal plant conditions.

   This is not only so the interface and related human factors issues can be designed taking into consideration such task issues, but also so that the training programme can consider these aspects. Of course, it is realised that often such system states and task scenarios are unpredictable. However, within any system design some failure modes are accounted for and indeed some occur quite commonly and become routine for the operator. The analysis of the operator's task should include such tasks, and the interface and training programmes should be designed accordingly.

3. Many task analysis methods show one means of achieving the goals of the task. Yet often it will be more appropriate for operators to have several alternative means of completing the task in their repertoires. A task analysis method should therefore permit several routes to the same task goals to be shown if appropriate. This gives operators optional strategies or means of approach to a problem, should they be needed.

4. As process control systems tend to be large, a single human will often only interact with specific parts of the system, working within a team that covers the total system. For a complete task analysis, a technique needs to allow firstly the allocation of tasks between humans in a team. Often methods will deal with one task only, rather than the allocation of tasks or of several tasks. However, many methods can be used at a 'meta' level of analysis where the general task goals are given, these task units can then be allocated to appropriate personnel. Following from this, the analysis method or methods that are used to analyse the individual tasks will need to complement each other to form an overall picture of the functioning of the humans in the system.

5. It is important for the analyses that are produced to be consistent, so that they can be compared on a similar basis when used for design. Biases in analysis can lead to biases in design.

The nature of the design and evaluation of process control means that there may be other constraints on the use of task analysis. These may include time, the availability of personnel, financial constraints, the expected system life cycle, the current stage in the process or system life cycle and resources available. These will be system specific and methods of task analysis should be selected and applied with these constraints in mind.

4.4.1 REVIEW OF APPLICATIONS

The literature review of task analysis methods carried out was comprehensive in looking at methods relevant to process control and complex control situations. However, methods in areas of human factors which were peripheral to the areas under study (for example, methods relating to areas of ergonomics such as biomechanics, which recorded the position of the spine during the performance of a particular task, or an analysis that looks at short cycle repetitive tasks) were not included. Within this context of process control and tasks in complex control situations, the literature review was wide reaching.

Figure 4.1 is a summary matrix indicating the different applications that the methods reviewed were used for. The matrix was constructed using information from task analysis literature and expert experience in the use of task analysis. It indicates previous applications of the task analysis methods and suggests other possible application areas. The following sections look at some of the principal application areas of task analysis within process control in detail.

In selecting a method of task analysis the first consideration is the application for which it is to be used (refer to section 3.3). This determines what information will be needed from the analysis and the form it should take for that purpose. It is important to ensure that the information produced by the analysis is the information required. An analysis can be applied and the information it provides may not be useful in form or content, if the method selected was not appropriate.

There are a range of applications for which task analysis can be used, some are directly linked to the human factors field whilst others are on the periphery and allied to other disciplines. Some contribute directly to the design process whilst others offer a more minor input. In figure 4.1 a matrix is given which indicates the applications which methods are intended for or have been applied to.

METHOD \ APPLICATION	Allocation of Function	HMI: Design/ Evaluation	Personnel Selection	Workspace Design	Communications Links	Knowledge Elicitation	Task Performance Evaluation	Complex Cognitive Control Tasks	Training	Operating Procedure Design	Workload Assessment	KEY REFERENCE
HTA		✓							✓			Annett et al., 1971.
GOMS		✓						✓				Card et al., 1983.
FAST	✓									✓		Williams, 1988.
Cognitive Task Analysis		✓						✓				Hollnagel, 1981.
Link Analysis		✓		✓							✓	Chapanis, 1959.
TAKD		✓							✓			Johnson et al., 1984.
Abilities Requirements			✓									Fleishman & Quaintaince, 1984
TAG		✓				✓						Payne & Green 1986;
JPC		✓			✓							Tainsh, 1985.
Miller, R.B.									✓			Miller, 1962.
Berliner et al.							✓					Berliner et al., 1964.
PAQ			✓				✓					McCormick, 1976

Figure 4.1 A summary matrix of task analysis methods and their applications

4.4.2 KNOWLEDGE ACQUISITION

The technology of automated systems continues to advance. Expert or knowledge based systems aim to emulate human functioning in a way that was not previously possible, by replicating the knowledge structures and rules by which humans perform tasks.

In order to do this, techniques to acquire and encapsulate the knowledge in a form that can be communicated to the expert system designers and programmers are needed. In many ways what is aimed at is the documentation of the cognitive task performance of the human. So although knowledge acquisition is the term which refers to information on the cognitive activity and knowledge which is required for expert system design; knowledge acquisition methods have much in common with cognitive task analysis, although the emphasis on what is documented is slightly different. Knowledge acquisition focuses on the rules of how the task is performed rather than the cognitive processes used. Several knowledge acquisition methods bear more than a passing resemblance to some task analysis methods. For example, decision trees that are used to represent knowledge (Hart, 1986) are similar to flow chart based methods of task analysis. Inference networks also have a parallel in the methods of petri-nets and state transition diagrams. Both task analysis and knowledge engineering take similar approaches to eliciting information such as walk/talk throughs and interviews.

The requirements of a task analysis that is to be used for knowledge acquisition are summarised briefly below:

1. The structure of the method is such that it helps the analyst to be complete and thorough and to indicate where further information is needed.
2. The method should allow for tasks to be easily simulated for testing purposes. As the task analysis effectively forms the content specification for the Intelligent Knowledge Based System (IKBS) it is essential that it is accurate and correct.
3. The method should allow for easy iteration and updating of task information. For example, so that new rules and knowledge can be added.
4. The method should allow knowledge structures and the different elements of knowledge such as rules and assumptions to be analysed and differentiated so that the output is in a form usable for expert system design.

Many existing task analysis methods have the potential to be used for knowledge acquisition, either directly or in a modified format. The problems that are being encountered in the quest to encapsulate knowledge for expert systems are those problems encountered in the development of task analysis methods which aim to deal in part or exclusively with cognitive tasks. Indeed knowledge acquisition is in a sense a specialised application area of task analysis, needing specific task analysis methods to document the required task information.

4.4.3 TRAINING

The area of skill psychology has given rise to a range of models and principles as to how a human acquires his or her skill in the working environment. From classical learning theory through to different models of the human as an information processor, there are many approaches to the learning of tasks and the acquisition of the cognitive and motor skills that this implies.

The development of training programmes was one of the earlier applications of task analysis. A task analysis that looks at both the overall goals and at the detailed performance of a task, gives information for both part task and whole task training approaches. The logical breakdown of the task into trainable elements would ensure that the task could be trained in a thorough and systematic way. There is also the quality assurance aspect of the analysis, as trained task performance can be evaluated against the standard described in the analysis. The effect of training can only be assessed by the results it produces,

> "Learning is therefore a hypothetical state which can only be inferred from the observation of measurable performance." (Stammers and Patrick, 1975),

and so task analysis provides a basis for both the development of training and for assessing its success.

Training is often associated with instruction and education, there is, however, occupational training, especially military and service training. In this area training overlaps considerably with the selection of personnel. Information that would generally be needed from a task analysis that was to be applied to a training application, would include:

1. Information on the overall goals of the task, which cumulatively contribute to the job description.

2. Detailed step by step information on how to perform the task, to allow systematic training to be developed. The analysis should also detail the cognitive aspects of the task, to enable such skills, even if they are not addressed step by step, to be included in the training program.
3. The analysis should make explicit information about the skills which need to be trained to allow the operator to perform the task. This would be to ensure that these skills are trained if necessary, rather than training the operator to control the plant for example, using only specific tasks. An example of a situation where this would be important is in a complex control task where normal plant operation can be trained and also some anticipated fault conditions can be trained for.

Training is closely related to the use of task analysis for both personnel selection and job or task design. Training becomes involved with the acquisition of skills, whilst for personnel selection the analysis needs to document the skills that will be needed and to call for the selection of personnel on the basis of these.

4.4.4 HUMAN RELIABILITY ASSESSMENT

Task analysis alone does not provide a technique for human reliability assessment (HRA), but most human reliability techniques are based on a task analysis.

The assessment of human reliability occurs mainly in large scale "high risk" complex systems where the potential for human error may be assessed either qualitatively or quantitatively. However, the potential for human error and the reduction of this by good human factors design is a concern in all fields of ergonomics.

With human reliability, in order to assess where and how error could potentially occur, the tasks must be broken down. A task analysis often only focuses on the task elements that are required to achieve successful completion of the task. This can form a basis for reliability assessment, where the possible modes of failure or error for each of these task elements are considered. Alternatively the analysis can take a similar form to a fault tree in that the analysis begins with a critical or common failure and then analyses the paths leading to this failure.

Human reliability assessment usually takes a quantitative form, with many of the methods concerned with the quantification of Human Error Probabilities (HEPs). Techniques such as THERP (Swain and Guttman, 1983) and SLIM-MAUD (Embrey, 1984), taking this approach.

Once generated, probabilities can be used to identify areas where ergonomic design needs to be carefully considered and to help in decisions concerning the distribution of resources. Task analysis has equal importance for qualitative approaches to human error. Here the identification of elements in performing a task are needed and must be described at a reasonable level of detail. For each the approach can then be taken to assess the different kinds of error (often based on theoretical models, eg Reason, 1987) that could contribute to different kinds of system failure.

A task analysis which is to be used in either qualitative or quantitative forms should have several salient features, ie:

1. A structured and thorough approach to analysing the task. Any analysis must be as exhaustive as can be practically achieved to allow accurate probabilities or identification of all errors; although this is dependent on the needs of any specific situation.
2. The method should allow a variable level of detail as probabilities need to be combined to give an overall estimate of probability in a multiplicative way. Due to this, a hierarchical method would be likely to be highly effective.
3. The method should show the relationship between task elements and their place and importance for successful completion of the tasks. The relationships between task elements is important when assessing how combinations of causal factors can influence error. Importance information is useful for indicating how critical the successful completion of any particular task element would be to the successful completion of the overall task.

4.4.5 ALLOCATION OF FUNCTION

In the system design cycle, decisions on the allocation of functions are often made early in the design specification to provide the basic assumptions for design. An indication is needed of which parts of the system function will be automatic and which will be carried out manually.

The basis of this allocation has often been the "fitting the man to the job approach", concerned with the automation of functions that can be automated and then consideration of how the human will be able to operate such a system, thus taking very much a system centred approach. As technology can increasingly mimic human attributes, then the decisions become more complex. It is not yet technologically feasible or practical to design the human out of systems. He or she has a flexibility, a knowledge base and a processing capability that cannot yet be matched by machines. It is essential to optimise the use of these capabilities in systems performance. Humans have certain abilities and skills as yet unmatched by machines, likewise there are tasks that humans perform badly such as monotonous and repetitive tasks, which a machine could be programmed to carry out.

The abilities of humans are not only important in deciding which functions will be allocated to them. The overall task structure and workload of the whole task allocation not only to an operator, but within an operating team, needs to be assessed. This is to see if it is feasible, a) in terms of the functions that the human is being asked to perform and b) in terms of the physical and mental workload imposed.

In choosing a method for analysing tasks for allocation of function purposes, the approach must be far more system centred than task analyses carried out later in design. The reason for this is that humans can only be allocated functions in their context as part of the total functioning of the larger system. This is to allow the analysis to be used as an aid to making allocation of function decisions, and not as documentation of those already made. System functioning information can help decide if a particular function should be reallocated to humans, either because they can perform it more effectively or to enrich their tasks. This may be to increase motivation or because the human can perform it more effectively (Fitts, 1951). Allocating tasks to the human, even if the potential for automation exists, enables tasks to be designed that are coherent and allow the user to participate more directly in system control. This leads to meaningful and varied tasks through which the user feels that he, or she, is contributing to system functioning. Alternatively, it helps decisions on whether to automate fully or partially functions previously allocated to humans. Therefore task analysis in its context of allocation of function decisions, should consider the following factors:

1. The method should focus on human performance and function as part of total system functioning, and not on the human as a distinct subsystem. This is so because the function of the human is set in context and the boundaries of the human and machine tasks are clearly marked to help any reallocation.

2. At the same time tasks should be documented in sufficient detail and in such

a way as to allow their feasibility to be assessed in terms of task type, workload, and the distribution of tasks within the team etc.

3. The points of interaction between human and machine tasks should be well documented so that automation and changes in functional allocation decisions can easily be made.
4. Different demands of humans in performing tasks should be identifiable, again for task feasibility, and to allow full training, interface and personnel selection needs to be addressed and considered.

4.4.6 HUMAN MACHINE INTERFACE DESIGN

One of the more obvious applications of human factors in process control room design is that of the human machine interface (HMI). This can take many forms, from the small switching panel on a piece of machinery or plant to a complex control room manned by a team of operators.

Although the problems are on a different scale, the approach still centres around the flow of information and communication between the human and the system. With technologically advanced systems, the human can be a major limiting factor on speed and performance, so the interface must be designed to help her or him function as effectively as possible. Time after time large scale process accidents are attributed to human error. Well known examples include, Three Mile Island 2, Chernobyl and Flixborough. The Three Mile Island incident gives an example of how a poor interface can lead to human performance which can have catastrophic consequences.

Vision is the human's main input channel, although other senses could be used, none can discriminate so effectively and accurately. Output ultimately tends to be in the form of motor activity although it may be preceded by cognitive activity in the form of decision making or problem solving.

Task analysis for HMI design needs therefore to consider not only the point of interaction between the human and the system, but also what the human task involves in the processing of that information and acting on it. Generally, an analysis for human machine interface design should consider the following attributes:

1. The method should consider both cognitive and physical task elements.
2. If the analysis is heavily dependent on existing systems information, what steps are taken to ensure that any existing human factors error or problems

are not replicated?

3. If the human is working as part of a team in interacting with the interface, are the points of interaction and the interface with other humans as well as with the system shown?
4. Are the information flows in and out of the system documented as well as the task the human uses them for?
5. Are the conditions and restrictions on task performance indicated?
6. Does the structure of the analysis allow it to be easily changed and upgraded in the event of a change to the interface?

4.4.7 WORKSPACE AND WORKPLACE DESIGN

Within any process control work environment, the complexity of the system and the functioning of the machinery or process mean that the layout of the working environment is of paramount importance to the way in which the task is carried out. Also the interaction of the user physically with parts of the system that would not be classified as the HMI, need to be documented and analysed for design. There are many factors which affect task performance in the workplace which most task analysis methods assume to be constant and already ergonomically designed. Such factors include the physical working environment and the social working environment (eg, factors such as motivation and teamwork).

However, in some situations it is important for those factors to be identified and considered. There were no methods identified in the literature review that directly addressed both the social and physical factors that simultaneously affect the task, although there are methods which document the social <u>or</u> physical factors. However, existing methods could be modified, with a decomposition format probably being the most flexible to allow this. Each task element could have the important social and environmental attributes annotated. This, however, requires skill on the part of the analyst and therefore needs to be carried out by a human factors specialist. An alternative option is to provide a checklist of important considerations.

Methods to determine the layout of the workplace are able to analyse the task in a more simple way than for other applications. They assess the relative importance and use of different system elements for different parts of a task and allow for design decisions based on this.

A task analysis to study workplace design should address the following aspects: (in some methods this information is not made directly explicit but can be inferred)

1. The layout and design of the workplace and workspace. What will help the operator to perform his or her task effectively, ensure that equipment, information and the tools needed are at hand and that a team can function together effectively in the environment?
2. The items of equipment that an operator will use in performing the task and so contribute to their design, aiming at aiding task performance.
3. Information on the relationship between items in the workplace from the point of view of how they are used in the task.
4. The analysis should reveal restrictions and constraints on the physical environment which limit the design.
5. The relationship between tasks and the relationship of these to different system elements and items of equipment and their relative importance in the task environment.

4.4.8 OPERATOR SUPPORT AND JOB AIDS

A task analysis will rarely be carried out to assess the support and job aids required by an operator in performing a task. Such information will usually be a by-product of either an analysis for HMI design or for training. However, if these are likely to be designed or used then it is important to select a method of analysis that allows exactly what is required of such support or aids to be specified. This may be an implicit part of the analysis or included as an annotation or notes to accompany the analysis, (many methods allow a "catch all" notes column for contingencies such as this).

The approach to job aids may be enforced from an alternative angle where a task analysis has indicated that such are needed or it becomes evident in design that they are needed. This would occur when training fails to give an adequate performance at the interface for example, or where a task with a high possibility of error may have that error reduced. Then the analysis for job aid design is retrospective and it is useful if the method allows this information to be added.

4.4.9 WORKLOAD ASSESSMENT (MENTAL AND PHYSICAL)

Workload can be viewed from several perspectives:

- The number of tasks to be performed over time.
- The sequencing of tasks.

- Types of task to be performed
  (some tasks being viewed as having a high workload).
- Peaks and troughs in load .
- The effort required (cognitive or physical) required to be expended on tasks.

The analysis and study of workload in tasks is important as it is felt to relate to the level of stress of the human. High or low levels of workload can have implications for task performance and may lead to degradation of performance.

The concept of workload can refer to the characteristics of the task itself and to the consequences of performing the task (for example high workload can have a psychological effect on the human). Individual capacity for workload also varies.

However, the assessment of workload in relation to a task can have several practical applications. The assessment of physical workload can help to identify attributes required for personnel selection. An example of this would be a firefighter needing the ability to lift a certain weight. This type of factor can also arise in the design of the task itself. For example, if it is repetitive short cycle work involving manual handling, then task performance may be improved by allowing self pacing or by adjusting the design of machinery to make the task less strenuous. The concept of workload, also assumes that in a cognitive sense, there is a time sharing of the tasks to be carried out. There are methods (for example, signal flow graphs) which allow this to be documented over time.

From a mental workload point of view, problems can occur both if the load is too low or too high. In modern process control, one of the contradictions of control room operation is that the operator may have long periods of carrying out a low load, repetitive, monitoring task interspersed with very high load decision making and problem solving tasks.

If low load can be identified, then the task design can be considered and perhaps, enhanced to help maintain operator attention, arousal and motivation. Task analysis, indicating high loads, allows the potential for two man operation, job aids and other aids to be assessed. This too can help personnel selection. The attributes of the operator can be specified to allow appropriate job aids or motivational and job enrichment factors to be designed into the task.

Apart from time, which is an important variable, and the sequencing of tasks, especially those which are concurrent, it is not possible to specify general factors that are needed of a task analysis method for both physical and psychological workload assessment. Both cognitive and physical tasks need to be specified, and allowances concerning other factors affecting system performance under different system conditions indicated. Also with mental workload, often both the normal system operation and system functioning under fault conditions should be analysed.

4.4.10 PERSONNEL SELECTION

When a task is analysed, certain assumptions are made about the human who will be performing it. These concern his or her skills, knowledge and abilities. An analysis can help to make explicit what these are and can suggest their relative importance in the performance of the job. It is assumed that given the task, and the training that will be provided, an individual will need certain aptitudes and abilities to perform a task. These three elements together should provide effective task performance. Without a task analysis it may be difficult to define what these assumptions are and the characteristics of the personnel that need to be recruited.

In considering a task analysis to specify this information for personnel selection the following considerations are relevant:

1. The analysis should specify the abilities, skills and knowledge needed by the operator to be able to perform the task.
2. It should also suggest the training anticipated to bring the operator's skills up to the level required for the job and the new skills needed should be documented.
3. The factors should be considered in terms of their relative importance. Each individual will bring different factors to the job. The analysis should help to identify which traits are essential and which are desirable characteristics.

4.4.11 PROCEDURES AND OPERATING INSTRUCTIONS

Procedural tasks and instructions on operating systems both adopt a step by step approach to analysing task performance. In many ways these tasks are relatively easy to analyse as each task element follows on from the previous one. However, decisions may be involved and the point of branching for all options should be made evident.

The importance of task analysis in process design should not be underestimated. Procedures are susceptible to human error. Steps can be omitted, added, transposed, reversed and replaced with an alternative. Furthermore, human nature means that shortcuts may be taken if parts of the procedure seem unwieldy, unnecessary or lengthy. In systems where safety is paramount, features often need to be designed into systems and its procedures to prevent the likelihood of error.

The representation of the task should show the procedure in a clear and unambiguous manner so that errors in translating the analysis into design will not be made.

Important considerations for an analysis to include are:

1. Step by step documentation of the task, indicating decision points, sequences, alternatives etc.
2. A systematic approach to analysing the task to ensure all elements are documented.
3. A clear representation that can easily be used for procedures design.
4. An analysis that can be easily updated as procedures change and the system is modified.

4.5 TASK ANALYSIS IN DESIGN

Just as different engineering approaches are appropriate to the assessment, design and evaluation of a system at different stages of the design life cycle, so different methods of task analysis help to make explicit the information concerning the human system component that is needed at each of these design stages. This chapter explores the design life cycle (figure 4.2) and looks at the appropriateness of task analysis at each stage and at the potential contribution it has to offer.

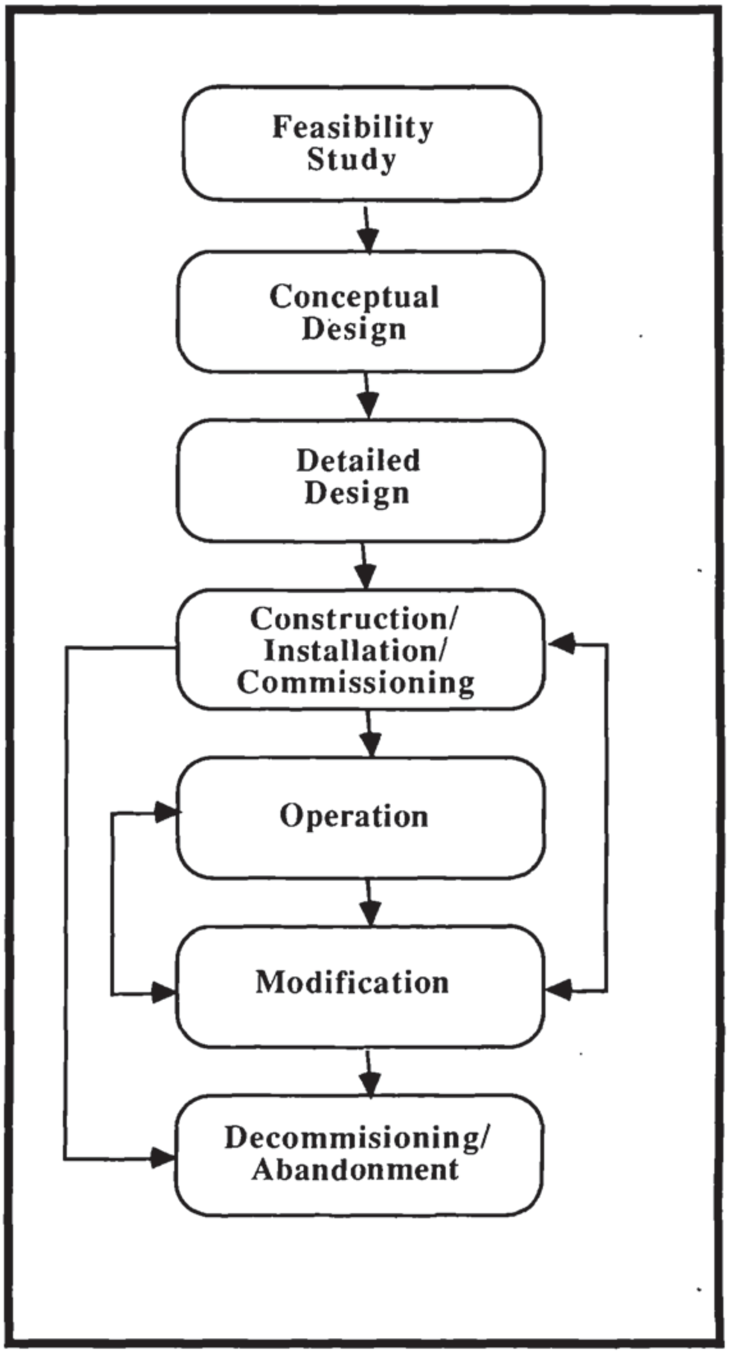


Figure 4.2 Design life cycle

Figure 4.2 gives an overview of the design life cycle, whilst figure 4.3 shows at each stage the information that would be required of a task analysis and potential methods that could be used.

A system centred view is often taken to the design process and methods of systems analysis such as SSADS, MASCOT and JSD are used to help specification of the system. But what about the humans? They too are an important part of the system yet they are often peripheral to the main design. Defence standard 0025 (Harvey, 1988) proposes four reasons why a user centred approach to systems design is justified.

1. "All computer based systems exist for human purposes", therefore they are designed by humans for humans and cannot function without human input and intervention.
2. The criteria on which systems are to be judged are the requirements of those who must use it.
3. The user must be involved in all aspects of the system development. This allows a system to be designed for the people who will be using it and not for the engineers who are carrying out design or for the mental model of the user that the design engineers have.
4. The system is explicitly designed to take account of user characteristics in order to achieve effective performance and acceptability to users.

Whether the design approach is completely user centred or not, task analysis provides a means of aiding specification and design of the human contribution to system functioning that complements systems analysis. It is recognised that in the design process of many systems it may not be possible, desirable or practical to carry out a task analysis at each stage of design. However, whilst the analyses are specified for a particular stage of design, many of them will carry forward and input into the next phase. Analytic information can often be used at many points in design and total effort needed is less.

There are a range of possible initiators for the process of design. It may be that market influences are demanding a new product or updates or replacements of an old product. Legislation may influence decisions, for example, a new law on safety may mean that a design must be reappraised or that a service needs to be provided.

Design Stage	Requirements of a task analysis	Examples of appropriate methods
Feasibility study	Methods that aid the assessment of the feasibility of tasks. For example, with regard to workload and allocation of functions and tasks.	Overview Task Analysis Time Line Analysis Functional Analysis Eg. FAST
Conceptual design (design specification)	Methods that aid the development of a human factors design philosophy and design specification.For example by providing details of performance requirements.	Hierarchical Task Analysis Link Analysis
Detailed Design /Commissioning	The use of task analysis methods at this stage of design is dependent on the requirements of the particular design context. However several complimentary methods are likely to be used to provide the required information. Commissioning a system requires specific procedures and task design that can usefully be considered alongside the main design.	Abilities Requirements Analysis T.A.K.D Job Process Charts
Operation	During the operational phase, the only use of analysis should be for evaluation or modification. All other applications should make use of, or build on analyses already carried out.(for example the use of Job Process Charts to update operating procedures)	
Modification/ Evaluation	Ideally at this stage of the design cycle there will be existing analyses that can be used as a basis for analysis. However,methods can be selected specifically to address the modification or aspect of task performance that is to be evaluated.	Hierarchical Task Analysis G.O.M.S. N^2 charts
Decommissioning	This stage (like the commissioning of the system) requires detailed and specifically tailored procedures and tasks to allow the abandonment of the system. Such methods should be able to make use of the wealth of existing task knowledge within the system.	Flow charts

Figure 4.3 Task analysis in the design process

A current system may be due for evaluation and modification or need updating to make it more efficient to keep pace with technology.

Any one or combination of reasons can initiate a design exercise. The first stage is to assess the feasibility of carrying out design and to specify design requirements and standards. Following from this, a full design is carried out and implemented. The design may then, or at a later date, be evaluated or modified. Eventually the system is decommissioned and the information on problems and successes used to feed into further design.

4.5.1 FEASIBILITY STUDY

The first step in the design of any new system or the evaluation and upgrading of an existing system is to assess the feasibility of design alternatives and to make recommendations on the overall feasibility of the project.

Task analysis at a general level can help to establish the intended role of the humans in the new system. It helps to determine their allocated functions and capacity to perform them. It provides stated assumptions about the physical and social environment, training and personnel.

As well as indicating where the human will fit into the new system, the task analysis documentation ensures that this can be input into the next stage of design. This feedforward of information ensures that any problems noted in the assessment of feasibility will be carried forward and reasons for design decisions will be understood. As well as defining initial standards for human factors design, a task analysis also provides a common pool of information for input into all areas of systems design. This common task specification encompasses not only the tasks of the operators of the system but of people such as the maintainers, trainers and management as users of the system.

Methods of task analysis that are useful at this stage provide a structured breakdown of the task, showing task goals, where the task fits into system functioning and a detailed decomposition of task performance at both cognitive and physical levels. It is helpful if the analysis can be independent of existing designs and allow an unbiased assessment to be made of feasibility. Figure 4.3 gives possible methods for use at this stage of design.

4.5.2 DESIGN SPECIFICATION

In this phase of the design cycle, the objective of the task analysis should be to provide recommendations, to set standards, boundaries and limits for design. The main aim of a design specification is to give standards which a design must reach and means of testing that these standards have been attained. It is the stage of the design cycle at which standards and specifications are set and against which the design can be tested for quality assurance purposes.

It is important that the ergonomics information given at this stage is accurate, thorough and covers all areas where human factors could contribute to the design cycle. One of the means of ensuring thoroughness and accuracy is the use of task analysis. Without task analysis the information may be collected in a haphazard fashion. Even if a systematic approach is adopted, without a task analysis it may be difficult to be certain that all the human's task have been covered. Task analysis can contribute to the specification of :

- The standards the human interface design must meet, specifically and generally.
- Likely problem areas in design relating to the human's role in the system.
- The staffing levels needed and justification for them.
- Areas where the design needs to especially consider the problem of human error and the use of design to maximise human reliability.
- Provisions that need to be made for training.
- Recommendations for the design of equipment with respect to maintenance.
- Recommendations on the organisational structure of the humans within the system.

If a "fitting the job to the man" approach is taken, the design specification may be idealised with respect to the human component. This means that in the actual design, tradeoffs and compromises will be reached. The use of a task analysis in the main design provides the documentation of the idealised situation, and from this all tradeoffs will be justified and documented.

At this stage the task analysis also needs to interact closely, at appropriate levels, with the system specification phases to ensure that the two are in accordance and to resolve any problems arising. The overall task analyses from the design specification should result in detailed guidelines and standards to be met in the design.

In the design specification phase, it is preferable that a task analysis gives assured accuracy and thoroughness. There are formal task analysis methods available, some based on language grammars others on mathematical modelling. Such methods can be useful as tools for producing an accurate design specification. However, for other stages of design they lack sufficient flexibility to enable them to be easily manipulated and updated to allow for the represented iteration that is common during the different phases of design.

4.5.3 DETAILED DESIGN, COMMISSIONING AND OPERATIONAL PHASE

The detailed design is the core of the design process, taking the specification and from it building and producing an operational system. The potential contribution of human factors to system design is considerable. If human factors and task analysis have been used in the earlier stages of system design their use and contribution to design should be well established. If not, then it is likely to be more difficult to introduce human factors principles into a design that has been specified, at least in part. It can be both time consuming and costly to introduce them at the main design stage. There may already be an organisational structure comprising project management and design teams etc, who may be reluctant be consider additional factors. These may influence the current design status which may, in turn, impact on the system design policy or philosophy.

However, it is at this point that introducing human factors into a system is most effective. The lack of human factors considerations at other stages of the design process can be overcome in part by considering it at the detailed design stage. Whilst if human factors issues are considered at a later stage, but not during the detailed design phase, the human factors aspects of the system can be specified or evaluated, the possibilities for exploiting its full contribution to design may be less.

In the main design stage, a battery of task analysis methods, complemented by other relevant design tools and guidelines is often needed to cover all the necessary human factors inputs into design. Some of the areas to which task analysis can contribute include training, detailed interface design, control and instrumentation specification and layout, design for maintainability, communications, workload assessment and personnel and staffing. In selecting a battery of methods it is important to ensure that both the relevant task information needed to carry out analysis is available and that the analyses do not overlap significantly in the information they provide (unless this is a specific requirement).

In the operational phase of the system, the role of task analysis is largely evaluative, assessing how the design has worked in implementation. The documentation of an analysis may help to show alternative solutions to overcome any problems with the design that are evident almost immediately or during commissioning problems or to modify the design in some way.

4.5.4 EVALUATION, MODIFICATION, REDESIGN AND DECOMMISSIONING

The final stage in the design of any system is the appraisal how successful the design has been. This assessment may occur immediately, or at a later date, perhaps when the need for modification of the system is evident or when it is decided to update the system in line with current technology.

Evaluation

Methods of task analysis used at this stage will evaluate existing designs and give recommendations for new designs. Problem areas and useful elements in design can be carried forward to a new design. It is important when using task analysis in this way, not to become too caught up in existing system design philosophy. The reasoning and tradeoffs behind the design may not be immediately evident or documented and can influence the design and bias of a new system.

Task analysis methods can be used specifically to evaluate certain parts of the system. For example, it might be that just an assessment of existing procedures is needed. Alternatively an evaluation of the whole system could be carried out using a more general method of analysis coupled with more specific analyses to give the necessary detail.

Decommissioning

At the end of the system life cycle decommissioning may be carried out according to pre-defined procedures and task analysis can help to define the human's role in this. Previous analyses may form a basis for a final system evaluation. Much of the information and documentation surrounding a task can prove valuable in the design and evaluation of related systems and can feed into new task analyses. Task analysis methods that are useful in this phase of the design life cycle include those that collect information to feed into other analyses and those methods that can be used in a comparative way for the evaluation of other systems.

4.6 DISCUSSION

It is evident that task analysis has a role to perform throughout the design life cycle of a system. It should be carried out alongside the engineering development of a system as it provides the documentation of the expected performance of, and constraints on, the human subsystem. A detailed task analysis provides the equivalent of the engineering specifications and functional descriptions for the humans who will operate and work within the system. If task analysis is commenced too late in the design cycle constraints may be placed on the human factors aspects of the systems design which are undesirable. In addition it may not be possible to fully take into account all the human factors constraints on the engineering design that should ideally be considered. The task analysis provides the foundation for the human factors design of the system and can be iterated and updated to take account of system changes and the process of design. Further, if a task analysis is carried out during design, any analysis required at a later stage (for example during a system refit) will have an existing basis and documentation of the constraints and principles that were taken into account in the original design. Overall the role of task analysis in design is to provide a basis for the human factors design of the system and to provide documentation of the functions, goals and tasks of the human in relation to the system mission.

CHAPTER 5
TASK ANALYSIS FOR OPERATOR INFORMATION NEEDS

OVERVIEW

Information is a unit of functionality that is common both to the human and machines operating within the context of a system. The links between the human and the system usually take the form of information flows, for example across the human machine interface. The links between humans within a system are also based on information flows, for example, logs and face to face communication. This chapter explores the issues involved in the use of task analysis for documenting operator information needs, in particular the use of CRT displays as a means of communicating system information to an operator. The development of such a method within the context of the theoretical background and empirical studies of the thesis is described. Criteria for a method of task analysis to analyse operator information requirements are suggested and existing methods evaluated against these criteria. Hierarchical Task Analysis (HTA) formed the basis for this method and the evolution of the method and its varied applications are outlined. Finally the developed method of HTA for documenting operator information needs is described in detail.

5.1 INTRODUCTION

Ergonomics as a discipline is a broad church and so it is not surprising that many task analysis methods are directed at specific applications rather than aiming to encompass information that relates to the whole discipline. Some methods do aim for generality and then fail to give the specificity needed in some areas for detailed design. Whilst both aspects are needed in their context, neither renders sufficient task information available for large scale system design. It would appear that an effective approach in such a system is to begin with a general overall analysis and supplement it with more detailed analyses when required, and only in the areas required. By this it is meant that all the analyses can be united by a common basis whilst still giving the detailed information where required.

In a design centred around the user, it is important to consider not only how the human or team of humans function as an independent unit within the system, but to look at how the human fits into the system as a whole. The human links up with the system by the transfer of information between the human and machine. Information is a unit of functionality that is common to both, although it exists in a coded form which has to be translated for use by either party. This communication between the system elements of the human and the machine takes place at the Human Machine Interface (HMI). Therefore the design of this interface and the presentation of the information is critical. This chapter presents the development of a method of task analysis that allows operator information needs to be specified in relation to the tasks to be performed within the system. This method is expanded in chapter 11 into a proposed approach to the development of a tool for specifying process control displays in a task and systems context.

5.2 THE IMPORTANCE OF INFORMATION

In technologically advanced systems complex information needs to travel not only within the system but also between the human and the system. The forms by which it is exchanged vary. For human use, the information is often output from the machine in the form of visual and auditory displays. Information is returned to the machine (in modern process plants this is usually a computer) via a variety of input devices such as a keyboard or mouse.

In large systems, the complexity of the information that needs to be used by the operator is such that often the visual sensory channel is the only one with sufficient discrimination to be effective. Auditory channels can be overloaded for example as occurred in the Three Mile Island crisis, where over 60 different alarms and warnings were activated and sensory discrimination was insufficient to deal with the vast amount of information. Speech recognition and speech synthesis technology is not yet sufficiently advanced to have the width of application that the range of current visual displays have. So visual displays are still the primary media for the communication of complex information to the operators of complex and large scale systems.

With highly complex automated systems, the operator usually does not deal with the system directly. Increasingly operators in automated systems are becoming more removed from close operation of the system itself. In some tasks, operators on the plant may operate hardwired control panels where one display relates to one control and sensor. This progresses towards a highly flexible computerised system with a range of Cathode Ray Tube (CRT) displays, giving a vast amount of data on the system. Sensors and systems data abound, often the approach is taken that as the data is there it should be made available to the operator in one form or another. In most instances, the operator does not need all this information to perform the task, and an information overload can hinder task performance .

In this context a task analysis would offer a solution if it could determine exactly what information the operator needs to perform the task and how it will be used. If the information exchange needed by both parties (ie, the human and the machine), to perform their allocated functions, can be stated, then the allocation of displays, controls, job aids etc to transmit one to the other can be selected. These must fit the content of the information and the task demands, rather than indiscriminate display of the available system information.

Increasingly information is presented via computers on CRT screens. CRT screens are in popular usage due to:

1. Their flexibility and because within complex systems there is such a vast array of information to be displayed that it would be difficult to present it effectively on back panels or using non electronic display media.
2. Their ability to provide a high degree of flexible coding of information, for example by the use of colour.
3. The possibilities they provide for the dynamic display of information that cannot currently be replicated by any other display medium.

In order to make the most of the flexibility of such displays, the human factors designer needs to be able to design information based on what the operator needs to know for the task. This has to be presented in a way that is suitable to the task. This is why task analysis needs to address the issue of not only what the operator does with the information or how he or she processes it cognitively, but also what the content of the communication is and how it will be processed and used.

5.3 HUMAN INFORMATION PROCESSING

To achieve information design the two aspects of how a human processes information and the alternatives for the transmission and reception of information via the interface, need to be studied. The way in which humans process information has gained importance as tasks have had the emphasis placed on the cognitive rather than the physical and manual features of the task. Understanding how information is processed enables information to be displayed in a way that facilitates this.

Information is received from the system via a stimulus, this is usually visual but can be auditory or tactile. We then interpret and process this information and produce an output, which, if appropriate, may lead either to the transmission of information back to the system or the passing on of that information to another information processing chain. When we process information it acts as a transfer function, changing an input into a different output. Information from the system can be direct, as in the visual information we get when driving a car, or indirect, as in most process systems, where the information about system functioning is conveyed to the operator by an intervening process and displayed in an encoded format.

Information is communicated to the system from the human by means of input devices. These are most commonly devices that can be manipulated by hand such as keyboards and switches, although for some tasks voice has proven to be a suitable input medium (Frankish et al., 1987; Hewitt and Furner, 1988). Several assessments of input devices and the tasks to which devices are most suited are given in the literature (Carey, 1985; Milner, 1988). The relationship between input devices and their suitability to different input tasks is better researched than the suitability of different display formats (especially CRT displays) for different process tasks.

There are different views and theories on the way humans process information. In 1958 Broadbent put forward a theory that saw a human as a processor with a limited capacity processing channel. There exists a single channel which limits the rate at which information is processed and the information processed by the channel at any moment in time is selected by a filter. The information is collected for processing in a buffer in the form of a short term memory store. Information that passes through the system is retained in a long term memory store. Although Broadbent was to later modify some of his ideas the basic concept of serial processing remained.

Alternative models of information processing were developed throughout the 1960s and 1970s, but may were similar in approach and are based on the "modal model" of information processing. For the purpose of task modelling, Card, Moran and Newell (1983) divided the information processing system into 3 subsystems. The perceptual system, the motor system and the cognitive system. The perceptual system senses the information signal, the nervous system conveys the information to a point where it can be processed and the cognitive system translates it into an action.

Most task analysis methods, especially those which focus on the transmission and flows of information rather than purely on motor activity, do not attempt to analyse the task in terms of its cognitive functions, but rather allow the external effects of such processing to be documented. Hierarchical Task Analysis (HTA) often has the criticism levelled that it is unable to analyse complex cognitive control tasks. It is true it does not provide an explicit structure for achieving this, but neither is the HTA structure orientated towards physical task performance. Information concerning cognitive tasks can be included in the analysis, but as with all task analysis methods, the information produced by the analysis is dependent on the quality of the information input and the skill of the analyst.

5.4 METHODS FOR ANALYSING OPERATOR INFORMATION NEEDS

Currently there are few task analysis methods available which allow the issue of the content and form of the information which flows to and from the HMI to be documented, and which relate this information to the tasks that it will be used for. Yet, for an operator to be able to carry out his tasks effectively the information displayed must be appropriate to the task and displayed in a way that facilitates these tasks. The operator needs all the information required for a task without having to decipher it from extraneous information. Further, the relationship between items of information should be clear to assist in operation. In a process control situation the quantity of information to be displayed means that it must be divided up for practical purposes, either for display on different control panels or for display on CRT screens. With the latter the content of each screen of information and its relationship to the task the operator will use it for is crucial. The space available for displaying information is limited. The information needed to carry out any particular task must be displayed in a form where it is available and usable for that task. Yet design of displays in terms of their content and the way in which the information is allocated to displays is often carried out without a task analysis or using a task analysis method that does not make display relevant information explicit.

Of the methods available which address the issues of communication or information flows, Job Process Charts (Tainsh, 1985) document the information that is displayed to the operator and the information the operator feeds back to the system. The method also shows machine and human tasks in parallel and so any reallocation of function and change in the format of the information exchanged is easily shown. At the level of stimulus-response activities, signal flow graphs and trigger check lists show the stimulus which 'triggers' a response from the user, for example, a trigger may be in the form of information provided to the user.

N^2 charts (Lano, 1977) offer an alternative approach where an attempt is made to assess and describe the interface in terms of its input and output functions rather than in terms of transfer functions, which is the usual analytical approach. The N^2 chart is described as:

> "An implementation tool and methodology for the tabulation, definition, analysis and description of functional interactions and interfaces."

However, the emphasis is very much on information flow rather than on the task itself. One advantage of this method is that the structure is such that it allows most of the task information to be represented on the diagram and it enforces thoroughness on the part of the analyst.

PTR (Personalised Task Representation)is a method developed in the context of naval engineering specifications and standards (Defence Standard 0025). Implicit in the analysis is the identification of functions and message flows of the user as well as a separate stage involving the representation of system tasks. In determining the functions of the user, questions are asked in relation to why and how the task is to be performed, what the next, previous, concurrent tasks are and what are alternative options and flows of message and control data. The disadvantage of this method is that although control data and messages are recorded, these are not explicitly included as part of the method and so may be omitted.

No other method reviewed in the literature explicitly notes information flows and shows their relationship to tasks. However, in the assessment of analytical methods in the case studies other methods were examined by virtue of their methodology or proven validity in the area of process control.

5.5 CRITERIA

Having established the importance of analysing information flow between the human and the system and assessing the information needs of the operator in relation to the task they will be used for, the criteria which a method should ideally meet can be outlined theoretically. However, empirical testing is needed to ensure validity.

1. The method should show the flow of information from machine to the human at the point where they interface. The way in which this is presented is dependent on the stage in the design cycle. If allocation of function is not yet decided, information flow cannot be accurately documented, for example because the requirements for the redundancy of the information will be different for the system and the human. In theory, the content of the

information should remain the same whether it is transmitted within the system or from the system to the human, and so the description of this may not change.

2. System analysis should take a user centred approach to ensure that what is presented is the information that the operator needs rather than the information the system has available. It is useful to compare the two so that if there are inadequacies in the information the operator needs then options for overcoming this can then be considered such as training and the use of job aids.

3. In line with any useful task analysis method the method should be both valid and usable.

4. Assumptions about the task such as environment, personnel selection etc, should be stated before the analysis is carried out.

5. The analysis should relate information about information content and input and output to the transformation function or task it is to be used for. Information may be used in quite different ways for different tasks and display design decisions may be contingent upon these items of information being both available and related.

6. The information exchange within a system should not be considered in a narrow way. It is likely that the same information may be needed for use in tasks by personnel other than the operators such as maintainers and supervisors.

7. The analysis should not restrict itself to consider the human simply as part of system functioning. There is other information that may be needed to help the operator, for example, information on how the computer processing the information works, information on operating the display system, information on system configurations outside normal system operation and so on.

5.6 PROPOSED DEVELOPMENT OF A METHOD

As no existing method adequately fulfils the criteria outlined, two approaches for methodology development were considered.

(i.) Draw from existing methods in the literature and synthesise *a new method.*

(ii.) Take an existing method that has proven adequate both empirically and theoretically and extend it.

The initial approach was to assess existing methods on a common set of tasks deemed to be representative of process control tasks. Deficiencies and problems could then be identified, the methods could be comparatively assessed against each other and against the criteria outlined. If a method was found suitable for extension this approach may prove the most profitable as the method would have been tested and have an established theoretical application.

A review of almost 90 task analysis techniques was carried out, and using the criteria outlined, methods were selected for comparison. This comparative analysis is described in case study 1, and covered the criteria above, focusing on factors such as the usability of the method and the results it produced. As a result of this review, HTA was selected as a basis for modification. The following sections outline the background and evolution of the method, previous applications and modifications to the method. The modification of HTA to analyse operator information needs is then described.

The initial aim of the research for this study was to evaluate existing methods of task analysis for assessing operator information needs, to assess their strengths and deficiencies against criteria of an "ideal method". The first step in developing a method to analyse operator information needs in a process control environment is to assess currently available methods and techniques and the relevant literature in both the human factors area and from other disciplines such as computer science, systems analysis and engineering.

Initially the methods were selected and assessed against the criteria in a theoretical way. The list of methods considered initially is given below:

Rasmussen - cognitive task analysis
Task analysis for knowledge description
N^2 charts
Job Process Charts
Petri-nets
Hierarchical Task Analysis

These were to be assessed and compared by carrying out an analysis on data taken from case study 1 : Rawdon Coal Preparation Plant. As no method had been selected or developed for use in the case studies at this point in the research, the data collection concerning the task occurred in a very general form, mainly consisting of overall task descriptions and event logging. However, for each analysis, if more information was needed it was possible to request this. The task selected for the evaluation was considered to be a critical task in the operation of this plant and representative of the operations in the plant as a whole. Ideally, several plants were to have been surveyed for potential tasks before the assessment was carried out. However, because of the Miners Strike, the project was delayed and so a compromise had to be made of selecting the task from one plant context to avoid further project delay. These time constraints also meant that it was not possible to apply all the methods to a full task analysis of the control room operator.

The task selected was that of controlling and monitoring the ash controller on the plant. This was a critical task as the ash content of the prepared coal defined its acceptability to the customer. If the ash content was too high the product would not be accepted, if it was too low there was an economic impact on the plant which resulted from a product of a higher grade than was necessary.

Excerpts from the results of the analyses are shown in Appendix C for each method. In addition, a description of the task is given. The aim was to apply each method to a range of task elements involved in the ash controller task such as monitoring, fault detection, procedural tasks and so on. A brief analysis was carried out for each to determine how each method related to the criteria in an empirical setting. The results of the methods were also compared to one another, and are considered in the following section.

5.7 COMPARATIVE EVALUATION OF METHODS

The first stage in analysis was to comparatively assess the task analysis methods selected on data from the Rawdon Coal Preparation plant, specifically on the task of monitoring and controlling the ash content of the final plant operation. The results of these analyses are given in appendix C.

The methods were assessed on the criteria outlined and how effective they were in empirical use. They were also considered in terms of how they were to be modified to include further details of operator information needs. However, a brief review of each is given here.

Rasmussen

In process control contexts, the tasks of the operators have an increasing cognitive content and tasks such a planning, problem solving and decision making are as commonly encountered as operational tasks. The method of analysis proposed by Rasmussen (1985) focuses on the decision making and cognitive elements of the task. In the analysis of a complex system where the behaviours required of the operator are correspondingly complex, an analysis method must aim to address all facets of these behaviours both cognitive and physical.

The method was selected as it provided a unique approach to the analysis of complex tasks, which addressed the issues of decision making and levels of task performance. The analysis method makes a distinction between three levels of behaviour: skill based, rule based and knowledge based behaviour. Skill based behaviours are for those task elements which are carried out at a relatively low level of performance, and which have become almost automatic in their execution. Rule based behaviours correspond to those task activities where, for example, a procedure has to be carried out, they relate to tasks where simple rules of operation can be given and learnt for task performance. Knowledge based behaviours are those behaviours with primarily a cognitive content which require the human to apply his or her knowledge to the task in hand and to reason out approaches to the task and make decisions. It was also anticipated that the analysis could be extended to explicitly document the elements of information that would be required in the task performance of each object-action pair.

However, it was not possible in the literature to find detailed guidelines on how to carry out the method, although the representations of the three levels of analysis were described and discussed. The method itself provided a framework in which the information could be collected. However, the collection of cognitive task information presents a variety of problems to the analyst, and approaches which could be taken to deriving this information and to task elicitation were not suggested. The three levels of skill, rule and knowledge based behaviours, allowed consideration of both the physical and cognitive aspects of task performance. However, the analytical focus was on the analysis of cognitive tasks. Whilst the representation clearly indicated decision points in the task, it did not easily allow these to be related to the control actions of the operator. As this analysis was based on the knowledge of the operator, it was inherent in the analysis that much of the information required for task performance would be in the form of knowledge, and the information flows between the human and the system were therefore not explicit in the analysis. The format of the analysis reflects the complexity of the task and can be difficult to apply to design, it is also difficult to adapt and update to incorporate changes in the task.

Task Analysis for knowledge description

This method has been developed by Johnson and his co-workers for describing the knowledge required to perform tasks and is described in detail in a collection of papers (eg, Johnson et al., 1986). Of the methods considered, this adopts the most formal approach to analysis, as it is based on a defined task grammar which then forms the basis of the structure and content of the analysis. It has been applied to contexts such as the definition of a syllabus to specify the training requirements of information technology and to interactive systems design. Its application to contexts such as the design of the human computer interface and intelligent knowledge based systems have also been considered.

Task Analysis for Knowledge Description (TAKD) was selected for study as it provided a method which documented the knowledge required to perform a task alongside actions. It allows for the systematic analysis of tasks in terms of the objects, actions and knowledge that constitute task performance. It offers a hierarchical approach which gives a variable level of task detail. The method also provides an analysis of both the cognitive and physical aspects of task performance, giving a task description from which the knowledge requirements are specified. The approach to analysis is rigorous and clearly documented.

The method is carried out in a bottom up approach to analysis (once the grammar has been defined using a top down approach), moving from the most detailed task elements of task description to the more general levels of analysis. It can be difficult to modify and update an analysis once carried out, as it may require the upper levels of analysis to be changed and so the total structure of the analysis can be affected. With more formal methods, high levels of consistency can be achieved between analysts. However, the flexibility of analysis and the nuances of task description that can be achieved by the use of natural language are lost. Further, as the analysis aims to provide a more generic task model in a given context it can be difficult to carry out iterations in analysis and to easily update the information. Finally whilst the method can be used to synthesise tasks, an existing level of task information is required to generated the object action pairs and this may not be readily available in a new system undergoing design and so in the early stages of system design it may not be possible to define the grammar to carry out the task analysis.

N^2 charts

The N^2 chart originated from work by Lano in 1977. It was developed to meet the problem of:

> "Timely and accurate definition of system element interfaces and task activity relationships" (Lano, 1977).

The analysis takes the form of a division of task into functional blocks (figure 5.1) for which the input, output and transfer functions are defined. The method is described as:

> "An implementation tool for the tabulation, definition, analysis and description of functional interactions and interfaces", (Lano, 1977)

It is intended to be generally applicable. The method presents a top down approach to analysis orientated towards design. It also incorporates consideration of the system control interfaces alongside consideration of the task functions and the flows of information between them. The definition and description of the method is very thorough and well documented. The method has also been compared to other similar approaches such as flow charts and PERT diagrams.

The task is represented in a diagrammatic format with the task information included in the graphical representation. There are variations on the format of representation to allow the functional elements to be represented clearly. The diagram is in the form of a square matrix. The task functions are arranged along the diagonal and each box in matrix represents the information flows at the point where two functions interface. Each function is considered in its relationship to the others.

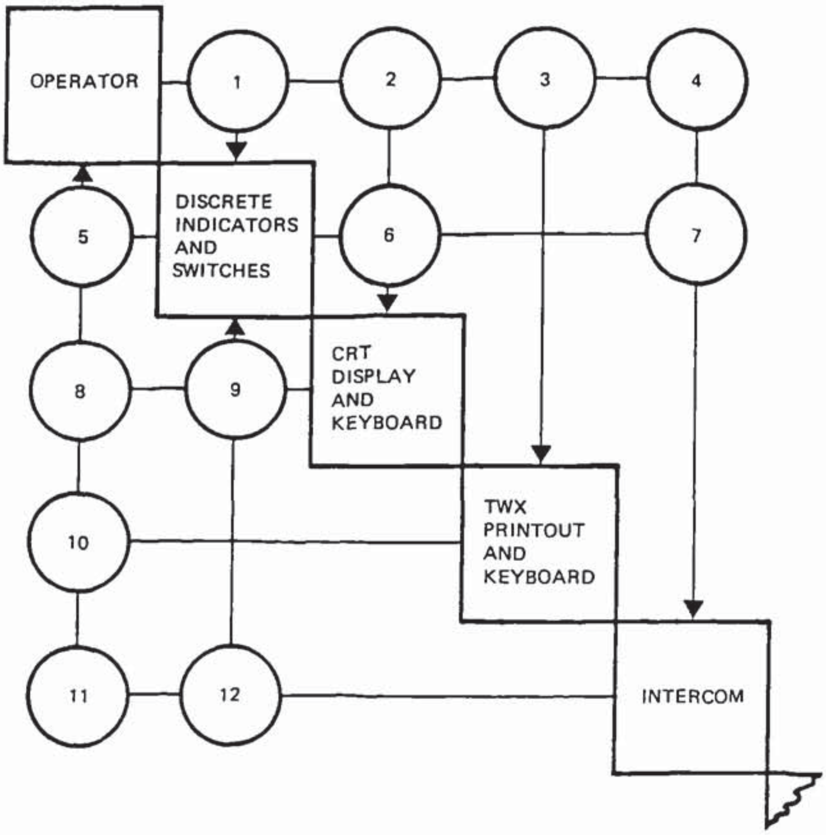


Figure 5.1 N^2 Chart

The method was selected as it treats information flows in a systematic way and documents them very clearly, indicating the content and direction of the information flow. However, the task elements are only described in terms of task functions and the analysis contains no information on the relationships between task elements other than their information flows, or on the conditions which govern the way in which the task elements are carried out. The level of detail can only be varied by taking a functional element and using it as the basis to construct another N^2 diagram. The ordering of the functions in the analysis is dependent on the optimisation of the information flows. Whilst the approach to this is effective for control and hardware interfaces, there are no rules governing how this can be achieved for functional task elements. Finally, whilst functional elements can be added to the diagram and easily included in the analysis , it is not easy to carry out the analysis as an iterative process or to adapt the analysis to include other forms of task information.

Job Process Charts

Job Process Charts (JPCs) were developed by Tainsh (1982) for applications in a Naval context as a means of identifying man-machine communication. The method is based on a flow chart type approach superimposed on a tabular format. The technique analyses the task at three levels of detail, the final level specifying the communication flows in detail. The method has been successfully applied in Naval contexts. It aims to allow analysis of both the cognitive and physical aspects of analysis, but focuses on the tasks which relate to the information exchanged at the interface.

There is no available step-by-step guide to carrying out the analysis. Whilst the three levels of analysis offer varying degrees of detail, there is limited flexibility in adapting this to meet the task context. Within the JPCs there is no easy means of varying the level of detail of description and showing where this varies. This is potentially confusing when using the analysis in an information design context. When the differences between levels of detail in task information cannot be shown, then to extrapolate from the analysis to display and information design is made difficult as the varying levels of detail required on the displays cannot be directly related to the analysis (see figure 5.2).

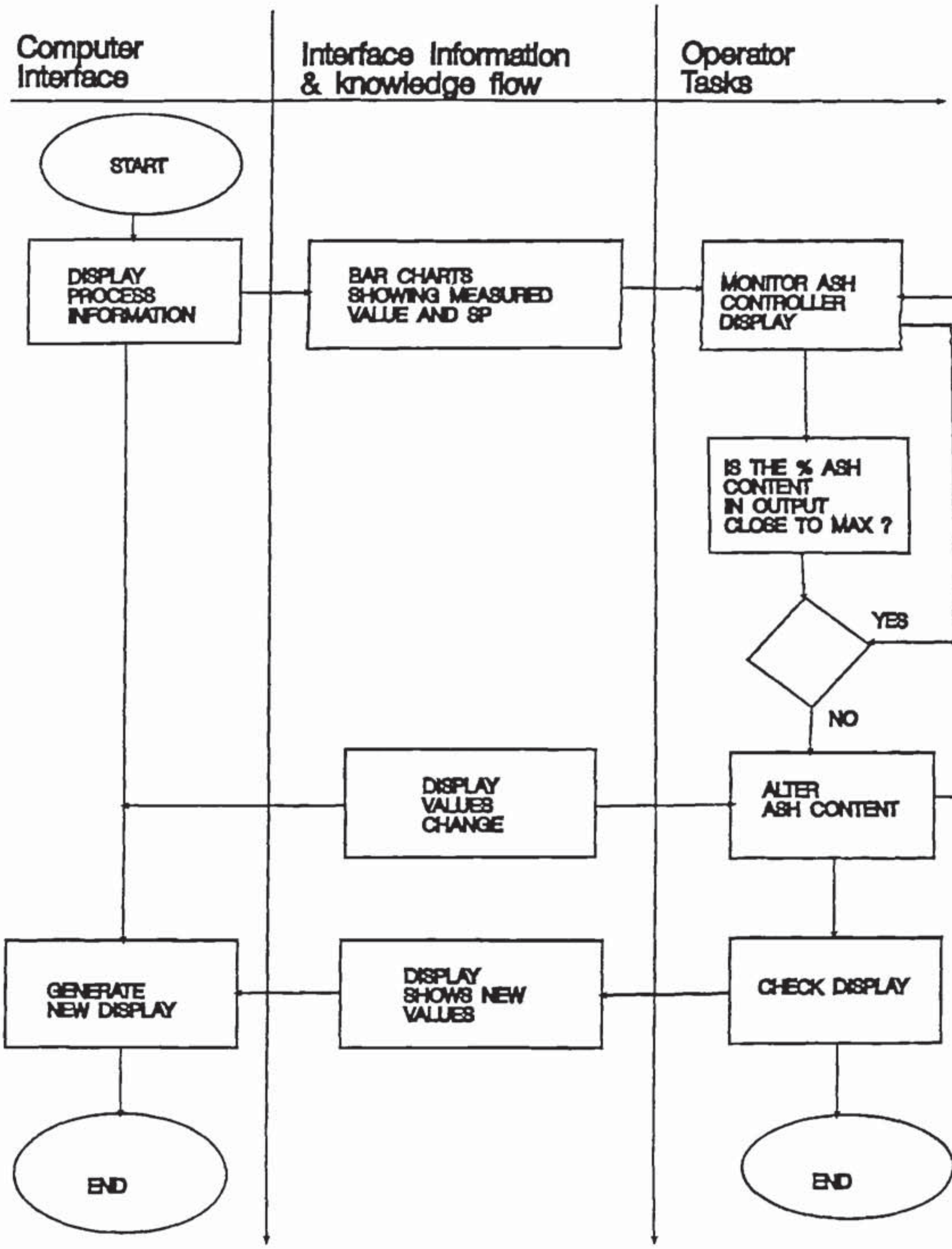


Figure 5.2 A Job Process Chart

The flow of a flow chart type analysis makes the decision points and task options very clear. However, the flow chart primarily indicates task flows. This is very useful in the analysis of procedural tasks and of simple decision making tasks. However, for more complex tasks it is difficult to demonstrate the relationship between task elements in terms other than the progression of the task and branching points.

Finally the analysis is not easily changed. Each task element is contingent upon the preceding task element and forms the basis for the subsequent task elements. Therefore the change of any one element has ramifications and the potential need to modify and update large parts of the analysis.

Petri-nets

Petri-nets were originally developed for use in systems analysis, but they can similarly applied to the analysis of task contexts. They originated from work carried out by Petri (1976) and aim to represent complex contexts where the elements of performance operate concurrently and asynchronously. Whilst the method has not been extensively applied to task analysis, there are some applications in process control contexts reported in the literature. For example, Visick and Law (1987) used the method to describe and analyse operating procedures. There are many instances of the method being applied in computer science contexts, and different adaptations of Petri-nets have been made to describe, analyse and model production processes.

The method was selected for consideration because of its use in representing and analysing complex process situations (figure 5.3). Its representation is in the form of a network diagram and networks offer a very flexible approach to analysis. The relationships between task elements is clear and the conditions which have to be fulfilled to achieve each task goal can be made explicit. The method allows the analysis to be extended and updated as required and within the structure there is the potential to describe both cognitive and physical task elements.

However, in the application of the method to task analysis, several issues became evident which could impact on its use for the identification of operator information requirements. Firstly, the network does not make explicit the different levels of detail at which the task elements are described. Whilst this can be overcome by using a hierarchy of nets (where a node is taken and forms the basis for another more detailed network), the analysis can become very complex and difficult to use. There is no formal means of describing the relationships between networks. For complex tasks, whilst it is easy to identify the relationships between closely related task elements, it is difficult to show relationships between elements in the net that are less closely associated with each other. The diagram itself restricts the amount of task information that can be included, and so it must be accompanied by annotated information for which there is no documented structure. For example, the nodes and transitions can be numbered and the numbers referred to in the accompanying textual description of tasks. The analysis also places emphasis on the means of achieving the task goals rather than the goals and required system states.

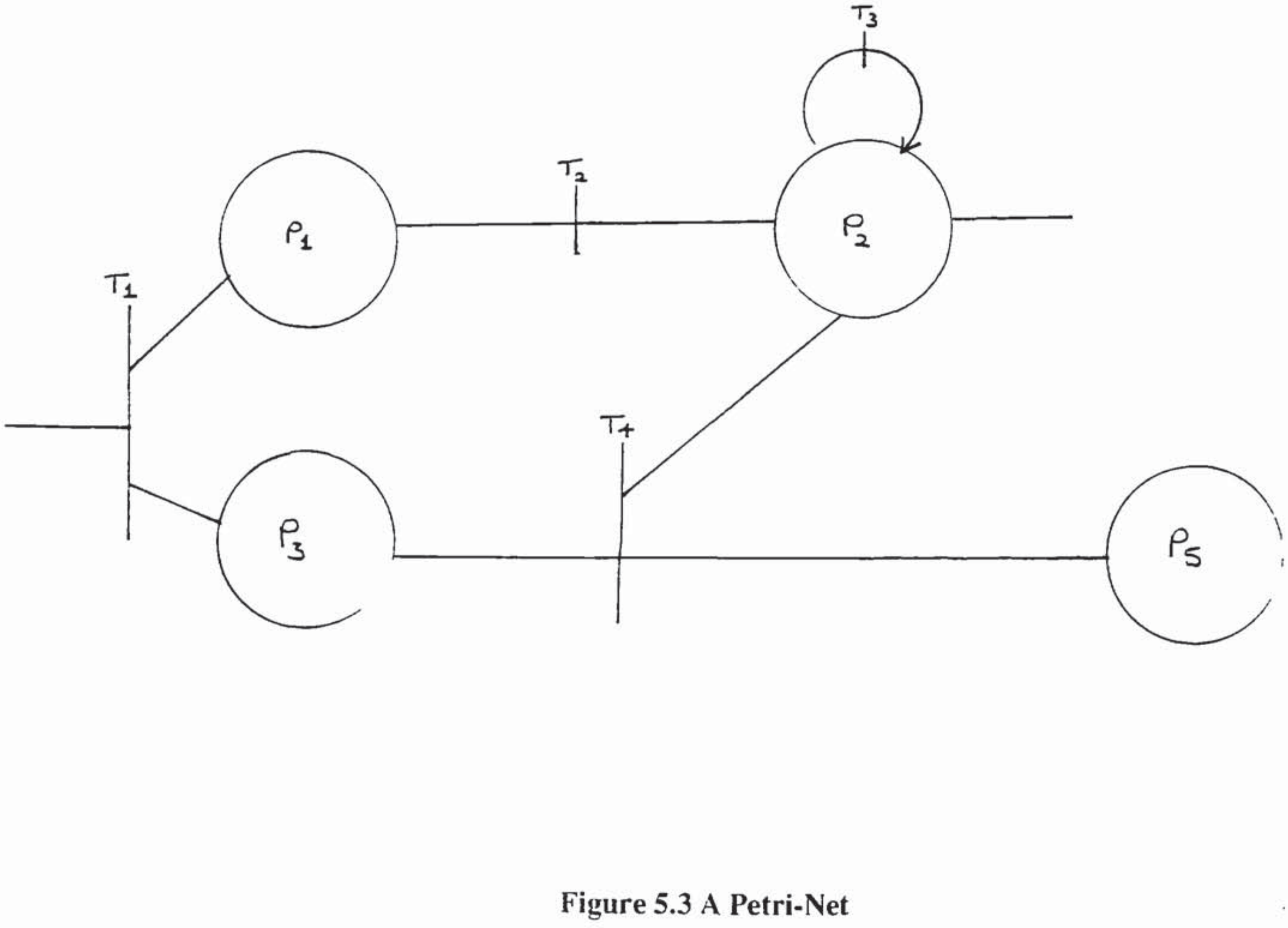


Figure 5.3 A Petri-Net

Hierarchical Task Analysis

Hierarchical Task Analysis (HTA) is a hierarchical approach to analysis developed in the late 1960s for application to training in process control contexts (Annett et al., 1971). HTA has been widely and successfully applied to a variety of task issues, in particular to training and to interface design. It has been evolved over time to meet the changing demands and tasks in process control contexts (Shepherd, 1976; Piso, 1981).

The technique was selected both because of its widespread application to process control contexts and because of the flexible and systematic framework it provides for an analysis. The steps to analysis and the method are also clearly documented, and the rules for carrying out analysis defined. It does not specify information flows in its current form, but previous adaptations of the analysis and applications of HTA (for example, Hodgkinson and Crawshaw, 1985) indicate that the method could be adapted and extended to incorporate this information. The method provides a context for the consideration of both cognitive and physical aspects of task performance. The representation is in the form of both a hierarchical diagram and tabular format. The hierarchy provides a clear description of the tasks and the conditions under which they are carried out, whilst the tabular format allows each of the task elements to be examined in detail. The analysis gives a framework for analysis which permits tasks to be analysed in an iterative and increasingly detailed way.

However, the analysis does not present a formalised means of documenting the assumptions underlying the analysis. Additionally, in the applications carried out to date it has been applied only to task performance under normal operational conditions with only one means of achieving the task goals described.

5.8 DEVELOPMENT OF A METHOD

No one method examined in the course of the literature review met all the criteria outlined for use as a method of analysis to specify operator information requirements.
Of the methods assessed it was considered that of the approaches provided it would be most appropriate to, if possible, modify an existing method to include the relevant task information, rather than to develop a new method. As a basis, the method would have to be sufficiently flexible to allow modification whilst retaining its original attributes. It would have to provide a structure and representation that could be modified. HTA offered a combination of decomposition and hierarchical approaches and was selected for the following attributes:

1. The method was both systematic and thorough in its approach.
2. It had been successfully modified and applied previously.
3. It provided a flexible and easily adaptable structure, and the analysis could be easily updated.
4. It allowed the analysis of both cognitive and physical tasks.
5. Task goals were made explicit, so the aims and use of the information could be easily identified.
6. The method was clear and well documented.
   Many of the methods selected did not have a step by step guide on how to carry out the method, and without this there is increased difficulty in ensuring consistency amongst analysts and in avoiding ambiguity. It is also difficult to ensure that the way in which you interpret the way that the analysis should be carried out was the way the author originally intended.
7. The method had already been successfully applied and shown to be empirically valid.
8. The method had already been widely applied in a process control context. The theories and ideas underlying it are described in papers by Annett and Duncan (1967) and Annett et al. (1971). Furthermore studies on consistency amongst analysts showed that the method can achieve a reasonably high level of reliability if it is used correctly and trained.
9. The analysis allows a variable level of detail, yet it is complete as an analysis at any level.
10. The formats for HTA are both hierarchical and decompositional, the two complement each other and both should be used wherever possible. The hierarchical format provides a kind of task map showing the relationships between the different task elements; whilst the decomposition format allows a much greater level of detail and is flexible in its layout. This is the part of the analysis that is the most amenable to modification.

Overall, HTA was found to have the best balance of elements needed for such an analysis. Other methods considered presented a variety of problems which when assessed offered a less flexible and adaptable approach to analysis.

5.9 HIERARCHICAL TASK ANALYSIS EVOLUTION AND DEVELOPMENT

Hierarchical Task Analysis (HTA) emerged as a method of task analysis in the late 1960s. It was developed with the aim of analysing tasks to determined the content of training programmes. The original paper by Annett and Duncan (1967) which outlined HTA, was influenced both by their experiences in the field of training and by the ideas of Miller et al. put forward in a book published in 1960. Their paper was based on the idea that training should be task orientated rather than based on a theoretical knowledge of subject matter, this knowledge was then put into practice.

The objective was to detail performance both to describe the content of training courses and also to provide a measure against which training could be evaluated for its effectiveness.

Their approach was to describe performance in a hierarchical manner stopping only when the importance of a task element at the bottom of the hierarchy was such that its non performance (due to no training) was an acceptable cost to the system. The notion was that some tasks would need to be described in greater detail than others to meet this acceptability criterion.

All the operations (individual task elements) were viewed as part of the hierarchy but each also had its individual inputs and initiating cues and outputs or responses. There would also be the need for feedback to indicate successful completion of the operation. Annett had highlighted the importance of knowledge of results in his paper with Kay in 1956.

5.9.1 THE HIERARCHICAL BREAKDOWN OF TASKS

The notion of a hierarchic approach as a means of breaking down a task was influenced by the ideas of Miller, Galanter and Pribram (1960). Their approach broke the tasks down into a series of TOTE (Test Operate Test Exit) units which were hierarchically organised. The idea of a TOTE unit was very much as a goal orientated task element in which the actual system state is continually compared to the required system state. If the two do not equate to each other then the existing system state is operated on in some way and the two system states reassessed. This process is then repeated. The TOTE units can be arranged in a diagram so that it becomes evident how each goal should be reached.

The notion of a hierarchy appeared useful for training design, as elements could be repeatedly broken down until they achieved task units which could be manageably trained. The method allows for part task approach to training to be easily handled and helps to identify where is is appropriate.

5.9.2 TASK ANALYSIS AS A GOAL ORIENTATED ACTIVITY

The idea of a task as a goal orientated activity is reflected in the "operations" (an operation being a term used to describe a task element in a noun-verb format) and structure of the method of HTA, and follows from the goal orientated structure of TOTE units. In effect, most task analysis methods assume that task performance is goal directed, some document the goals explicitly, whilst other method focus on the means of achieving the goals and the goal itself is implicit and not directly stated. Within HTA each operation, which has subordinate operations, forms a goal, and each goal forms part of the progress towards achieving the higher level goals until the main operational goal is reached.

5.9.3 THE BACKGROUND AND HISTORY OF HIERARCHICAL TASK ANALYSIS

In 1971, a detailed booklet outlining ideas of task analysis and the method of HTA was produced by Annett et al. for the Department of Employment. The aim was to disseminate current research in the field of training much more widely.

The Psychology Department at Hull was commissioned to look at task analysis methods for training, especially in control and non routine tasks which were not adequately covered by existing methods. Experimental training schemes were to be set up to empirically test the results.

Their criteria for a task analysis method were summarised into 3 questions

1. Does the information obtained lead to positive training recommendations?
2. Does the method apply to more than a limited range of tasks?
3. Does the task analysis have any formal or theoretical justification?

HTA was then designed with the aim of meeting these three criteria. In order to concentrate training effort where most needed the process of task analysis was preceded by a training checklist to determine those tasks that were suitable or needed further analysis. Task information is recorded both in hierarchical form and in a tabular diagram.

Following from this initial work Duncan looked further at the problems of documenting tasks and task analysis (Duncan, 1974). Some of the problems explored include taxonomies, of approaching the task from the point of view of purely mechanistic performance and describing skill and of collecting data about a task.

> "The analysis of problem solving and decision making tasks is thus likely to be closely involved in the overall personnel policy of the system in which he is working. In some situations it may be highly desirable to proceduralise such tasks, in other situations the need to train for retention or transfer for flexibility is more important. " (Duncan, 1974)

In his papers in the 1970s Duncan explores other task analysis methods and their utility and inadequacies. The aims of HTA are made explicit and it is seen purely within the context of training applications. HTA aimed to overcome some of the problems of task analysis although the limitations of the method were recognised. These were outlined by Duncan in five main areas:

1. HTA does not define which tasks it will be useful to analyse; however, it makes explicit when the analysis that has been carried out is detailed enough. Many methods do not provide rules to judge when analysis is complete and this can result in a great variability in the detail of analysis produced.
2. Allowing flexible documentation of both decision making and problem solving behaviour as well as overt task activity. This flexibility allows problem solving and decision making tasks to be broken down into decision trees and procedures where appropriate but also allows more flexible options for performance where it was not appropriate.
3. With HTA Duncan recognised the need to use other methods for making more specific decisions regarding tasks when it was necessary.
4. Task analysis is not seen as a design solution in itself (in this instance for training) but as a hypothesis generating mechanism which has to be complemented by empirical testing. One interpretation of this is that a task analysis and its results cannot be assessed until they have been used as an input into design or evaluation, and the results tested in a real world situation.
5. The influence of other disciplines on the priorities of task analysis and especially the need to collaborate with design engineers and the selection of personnel. Also the influence of task design on factors such as job satisfaction and motivation are noted and recognised.

Duncan also states the assumptions that are made in the use of HTA. Firstly stating that for an analysis to be viable in practice a rule or rules are needed to specify what to include in and what to exclude from a task analysis. In HTA this is achieved by use of the **p x c** rule (probability times cost rule) in the first place and also by the stopping rules. Secondly the relationship between the task elements in the analysis must be made explicit, within HTA this is achieved by the inherent structure of the hierarchy and by the use of plans. HTA uses natural language to describe the tasks. This has the advantage that procedural guides and operating instructions can be almost directly extracted from the analytic information.

Any method of task analysis cannot make categorical statements about psychological processes as the same task performance can be supported by quite different psychological processes. In accordance with this, the method of HTA aims to represent "flexible and adaptive" character of skilled performance, and the facility to achieve constant outcomes in a variety of ways. Whilst HTA does outline the goals of a task, at the same time the method only outlines one of several possible task routes for achieving that goal. Indeed this is one point on which many task analysis techniques fail to account for the flexibility of the human. Whilst a task can be trained in one particular way, there may be other more optimum ways of achieving the same task performance under differing circumstances. Alternatively the operator, once familiar with the task, may not perform it in a textbook fashion. If the method only gives one, albeit optimal task performance, then an inaccurate view may be gained of the task or the trained operator's repertoire may be found to be limited. This is not to suggest that all possible means of achieving any given goal be documented, just that viable alternatives should be noted where necessary.

Any analysis should study the task in the context of the system in which it is to be performed. In order to achieve this, HTA will often produce several solutions to a problem which need to be considered in the context of total system values.

5.9.4 EVOLUTION OF HTA

In the 1970s HTA became more widely applied and used as a task analysis method. Its flexibility of approach meant that its use diversified into 3 main areas:

- (i.) It formed the basis of new techniques along similar lines for other applications.
- (ii.) It was evolved and modified to meet the demands of modern technological process control situations.
- (iii.) It was widely used for other areas of application such as Human Machine

Interface design, and as a basis for other applications.

Application in its current form

The application of HTA both in the original forms and in the forms as proposed by Shepherd (1976, 1981) has covered a variety of industries. These have not been limited to either process control or training. The examples below serve to illustrate empirical applications of task analysis.

1. TRAINING IN NAVAL COMMAND SYSTEMS
   Stammers and Morrisroe (1985)

This report outlines research into improving the effectiveness of training systems for naval command systems. A task analysis of an existing demonstrator system was carried out using HTA. The outcome was a set of recommendations and guidelines for the provision of instruction using computer based training.

2. THE REDEPLOYMENT AND REGRADING OF PERSONNEL IN INDUSTRY
   Patrick et al. (1980)

HTA was used as an initial step in the development of training material for the upgrading and redeploying of personnel in industry. The application involved a battery of job analysis and task analysis methods being employed to address the issues involved.

3. HUMAN MACHINE INTERFACE DESIGN OF A SOUND MIXING CONSOLE
   Hodgkinson and Crawshaw (1985)

This study also took the use of HTA away from training and process control related tasks. The method was applied to the design and evaluation of the interface of sound mixing consoles. A task analysis of the console operator's task was carried out and used as a basis for a comparative simulation to assess alternative console designs. In this study the HTA format of Annett et al. (1971) was applied.

4. HUMAN RELIABILITY ASSESSMENT
   Embrey et al. (1984)

HTA was used to provide a breakdown of a task into its constituent elements so that the human reliability assessment techniques of SHERPA and SLIM MAUD could be applied to a process operator's task.

5.9.5 THE CONTINUING EVOLUTION OF HTA

Whilst HTA was being applied and used for training and other tasks work on HTA was continuing. The method continued to evolve to keep pace with technological developments in the process industries.

The continuation in the evolution of the method has been carried out by Shepherd. His main adaptions to the method have been in the form of :

- a revised tabular format
- reconsideration of the rules for redescription
- numbering
- plans
- omission of the IAF (Input, Action, Feedback) classification scheme

The HTA resulting from Shepherd's work is the version widely in use today. Plans are now annotated onto the hierarchical diagram and for complex plans (which are necessary to describe a complex task) a hierarchy of plans can be introduced. The adaption of Shepherd sets out the operations in a clearer form in the tabular format which adds clarity to the analysis although it often means less information on a page. In addition
The numbering system adopted by Annett and Duncan made an operation's position in a hierarchy clear. Each operation has a unique number running from 1 to n. Each operation was numbered in the tabular format using this number and two numbers below it to indicate it superordinate operation and its place in the sequence under this superordinate operation. So operation $\frac{4}{1,2}$ would be operation 4 which is the first subordinate operation of operation 2.

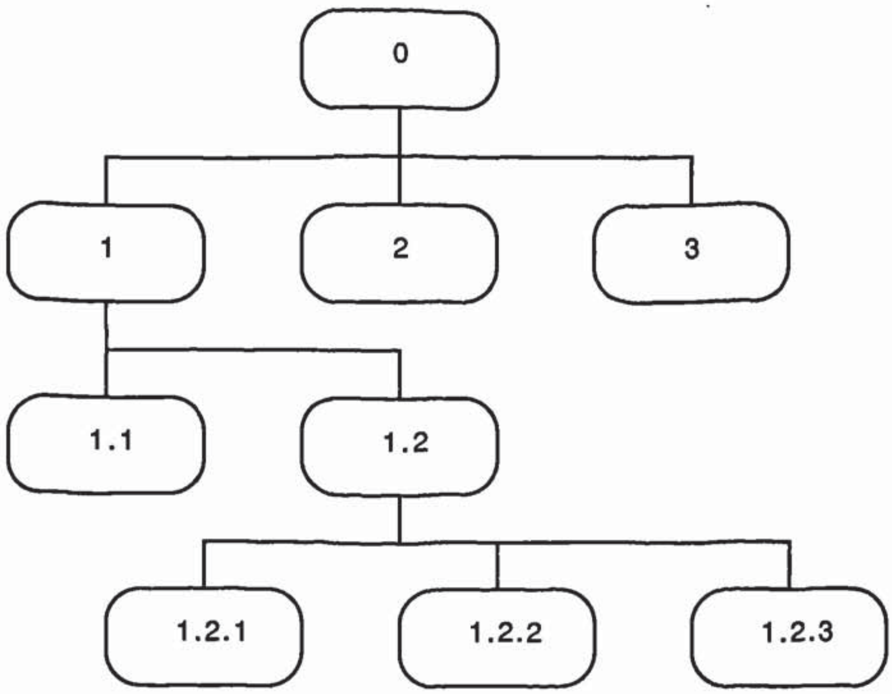


Figure 5.4. The numbering of HTA operations

Shepherd simplified this system immensely and his final version adopts a simple convention of numbering in which the main task goal is numbered 0. The operations under this are numbered 1 - n, then the operations subordinate to operation one are labelled 1.1, 1.2, 1.3...1.n and under operation two, 2.1, 2.2, 2.3...2.n and so on, this continues at the next level down to operation 1.1.1, 1.1.2 to n.n.n.n etc. This principle is illustrated in Figure 5.1. This system helps to avoid errors and complications in the plans, whilst uniquely labelling every element in the hierarchy, indicating both its level in the hierarchy (by the length of the number) and its position in relation to its superordinate operation.

Shepherd also dispensed with the input or feedback and action columns and replaced them with a simple remarks column, this allows notes relevant to training or any other discipline to be made. This information was also included in the analysis by providing more detailed plans. In earlier versions this included a 'reason for stopping description' column which was later eliminated.

5.9.6 MODIFICATIONS TO HTA

The nature of HTA is such that it is intended to be a tool and framework for designing and analysing a task rather than a constrained and rigid approach to the study of a task. Duncan states:

> "Task analysis is a hypothesis generating activity, the aim is to help design or evaluate systems by the use of task analysis"

The need to put a task analysis into context and to use the task information for design in this way is widely recognised. In some contexts however, whilst HTA provides most of the task information needed and an effective framework for gathering task information, more task information may be required for a specific application. In some cases rather than make use of another task analysis method, HTA has been extended or modified. In modifying a method of task analysis several issues merit consideration, these are outlined below:

1. Is the analysis still based on the same fundamental assumptions and if not, are the changes clearly documented? For example, is the definition of task accepted to be the same in both analyses?
2. What further task information needs to be included in the analysis and can this be incorporated into the analysis and representation in a coherent manner that does not alter the meaning or significance of the original analysis?
3. If the modification deals with specific task issues can these also be incorporated into the representation adequately?
4. If the analysis is modified does this affect the task description and the representation of the analysis, and if so are these given adequate consideration in the approach to the modification?
5. Are the existing stopping rules adequate in the light of the modification and if not what should they be?

HTA has been modified for application to a range of tasks including dialogue design, the study of process information flows and allocation of function. In most instances some addition or adaption has been made to part of the method itself, however one modification has used the fundamental principles of HTA to create a task analysis method with a different purpose, that of analysing the system at a more general level. This method is known as overview task analysis (Patrick et al., 1980). Case study examples of specific modifications to illustrate the range of application are given below:

1. AIR TRAFFIC CONTROLLER'S TASK - Allocation of function,Crawley et al. (1980)

The study looked at the extent to which Air Traffic control tasks should be automated. A major factor in this decisions was to consider the maintenance of job satisfaction amongst air traffic control operators (ATCOs). The study involved:

1. Production of guidelines for the allocation of tasks between the ATCO and computer.
2. Prediction of the effects of automation on ATCO attitudes
3. An evaluation of the cost of effects caused by 1 and 2 to the whole system.

Overview task analysis (OTA) was used to help in the evaluation of the impact of automation on the operator's job content and attitudes in terms of points 1 and 2. An example of the analysis is shown in figure 5.5.

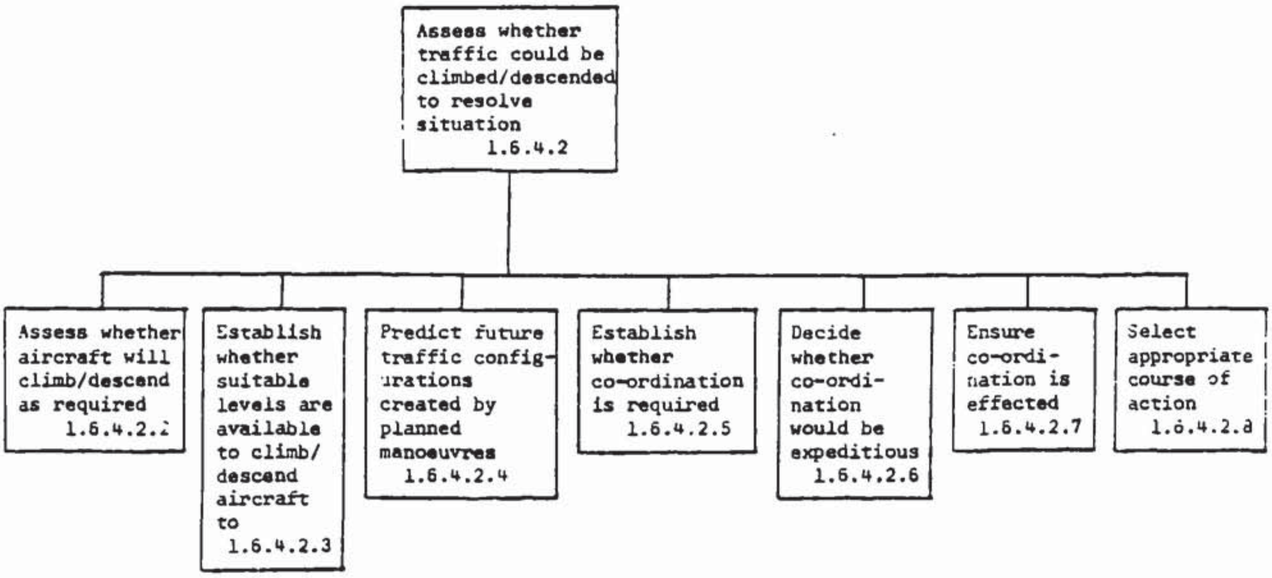


Figure 5.5 ATCO - partial overview task analysis

2. HTA AND DIALOGUE DESIGN - Hallam and Stammers (1985)

HTA was applied to an analysis of a naval command task. An existing system demonstrator was used to assess current dialogue formats and to evaluate alternatives. Both the hierarchical diagram and the tabular format of HTA were used with the table modified (figure 5.6) to allow dialogue features to be assessed in line with the task.

Super-ordinate	Task Component - Plans and Operations	Notes on Dialogue
	*119 Switch on TFD 120 Set-up and modify TFD 121 Note TFD information	
104	ACCESS CEP INFORMATION P.104 The operator has to switch on the CEP with the required set-up or modifications. Information may be accessed from this graphical display. *122 Switch on CEP 123 Set-up and modify CEP 124 Note CEP information	See Notes on Dialogue at P123 and P124 below
105	ACCESS SITREP INFORMATION P.105 The operator has to switch on Sitrep with the necessary set-up or modification and note the required information. *125 Switch on Sitrep 126 Set-up and modify Sitrep 127 Note Sitrep information	See Notes on Dialogue at P126 and P127 below
106	ACCESS EW SITREP INFORMATION P.106 The operator has to switch on EW Sitrep with the required modification in order to note the necessary information. *128 Switch on EW Sitrep 129 Set-up and modify EW Sitrep 130 Note EW Sitrep information	See Notes on Dialogue at P129 and P130 below
107	ACCESS PASSIVE CLASSIFICATION INFORMATION P.107 The operator has to switch on the passive classification page, set-up the required track number and note the necessary information. *131 Switch on Passive Classification page *132 Set-up track number 133 Note Passive Classification information	See Notes on Dialogue at P133 below
108	ACCESS ACTIVE CLASSIFICATION INFORMATION P.108 The operator has to access the Active Classification page, set-up the required track number and note the necessary information. *134 Switch on Active Classification page *135 Set-up track number 136 Note Active Classification information	See Notes on Dialogue at P136 below

Figure 5.6 - Modified HTA for Dialogue design
Hallam and Stammers (1985)

3. HTA APPLIED TO A PROCESS INFORMATION SYSTEM - Piso (1981)

Piso's use of HTA in a modified form was set in the context of the design of an improved process information system for the Phillips glass factory. His approach consisted firstly of a process analysis which produced information for the input to the task analysis. The modification considered how operators control the different process variables and so the analysis focused on control tasks. The control loop model of operator's performance was used to help modify the method to produce the information required.

Firstly the hierarchical diagram was modified. At the top, the overall task goal is noted. Under this the primary goals of the task are described and the next level gives the specific task to be analysed. Each task is divided into a further level of description according to the control loop model of pre-phase action-phase evaluation, but the pre-phase is also divided up into perception and decision.

The stopping rule used was that analysis stopped when both operator and analyst decide that a task or operation is clear to them. The tabular format was modified in line with this, omitting the p x c column and adding a column to note when more task information is required. At the completion of this study HTA had been applied to 45 operator control tasks.

5.9.7 HTA AS A BASIS FOR NEW TECHNIQUES

Although HTA is the title given to a particular method, the hierarchical approach to task analysis has become one that is recognised as being very useful for task analysis. Before HTA, few methods adopted this form of breakdown. The advantages given by a hierarchical approach include systematic analysis, outlines of both the goals and detailed performance of the task and the easy combination of the diagram with a tabular or other more detailed format that gives analytic information.

Annett and Duncan (1967) recognised that for many applications, HTA alone is insufficient. It could provide the basis of task information for more detailed analyses specific to other applications. For example, for personnel selection it may be useful to address the issue of the particular abilities needed for that task.

So HTA has given rise to methods which begin with HTA, almost as an aid to systematic organisation and description of the task information and data. The method then analyses the task information for a specific application. Two examples are given below, one is an application for human error assessment, the other an approach to describing knowledge.

1. SHERPA - Embrey (1984)

SHERPA (Systematic Human Error Reduction and Prediction Approach) continues to evolve and develop as a method. Its aim is to provide a framework for the assessment and analysis of human error. The method also aims to give recommendations for error reduction in the areas of procedures, training and Human Machine Interface design.

SHERPA is intended for the design of new systems but can be applied to the modification of existing systems. The first stage in SHERPA is to carry out a task analysis. In this context the objective of the task analysis is to both describe in detail the task and to document the characteristics of the task that could give rise to error. HTA is recommended here in the format given by Shepherd (1985). The information that the method uses from the HTA includes the plans to provide input into training and procedures and the definition of the main task elements and primary task path which help to provide a basis for the reliability assessment.

2. Task Analysis for Knowledge Description (TAKD) - Johnson et al. (1985)

TAKD was originally developed for the design of a national IT syllabus. It has been applied to such areas as electronic messaging systems and user interface design. The analysis itself is carried out in 4 stages, HTA is used a method for detailing the task description on which the knowledge description is based. The stages are as follows:

1. The collection of task information and task description (HTA)
2. The identification of knowledge underlying the task, this knowledge is specified in terms of the actions and objects which comprise the task.
3. The classification of objects and actions in terms of generic objects and actions.
4. The use of lists to represent pairs in a knowledge representation grammar.

3. OVERVIEW TASK ANALYSIS - Patrick, Spurgeon and Shepherd (1980)

Unlike the previous two methods this takes the principles of HTA and modifies them to produce Overview Task Analysis (OTA).

OTA aims to be more general in its application instead of analysing a task in detail it provides a more descriptive set of tasks across an area of work. The essential difference between the two methods are the stopping rules used. The task breakdown stops at the lowest level at which the tasks are generalisable between plants or companies operating in the same area or in the same way.

Its aim is generality within an area of task performance rather than the specific task detail generated by a HTA.

Discussion

HTA has been widely applied in a process control context in areas other than training and also outside the process control area both directly and indirectly. In its indirect form HTA has been used in applications where it provides the initial task breakdown. This analysis is then used as a basis for more detailed analysis for a specific application.

The flexibility of the method has allowed it to be applied as it exists, in modified form and a basis for new methods whilst still retaining the essential structure and process of task decomposition, description and analysis. Overall the method has evolved to allow its application and to remain useful and relevant as technology has progressed both within process control and other areas of application.

5.10 AN ADAPTATION OF HTA FOR OPERATOR INFORMATION NEEDS ANALYSIS

Of the methods assessed it was considered that of the approaches provided it would be most appropriate to, if possible, modify an existing method to include the relevant task information, rather than to develop a new method. As a basis the method would have to be sufficiently flexible to allow modification whilst retaining its original attributes. It would have to provide a structure and representation that could be modified. HTA offered a combination of decomposition and hierarchical approaches and was selected for the following attributes:

1. The method was both systematic and thorough in its approach.
2. It had been successfully modified and applied previously.
3. It provided a flexible and easily adaptable structure, and the analysis could be easily updated.
4. It allowed the analysis of both cognitive and physical tasks.
5. Task goals were made explicit, so the aims and use of the information could be easily identified.
6. The method was clear and well documented. (Many of the methods selected did not have a step by step guide on how to carry out the method, and without this there is increased difficulty in ensuring consistency amongst analysts and in avoiding ambiguity. It is also difficult to ensure that the way in which it is interpreted that the analysis should be carried out, was the way the author originally intended).
7. The method had already been successfully applied and shown to be empirically valid.
8. The method had already been widely applied in a process control context. (The theories and ideas underlying it are described in papers by Annett and Duncan (1967) and Annett et al. (1971). Furthermore studies on consistency amongst analysts showed that the method can achieve a reasonably high level of reliability is it is used correctly and trained.)

9. The analysis allows a variable level of detail, yet it is complete as an analysis at any level.
10. The formats for HTA are both hierarchical and decompositional, the two complement each other and both should be used wherever possible. The hierarchical format provides a kind of task map showing the relationships between the different task elements; whilst the decomposition format allows a much greater level of detail and is flexible in its layout. This is the part of the analysis that is the most amenable to modification.

Overall, in relation to the other methods used for analysis, HTA was found to have the best balance of elements needed for such an analysis. The results of the comparative assessment of the results of an HTA with other methods selected from the literature, to analyse operator information needs, are described in case study 1.

The modification to HTA

HTA as a method fails to make operator information needs explicit. Despite adaptions to the original method by Shepherd (1976, 1985) and Piso (1981), the information made explicit by the analysis is useful principally for training applications. In order to move towards fulfilling the criteria outlined in section 5.7 the method must be modified.

The suggested modification /extension to HTA is shown in figure 5.7 The first columns A to C are as outlined in Shepherd's description (1976). This variation of HTA was selected because it separates out the elements of the analysis and allows them to be related horizontally, something which earlier versions did not easily allow. Also the format is less orientated directly toward training applications and is more flexible. The additional column allows the information needed for each task element to be documented with arrows indicating if the information is needed from the interface or must be input into it.

The second column aims to make explicit the assumptions made in identifying these information needs. In setting the information at a certain level the analyst assumes that the human operator has specific knowledge and skills that will allow him or her to use that information to perform the task. These assumptions need to be stated, firstly because if an existing system is being evaluated these assumptions are being made but the training is not necessarily being given or it may be that an operator has an incorrect model of the system and is operating under false assumptions. At the other extreme it may be that the operator does not need all the information that is provided as he/she already has sufficient plant knowledge. In this situation information overload may hinder task performance.

Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
0. Operate Coal Preparation Plant	1 or 2 Some duties overlap	1. Operate main plant 2. Carry out other related activities	← main plant status & operational information ← other plant & related information	Operate has knowledge to operate plant	Operational Operational	1 and 2 usually allocated to each of the 2 operators on shift
1. Operate Main Plant	1 → 2 & 3 → 4	1. Start up plant 2. Normal plant operation 3. Carry out fault detection 4. Shut down plant	← start up information ← plant operational information ← faults ← shut down information	Start up procedure Operation procedures Some fault knowledge Shut down procedure	Procedural Operational Procedural Fault detection Procedural	
1.1 Start up Plant	Do 1 → 2 → 3 → 4 for all groups in the order 4a, 3, 4b, 2, 5, 6, 7a, 7b, 8, 9, 10, 11, 13a, 13b, (steps 1 & 2 can be omitted)	1. Display group on mimic 2. Check plant items in group ready 3. Start group 4. Check group is running	→ display group ← group displayed ← plant items ready → start group ← group started ← group running/ not running	Control sequence Checking procedure Start group procedure Checking procedure	Operational Procedural Procedural Procedural	

Figure 5.7 The modified tabular format of HTA

If the analysis is being carried out for design, the interaction between the information provided and the skills and knowledge the operator needs to use the information may be flexible. As both together should give total task performance, both need to be specified to allow this flexibility and for decisions and judgements to be made on the basis of task information. This part of the analysis may also be useful in evaluation where the designof the interface is to be upgraded or changed as the allocation of function between the human and system can be reassessed.

One further addition was made to the analytic content of the analysis. If the information needs of the operator are specified at each level then the content of the displayed information is made explicit. However, the format that displayed information will take is very dependent on the type of task it is to be used to perform. A classification of the principal tasks any process operator will be required to perform was made. These were based on literature and discussion with experts on the types of task which humans are allocated in process plants. The resulting classification is shown in figure 11.1 (chapter 11).

The final stage of the analysis is to classify each task element according to its process control task type. The taxonomy is not designed to be mutually exclusive. Some tasks may fit into more than one category. This classification scheme was developed to allow decisions to be more easily made on the most appropriate way of displaying task information so that it can be most readily be used for that task. The development of the classification scheme and its use in deriving display guidelines for process control is described in chapter 11.

This extension to the analysis is carried out at all task levels within the hierarchy. This is important as information may be used in quite different ways at different task levels. By doing this more complete information can be made available for design, very few task analysis methods actually allow movement towards an input into the design process, for example, Fleishman (1975), and none make explicit the information content needed in displays. By providing this within an analysis that has been shown to be usable, not only by human factors experts, but also by engineers and designers, then a step can be made toward a task analysis that provides not only a framework for analysing a task but a more direct input into the design process.

This method has provided the basis of the task analysis technique which was applied in the context of the case studies outlined in chapters 6-10. The method and the tabular representation evolved throughout the case studies and the final format illustrated here.

However, the method also provided a basis for further work which is outlined in chapter 11. Task analysis methods provide a framework in which tasks can be broken down and analysed. However, guidance on how to use the information obtained in design is often not available. The next stage of the research therefore, examines the use of the extended method of HTA as a basis for recommendations for display types to be used in a process control context and describes an approach to deriving display format guidelines from the HTA.

CHAPTER 6
INTRODUCTION TO THE CASE STUDIES

OVERVIEW

The following chapter introduces the approach taken to the case studies and describes the rationale for adopting an empirical case study based approach to the development of a method. The plants selected for study offer a variety of differing process control contexts to allow the method to be tested as fully as possible and to allow issues and problems to be highlighted. The case studies are reported in a similar structure as far as practicable and this structure is outlined.

6.1 INTRODUCTION

To complement the theoretical assessment of task analysis methods and their evaluation against defined criteria, an empirical evaluation and evolution of task analysis methods for analysing operator information requirements was implemented. A total of four case studies were carried out on a variety of plants to test the robustness and utility of the method. There was also the need to allow for the evolutionary development in real world contexts of a method, developed as a result of the theoretical studies, into an applicable and usable form. This section outlines the general aims of the case studies and the rationale for the approach taken. The detailed aims and approach taken in each case study context are described in detail in the relevant chapter.

The case study approach

As previously stated the theory surrounding the idea and concept of tasks and task analysis is not well developed or documented. One possible approach that could have been adopted in the thesis was to systematically study elements of tasks and task analysis in a laboratory context. However, a more practical approach to analysis was selected for a variety of reasons.

To examine tasks in a laboratory context would enable elements of analysis to be assessed. However, in a complex system there are many influences on task performance and it would be difficult to anticipate or simulate all of these in a laboratory context. These influences will also differ between plants depending on factors such as the operating environment, management philosophy etc. To fully examine the robustness of a method these would need to be identified and systematically studied. To then ensure that the results of a laboratory study could be used in process design would involve applying the task analysis to an empirical context.

To realistically study tasks in a laboratory context, they would have to be selected from the real world to be representative of the task context to be studied. This would involve obtaining task information from real world contexts, an activity which is resource intensive in terms of both time and manpower. Within the timescales available for the study, this would not have been practical. This is especially so if the variety that exists in process control contexts was to be considered. For example, tasks from continuous and batch processes, from highly automated and semi-automated plants etc, would need to be included.

To train analysts in the use of a method is also a very resource intensive activity. To enable tasks to be studied in the laboratory, subjects would have to be trained in the use of task analysis methods. This may involve training analysts in a variety of methods. To be thoroughly prepared in the use of the method, the analysts would need to be able to be trained using real world contexts, which would have been impractical, given limited access to plants. This would of course be dependent on the approach taken in the laboratory, but would also restrict the laboratory studies that could be carried out. Whilst the use of a variety of analysts also applies to empirical contexts, there are often existing personnel on plants who have applied some form of task analysis to that plant. Such personnel may also be more representative of the type of analyst who will use task analysis in real world process control contexts and so give a greater indication of the problems likely to be encountered in the use of particular methods of task analysis.

To allow a method of task analysis to be evaluated for use in task synthesis as well as task analysis requires consideration of the information that is available at the design stage of the plant. As well as the task documentation, much of this information must also be gained from the experts on the design team. There may also be a variety of other sources of information which could include experts who have operated similar plants. To simulate a task synthesis environment in the laboratory would impose a wide range of problems to effectively simulate the context found in the real world.

An empirical case study approach was selected for two further reasons. Firstly, as the theoretical background only of task analysis had been considered and secondly because the project for which the work was to be initially carried out, the study for the European Coal and Steel Community, required a method of task analysis to be produced that could analyse operator information requirements within a constrained timescale.

This offered the opportunity to evolve a method based both on the theoretical issues that had been identified previously and also within a variety of different plant contexts, each plant offering a different application of the method and its use for identification of task information flows, whilst providing the commonalities that exist in process control task contexts.

Variety of plants

The plants studied were selected to provide a range of plant contexts and applications of the analysis method. The plants studied were dependent on where adequate access could be granted. Within the timescale of the project, it was possible to study selected tasks from four different plant contexts and to apply analysis to a total of six plants.

CASE STUDY 1 - COAL PREPARATION PLANTS

The first case study involved the analysis of three Coal Preparation plants. These differed in the scale of the process and in the level of automation. The process was continuous and involved a high bulk, low value, product. The tasks involved the use of VDU based displays and a variety of means of communication including CCTV, intercom systems and log keeping.

CASE STUDY 2 - BOOTS IBUPROFEN PLANT

The second case study provided a batch plant context as a contrast to the continuous processes of the first case study. The plant was highly automated with a VDU based display system. The product was a high value, low bulk, pharmaceutical product. The control room provided the context to study the use of analysis, not only for information flows as related to the display system, but also for logging, communication with maintenance personnel, plant operators, external bodies (such as the suppliers of raw materials) and other plants on the same site.

CASE STUDY 3 - A HIGH RISK PROCESS

The third case study involved the synthesis of tasks for safety critical systems in a high risk and complex process context. This study also involved the application of task analysis to the evaluation of a panel display and its related information requirements. The plant was highly automated and the control room context comprised highly trained operators, using both VDU and panel displays in conjunction with each other.

CASE STUDY 4 - A POWER PLANT

The final case study considered the use of task analysis for a continuous process. The operational context was highly complex. The plant control room comprised four identical operating units each controlling an identical process. Each of these units presented different technologies from a mainly panel based control unit to a unit operated from touch screen, VDU displays. This plant provided the opportunity to consider how tasks and information requirements varied as a plant became increasingly automated and different technology was used to transmit the information.

Timescales

The studies took place over a two and half year period. The first case study took place over 18 months, in line with the overall project context in which it was carried out. The plant visits were primarily concentrated within a 6 month period with the plants being studied sequentially. Timescales for this study were affected by limitations on access to plants which were imposed as a result of the Miner's Strike. The second case study took place during the same period as the Coal Preparation study, but was considerably shorter in length. A total of 3 days were spent on the plant with extra time being allowed for plant familiarisation. This was split into two visits which were approximately one month apart. The third case study followed on from the first case study and was spread over a 12 month period with one day per month being spent at the design team site. The final case study was carried out towards the end of the third case study. A total of four days were spent on plant and this included time for system familiarisation.

Case study structure

To enable them to be easily followed and compared, the case studies are presented in similar formats. These differ slightly according to the content of the case studies, but for the most part are presented with the following sections:

Introduction	An introduction to the case study and its context.
Aims	The aims of the case study in terms of its contribution to the development of the task analysis method and its evaluation and evolution.
Approach	The approach that was taken to carrying out the case study, ie, the collection of task data,

	selection of tasks for analysis and the approaches to analysis taken on that plant.
The plant and control room situation	A description of the plant, type of process and the control room and operating environment.
Information collection	The method and approaches to the collection of task information on the plant.
Results	The results of the analysis. These are divided into sections according to the particular application of the analysis to that plant.
Discussion	A discussion of the way in which the analysis met the aims of the study and the implications for the development of the method of task analysis. This includes the issues concerning analysis which arose as a result of the case study.

The case studies are outlined in the following chapters, 7 to 10, in a chronological order.

CHAPTER 7
CASE STUDY 1
COAL PREPARATION PLANTS

OVERVIEW

The first case study involved the application of task analysis to three Coal Preparation Plants. These were all continuous plants of varying size and with a high degree of commonality in the process technology employed. The aims of the study were to provide a basis for the development of the method for the analysis of operator information requirements and to apply this method to the development to the design of display formats within European Coal Preparation Plants with the objective of reducing future design effort. The adapted HTA method was applied and assessed for the three plants. From these analyses a generic task analysis representing the common aspects of the Coal Preparation operator's task was developed and used as a basis for other project work on the development of display design recommendations.

7.1 INTRODUCTION

The first section of research took place within the context of a project for the European Coal and Steel Community entitled:

"Improved information presentation in modern Coal Preparation Plants".

The aims of the project were twofold, firstly to develop a method of task analysis for looking at operator information needs and secondly to assess current information display and to make recommendations for Coal Preparation Plant display design. The project proposal suggested that Hierarchical Task Analysis be taken as a starting point for the development of a method and for comparative evaluation of other methods. This was because it was a method with a proven validity and had been extensively applied in process control contexts.

Coal Preparation Plants (CPPs) are continuous process plants which take "raw" or "run of mine" coal and process it, crush, wash and blend it to produce an output that is of an acceptable quality either for domestic or commercial, usually power station, use. CPPs within Britain have been developed on a regional basis and the development and automation of CPPs occurs within regions rather than nationally. Within coal preparation technology, the process equipment varies little between plants; this is true not only in Britain but throughout Europe. Since the 1960s there has been an increasing trend towards CPP automation. Britain was the first country to be automated and there are now a total of 88 CPPs in Britain. However, despite the common technology, the control rooms in automated CPPs are not designed in a standard way. Most use CRT based displays with keyboards, but the number of CRTs used, and the display types, differ greatly.

As the plants have common features the actual display content should be similar. One objective of the project was to help reduce future design effort by identifying common operator tasks and making design recommendations in relation to this which would then be applicable to the display designs of future automated CPPs.

Note: This case study was carried out in the context of a larger study entitled "Methods of improving information presentation in modern Coal Preparation Plants" (Astley, Gent and Visick, 1988). Sections from this chapter are reproduced in that study.

7.2. AIMS OF THE CASE STUDY

The primary aims of the case study were twofold. Firstly, to develop a method of task analysis for the identification of operator information needs, or to identify a suitable method in the literature. Secondly, to apply this method to the design of display formats within Coal Preparation Plant control rooms with the aim of making recommendations to reduce further design effort.

Following this, the aim was to apply the method to CPPs both within the aims of the project, to assess its usability in application and in design and evaluation, and to look at the validity of the results produced. The assessment of validity could not be carried out directly, as personnel were not available to compare the analysis between different analysts and access to the plants was limited.

The analyses and recommendations produced were not to be applied within the scope of the project. The European Coal and Steel (ECSC) organisation is such that research is carried out within the context of one project and then applied within the context of an "action" project. The action project following this research began in 1987.

The application of the results therefore, and their usefulness in practice will not be available until completion of the action project in 1989. Although the information in design will not be available, the analysis allowed recommendations to be made in an evaluative way. Current displays were evaluated within the timescale of the project and recommendations made.

7.3. APPROACH

The approach taken to the study was to firstly establish a theoretical basis for the work. This involved a literature review to examine research into, and applications of, task analysis techniques and the concepts surrounding the idea of a task. The literature that was explored for these applications included the human factors and psychology literature. Additionally, the systems analysis, computing and engineering literature, where analysis methods used in systems applications may be applicable to task contexts, was examined. In parallel to this review, a survey was conducted of the displays literature. To complement the information gained from the literature, experience of the display types used in process control and their formats was also incorporated into the review. Finally, the literature relating to mines and coal preparation plants was used as a further information source for the study.

Arising from the literature review, and practical experience of process control contexts, the next stage was to develop criteria which would need to be met by a method of task analysis for identifying operator information requirements. These criteria would be used to select task analysis methods. Methods meeting the criteria, in whole or part, would then be comparatively assessed on a representative task. The evaluation of the methods for use in the study was therefore both absolute (based on the criteria) and comparative (based on expert judgment).

Following the evaluation, a method of task analysis for operator information requirements would then be proposed. There were three possible options:

1. One method would emerge as meeting the requirements of the study.
2. A method would be selected that provided a useful structure for assessing operator information needs and display design but would require modification before being applied to the study context.
3. Several of the methods in the evaluation would provide useful and complementary aspects to the analysis which could be synthesised into a task analysis approach.

Once a method had been selected or developed, it would be applied to a range of representative Coal Preparation Plants (CPPs). The method could then be evaluated in its practical application as well as from a theoretical viewpoint. The final output of the study is therefore intended to be a method of task analysis which could be applied to the analysis of operator information needs and display design in CPPs. Such a method should be of sufficient generality to be applicable to other process control contexts and also to other task areas where an operator is required to operate a complex system. Such control would involve the manipulation, interpretation and utilisation of information and tasks with cognitive elements such as planning and scheduling as well as physical control actions.

Timescales

The first case study had a duration of 18 months in line with the ECSC project under which it was carried out. The project was aimed to be applicable to Coal Preparation Plants throughout Europe, but, due to administrative problems it was not possible to visit the plants originally planned to be studied in France and Germany. A total of 3 plants within different regions of Britain formed the basis of the study. Although the project team had some access to the plants, this was restricted due to the Miner's Strike and its after effects. Much of the data collection on plant was carried out by the Ergonomics Branch of the Institute of Occupational Medicine, based at British Coal Research Centre.

The review of the literature and the development of an analysis began at the same time as the plant studies. Because of this, data collection at the first plant studied was very general. Information from the other two plants was collected specifically for the analysis. From these a common task analysis was compiled.

7.4 THE PLANTS AND CONTROL ROOM SITUATIONS

There are 88 Coal Preparation Plants (CPPs) operating in the UK. As the CPPs have become larger and more complex, so the Coal Industry has introduced more advanced automatic control techniques. The three plants studied all had a relatively high degree of automation and similar operational philosophies.

Rawdon CPP

The first plant studied was Rawdon on the Staffordshire field. This plant has both manual and automatic washing processes and a capacity of 600 tonnes per hour (tph).

The plant also has on-line ash transducers for the quality assurance of the output. Ash content of the final product is one of the most important variables. The task of controlling this was selected as a basis for the study of the comparison of task analysis techniques. Rawdon was the medium sized plant of the three studied and had one operator in the control room who was responsible for the coal preparation process. The control room did not provide direct visual monitoring of the plant, although there was a CCTV system.

The central control room deals only with the automated plant, ie, the large coal stream and not the ancillary task, which were carried out on the plant. Consequently, the task analysis was restricted to the control room operator's task as this related directly to the use of the VDU displays. The operators have contact with the non-automated plant and local operators via telephones, public address systems and CCTV. There are three VDU displays used in the control of the process. The central display gives an overview of the ten major groupings of plant equipment or plant "blocks". Each of these blocks can be displayed in detail on either two of the ancillary screens, as a set of "controller faceplate mimics " or bargraphs. The central display also provides space for three plant variables to be displayed in more detail.

Renishaw Park CPP

The second CPP studied was Renishaw Park. This was the smallest of the CPPs studied and it handles only 350 tph. The central control room was also the control room for the colliery and whilst there was a dedicated operator for the coal preparation side, the operators worked a five shift system in which they alternated between colliery and coal preparation control.

The CPP is under full computer control and is organised into seven groups of plant equipment with two major preparation systems for control. The display system has two VDUs. The first can provide nine displays relating to the CPP system, but updates at a very slow rate. The second display provides 80 display pages and updates much more quickly. The displays available include mimics, controller faceplate type displays, textual sequence displays. Additional windows on the displays give alarm information and sequence status information for start up and running status.

Kellingley

This was the largest plant studied and can handle 1500 tph. It has an associated colliery and also processes coal received from other plants. Coal is processes using BAUM technology for the washers.

All the major plant items are under control from the central control room, although there are a few manual and local operations. The control room has at least two operators involved in coal preparation operation. There is a master console with two VDUs and a keyboard. This master console can be used to display any plant information. There are five more slave VDUs each with a keyboard. Each of these five slaves is associated with a plant group (or in one case two) and can display information relating to this group but no others. Communication with plant operators was via a tannoy, and a CCTV system provided visual contact with the plant.

7.5 INFORMATION COLLECTION

Task information collection was carried out by similar approaches in all three plants. However, the information collection from the first plant studied, Rawdon, was more extensive as this plant was used to define the boundaries for the Coal Preparation study. It was also used as a basis on which to develop the method of task analysis which was applied to the two other plants studied.

Data collection was done by on site observational studies and informal interviews with both operators and plant management. As the requirements of the enhanced method of HTA were defined, so the information collection became more tailored to the requirements of the analysis, for example, in the collection of information concerning the information flows of the task. The observational studies included general information collection and activity analysis which was both manually and computer recorded. Both normal operational and fault situations were examined. Informal interviews used operational expertise to describe tasks and the conditions under which they were carried out. These were also supplemented by informal 'walk/talk throughs' of certain tasks.

7.6 THE RESULTS OF THE ANALYSES

Introduction

This series of case studies was used to develop and evolve a method of task analysis to identify operator information requirements. The results of the analysis were not applied directly to the design of a system, as this application was to form the second phase of the project. The analysis was used to identify issues in display design which could be considered and then form a basis for display evaluation in the context of the larger ECSC project. Analyses were carried out for each of the three plants, and within each, the information flows that were required for the task documented. These analyses are given in Appendix B, an example of the tabular format of an analysis carried out for Rawdon CPP is given in figure 7.1.

The operator roles varied from plant to plant, partly because in some cases shift patterns rotated CPP operators and colliery operators, and partly because the level of automation differed on each plant.

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
3 2 Fault Diagnosis	Diagnose fault from 1 + 2	1. Check visual alarm information	← visual alarm information	Operator can access alarm information	Fault diagnosis	Fault information is retained on a hard copy
		2 Clear alarm information //	→ clear alarm ← alarm cleared	Procedure for alarm clearing	Procedural	
3 2 1 Check visual alarm information	1, 2 and 3 + 4	1. Note nature of fault //	← nature of fault	Operator can understand implications of fault information or is aware of the procedure for informing appropriate personnel	Fault diagnosis	
		2 Note mimic it is displayed on //	← location of fault group number		Fault diagnosis	
		3 Note fault item //	← fault item		Fault diagnosis	
		4 Preliminary diagnosis of fault //	← all information related to the fault that is relevant		Fault diagnosis, Decision Making, Problem solving	
2 1 2 Monitor Plant Status	1, 2 and 3 regularly 4 as appropriate to the operational situation	1. Monitor plant input	← plant input	Plant input parameters	Monitoring	
		2 Monitor main plant parameters	← main plant parameters	Limits of main parameters	Monitoring	
		3. Monitor plant output	← plant output	Plant output parameters	Monitoring	
		4 Monitor trends	← trend information	Likely effects of trends	Monitoring	

Figure 7.1 An example of the tabular format of analysis carried out on Rawdon CPP.

Rawdon

The overall operational aim at the Rawdon plant is defined as maintaining the running of the plant at an optimal level. This involves the Coal Preparation Plant Control Room Operator (CPCRO) in a primarily monitoring role, with the additional tasks of adjusting set points and detecting faults when he is required to do so by the shift foreman or plant manager. Monitoring the plant involves ensuring maximum possible throughput of coal from processing, whilst maintaining the quality of processed coal as near to the customer's specification as possible. The quality of the prepared coal is determined by ash content, which is controlled by the CPCRO using an on-line ash controller. Too much ash means that the coal may be of an insufficiently high quality when compared to the customer's requirements. Too little ash means that economic losses result for the plant.

The main displays the operator has available to perform the task are mimic and loop displays. Faults are signalled to the operator either as a change in colour (on the symbols or blocks indicating group status) or as a single line of fault information at the top of the central VDU screen. Only the most recent alarm is shown here. Alarm messages are accompanied by an audible alarm.

As the analysis shows (Appendix B), the information presented to the operator could be improved to allow quicker and easier detection and diagnosis of faults. The number of the plant item is given on the fault message, but no indication is given as to the group that the item falls in, the type of equipment or nature of fault. Furthermore, the alarms are numbered, but this information is redundant to the operator who only has a single most recent alarm displayed at any one time. Time of occurrence would be a more useful way of presenting this information. Alarm messages are also orientated towards an engineering understanding of the plant rather than towards the operator's mental model or understanding of the plant. They also fail to help the operator find the relevant mimic display, to then be able to study the fault in greater detail.

A useful display would be an overview which shows plant functioning, trends and faults, the loop displays achieve this to an extent. The mimic displays could then be used to help with further fault diagnosis or specific plant problems, rather than the principal source of plant information. However, for accurate fault diagnosis to be achieved in the control room, further sensors in addition to those in existence on the plant at the present time, would be required.

The present system at Rawdon requires the operator to have a significant plant knowledge in order to achieve effective operation. Of the range of displays available few are frequently used operationally . The operator tends to use the loop displays to provide an overview of plant activity. To meet the information needs of the operator, displays should be structured to allow for fault detection as well as for normal plant operation.

Renishaw Park

Much of the operator's work at Renishaw Park is of a highly procedural nature. As the process is highly automated, the operator needs information to assure him that all is proceeding normally and to alert him to any fault conditions. Other plant information is used less frequently and mainly in response to requests from the plant for information. The knowledge of the operator is called upon in making selections for start up, although there is a manual to help in this.

The tasks which provide the highest workload for the operator are start up and shut down, monitoring for faults and responding to requests for information. Requests from the plant for information are usually of a highly specific nature relating to particular data for an item of plant. Therefore, the knowledge of the operators requires them to know exactly where to find a specific item of information, rather than general information relating to groups of items or a generic type of equipment, for example, bunkers or valves. For this particular plant, two areas that are important for monitoring, are the maintenance of ROM flow and the avoidance of under and over load on number 62 conveyor (which relates to plant input flows). The operator must continually monitor three groups of parameters, input, output and normal plant parameters in order to optimise plant operation.

The displays available are mainly mimic displays. These provide the operator with a vast amount of plant information. This is more than is needed to perform the majority of task requirements. Furthermore, presenting the operator with the additional information tends to have a detrimental effect on the performance of the main operating tasks, distracting attention from the relevant task information. An indication of this problem is shown in the present plant where the operator often bypasses the displays and inputs control functions from memory. This is effective until a fault or input error occurs. If a problem arises it is difficult for the operators to react quickly, as they have had no feedback on control actions from the displays.

Possible reasons for an experienced operator bypassing the displays are, the response time of the system, which gives a delay in bringing the appropriate displays to the screen, over complex displays which give the experienced operator too much redundant information for the task being performed and the poor availability of dynamic task information.

Kellingley

All main items of equipment and process functions are controlled centrally by the CPCRO, with notable exceptions being the loading of trains and some conveyors. The main displays are mimic displays, one or more for each group of plant items. On the mimics, the items are represented graphically and the status of each plant item on the mimic is indicated by colour coding (green = ready to run, red = running).

The plant start up procedure is automatic, once initiated. The operators simply require information to assure them that all is proceeding satisfactorily. There is no rigid demarcation of task functions between the control room operators. However, all shifts have a principal and assistant operator working on the CPP at any one time, and their task functions are flexible according to the needs of the plant. Experienced operators tend to input control actions without the use of the displays which they feel slow them down. However, they do this at the tradeoff of feedback on the result of their control actions: as with Renishaw Park CPP this can be a problem should a plant fault occur. The structure of the display system and its response time are possible contributors to frustration in operators which leads to an adaption of the task in this way.

The operator has several procedural tasks to be carried out. These include filling in an hourly log sheet and also reporting stoppages. These figures are used by the plant manager to indicate if a plant is functioning effectively and if a bunker is sufficiently full to fill a train. The hourly tonnage figures are reported back to the colliery.

There are six VDU screens available and the operator can select any plant group for display. The mimics chosen when the operator wishes to monitor the plant reflect the important parameters for optimal running of the plant. The operator especially needs to monitor the raw coal input and dry screening plant, to ensure there is always coal to wash, the baum filters and the level in the blend bunkers feed to the rapid loading system. At present, the operator gains this information from six VDU displays which also give a lot of information that is redundant to the task. In this instance, an overview display showing the major plant parameters of concern would probably be more effective in giving information to the operator. A separate message VDU displays the faults messages from the system. With the display of fault information, it is important to display the message so that the operator can act quickly and effectively. It is equally important to obtain a balance in the fault threshold level at which the system operates. If faults are flagged too frequently then the operators will tend to ignore them, too rarely and they have insufficient information to effectively minimise plant down time. The former is the case at Kellingley, where many of the faults are expected by the operators as a result of the current operating state of the plant, and so operators tend to ignore faults, unless they have a stream of audible alarms indicating several faults in succession. Fault diagnosis at Kellingley is really the responsibility of the men on the plant, although control room operators may be able to help as they gain experience. So the detection of faults is a crucial task of the operators, along with the co-ordination of fault information to the people on the plant.

At Kellingley therefore, the bulk of the operator's work is concerned with the procedural aspects of the plant, such as start up, logging and monitoring. As the plant start up is highly automated, improvement in task performance can be achieved mainly in the areas of monitoring of plant parameters and trends for early detection of faults, and by the improvement of the information design in these areas.

Common Task Analysis

In order to move towards generic design guidelines for display design in a CPP context, the next stage, having analysed the tasks on different plants, was to identify the task commonalities between these plants. If this revealed that there were few commonalities it would be likely that no generic design guidance could be offered that would be applicable throughout CPP process plants. However, if a high degree of commonality could be identified, then it would be possible to use such an analysis, using the extended method of hierarchical task analysis, to identify design guidance for VDU displays that could be applied throughout CPPs in Europe.

The aim of developing the common task analysis was threefold. Firstly to enable common design factors to be applied to all automated plants, thus achieving a degree of standardisation; secondly to minimise the analytic and design effort that needs to be input into the design of future systems; and thirdly, to provide a basis for research into display design which would be applicable to a wide range of plants.

The analysis was compiled by studying the three analyses of CPCRO tasks and extracting tasks that were common to all plants. Some tasks were similar in all three plants, but were described in the analyses under slightly different headings, a new common heading was used to describe these groups of tasks. Although the common task analysis is quite brief, this does not reflect a lack of commonality between the CPCROs tasks; on the contrary, the four main groupings of tasks were found to be common to all plants studied. Although the overall goals and main types of task are common at the more detailed levels of analysis, the task information becomes more task specific here. Figure 7.2 illustrates the top level of the common task analysis.

Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
1 and 2 as required	1. Monitor via displays	← current status of plant parameters	Knowledge of important and minor plant parameters	Monitoring	
	2. Monitor via CCTV //	← direct visual feed-back on plant status	Which parameters have the most impact on the plant	Monitoring	
1 and 2 in parallel	1. Monitor main plant parameters	← main plant parameters status	Understanding of how the main parameters relate functionally to the plant	Monitoring	
	2. Carry out fault detection	← faults occuring ← information on the limits and trends of the parameters being monitored	An understanding of the relevant importance of faults and how they affect the plant	Fault detection	
1, 2, 3, 4 and 5 in parallel, 1 and 4 are particularly important	1. Monitor plant input	← status of plant input parameters	Knowledge of limits of parameters and the effect of faults on overall running of the plant		
	2. Monitor main plant items //	← status of main plant items	Knowledge of limits of parameters and the effect of faults on overall running of the plant	Monitoring	The major plant items vary from plant to plant but would include the washing parameters, grading etc.
	3. Monitor flows //	← Flow information	Knowledge of limits of parameters and the effect of faults on overall running of the plant	Monitoring	Flows are especially important (a) to ensure the plant is running at its optimum efficiency

Figure 7.2 An extract from the common CPP task analysis

Overall, the operator tasks divided broadly into three categories, *startup and shutdown, steady state normal operation and fault management.* The analysis highlighted two main areas for research to be carried out in the context of the larger project. Firstly, the fault detection task, (as part of monitoring) which is especially important for main plant parameters (such as the input and output rates), and secondly, the overall state of the different stages of the process between input and output. In general, operators did not need details of the actual process units until a fault occurred and they had decided or were told (either by the plant manager, shift foreman or a plant operator) that action had to be taken.

Improved fault detection has the most important ramifications for improving plant performance of all the tasks studied. If operators can detect a fault quickly they can notify the appropriate personnel and act on their advice or a decision on averting action can be taken, for example by the re-routing of flows. This can reduce any likely plant down time and further common mode failure. Often a combination of displayed information and communication with plant personnel is needed to determine what the fault is. If the general fault area can be quickly communicated to the plant, or if possible the exact nature and location of the fault, then the faults can be more quickly rectified or maintenance carried out.

The other main operator task is that of start up and shut down. This is given less emphasis, as in all three plants it is highly automated. Often all the operator is required to do is to set the relevant parameters and begin the start up. His task then becomes one of monitoring and checking for faults. However, it is important for the operator to be able to check that the procedure is being carried out correctly and to know the stage reached to rectify the faults and problems as quickly as possible. In most plants the equipment must be started up "output last" to avoid pile ups results from non-started equipment. The numbering of the plant groupings at present may not reflect this; indeed, in some plants the groups are not in fact started in the sequence of ascending order, this seems an unnecessary and unhelpful complication.

The monitoring task of the operator is important especially for the co-ordination of activities that are related to the input and output flows of the plant. No less important are the auxiliary tasks that the operator has to perform. These include manning the plant telephone and tannoy, and monitoring the plant, via the CCTV system, for parts that are not included in the display system, such as the stockpiles. These also give the operator a direct link with plant personnel and also to sources of information other than the display system. The auxiliary tasks help to maintain a reasonable workload level for the operator. It is rare that workload will exceed acceptable limits, and in such cases there is always another operator available to assist.

7.7 DISCUSSION

Evolution of a method

The evolution of the method of task analysis during the progression of these case studies is described in detail in chapter 5. However, the intention of the application of the method of task analysis developed in this context was to provide both a usable method of task analysis to identify operator information requirements, and to allow the use of this method to be tested in an empirical context . This would allow problems of practical use to be highlighted.

There were three potential problem areas arising from application of the task analysis method (extended HTA). Firstly the column in the analysis entitled "information flows across the interface" allowed identification of the information flows that existed in the system which corresponded to the different task elements as outlined in the analysis. However, in terms of documenting the information requirements of the interface, whilst it allowed what was there to be documented, there was no direct means of comparing this with the information that should ideally be available to the operator. It was therefore proposed to include an extra column in the analysis entitled "optimal information flows" and to rename this column "existing information flows". This new column was to be placed directly next to the existing information flows column. This enhancement to the analysis offers several helpful advantages in assessing information flows. The mismatches that exist between information that is currently provided and information which is optimally provided can be more easily identified. This allows issues such as redundancy, or the display of information that is superfluous to a task, to be considered. It also provides a basis for the evaluation of a display system.

Secondly, the information given by a system must be complemented by the knowledge, skills and abilities of the operator. If operators are highly trained and have in depth knowledge of the system, the amount and type of information to be provided will be different to that for operators who have little skill and require the system information to guide them through the task. In a task context, the information provided, and the skills and knowledge of the operator must complement each other to allow the task to be performed in its totality. If operators are highly skilled and require less information than is provided by the system, then they may become frustrated with the system. Conversely, the displays designer may assume operators have a greater plant knowledge than reality and so there is a gap in the information provided by the system and in the knowledge that the operator is able to apply to system operation. To allow consideration of this issue it it proposed to add a further column to the analysis to allow the skills, knowledge and abilities required and assumed of the operator in relation to each task element to be documented. For each task this issue can then be considered to a greater or lesser degree of detail and its implications for information design taken into account.

Finally, the task classification scheme, whilst useful, offered potential for improvement and this is discussed further below.

The task classification scheme

The task classification is not intended to comprise mutually exclusive categories. The intention was, that by classifying the tasks, display design and the selection of displays for use with a particular type of task (for example, procedural tasks) would be assisted. However, in the practical application of the classification, although the definition of each category was very clear, it was felt that the categories could be improved to be more useful in the application of the analysis to design. In particular, it was felt that the "operational" task category was being used as a "catch all" category for those tasks which did not "fit" into the other categories. For this reason an updated classification scheme was suggested and this is outlined in Figure 11.1.

Common Task Analysis

The common task analysis emerged as a useful tool for both reducing design effort and for increasing standardisation amongst plants where there was commonality in the plant and process. The extended method of HTA provided a useful framework in which to structure this analysis. In the case of such an analysis the usual stopping rules of HTA could not be applied. Analysis was stopped when the tasks became plant specific and were not common to all the plants. If a critical task was found in more than one plant but not in all, then this was included. A note was then made in the plans that it was not always a relevant task, or that it provided an alternative to another task option. The use of this common task analysis also highlighted the usefulness of HTA as a framework in which similar tasks can be compared from a common starting point.

Generic or common task analysis would therefore appear to have the potential for application in a variety of process contexts. This is especially so where there are plants with commonalities, which would benefit from a common approach to task and information design. However, there are issues which arose from the studies which need to be considered in such contexts. Firstly, it is important that the plants which are to be considered in the common approach do have a high degree of commonality. This may include, the process, the equipment hardware, the use of sensors and the potential for common software. This is because the task of operation relates directly to the control of the process. Whilst differences in the hardware may not be significant, differences in the process will almost certainly impact on the tasks of the operator. Finally, the commonalities in the operating environment can impact on how common the tasks of the operators actually are. This includes management style and philosophy and the organisational structure of the system.

This study therefore provided the basis for the development of a technique to analyse operator information requirements. The evolved method of HTA was applied to three differing Coal Preparation Plant contexts which highlighted the usefulness of the method and problems and issues in its empirical application. The output of the case study was to provide a basis for further evolution of the method including reworking the task classification scheme to provide a more useful basis for display design and analysis and the addition of a further column to the analysis to document the skills and knowledge of the operators which was required to complement the information provided on the displays.

CHAPTER 8
CASE STUDY 2
A PHARMACEUTICAL BATCH PROCESS

OVERVIEW

The second case study involved the application of the adapted HTA task analysis method to a pharmaceutical batch process. This allowed the method of task analysis to be assessed in its application to a batch process which was highly automated. The operating environment offered an information rich context in which the method could be applied, not only to the consideration of display design, but also to the other flows of communication and information involved in operating the plant. Problems and inconsistencies in the flow and use of information were highlighted as a result of the study. The study led to recommendations for the further development of the task analysis method including modification of the task classification scheme and the inclusion of information concerning the skills and knowledge required in the performance of the task.

8.1 INTRODUCTION

The second case study was based on work carried out at the Boots Co Plc, Beeston Nottingham in the period March to May 1987. The Boots Company kindly allowed the D72 Ibuprofen plant to be used as a testbed for the theoretical basis of the thesis.

The study was carried out to provide a complementary case study to the Coal Preparation Plant study. By contrast to the CPP context, the Boots plant was highly automated with manual input to the process occurring only at the beginning and final phases of the process. In addition, the plant operated on a continuous batch basis. The information flows within the control room also provided an information rich environment in which the proposed adapted method of HTA could be assessed. Furthermore, the information flows were not limited to those across the human machine interface, between the operator and the system, but also written documentation of the batch, communication with men on the plant, with men carrying out maintenance and in the organisation and acceptance of the deliveries of raw materials. Therefore the method of task analysis could be applied to the information flows within the plant in their totality and assessed for its usefulness in such an application.

The constraints of the study in terms of timescale and manpower meant that the technique could not be assessed for consistency amongst different analysts applying the technique to the plant. Three and a half days in total were spent on the plant, including familiarisation with the process and the control system and displays. In this time the data were gathered for the analysis. Given these constraints, it was decided that the study would aim to give an overview of the whole of the range of operator tasks at a general level. This approach was chosen in preference to the study of particular tasks so that an overview could be gained of the flow of information within the control room. The alternative would just be examples of the types of information flows and media available in the information rich environment.

8.1.1 OBJECTIVES OF THE WORK

The aims of the study were as follows:

1. To assess the method of adapted HTA in the context of a batch plant environment.

2. To test the utility of the classification scheme in such a context.

3. To provide a basis for recommendations for improving and developing the method.

4. To assess the utility and application of the method to the analysis of other forms of information in a control room context, other than the information flows across the interface.

This latter aim was of particular importance as within a control room environment information can be communicated by a variety of media. Within the existing design the media used may be inappropriate, ineffective or the information exchange may be repeated over several media without such extensive redundancy being required. If the information content is documented independently of the media, then decisions can more easily be made concerning the media to be used and the most effective means of information flow. This case study provided the means for assessing the method in this context.

In this plant situation, the operator was required to assimilate and manipulate information from a wide variety of sources. The media for transmission and reception of information were also varied, including VDU screens, paper, charts, telephone, CCTV and intercom.

This allowed the developed method of analysis to be applied in a context which tested; firstly, its utility on a batch as opposed to a continuous process, and secondly for the analysis of a variety of information in relation to the task and not just the information from the interface (as was largely the case with the CPP study). The safety and documentation requirements of the plant gave rise to this topic, which was unusual for a process plant. Also, the mix of automated and manual information recording, and the paper, pencil and VDU information display, allowed the opportunity to assess the media through which the information was displayed.

8.2 THE PROCESS

The process is a continuous batch process dealing with a high value, low bulk, product. This product has markets both internal and external to the company. The process is semi-automated and divided into three stages, each stage utilising several units. Some of the units are manual, however most of the manual input into the process is concentrated at the end and the beginning of the process. This concerns the initial input of raw materials and the drying and packaging of the product at the end of the process. The complete process is coordinated from the control room. This activity means that the Control Room Operator (CRO) has the responsibility of ensuring the efficient processing of batches.

8.3 THE CONTROL ROOM SITUATION

The control room is situated by the plant, but it does not have direct visual contact with it. It is lit by both artificial and natural daylight. There are three operators in the control room, they control the plant and are in constant communication with the shift foreman and the plant operators.

The control room comprises a bank of Visual Display Units (VDUs) with associated dedicated keyboards and these form the main Human Machine Interface (HMI); also situated on the HMI are the radiopager controls, an alarm panel and two printers. Peripheral to these is a pigeon hole system for documenting the process of a batch, the shift foreman's desk, additional telephones and the master batch record.

As the control room provides a coordinating point for the process; the workload of the operator can vary due to a whole range of factors including the time of day and the stage of production reached.

8.4 PERSONNEL

8.4.1 Staffing

The usual staffing levels are eight men per shift for the plant. These comprise:

The shift foreman
2 Control room operators (CROs)
1 Assistant control room operator
2 Senior plant operators
2 Plant operators

The task of the plant operators is to liaise with the CROs and to provide any manual input to the process that is required. The process is controlled centrally from the control room including the manual on plant stages (carried out by the senior plant operators) which need to be documented and logged. To ensure the efficiency of the process, communications between men in the team are crucial in ensuring minimum delay between the consecutive stages of a batch.

8.4.2 Training

Once an operator has some plant knowledge, training usually occurs in a "Sitting-by-Nellie" fashion. The trainee operator sits with an experienced operator and learns the task by watching and performing it under the guidance and supervision of the experienced operator. In some cases, the operator gains information and knowledge about the control of the process by working on a plant (on the same site also producing Ibuprofen) whose Human Machine Interface consists of large panel mimics. Here the operator has more direct control of the process and fewer of the stages are automated. A deeper understanding of the mechanics of the process can thus be gained.

The analysis contained in the report can be used as a source of training information. The task of the operator is described in detail, including the conditions of performance. The high and low level goals of the operator can be derived and the procedures needed to achieve them are made explicit in the analysis. However, the training implications are not discussed in this report.

8.5 THE IMPORTANCE OF COMMUNICATION FLOWS

From a human factors viewpoint it is useful, for a range of reasons, to detail the information and communication flows used to perform a task:

1. Firstly, to identify all the information the operator needs to be able to perform the task that is required of him. It is important to ensure all the information needed is available, so minimising the risk of human error and maximising plant safety and reliability.

   Some of this knowledge comes from the training received and the skills the operator brings to the workplace. However, the information that he does not have *a priori* to performing the task, must be provided in the workplace, either from the interface, in the form of job aids, or by other means. Only by exhaustively identifying the information needed to perform each task element can all this information be noted.

2. Secondly, to allow the type of information displayed to be related to the type of task it is to be used to perform. This is important for interface design, as the same information can be used in quite different ways for different tasks. So the way in which information is presented for one task can be quite inappropriate for another.

3. The third consideration is to identify information that is not provided by the interface but which is needed to complete the task effectively. Assessing this helps to delineate the level of operator skill and ability required to perform the task and it highlights the training, knowledge and skills that the operator needs to have. This gives guidance in personnel selection and in formulating training programmes.

The Legal and Safety requirements

Further to their usefulness for human factors applications, information and communication flows within the context of this particular plant are important for the safety and legal aspects of the process. Optimising the efficiency of the information flows can also enhance the economy and safety of the process.

From a legal viewpoint, accurate documentation and records of each batch are essential. Firstly, this is for batch traceability to comply with the standards of the FDA (US Food and Drug Administration) and with British DHSS regulations. Secondly, if product contamination was to occur, being able to pinpoint the batches where contamination starts and ends can help to minimise the cost to the company. At present, the system used in the D72 plant can accurately identify a batch where contamination begins but would be unable to locate accurately where contamination ends. It is also necessary to be able to identify the sources from which a batch was manufactured by means of documentation of the raw materials which are used in the manufacture of the product.

For safety purposes, information is required as to who is where on the plant and working on what, both in routine operation and for maintenance purposes. This will ensure that any parts of the process which need to be isolated are, and that safety procedures are met. For the manual stages in batch production, the CRO needs to be informed as soon as that part of the procedure is completed so that he can initiate the automatic continuation of the batch.

The logging procedures form a large part of the information flows within D72, these are to comply with legal requirements. The logging is largely by paper and pencil means and this information is then transferred to the computer, which can then provide information on the progress of the batch rather than traceability of the batch and its constituents. However, at the end of each automatic unit in the process, a batch log is automatically printed out detailing information about that unit.

Overall, as it is such a large part of the CRO's task to co-ordinate and collect this information, the system itself should be as efficient and thorough as possible.

8.6 CURRENT PLANT INFORMATION FLOWS

In the present control room situation, the operator has a variety of information sources available to him, these are outlined below.

Existing means and methods of communication.

In the present control room, the CRO has a variety of information sources he can access:

(i.) The human machine interface

(ii.) Face to face communications

CRO and CRO

Plant operator and CRO

CRO and visitor

Foreman and CRO

(iii.) Telephone

(iv.) Radiopaging

(v.) Documentation

(vi.) CCTV

(i) *The Human Machine Interface*

This is the principal source of plant information available to the operator. The interface comprises three VDU displays, which allow a range of displays to be called up by the operator. These are detailed in Appendix E. The configuration that the operator uses for the majority of the time is a summary screen on the central screen and mimic displays of current batch parameters on the two peripheral screens.

The main central display gives a summary of all batches currently being processed. The information includes a unique batch number, the place in the process reached, the current status of the batch and information to show that a unit is ready to move onto the next stage of the process. This includes the position it has reached within that particular unit, which can be directly cross referenced to the Standard Operating Procedures (SOPs). This is of particular importance to the operator in detecting faults as it allows him to note, as quickly as possible, if a process parameter is out of bounds, has not reached a correct value, or that a process is progressing in an abnormal way.

The display will also show that a unit is in hold, which means that it is no longer processing. This may signify that a batch has completed that part of the process or it may mean that the unit is in hold due to maintenance work or a fault. No details concerning this are given on the display and the operator must note the reason for the hold status and decide on the appropriate action.

The two peripheral VDU displays are normally used to display process information on a unit in the form of mimic diagrams. These show functional plant and process information in a graphical form. Symbols are used to represent plant items and colour coding is used to represent plant item status and flows. Briefly the basic colour coding conventions used are:

Blue	Information that does not change
Red	A plant item that has stopped or is in hold

Green	Plant item is running
Yellow	A plant item is in limits/running and process variables.

The displays give the operator more detail on a particular process unit, detailing such information as set points, measured values and the status of items of equipment. For each process parameter and item described, the operator can interactively request more information. This is displayed on the lower portion of the screen. Information on any unit can be called up on either display.

The operator interacts with the interface via one of two dedicated keyboards.

(ii) *Face to face communications*
As an alternative to the radiopaging system for the shift foreman and plant operators, face to face communication is used equally frequently. If plant operators are in the control room it may be used to deploy the plant personnel in the most effective and efficient way. It is also used as a means of discussing and assessing alternatives to plant problems encountered in operation. For the maintenance and repair personnel it is the sole means of reporting and gaining access to the plant, and similarly for visitors.

(iii) *Telephone*
There are four internal telephones in the control room, used for communication external to the plant (but internal to the company) and to notify technical services of a request for maintenance or repair.

(iv) *Radiopaging*
Each plant operator and the shift foreman carries a radiopager. This allows communication between men in the control room and plant operators. Its essential functions include quick notification of plant faults to allow the control room operator to co-ordinate the manual units of the process effectively.

(v) *Documentation*
As hardcopies of the paperwork are used for logging and batch traceability, there is a system of cross checking used to check on the progress of batches and for raw materials etc.

Raw materials
The flow of information relating to a particular batch begins with the logging in of raw materials. A two stage system exists. Firstly, a wall system where each tank on the

tank farm has a slot and as a tanker load is delivered it is allocated a slot using a card system. In addition to this, each new load for a particular raw material is logged into a cardex system. This notes the time of the delivery, date and material. These cards are also logged with the batch number(s) that each delivery of raw materials is used for. The ordering of raw materials occurs centrally and automatically, via a computer situated at the central Nottingham site.

Batch Log

When a new batch is started, it is firstly logged onto a monthly batch log (Master batch log). This records the batch number which is consecutive to that of the previous batch. This log is also used to record the time that a batch passes through each unit and the weight if it passes through a header tank.

Computer Log

The batch number is entered from the master batch log by the operator into the computer. The operator initiates each unit of the process either from the keyboard, or by notifying an operator on the plant that action needs to be taken. As each unit is completed, a batch log sheet is completed. Either the computer prints it out automatically, if the unit was computer controlled, or a sheet is filled in by the plant operator as each stage of the unit is completed, using a batch log sheet. There is a pigeon hole system located in the control room, each of the pigeon holes is labelled with a unit number in the order they occur in the process. As each batch log is completed, and the next unit initiated, the sheet is attached to others relating to that log and put into the relevant pigeon hole. These sheets are stored and collected monthly. In order to distinguish the initial two streams of the process, the batch sheets are colour coded pink and white to denote the separate streams.

In order to allow the CRO to follow the process and to check that each unit is progressing in an expected way, a system of manuals is available detailing all stages of the process. These are the Standard Operating Procedures (SOPs). As well as providing a job aid for the operator, they help the process to conform to the Government guidelines that:

> "...The operator must have ready access to the currently approved method...(of manufacturing the batch)" (Good Pharmaceutical Manufacturing Practice; Sharp, 1983).

Maintenance and repair

In addition to the records of the batches, records are also kept of visitors, and maintenance and repair work carried out on the plant. These are recorded in a separate log book and authorised by the shift foreman. For routine maintenance work, there are pre-printed cards detailing the work to be carried out. For repair work, a job sheet has to be filled in, in triplicate. For safety reasons, if necessary, a flame permit must be obtained, documented and authorisation obtained from the shift chemist.

Quality control

Quality control is often the only way to detect with relatively immediate feedback, if a product has been contaminated. Such contamination may be by abnormal occurrences in the process, such as abnormal weights in the header tank, or by part of the process failing to occur in the prescribed manner. Samples may be taken for quality control purposes from Stage 1 or Stage 2 as they are transferred into the header tank. On completion of a batch, quality control is notified of the estimated number of total containers from that batch. Quality control then issue batch labels, which are labelled with the batch number by operators. The containers are then stored in the warehouse until passed by quality control who issue green labels. If the batch is sent to D95, the label remains, if the batch is sent elsewhere it is relabelled. A batch label usage record is completed as the batch is labelled.

(vi) *CCTV*

The other main source of operator information is via the CCTV system. The operator has available three CCTVs which can be set to pan, zoom and rotate around areas of plant, providing the operator with visual feedback. Much of the process occurs in sealed vessels and so does not permit visual feedback in this manner, but visual monitoring of plant personnel is possible.

8.7 INFORMATION COLLECTION

The information on which the task analysis was based was collected on the plant over a period of three and half days. The first visit comprised one and half days. The second visit was made approximately one month later to complete the information collection. The methods adopted to collect the task information were primarily informal interviews, observation of the tasks and "walk/talk throughs". In addition, the SOPs, COPs (Computerised Operating Procedures) and the logs were used as further sources of task information. Interviews were carried out with senior and other plant operators, both in the control room and on plant, the plant supervisor, the designer responsible for the displays and the computer programmer. Also interviewed were high level management, who gave information on overall plant policy.

8.8 APPROACH TAKEN TO THE ANALYSIS

The analysis (appendix D) compares existing information flows with the theoretically optimal information in relation to the operator's task. Useful information can be gained at all levels of the analysis, especially where the existing and "optimal" information coincide or where there is a mismatch.

If a mismatch occurs at the higher levels of the analysis, it may indicate a more serious problem regarding the information design of the interface, than if it occurs at the lower levels. At the lower levels, a mismatch is more specific and it is likely that it can be more easily rectified, for example by modification of the interface or by provision of a job aid.

Due to the limited timescale of the work on the plant, the analysis aims to give a general overview of the task. The detailed interactions for all the operator's tasks were not studied but are described at the control level in the SOPs. As a result of this, the appraisal of the interface and existing information flows is preliminary and for a full appraisal a more detailed extended analysis would be necessary.

8.9 INFORMATION MISMATCH

The analysis identified points in the task where there is currently a mismatch between the information that is required for the task and that which is currently available. This mismatch can indicate that information is not provided when it is required, that too much information is available, that necessary redundancy has been built into the information or that information additional to that existing, which was not anticipated, is required. These mismatches that were identified in the overview analysis of the Boots plant are identified below:

Information required but not displayed or formally communicated:

0 Information on the timing of the arrival of raw materials.

0 Information concerning the ordering of raw materials (at present this is automatic, but no feedback is given to the operator).

2.1.4.3 There are no detailed formalised procedures for dealing with the communication of fault information between the operators on plant and in the control room.

2.1.5.4 There is inadequate communication at the points of interchange between the manual and automatic parts of the process.

3.2 There is no mechanism for the checking of information once it has been entered into the computer or onto the paper log sheets.

3.2.1 Time is not displayed on the central computer displays and a common time source is not used.

Information transmitted in an inappropriate format or inadequately

2.1.3 Information exchange at the handover of the shift log is inadequate (operators on the following shift are expected to check displays for information which may not be immediately evident, only exceptional events are noted verbally 2.1.3.4).

2.1.7 Fault information is only available in a restricted format.

2.1.5.3 The operator is ideally expected to anticipate process problems; however, no explicit display is given of acceptable process boundaries.

2.1.6.1 When a load is allocated to a tank, the information is only noted on the card system and not on the VDU displays or logs.

2.1.7.1 Alarms are only given on the printer in an audible form for detection

1 Information about potential safety problems is only kept in the daily log.

Repeated information

2.1.4.1.2 Information on the documentation of maintenance work may be repeated: however, in this context any repetition that is carried out is observed for reasons of plant safety.

3.3 Batch labels are logged extensively, this redundancy is considered necessary because of legal requirements (FDA).

The examples highlight areas of the task where there is a definite mismatch between the information flows that exist and what the theoretically optimal situation would be. This includes the interface and communication flows within the system. For example, a mismatch is identified in the shift hand over (Operation 2.1.3 in the analysis), in that there is redundancy in the information available. It is coded into two forms, verbal and written. This is an example of a mismatch identifying where the information presented may be more than is necessary. However, in this instance, as in many cases, redundancy can be a positive feature, each situation must be assessed uniquely.

With regard to the fault and alarm information available to the operator, all the detailed visual information available is printed out in hard copy (Operation 2.1.7.1.1). There is no direct summary display of current faults. Indications to the operator include, a tone from the printer when the fault occurs, the fault displayed in the specific item on the mimic, the unit going into hold. Whether the latter occurs depends on the preset parameters. It would be useful for the operator to have a more direct auditory alarm that signalled that he must take direct action. Although the operator is not required to give a complete diagnosis of faults, he acts as the coordinator of information and passes relevant display information to the plant operators. One small problem is related to the printout of fault information. The design of the printer did not allow the operator to see the information as it was printed out. The operator therefore had to prop up the printer case, which then increased the ambient noise level in the control room.

Additionally, when a unit is not in use or in hold due to a fault or maintenance, then the operator has no easy means of telling when it can be restarted until it is verbally reported from the plant. The procedures must ensure that this verbal notification occurs, otherwise valuable processing time could be lost.

The other area where information flows could be problematic has already been discussed. There are maintenance situations where, unless he scans with the CCTV, the CRO has no direct reference on the interface to the parts of plant where men are working.

8.10 APPROPRIATENESS OF INFORMATION MEDIA

The nature of the product means that the process is subject to strict legal controls on the production and documentation of batches. This leads to the necessity for records to be kept in a systematic and thorough manner and to be accurate enough to trace the origins and production details of a batch should it prove necessary. This requirement led to the use of extensive paper batch logs at the Boots plant. It also led to the frequent transfer of information between the VDU displays and paper logs and vice versa. The scope for error resulting from this could have been avoided by effective design of the information flows. For example, for each new batch log, a number would be generated as a label on the computer based system. From this point there was no means of providing a computerised log, although all the information required was already contained on the computer based system. Instead the relevant information had to be transcribed from the VDU screens to the paper based log. Whilst this introduced an opportunity for error, it also provided regular points in the process where the operator had to move from the control desk and carry out a very different activity. The benefit of this variation in the task would have to be weighed against other, more efficient information design alternatives that could be suggested.

Within the control room, there were several record and logging systems which formed separate systems between which information had to be transcribed. Sometimes the information from one source would be transcribed manually to several other logs. Such systems included the raw materials handling system and the records of maintenance activity. Much of the information for these could have been included within the computer based system or the information coordinated more effectively, or both. However, in order to make effective recommendations, the information would have to be analysed in more detail than was possible in this context.

8.11 THE STRUCTURE AND PROBLEMS OF THE CURRENT DISPLAYS

The displays take on a hierarchical structure, with the summary display giving an overview of the current status of all the batches in the process. Information on each process unit is given in more detail on each of the mimic displays, and for each item of equipment or parameter the operator can request more information. This is displayed on the lower portion of the screen.

Summary display

The summary display presents the information needed to monitor batch progress clearly. However, due to modifications to the plant all the units are not in process and numerical order. This presents the possibility of increased likelihood of human error. The effect this could have on the process includes delay in initiating the next stage of the process for a batch or making an error in taking units out of hold when, for example, maintenance is being carried out. This particular display aspect increases the probability of an error occurring.

One problematic issue of the safety procedures is where reliance is placed on the operator to note where on the plant maintenance is occurring, and to ensure that the relevant parts of the process are in hold, switched off or isolated. If an operator is distracted for some reason, or if the CRO failed to report it directly to the next shift, then the possibility for error is increased, and safety boundaries could be violated. Human memory is prone to interference (Baddeley, 1976) and in this instance a job aid, or some means of annotating units on the display to indicate maintenance or repair work would enhance the task and minimise the risk of the CRO forgetting or failing to note the incident in the shift log book.

Mimic displays

The most important factor regarding the mimic displays is that consistency is observed throughout the design of the range of displays. For example, the use of colour must be consistent and labelling must maintain the same position and format. This is to minimise error or misinterpretation by the operator due to a display deviating from his expectations. The use of mimic displays gives a graphical representation of the functional relationships amongst plant items and it also provides a basis for monitoring of the process. If consistency in display formats and content is observed throughout all the Ibuprofen plants, then if a control room is used to control one of the other plants in the case of a fault or breakdown, the operators will have positive transfer of training and knowledge from one system to another.

The mimic displays are the means by which the operator can detect if the process is not progressing or producing the results it should. One example would be the noting of an abnormal weight in a header tank or noting that a parameter is out of bounds. This is often the first sign that there is a fault, or that a fault condition is likely to occur on the plant. This can be either a fault with an item of equipment, or that product contamination has occurred. Given the importance of early detection of such an event, the display should be designed so that detection of any fault is enhanced. At present the operator either has to rely on his own skill or on comparison with the method laid out in the SOPs, to detect any abnormal events, such as a blockage in a pipe. However, some faults are only detectable once a unit has reached hold status, for example, with timeout faults. These, and all other faults occurring, are detailed on a printout when the fault sends the unit into hold.

Other display options

Work has been carried out to assess the usefulness of computerising the SOPs with the aim of allowing easier and more effective interaction with the process information by the operators (Visick and Law, 1987). However, the trial was not successful for several reasons. Firstly, the system was not integrated into the interface, making it difficult for the operators to refer to the displays and the appropriate information simultaneously. Secondly, the operators, already familiar with the existing technology, found the system more time consuming with less information available at any one time.

Possible solutions for the above problems include integrating a more dynamic data base system into the interface, which would allow windowing etc of several pages of data. Another alternative would be to include an optional display area that could be called up by the operator onto the mimic displays. This would include approximately three lines of the SOP relating to the current part of the process reached. This would help to indicate to the operator:

a) If the values and parameters were as expected.
b) If a control input by the operator was needed or would be required imminently.

However, either solution would be expensive to implement, and overall the present system of 'manuals' provides all the information needed in an easy referenced format.

The use of colour in the displays does not conform in all instances to human factors guidelines. For example blue should be used as a background colour and not for text. The way in which the human eye perceives blue means that text will tend to be fuzzy and less readable. The use of green to represent "on" and red to represent "stopped" conforms with normal population stereotypes. However, it should be noted that some of the symbols used such as pumps, have small areas of red (or green) inside a larger green (or red) symbol to denote for example, a valve position. As the two colours appear to be of a similar brightness (no actual light measurements were taken), problems could arise if any of the operators experience red-green colour blindness (protanopia, protanomalia, deuteranopia or deuteranomalia). This would make it difficult to distinguish the equipment status as well as making the blue and yellow of the display appear brighter. All the colours used are quite saturated and bright. As long as a reasonable contrast level is maintained (approx 1:10), then more restful less saturated colours could be used.

There is no standard accepted set of symbols for mimic displays that is used across the whole range of process industries. However the displays used are generally effective. As the workload of the operator is generally low under the context of most operational situations, error is only likely to occur in a situation where the operator is under stress and has a high mental or physical workload.

Documentation

The documentation of the batch is very thorough and conforms with government guidelines (Guide to Good Pharmaceutical Manufacturing Practice in the Pharmaceutical Industries; Sharp, 1983). It documents both the raw materials, the batches and details of each batch processed. However, information regarding the raw materials input into any given batch is not directly related to the batch log, except in the cardex system. Cross referencing could be improved by including the information on the monthly, master, batch log. This would allow easy visual reference as to which batches a particular load of raw material input relates to. This would help if problems were to occur, for example, due to contamination by a raw material. The rapid identification of the relationship between batches and a specific raw material would be possible.

The Guide to Good Pharmaceutical Manufacturing Practice emphasises the avoidance of transcription errors in transferring batch information from one record to another (Sections 3.30, 3.34, 3.48). The present D72 system is open to human error in that the data concerning a batch is transferred across several sources during the production of a batch. This is highlighted in the procedures shown in the analysis and occurs from the logging in of raw materials to the filling in of the batch labels.

Much of the documentation could be computerised and supplemented by hard copies. At present, only the batch unit records are printed out automatically by the computer, and the system requires each consecutive batch number to be entered by the CRO. The only system for checking the information is by the CRO himself. All the information needed to complete the master batch log is currently available within the computer's data processing system. The system of filling in batch labels by hand also gives scope for human error. However, the task could be automated and the labels printed by the computer. The human would then have more of an objective monitoring and checking role in the system. In addition to the above, a more fully computerised batch logging system would have the advantage of giving an on-line data base for easier statistical, historical and predictive manipulation of batch trends.

Despite the above suggestions, the operational situation often requires the operator to monitor the plant for long periods with relatively few control inputs (operations 2.1.5.1.1 and 2.1.5.3 in the analysis). Studies have shown that over long periods of monitoring the arousal level of an operator decreases and a performance decrement can result (Hockey, 1983). One solution is to provide frequent breaks away from the task.

The present system of documentation ensures that this occurs at regular intervals as the operator needs to physically leave the control desk to fill in the master batch log and to file the batch sheets. This may help, therefore, to reduce error in the monitoring of the process.

Standard operating procedures

The Standard Operating Procedures (SOPs) have already been mentioned. However, they not only have a role to play as a job aid but can also help the operator in his understanding of the task. They aid both the experienced and novice operators. For inexperienced operators they provide a training aid. They show for each unit, which relates directly to a mimic display, how it relates to the overview display, the stage the process has reached (in graphical and numeric form), what the process values should be and what parameters are required for progression onto the next stage of the process. Furthermore, the allocation of function between man and machine is clearly shown, and areas where the human must have an input into the process are clear.

Verbal communications

Continuous communication with the men on the plant and the foreman is essential. Only the CRO has an overall view of the stages of all the batches currently being processed. Consequently he is in the best position to predict problems which may occur and to instruct the plant operators of any actions or contingencies that need to be taken (operations 2.1.4.3.2 and 2.1.7.1.3.2.2 in the analysis). Figure 8.1 illustrates an excerpt from the task analysis showing the communication tasks of the operator.

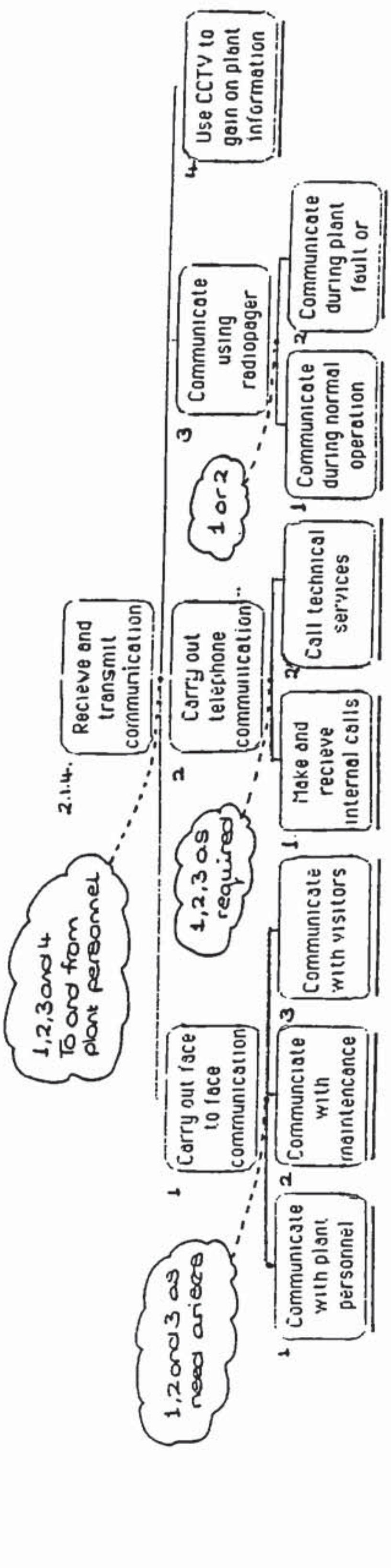


Figure 8.1 An extract from the analysis of communications tasks on the Boots plant.

The radiopaging system is essential, without it communications would be very difficult. One means of improving communications with the plant, and helping the plant operators to follow each particular process in the context of a whole, would be to provide a VDU terminal on the plant. This would not be interactive, but would be slaved to one in the control room, or would allow displays to be selected, but not interacted with.

8.12 DISCUSSION

Potential for process improvements

A range of problems can occur on the plant; however, quick action on the part of the operators could often help to minimise the cost to the process. In many cases improved communications and information flows can help this, especially where the task emphasis is on problem solving or decision making by the operators.

Issues and problems in the control of the process

Operator detection of possible contamination has already been briefly discussed . Detection by the operator that there are problems with a batch can occur either from displayed information or by verbal communication from an operator on the plant. Such problems can range from suspected contamination, to the need to rework a batch, due to colour, crystal size or particles in the product. The CROs on the plant did not perceive the operation of the process as having any processing time constraints. This was possibly because some of the units have a long processing period. Quick and effective action, where possible in such instances, could contribute to the economy of the process. For example, if just ten minutes of processing time per shift was saved, this would total 7.6 days of processing time over a year. This could either relate to actual processing time due to equipment, or to a delay in reporting to the control room by a plant operator that a manual part of the process is complete.

Many of the bottlenecks in the process occur at the points where there is a manual input into the process, eg, with the drying of the product or in the clean area. The drying process must be supervised by an operator. However, it is likely that if further dryers were installed, only a single operator would be needed. Other problems occur with the input into the process. In approximately one in four operations of sodium transfer, the transfer pipe becomes blocked and the operator has to manually unblock it. However, the study did not look at the allocation of function between the human and the system in detail or at the task of the operators on the plant.

Information and communication flows
Generally, the information and communication flows in the existing control room situation allow the operators to perform their tasks effectively and efficiently under normal working conditions. The workplace layout allows a flexible division of labour between the operators so that one operator can deal with the displays and progress of the batches whilst, the other operator, as his main task, is able to carry out the main communications with the plant.

As the process is semi-automated, the CRO has an important role to play in coordinating the processing of the different batches through their unit stages. The information and communication flows are essential to this, so any enhancement of the communication by the use of human factors principles will enhance the efficiency of the process.

The display structure and the displays used provide the information the operator needs to control the process in normal operation. Under fault conditions there are several means by which both fault detection and diagnosis could be enhanced, so helping to co-ordinate and initiate action more rapidly.

Although much of the necessary documentation is in paper copy form at present, the system could be made more efficient by using a computerised database or similar system. However, the present system helps to provide the operator with frequent breaks from a task that imposes a relatively low workload and high vigilance requirement. If the system were computerised, it would be possible to transfer some of the operator's task to a data input task, using the control interface rather than paper and pencil.

There are only three VDU display surfaces available to the operator. Whilst it would be possible to computerise the SOPs, the paper copies provide many advantages, such as easy reference of several pages of information and quicker reference to particular items of information.

The documentation given complies with the guidelines laid down by the Government; however, the system used at present is potentially susceptible to human error, as the operator both transcribes and checks the information. The current training of the operators means that it may take a while before sufficient familiarity with the process is gained, both of normal operation and of fault procedures. Some introduction to the plant in terms of more formal training may result in operators who are both ready to operate the plant earlier and who are better equipped to deal with unexpected process situations.

In brief, the recommendations for information design suggested in the report presented to the plant are outlined below:

- The summary display should present consecutive plant items in numerical order.

- The operator should be able to annotate information regarding the current maintenance situation on plant, somewhere on the interface.

- The colour coding on the mimic displays could be adapted to conform more readily to human factors guidelines (although given the present task the existing interface should not lead to decrements in performance).

- An audible alarm at the interface (which can be acknowledged and cancelled by the operator) would help to ensure that the operator is able to respond more directly to faults, especially if it included a brief message on the unit location of the fault and type of fault.

- The likelihood or error resulting from documentation could be reduced if more of the existing system were computerised. This would also make manipulation of the batch data easier.

Implications for the method of analysis

The method of analysis in this context proved a useful framework for the examination of all the information sources relating to a particular task. However, it proved difficult in the collection of the information to always disassociate the information from the medium it was transmitted by, for example when the task itself involved operation of the means of transmission (eg, the CCTV). One possible approach to this problem (which was in part, the approach taken in the CPP study) is to document the task at a generic level, perhaps using information from the other plants which produce Ibuprofen on the Nottingham site. This generic task analysis can then be used to generate more detailed task information, independently of the currently available media. The tasks are documented in a way that makes no assumptions about the way in which the information will be transmitted.

This study was carried out during the period of the Coal Preparation Plant study and as a result of the two analyses it became evident that the task classification scheme used in the analysis could be improved. Whilst it was accepted that the categories could not be mutually exclusive and that inevitably there would be some tasks that would be classified into more than one category, the classification was not useful in terms of some of the categories. Therefore, following the case studies, the classification scheme was revised and some of the classifications redefined (figure 11.1). In particular the **operational** category was felt to be very much a catch-all category which did not define the classified task in a useful way. This therefore became the sensory-motor tasks category.

In the revised method of HTA used in this study an additional column was included in the tabular format, this was **knowledge and skills.** Within any task context the information flows and requirements can only be determined in the context of the operator who will be using them. Whilst experienced operators will obviously have different needs to novice operators, this is usually anticipated on the plant and appropriate training given. However, assumptions may be made about the operator in relation to the task context and these must be made explicit. Firstly, to ensure that all members of the design team are working to the same assumptions. Secondly, to communicate these assumptions to anyone who may use the analysis at a later date. The profile of the operator and his or her knowledge and skills should be considered in line with the task to be performed and the information flows. Issues such as the amount and detail of information required will all depend on the knowledge and skills of the operator. Any information that is required for the task must either be displayed in some format or be part of the operator's repertoire of knowledge or skill. The extra column was intended as a checking mechanism. This was firstly, to allow assumptions about knowledge and skill to be integrated as part of the analysis. Secondly, it should ensure that the information flows, specified coupled with the knowledge and skill described, allowed complete task performance. Any gaps where knowledge or information was inadequate, could be compensated for by improving one or the other.

In the context of this analysis full details of training and skills could not be collected. This means an approach to information collection for this column cannot be combined with that for the main analysis easily. Additionally, as there was restricted time available on the plant, it was not possible to collected detailed information on knowledge and skills. It appears that this part of the analysis will take considerable time to complete and so it may not always be possible to include it in analyses where manpower or time constraints exist. However, it does help to provide an overall checking mechanism for completeness of analysis and to provide valuable information for training and selection.

The analysis of the Boots Ibuprofen plant proved a useful case study in contributing to the development of a method for analysing operator information needs. Firstly, it allowed the method developed to be evaluated in the context of a batch plant to complement the analysis of a continuous plant in the CPP study. Secondly, the case study allowed the analysis to be applied to a wide range of information flows from varying media in the control room and to assess its use when applied to information other than that displayed on the VDU display formats. In this application it proved very successful and gave the potential for decisions to be made about the suitability of different media for the different forms of information to be transmitted. The use of the additional column for documentation of knowledge and skills gave the potential for the analysis to generate more information for other applications. The analysis may then be used for training design and the specification of selection criteria. The classification scheme is also able to offer information for training and selection by specifying the type of task to be performed. Finally, as a result of this analysis, the task classification scheme was updated and revised to provide and more useful and clearly descriptive categories.

CHAPTER 9
CASE STUDY 3
A HIGH RISK PROCESS INDUSTRY

OVERVIEW

In the third case study the evolved method of task analysis was applied to a power generation plant that was still undergoing design. This offered the opportunity to assess the use of the method for the synthesis of tasks. The method was also applied to the assessment of information flows on a panel display. In the context of the study the evolved method of HTA was compared to the task analysis method currently used by the design team, FAST (Functional Analysis Systematic Technique). In its use for task synthesis the HTA proved to be complementary to the functional analysis, providing a means of structuring the tasks and identifying the required information flows once the functional role of the human in the system had been defined. In its application to the assessment of the panel design, the evolved method of HTA provided an effective means of documenting the information required by the operator and for the identification of likely problems and anomalies in the current design.

9.1 INTRODUCTION

The third case study aimed to assess the use of the evolved task analysis method in providing a task synthesis for a power generation plant that was still undergoing design. No other existing plant was directly available on which to base the analysis, although the design was able to some extent to draw on similar plants in operation within countries other than Britain. At the time of the study, the functional requirements and specifications of the system had largely been defined and, in some cases, the initial design was specified.

The study took place over a period of twelve months, with visits being made to the design team, and control room mock-up, at monthly intervals. The study and the analyses took place in two phases. The first stage involved analysis of the functional and task requirements of four of the safety critical systems of the main power generation system. Within the functional specification of these systems, the analysis was to provide general information on operator information needs and the design of procedures, allocation of function and possibly training. The systems for study in the analysis were selected for study by the Ergonomics sub-group of the project management team.

The second phase of the study was to evaluate a proposed design for the panel display of the power plant's electrical services and utilities. The analysis was carried out and used to compare existing information flows with the information requirements of the operator's task.

As the design was not yet complete, sources of information for the analysis included experts who were familiar with the design of the system or with the design and operation of similar plants in the United States. The existing system documentation, the control room mock-up which represented the layout of the control room and, for some systems, representations of the user interface were also used.

For reasons of confidentiality the results of this study are not described at a detailed system level. However, the general results of the study and their implications for the task analysis method are described and discussed.

9.2 AIMS OF THE STUDY

Within the context of this research the aims of the study were as follows:

1. To assess the modified version of HTA which has been amended in line with recommendations from case studies 1 and 2.
2. To test the utility of HTA for a task that had not been previously defined.
3. To compare the usefulness of HTA in comparison with a technique, FAST, developed and used within the plant for functional analysis of human tasks.
4. To identify problems and weaknesses and to evolve the method further.
5. To assess the usefulness of the task classification for describing process tasks.

For the plant project management team the output was to provide information that could form part of the overall task appraisal of the main systems, and in particular of those systems critical to safety. The aim of the task appraisal was to look at the major interactions within the main systems and to ensure that the tasks are commensurate with operators' capabilities and limitations.

The objectives of the use of task analysis within the main systems design was to:

1. Identify the main control and display information for the HMI required to successfully perform tasks.
2. To identify any human factors problems with the current design.
3. To assess the procedural information required to perform relevant tasks.
4. To identify the skills and knowledge required of the operator and other personnel in the operation of the systems under study.
5. To put forward human factors recommendations which may be applicable to the design.
6. To assess the interactions of the human with the system in terms of:
   - Task feasibility
   - Task allocation
   - Interface design
   - Content and presentation of procedures
   - Workspace design
   - Workspace evaluation
   - Environment
   - Training needs.

Therefore the output of the analyses, in addition to consideration of the use of the method, was to identify the information, training and communication requirements of the human and to assess the importance of the tasks for safety, availability and reliability.

The design process

As a means of input into the design process, the task analysis must be cost effective, meet the safety and functional requirements of the CEGB's (Central Electricity Generating Board) specifications and meet the requirement of Her Majesty's Nuclear Installations Inspectorate.

Within the formal strategies for the design process there are three phases, the provisional, the intermediate and final phases. Initially the functional requirements are identified and these are formed into a provisional design taking into account safety and the ergonomic requirements of design. This was verified, corrected and if necessary reverified to produce the final design.

From a human factors viewpoint the input is in the form of a functional definition and hence design bases which require that :

1. The operator's activities are supported by the HMI design.
2. Tasks recognise capabilities and the limitations of control room operators.
3. The highest possible reliability is achieved under fault and hazard conditions.
4. Information displays for safety are easily assimilated by the operators.
5. The control room is engineered to reduce possible human error.

9.3 APPROACH

The approach taken within this case study had to be adapted for a system still undergoing design, and for which there were no other existing plants operational in the UK to provide a source of data. At the time of study, the plant was still in the design stage, with certain design "freeze" points being applicable at different stages of the study. Therefore, the information gathered for the study and used as a basis for the analyses, was based on the design as it was presented at the time of the study.

The case study was carried out in two phases. The first part comprised analyses which had the potential to contribute to the analysis of main systems, and in particular the safety systems of the plant. The systems for study were selected by the project team, based on the specification that they could form a basis on which to try out the evolved method of HTA. The second part of the study comprised a participation in the review of the plant's electrical services panel. The review aimed to assess the content and layout of the panel. This allowed a quite different application of the evolved HTA method. Whilst the method was aimed primarily at the analysis of VDU displays for process systems, this system offered a combination of both. At the design stage reached, the exact nature of the information display had not been set. This allowed the application to be tested for flexibility and application to a system where the exact nature of the display of each item of information had yet to be decided. For the study of the display panel, the method was used simply to compare information displayed against the information required by the operator. This was in a situation where the information remained static and all information was available to the operator at all times.

These two applications offered two very different uses of the method of task analysis. Once completed the analyses and results were made available to the design team for use within the system context, should this be applicable.

Task Synthesis

This case study offered a unique opportunity for a task synthesis to be carried out. Task synthesis is the term applied to the breakdown and analysis of a task or job which is not currently in existence. The requirements placed on a method of task analysis, when it is used to examine tasks in this way, are different to the demands of a method for analysis in a variety of factors. A synthesis has no previous or existing task situation on which to base the study of the task in its entirety. It may be possible to extrapolate from similar task situations. However, this can only really be carried out using expert judgment as to what constitutes a similar task, and a task analysis of some nature is almost always required to systematically define the similar elements.

The information available concerning the operator tasks for a new system is often patchy and may be inconsistent. For this reason, any technique that is used to document the tasks must be sufficiently flexible to accommodate the variety of information that is accessible (this may include documentation, interviews by system experts, simulations and so on). It should also allow for updating and expanding as the system evolves.

The synthesis must allow the tasks to be evaluated as it is developed and progresses towards a full description and analysis of the tasks, in line with the design of the system. This allows both the engineering descriptions and the task descriptions to evolve together as the system becomes more rigidly defined.

The aim of a task synthesis must be to fulfil the following criteria:

- To be expandable and updatable to adapt to the evolution of the task and the system.
- To be flexible, to cope with input from a wide range of information sources.
- To facilitate decision making concerning the nature of tasks in the system.
- To allow assessment of the viability of proposed tasks (for example in terms of workload, the design of the workspace and the grouping of tasks).
- To highlight likely problem areas for task performance within the system.

Some existing methods of task analysis lend themselves well to the synthesis of tasks, others require an existing task to provide the information input required. In general, methods which provide a framework for representing the task in a format that allows the task to be broken into increased detail (for example, a hierarchy) can be used as such a framework. Often such methods can be adapted to meet the requirements of a task synthesis.

The modified method of HTA was felt to have the potential to provide a useful tool for task synthesis. It provides a framework for entering task information at different levels of detail.

At an early stage of the system, the role of the operator is most easily defined in terms of its functionality in the context of the whole system. At this early stage a synthesis should aid in decisions concerning the allocation of function between humans and machines in the system. Once the allocation of function is determined, the functions of the human can be grouped into coherent tasks (and adjustments made to the way in which tasks are allocated if necessary). The tasks can then be synthesised and the feasibility of their execution assessed. Once a framework has been established, and task goals defined from the functions, then studies of other aspects of task performance can be carried out. An example of this would be studies of anticipated operator workload.

The problem in assessing a task synthesis, is that of being able to predict and foresee all the factors that will influence task performance in the empirical task setting. Even high fidelity simulations are unable to completely represent all the factors that will influence task performance in the actual task situation; especially in a high risk plant such as the one under study, where it can be difficult to replicate all the pressures on the operator. However, the assumptions that are made concerning the system can be stated at the time the analysis is carried out. This provides written documentation for anyone who will make use of the analysis, and provides a basis on which it can be updated.

9.4 INFORMATION COLLECTION

The study took place over a total time scale of twelve months, during which time approximately two days per month were spent on the project, one of those days being spent on the design project team site. The time on site involved system familiarisation, access to confidential documentation, access to the control room mock-up and interviews with both members of the human factors sub-group and with experts on the design teams of the different plant systems.

Electrical Services Panel

The task and system information to carry out an analysis of the electrical services panel was gathered from three principal sources: documentation, full scale mock-up and layout drawings and a "walk and talk through" exercise.

Documentation on the system and its intended mode of functioning formed the background information of the study. The initial layout of the panel had already been decided, and this formed part of a full scale control room mock-up. This mock-up was static and took the form of a paper based representation of the interface on wooden mock-ups of the control panels, built to actual dimensions. The mock up offered a full scale representation of the panel set in the context of the whole control room layout.

In addition, full scale drawings were available for study away from the control room mock up, which provided detailed and accurate information on the layout. Control and Instrumentation (C & I) information was available to give functional details of relevance to the displays. In addition to the use of the scale drawing layouts of the panel for static analysis, a dynamic view of the panel's usage was gained using a video analysis. Since no plant operators for the proposed new plant were trained, a subject matter expert who had experience of similar plants in the United States, and who had worked with the plant project team previously, provided the source of expert information. Typical scenarios were selected by the human factors sub group of the project management team for analysis. These were selected on the basis of what were considered in the opinion of the project team to be normal operational manoeuvres.

The scenarios were placed before the expert, and the video data collected in the form of "walk/talk throughs" of the scenarios. Actions made and decisions taken were described whilst the expert was performing the task. Questions were asked as the task was performed to allow clarification of unclear points or issues that required some expansion. All the scenarios were recorded to allow for retrospective analysis. Whilst it would be possible to clarify points at a later date, further analysis of different scenarios would not be possible.

Four Plant Safety Critical Systems

The safety systems of the plant were documented both in descriptive and functional formats. This provided a background for the analysis along with information gained from structural and informal interviews with systems engineers and subject specialists/experts working on the different plant systems. In addition the current C & I layouts were available for viewing in the control room.

Based on the current design status at the time of analysis, the available information formed the basis for the analysis of the tasks and for interviews carried out with subject matter experts.

9.5 ANALYSIS OF FOUR SAFETY CRITICAL SYSTEMS

As part of the analysis of tasks critical to system safety to be carried out by the project management team, four safety critical systems were selected as an appropriate basis for the assessment of the method. The analysis was system rather than task based, in that the system itself provided the starting point, rather than consideration of any particular group of tasks to be performed by the operator. Throughout the study the safety analysis of the system was considered in terms of tasks related to specific systems and not systems as the related to the tasks of a particular operator. As the tasks were not fully defined, the latter would not have been a feasible approach. For each of the four systems it was the operational tasks associated with that system that were to be synthesised/analysed.

Each of the systems were to be analysed using the same approach. A task synthesis, based on the information, would be carried out using the modified HTA and using the technique employed by the design team at the development site, FAST (Functional Analysis System Technique, Creasy, 1980). The information collection was to be carried out with the requirements of both methods for information input to be taken into consideration. The two methods would be applied independently of each other.

In order to try to minimise bias that may be introduced into the application of the methods, for two of the systems, HTA was the first method applied and for the other two FAST. An effective and independent comparison of the two methods could not be carried out as there were no other analysts available to offer a check and control. Despite this, the syntheses allowed the methods to be compared, conclusions to be drawn and recommendations to be made. The methods were compared on a range of criteria, which included:

- The extent to which each method provided an effective framework and systematic approach to the synthesis.
- The ease by which the task representations could be iterated and updated.
- The extent to which they facilitated decisions about format, design and

allocation of function.

- How the methods made use of the information sources that were available, which typify the early stages of system design.
- The extent to which the methods allowed problems relating to the tasks to be highlighted and identified.

Assumptions

Certain assumptions existed concerning the four systems. As these four safety systems had several commonalities, some of these assumptions are general and can be outlined (for reasons of confidentiality it is not possible to be specific). In some cases, the assumptions resulted from the engineering design and systems operations concepts that had already defined the operational scope of the system. In other cases, the assumptions were a direct result of the system's design philosophy.

All of the four systems analysed were highly automated and, apart from exceptional circumstances, manual intervention in system operation would not be permitted for a time period following system initiation (usually 20-30 minutes). Additionally the synthesis took the C & I as described in the design documents as the current basis for design.

Results : HTA versus FAST

The results of the analyses showed that instead of a direct comparison of the two analysis methods HTA and FAST, consideration of the complementary aspects of each was more appropriate (figure 9.1). Each contributed a different viewpoint to the task synthesis. Both provided very necessary information for the analysis of the operator's role, goals and tasks within the system. The FAST was an essential first stage in defining the operators' functions and roles in the system. HTA then provided the means of grouping the task elements into defined operations and coherent groups of tasks.

FAST only defines the tasks on a functional level, ie, what function is required to be achieved in order to fulfil the system mission. HTA then translates these into task operations and gives details of the conditions under which these elements are to be performed. The HTA then provides the basis for more detailed study and consideration of the tasks themselves. This will include the definition of issues such as the allocation of tasks between operators, which skills are to be selected for and which trained, workload (physical and cognitive), manning levels and task feasibility.

Both FAST and HTA are hierarchical methods, and so both provide a breakdown of elements that is at an increased level of detail. In FAST, however, it can be difficult to pick out the task elements, although this would be made easier by annotation on the representation of the functions which are allocated to the human.

HTA	FAST
Analysis is centred on the operational tasks.	Analysis is centred on the functions and achievement of the system mission.
Analysis shows task goals.	Analysis shows system goals which may include task goals.
Can be applied where task goals are identified.	Can be applied where only a functional description of the system exists.
Representation is flexible and easily updated to include new information, especially the tabular format.	Representation can be updated, but is restricted by the use of and/or gates, easiest to increase level of detail at lower levels of the hierarchy rather than in the main analysis.
Enforces systematic analysis by rules of redescription.	Enforces rigorous approach by the use the of how and why logic.
Most useful once allocation of function and automation issues defined.	Most useful in defining allocation of function and automation requirements.
Provides a flexible structure to which new forms of task information can be added.	Structure cannot be easily adapted to accommodate other forms of task information.
Identifies role of the operator in relation to other operators.	Identifies the role of the operator in a system context.

Figure 9.1 A TABULAR COMPARISON OF HTA AND FAST

9.6 ELECTRICAL SERVICES PANEL ANALYSIS

Panel Displays

The analysis of the Electrical Services panel provided an opportunity to apply the modified HTA to the analysis of information flows and the assessment and design of panel displays as a contrast to the design of VDU plant displays. Whilst CRT displays are becoming more common as process plants become more automated, are updated or as new plants are designed, panel displays are the usual form of human machine interface in older plants. It is rare to find a plant that is controlled entirely from a VDU based display system, most plants have panel displays either as an emergency back up system (for example, for when the CRT display or computer goes down and hardwired information is required) or as a means of control for certain selected plant systems. The fourth case study looks at the progression from a panel based control unit to one that is intended to be operated entirely from CRT displays. However, in the context of this plant the panel display unusually provided the main means of control for the system and the information was repeated on the CRT displays.

This section of the study therefore allowed the task analysis method to be assessed in an application that forms an essential part of the information flows within a control room situation. Panel displays in a smaller format are also often found where control is localised at the equipment on the plant itself. CRT displays are very rarely found on plant. This may be due to a requirement for robustness of the equipment on plant, also the control requirements of localised interfaces are often very simple and a more complex CRT based system would not be required. The results of the study are presented below. Both FAST and HTA were applied to the evaluation of the panel.

Scenarios analysed

The primary sources of information for the analysis of this panel were the existing panel layout diagram and a video analysis of a "walk and talk through" of the main tasks relating to panel operation by a subject matter expert from the operational division of the company. Thus the analysis was able to take the format of an iteration in design and an appraisal of a proposed design format. The likely uses of the panel were prescribed by a subject matter expert, and from this the scenarios for the "walk and talk throughs" were generated. These scenarios were:

1. A general introduction to the uses of the panel and its layout.
2. The use of the panel for start up following a reactor trip and hot shut down.
3. Loss of station board 2 and the turbo generator.

4. Bringing back plant following the loss of a station board.
5. Opening a breaker to the diesel generator following a cold shutdown.

For each of these scenarios a HTA was carried out and the tabular format used to identify the information flows. The analysis was then applied to the evaluation of the current design of the control panel and its adequacy for the defined scenarios.

The specific contents of the analysis cannot be used as examples for reasons of confidentiality. However, the analyses took into account the parameters of the system influencing task performance and the system status at the beginning of the task. The scenarios and tasks considered were primarily concerned with getting the system back on line and supplying the system product. Time was important but in most cases not a critical parameter, so it was not specifically highlighted in the analysis. The assumption was that the task would be carried out in the control room by an operator who was not dedicated exclusively to the task, but who would be able to complete the task singlehandedly.

9.6.1 RESULTS OF THE ANALYSIS

The HTA analysis

In the analysis of information flows, the modified HTA was able to highlight discrepancies in the information that was provided by the panel compared to what would ideally be required. For most task elements the required information was available on the panel; however, it was a further dimension to the information that was a source of operational difficulty, that of the panel layout.

This added an interesting dimension to the use of the technique for the general analysis of information. It allowed the use of the analysis for evaluating the design of the information and its layout as well as the required content. This served to emphasise one of the problems identified as a result of the research with respect to the design of VDU displays in process control and task analysis. The analysis is able to break down the task and it can provide an analysis of its constituent components, but it fails to provide a means of deriving information that can be directly translated into design criteria in a consistent way.

This means that a human factors specialist has to use the information provided in the analysis and apply expertise to produce design guidelines or an assessment of the design. In the case of CRT displays for process control, the problem is further confounded as there appears to be no coherent set of guidelines available for the design of such display formats. For panel design, however, there are a wide variety of guidelines given in the literature which can be used as a basis for design. Whilst the specialist knowledge of human factors engineers can be used effectively in this way, an accepted set of guidelines has the advantage of helping to provide consistency in the way design is carried out in a system, and can illustrate the research that has been carried out to show the approaches that can be used for different tasks and alternative formats. Further, if the task analysis provides an output in a format that can be used in a more direct way for design and assessment, then the analysis provides a more useful tool in the ergonomist's repertoire.

The results of the analysis were therefore applied to enable the layout of the panel to be assessed. As no guidelines were available to carry this out directly, the information contained in the analysis was applied as relevant. The information provided in the framework of the HTA that was used included:

- The inter-relationships between task elements.
- Situations where the same information was used for a variety of different tasks.
- The types of task for which the information was used.

At a general level, the following problems were identified from the HTA:

1. The layout of the control panel and the use of mimic lines.
2. Inconsistencies in the use of information and its display.
3. The flow of information on the panel did not match the flow of the task.
4. The use of labelling was inconsistent and some of the labels did not conform to standard plant abbreviations or were meaningful on an engineering but not operational level.
5. To perform one major function the operator was required to use information from a panel on the opposite side of the control room.
6. The same critical relationships between elements on the panel were not shown.
7. The hierarchical organisation of the panel was not always accurate in reflecting the hierarchy of the plant elements.
8. The status of two sets of pumps was not indicated on the panel although this could be critical should fault detection and diagnosis be required.
9. The design of discrepancy switches on the panel was such that under fault

conditions they could be mistakenly redressed.

10. In some places a dynamic rather than static display of the plant parameters would be appropriate.

The analysis also allowed identification of points in the task where information was used in a task that was not present on the panel but elsewhere in the control room. The tabular format allowed this to be annotated in the analysis. If this presented a particular problem in the task execution this could also be identified.

The FAST analysis

The FAST analysis identified the goals of the system at a functional level but did not prove directly useful in the evaluation of the panel's layout and design. This was primarily because the analysis focused on the operator's role in achieving the functions of the system and not on task goals per se. As the tasks were not grouped in the analysis into coherent task units, it was difficult to apply the analysis assess to the grouping of the control and display elements of the panel. Information flows were not part of the FAST analysis, so details of anomalies in the information content of the panel could not be derived from the analysis.

9.7 DISCUSSION

Issues arising from the analysis

Only one analyst was available to carry out the task analyses of both FAST and HTA applied to the system (eight analyses in all). This may have led to some bias in the analyses, although the analyst had become familiar with the FAST technique before commencing the project, and so was trained in the use of both techniques.

It became evident that a functional analysis that included the functions of the human operator was essential at the early stages of system design. If such an analysis was not carried out, there was no direct means of ensuring that human factors issues could be considered in the allocation of functions between humans and machines. The functionality of the system was defined at a primary level in the conceptual design of the system, at such a stage detailed operational information could not be documented. Therefore the FAST analysis provided a critical basis for defining the conceptual role of the human in the system. Within the context of this plant, FAST was also applied to the decisions concerning the automation requirements of the plant (Williams, 1988).

The two phases of the analysis (ie, the analysis of systems critical to safety and the evaluation of the electrical services panel) were applied to systems which were at different stages in the design cycle, and this had significant impact on the approach taken. Whilst the functional and system descriptions of the systems critical to safety were clearly defined and the control and instrumentation outlined, the operational tasks had not been studied in detail as a coherent unit. Some of the operating procedures were, however, beginning to be considered. The synthesis was therefore carried out based on the system information currently available.

By contrast, the layout of the electrical services panel had already been defined and the approach to the study of tasks was more an evaluation of the design, rather than a synthesis of tasks.

Representation

Both FAST and HTA representations provided a clear hierarchical diagram of the task (Appendix F). FAST utilises the traditional and/or gates which are usually applied in fault tree analysis or other engineering contexts. However, the usual symbol set used in logic diagrams did not allow the relationship between elements in the hierarchy to be clearly shown. This is one of the reasons that FAST may be more easily applied as a task analysis technique by engineers than HTA, which uses concepts more founded in the ergonomics specialisation. The FAST representation has problems in two respects. Firstly, there was no means of identifying which task elements were allocated to the human and which to the system from the FAST diagram. This not only made the identification of functions/tasks to be included in the HTA difficult, but it also made allocation of function decisions difficult as the interface between the human and the machine/automated functions was not clear. Secondly, as only and/or gates were used, sometimes it was difficult to define accurately the relationship between functional elements and how functional elements on one level combined together to achieve the overall function.

These problems could be easily rectified by the use of further annotation on the diagram. This would clarify these issues, enable more information to be included on the diagram and would not overcrowd the diagram. Based on the analysts experience of the use of FAST and that of the system design team, input was given to the design team for the development of further symbols. Many of these were also derived from fault tree annotation. The suggested new symbol set for use is illustrated in figure 9.2.

The HTA representation was very useful in the task synthesis, where both the hierarchical diagram and the tabular format were used. The hierarchical diagram was able to provide the starting point for the synthesis. It was helpful in structuring the tasks because it provided an easily understandable visual representation of the task, which could be easily modified and built on as the synthesis developed. Once detailed task information is available, then the tabular format can be used to structure the information and to provide a framework to allow further analysis of the task elements.

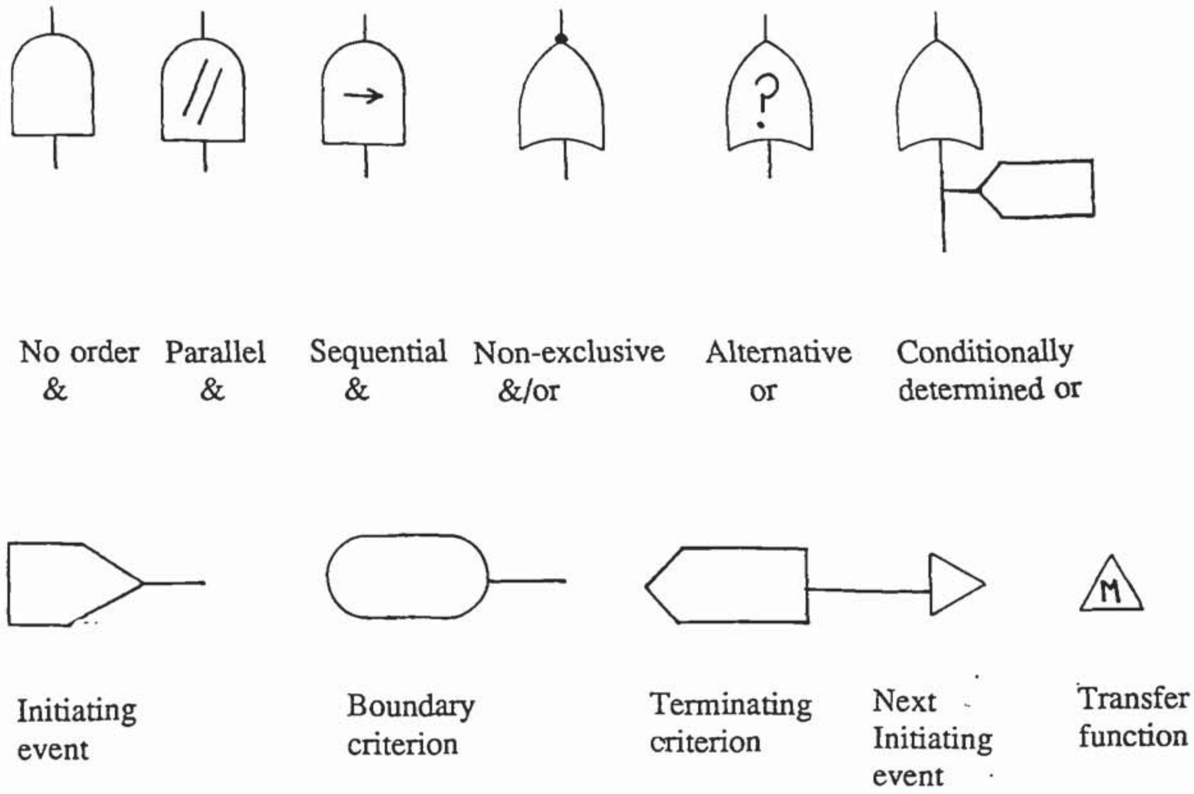


Figure 9.2 An updated symbol set for FAST

The rigour of analysis

HTA and FAST provide different approaches to the systematic analysis of tasks. The FAST analysis ensures thoroughness by applying a strict *how* and *why* logic to each functional element. An element at a given point in the hierarchy must contribute to the description of *how* the function above it in the hierarchy is achieved. In the same way that element must also provide the reason *why* the elements below it in the hierarchy contribute to the overall system mission. This vertical how and why checking ensures that all the functional elements of the system are included in the analysis. This is why FAST is particularly effective in identifying all the functional roles of the human in the system.

HTA provides a framework which allows a systematic examination of the means by which task goals can be achieved. However, the overall goal(s) of the task must firstly be clearly defined to allow this to be effective. Once these goals are clear, the analysis or synthesis allows each goal to be examined systematically. Rigour in the analysis arises from the way in which the description of super and sub-ordinate operations is carried out. Each set of sub-ordinate operations subsumed under a super-ordinate operation must, along with its associated plan, completely redescribe how that super-ordinate operation is achieved. One of the problems encountered in the use of HTA is that, in its usual format, it only describes one means of reaching the task goal. However, by the careful use of the plans and the structure of the hierarchy, alternative task options could be included.

Defining functionality

In the context of the analysis of safety critical systems the FAST analysis was essential for identifying the task goals and the role of the operator in the system. Whilst HTA provided a framework to structure the information that was available at this early stage of design, it was very difficult to generate the operations from the information. The HTA task synthesis had to make certain assumptions about the way in which task would be carried out. It was also difficult to ensure that all tasks had been considered, and all the possible functions of the operator in the system were included.

However, once the FAST analysis had been used to define the functional role of the operator, the next stage was to consider the tasks from an operator centred viewpoint. It was very difficult to do this using FAST as the tasks were represented in the analysis at the points in the system where that function was required. This meant that operational elements which would be considered to form part of the same task, may be located in quite different parts of the FAST hierarchy. At this stage, the HTA proved an appropriate tool for grouping together the task elements that had been systematically defined by the FAST analysis into a task synthesis. HTA provided a framework for an operator centred synthesis which could be updated and redefined as the system design progressed.

HTA for task synthesis

The two phases of task analysis carried out for this plant provided the context for the extended HTA to be applied both as a tool for task synthesis and to the evaluation of the information design of a panel display. As a tool for synthesis, HTA met many of the criteria outlined. Firstly, the task analysis provided a framework for describing and analysing the task which could be extended to include further task information as it became available and also to allow the task elements to be changed as the task changed through the iterations in the design process. This framework was not dependent on task information being derived in a constrained and particular form, and so it was able to lend itself to input from a variety of sources, such as documentation, and as the task is developed, "walk and talk throughs" etc. The way in which each task element is described in HTA allows information to be general and brief or be more detailed. The task operations can therefore become more detailed as the system design becomes more fixed.

The hierarchy of HTA enables the task to be described in general terms in the early stages of design. The depth of the hierarchy increases progressively as the system design develops. The grouping of the tasks into coherent units in the hierarchy and the plans which show task relationships, provide a basis for decisions concerning the viability of carrying out the tasks and partitioning of tasks amongst operators.

However, at the early stages of design, FAST proved to be a more effective tool in providing the initial task information required to make decisions. The functionality of a system is one of the first factors to be defined in a new system's design. A functional analysis which incorporates the functions of the human operator is therefore an important tool in defining the role of the human in the system in the first instance, and secondly in defining the goals of the tasks to be performed.

At this early stage, the allocation of function between humans and machines may not be clearly defined. HTA does not easily provide a basis for deciding allocation of function issues. Yet it is critical that the functions of the human are defined according to human factors criteria, for example, that the function can be performed by a human, that the skills and knowledge required would be within the scope of the operational capability that is envisaged. A profile of the operators of the system should also be broadly defined at this stage of the system life cycle. FAST outlines the functions that an operator would be required to perform, and so information on the likely skills, knowledge, abilities and training required can be derived and evaluated. General information on issues such as manning levels can also be derived.

HTA provides a systematic basis for the consideration of tasks, but an analysis can only be as good as the task information it uses. FAST, because it analysed the human in the context of system functionality, provides a rigorous framework for identification of all the parts of the system where the human contributes to system functioning. HTA cannot do this as the task is analysed with all the goals of the human as a starting point and not the goals of the system as in FAST. This point is critical to comparison of the two methods, as FAST presents tasks in a disjointed way, in the sense that they are shown as they fit into system functioning and not as coherent groupings of operational elements. The two methods therefore provide equally useful and critical elements to structuring tasks and synthesising effective task groupings in the design of a new system. At the outset of system design, FAST can be used to provide information that HTA cannot, that of allocation of function, the functions of the human operator in the system and the goals that the operator is required to achieve. However, once the system design becomes more detailed, and decisions concerning the design of the interface, allocation of tasks to operators and task feasibility are made, then HTA provides the ideal framework for structuring and analysing the task elements and goals identified in the FAST.

CHAPTER 10
DIDCOT POWER STATION
CASE STUDY 4

The following chapter outlines the fourth case study, carried out at Didcot Power Station. The plant was selected for the unique mix of technology demonstrated in the four separate units in its central control room. The units offered both traditional back panel type displays and controls and Visual Display Unit (VDU) displays coupled with touch screen control. During three and half days spent on plant, data were collected to analyse and compare two critical operator tasks, those of start up and of a procedure known as two shifting. The aim of the study was to further assess the adequacy of the method applied to a continuous process plant which provided a utility rather than a product. The plant allowed the information flows to be considered for old and new control technologies where the task to be performed was essentially the same. The results highlighted the problems and issues arising from a task analysis based study where the operators are highly skilled, and there are varying levels of automation in plant operation between units used for identical functions

10.1 INTRODUCTION

The fourth case study was carried out at Didcot Power Station, assessing the tasks and information display in the central control room of the station. The central control room at the station provided a unique opportunity for the study of the tasks of the operators and the way in which they had changed in relation to the evolution of the display and control technologies used for control. This was because control of the four turbines in operation at the station were controlled individually from four separate control units. Each of these units presented the use of a different stage of technology. The oldest unit, whilst incorporating two VDUs into its human machine interface, was controlled primarily from a back panel type display. The other units then represented intermediate stages of technology up to the most modern unit which was controlled entirely from VDU touch screen displays. This range of human machine interfaces allowed the changes in task in line with the technology to be studied. Additionally, recommendations for the information content could be made from consideration of the generic tasks of the operators and it would be possible to assess the extent to which these were incorporated into the older and newer interface designs.

Time constraints on the time available to be spent on plant (three and a half days) led to a restriction in the tasks that could be studied. Two representative tasks were therefore selected. These were considered to be critical to the effective operation of the plant. They were the start up of the plant and the two shifting procedure, which involves increasing and decreasing the output of the station to the National Grid as rapidly as possible. These were analysed and the information needs of the operator considered in relation to the technology employed.

Aims

The aims of the study were threefold. The first aim was to assess the adequacy of the method in its application to a plant where the information display and control medium were the same. Touch screens were used both to control the plant and to provide information on plant parameters. This indicates the utility of the method in considering a two way flow of information, between the operator and the plant, where the medium of communication is common to both. This is in contrast to more conventional control panels where the display and controls are separate, or the more usual application of VDU displays where the input device is a keyboard or another separate control device.

The second aim was to allow the method to be assessed in its application to new and old technology incorporating the same operator tasks. When a system updates its interface technology (but the control system remains basically unchanged), the tasks of the operator, at a generic level, and the information required, should not change. Only the detailed task elements, such as the control of individual items on the interface, should change. At the functional level (eg, start up turbine) the elements contained in a task should not change. This will only vary if changes in automation mean that the functional allocation between the human and the machine is altered. In such a situation, the task analysis has the potential to provide much of the detailed information required for the automation of the task. This is because it provides an analysis of the elements that are required to carry out the task. These can then be more easily encoded into a format (eg, a computer programme) that automates the task.

As a third aim, the study allowed further application of the method to a different kind of plant, to provide additional evidence of its utility in application across a range of plant types and industries. The plant in question represented a example from a service industry with a continuous process. The study was also to be used to provide some feedback for the recommendations for the types of displays most suited to use for different task types. This would be incorporated into the development of the mapping recommendations.

Approach

The approach taken to the study was to firstly gather task data on the plant. Given the limited timescale, the first step was familiarisation with the plant and then an overview analysis was conducted of the tasks that are carried out by the operators. From this overview, tasks were selected. The criteria for selection were that the tasks were representative of the types of task to be carried out and that they were critical to plant operation. In this case, criticality involved both cognitive and procedural levels of task operation. The first task selected was that of unit start up. This is largely a procedural task incorporating a range of decision making and problem solving elements. It was subjectively felt to be one of the more demanding tasks in terms of mental and physical workload and in the skills required of the operators.

The second task studied was that of controlling the unit output in response to requirements for variations from the National Grid and at other times. Adapting the output to meet national electricity supply and demand requirements by bringing a unit quickly up to power and then running it down again in known as a "two shifting procedure". One of the primary task elements involved in carrying this out, is that of bringing mills on line to increase the fuel supply to the furnace and then shutting them down again. This was one of the most frequently performed tasks and was studied in some detail.

10.2 THE PLANT AND PROCESS

The station is coal fired and has four 500 megawatt generating units supplemented by 4 x 25 megawatt gas turbines. The plant is controlled from a centralised control room and is highly automated. Each of the four units has an operator based in the control room and an assistant operator who works both on the plant and in the control room.

For each of the four turbo generators, a boiler is used to supply steam at 24,000 psi. The boiler is powered from a pulverised fuel system, comprising eight pulverising mills and feeders. The fuel is carried from the mills to the boiler via a draught system. This system, together with control of the mills, determines the capacity of steam produced by that boiler and therefore the output of the unit. Each unit produces 500 megawatts of electricity on full load, and this is passed on via a transformer to the National Grid at 400 KV.

In addition to the control of the main unit, the operator also has responsibility for the supporting and associated systems of the unit which includes the feedwater system and the gas turbines.

10.3 THE CONTROL ROOM SITUATION

The control room was situated adjoining the plant. The control room offered no direct visual monitoring of the plant; however, a viewing gallery for the plant was situated on the floor above the control room and was easily accessible. The control room comprised four identical "units", each used to control one of the four plant turbines. Each unit had a control desk and a control panel situated behind the desk, so that displays and controls could be monitored from the desk. Each of the four units represented a different stage of technology. The unit with the oldest technology was controlled both from the panel display and from the desk which contained conventional controls and displays (for example, knobs and dials) and two VDU displays. The unit with the newest technology could be controlled entirely from VDU touch screen displays, and the panel display was used only in the event of emergencies. For each unit there was an operator and an assistant operator. The operator was in charge of the unit and its operation and control, whilst the assistant operator was there to help in operation when the workload was high and to carry out any tasks, inspections and checking that was necessary on the plant.

Operator training was on the job, working alongside a unit operator as an assistant operator. Thus all operators had a high familiarity with the plant and understood the process in detail and the effect of control actions on the plant. The operator of each unit had full responsibility for the unit, both under normal operating and emergency conditions, with assistance from other operators or the supervisor, should it be required.

10.4 INFORMATION COLLECTION

The information collection on the plant took place over three half-day periods. This also included a period of plant familiarisation. Information on the tasks was collected by informal interviews with the operators and with supervisors. For examination of the tasks selected for study, "walk and talk throughs" were used, where appropriate, on both the VDU touch screen based units and on the panel based units. In addition, to supplement the subjective information, plant operating procedures and diagrams were used a source of further information . Some of the operating procedures were, however, not up to date. Within the control room, such operating procedures were available but were not regularly used by operational personnel who were highly trained in carrying out the procedures.

10.5 THE ANALYSIS

As stated, it was not possible, within the timescale, to examine all the operational tasks, so two tasks critical to plant operation were selected. However, the operational situation was complex and this had an impact on the conclusions and recommendations that could be drawn from the analysis. Ideally the tasks would have been studied in the context of all other operator tasks to include detail of the inter-relationships between tasks and their impact on information requirements. Initially, a very broad overview analysis of all the operational activities was carried out in order to identify suitable tasks for further study. The tasks selected represented tasks that were critical to plant operation. These tasks also contained both procedural, operational and cognitive task elements. Parts of the tasks had also been automated on the units employing the newer technology and these were selected to allow consideration of the impact that this technology had on task performance and execution.

Start up

The start up task provided a context for examining an operator's task with a high workload compared to many of the other tasks to be carried out in the system. A cold start up was examined and the analysis began with the pre-start up plant checks and did not include the preparation of the plant for start up. Before the operator can bring the unit on line he must firstly carry out a range of pre-start up checks in conjunction with the plant operator for that particular unit. These are principally procedural tasks involving the checking of the status of items of equipment. However, it is essential that the status of these items is correct, for example if the operator failed to open all the steam side valves (1.1.1.3) then a build up of pressure would occur on the plant as a result of the start up operations. However, the control room operator is highly dependent on the plant operator to check the status of items of equipment such as the boiler drains (1.1.1.1) and for many of the valves etc, he does not have a status indicator in the control room. This is particularly a problem when filling the boiler (1.2) as there is no level display in the control room and the operator must make use of the deaerator level display to estimate boiler level. The operator must also liaise with the maintenance operators to ensure that all maintenance carried out during shutdown is complete and that the plant has been restored to a normal functional status.

Therefore as well as the displayed procedural information, which on the back panel is laid out largely in the procedural sequence, the operator also has a primary communication task in relation to maintenance and the plant operator.

The second stage in carrying out start up is to establish the draught plant. Again this is a highly proceduralised task; however, it involves decision making on the part of the operator in order to achieve a balanced draught through the plant. On the units with older technology the operator requires information on each stage of the task to show initiation of the equipment and when it has reached its required value (for example, 2.3.3). Once an item of equipment has been initiated it is monitored for faults and the operator's skill enables him to estimate the timings within which start up should occur.

On the units with newer technology the procedural sequences which initiate the draught plant have been automated. This impacted on the tasks of the operators because the balance between the different task types that the operator was required to carry out changed. The emphasis shifted from procedural tasks to monitoring and fault detection, although the fault detection element was also present to a lesser extent on the units with older technology during the procedural tasks. However, the operator on the unit with newer technology had a sequence display which enabled him to identify with an almost equal accuracy to the operator of the unit with older technology, the point at which the fault occurred.

The next stages of the start up task were carried out according to a procedure. However, the procedure was not sequential and involved the operator using his knowledge of the system to optimise operation of the unit. The task involved a variety of decision making and problem solving operations (eg, 4.1 and 4.3). The operator was usually required to bring the plant on load within a timeframe and this timeframe often impacted on the overall efficiency of the plant (eg, the required load of the other units). It also required communication with the supervisor and other unit operators to establish the required output of the unit. As the task was not sequential the operator's task involved decisions as to when to initiate or change the status of certain equipment (eg, 4.4) according to the status of the unit. This also required continual monitoring of variables such as the high, low and intermediate pressure differentials. The operator had a series of goals to be achieved, for example, 4.3, which then allowed him to progress onto the next stage of the start up. Whilst the procedures for the task were documented, the operator made little or no use of them and was highly trained and skilled in achieving the task elements, although decision aids were provided for some tasks eg, 4.3.

Once the run up of the unit had been achieved, the plant was brought onto load and synchronised to the grid (5.4). These task operations involving giving the plant time to "warm" up (5.3 and 5.5), and so the operator was freed to carry out other tasks during these periods, although frequent monitoring of the relevant plant variables was required.

On the units with the older technology, the operator carried out many of the start up operations from the back panel rather than from the console, although some tasks (eg, 5.5.4) required the operator to control the unit primarily from the console with reference to information on the back panel. A link analysis, to accurately document the flows between information in different locations, was not carried out as part of the study. This would have been useful to allow recommendations concerning issues arising form the location of information to be suggested. In its current format the analysis only examines the information required for a particular task and not its location. As a result of this study it became evident that if the evolved method of task analysis is also to be used in the evaluation of panel based tasks and information, then details of the location of item of information should also be documented within the analysis. This could be achieved by the addition of a further column to note the location of an item of information at the level of individual displays and controls.

Such documentation of information location would also prove useful in the evaluation of VDU based displays. Whilst for such workplaces the physical location of the displays remains static, the allocation of information between display pages and its location in the navigational hierarchy of the system can have a significant impact on the use of the information and operation of the plant (eg, if the hierarchy of display pages is deep it may take several control actions to access the information). It should also be remembered that in using a VDU based system, the operator has not only to control the unit but also to control the system to locate information and to navigate through display pages, which also forms part of the operator's task.

The two shifting procedure

The unit most frequently used to provide the adjusted load required using the two shifting procedure, was Unit 4. At the time of the study, this unit was operated using VDU touch screen technology with a back panel display as an emergency back up to the system. In examining the two-shifting scenario, only this unit was considered. For this particular task, therefore, only certain of the task elements which were held in common for all units were considered in comparison to the older technology.

In particular in carrying out the two shifting procedure the control of the mills and draught plant were critical operations. The load of the unit relates directly to the number and configuration of the mills that are being operated for that unit. For these tasks both old and new technologies were considered.

The two shifting procedure is initiated by a request from the supervisor for a change in load. The load to be achieved is specified by the supervisor to meet the requirements from the central grid control for the total output of the plant. The efficiency of the plant is affected by the timescales of the response to meet changes in required load. Therefore the skill of the operators in understanding the limitations and functioning of the plant allowed them to optimise the two shifting procedures to respond as quickly as possible to requests for changes in load.

If two-shifting was anticipated then the operators would prepare the unit as far as possible in advance to anticipate the operational requirements.

Control of the mills and draught plant

In the context of the above two analyses, two sub tasks which are particularly important to controlling the load of a unit were evident and these were given particular consideration. These are the tasks of controlling the mills and the draught plant. The two tasks and systems are highly inter-related. The control of the draught plant is discussed and described in detail in the start up analysis and so will not be considered here. The draught plant must be established for a particular mill before that mill can be brought on line, conversely it is stopped once a particular mill has been taken off line. On the units with newer technology, the control of the draught plant is executed by initiating an automated sequence and monitoring that sequence for faults. On the units with older technology, the same sequence is executed manually with each procedural step involving monitoring for successful completion of the sequence to initiate the individual item of equipment, before progressing to the next stage of the procedure.

At a high level, the task of starting up mills and bringing them on line is proceduralised, at more detailed levels of analysis the required operational skill and knowledge involves problem solving and decision making. The mills are labelled A to H and each of the different mills has a different impact on the output of the unit. The impellers are the point at which the fuel from the mills is fed into the furnace and these are located at different points in the furnace for each mill. The operator must firstly make a decision concerning the mills he is to use for a particular task, and whether these will be implemented sequentially or in parallel. Establishing a mill involves monitoring of critical parameters not only of the mill equipment but also of the overall impact that the control actions are having on the unit. On the units with older technology the controls and displays for each mill are located on the console and the operator needs to remain at the console whilst he is operating a mill. However, some of the information on its

impact on overall system functioning is located on the back panel (and some of it is at the periphery of the back panel) and the operator must read this from the console.
For the units with the newer technology the task is carried out using several pages of VDU displays. Essentially the same information is given, but some of the sequences for the start up of equipment are more automated than on the older units. However, the procedure and the monitoring of the mill start up sequences are carried out on both units. Examples from the task analyses of the start up and mill control tasks are given in Appendix E.

Operation under emergency and fault conditions
It was not possible in the course of the study to examine fault scenarios in detail. However, during the period of information collection on plant, a fault situation arose and it was possible to observe the operational activity. However, it was not possible to carry out a detailed analysis as no interviews or retrospective protocol analysis could be carried out. Notes on some of the observations are included here as they impact on considerations for the use of technology in such task environments.

The fault occurred on Unit 4, a unit which is operated using the touch screen VDU technology. Alarms are indicated by both an auditory alarm and an indicator by the screen which indicate where in the system the fault has occurred. The operator acknowledges an alarm by pressing a button located by the VDU screen. In addition to the auditory alarm, all the units have fault annunciator panels located above the back panel displays. These annunciator panels indicate all faults that occur at all levels of the system. The operators are highly skilled in the use of the annunciators. The annunciator panels are laid out in a logical fashion based on the system, and all the annunciator lights are white. The operators appear to use the system on the basis of pattern recognition of combinations of lights, and can usually immediately identify from the panels, the nature and location of the fault. Even in the units where the touch screen system is available, the operators made extensive use of the annunciator panels in fault detection and management. They also enabled operators to quickly note and identify expected fault conditions where the fault had occurred as the result of an expected operational status (eg, unit shutdown). There are a variety of possible hypotheses as to why this occurs. As the majority of operators were highly familiar with the annunciator panels which were in use before the VDU touch screen technology was introduced, then it may be that they simply made use of the technology that was familiar to them. Alternatively, the annunciators provide the fault information without having to access a particular screen in the VDU system, and so provide immediate feedback for fault detection.

In the case of a fault scenario, it was observed that the operators did not operate the system mainly from the VDU system but reverted to operation of the system from the back panels. As two operators were involved in the operation of the system under this condition, it may be simply that it was easier for two operators to have access to the same information and to work more easily side by side on the panel display. It may also be that the operation of the system could be more easily divided between two operators on such a panel. Conversely it may be that familiarity with the technology for the more experienced operators (in terms of operational time spent at the plant) led them to revert to the older back panel technology.

10.6 DISCUSSION

The aim of the study was to allow evolution of the method and to evaluate its use in this particular plant context which offered two different technologies for which the same task was to be performed. These units operated identical processes and the differences were to be found only in the level of automation, allocation of function and human machine interface technologies. The analyses allowed consideration of how the tasks of the operator differed under these conditions.

Panel based and VDU touch screen based tasks

Whilst it was found that the task analyses remained essentially valid for both the panel and VDU touch screen unit operations, some of the tasks of the operator on the panel based units were automated to a higher degree on the units with the newer technology. This impacted on the balance of the tasks on the VDU touch screen units, in the sense that the tasks of the operator involved a higher degree of monitoring and fault management. Tasks which were previously procedural in the analysis were now monitoring tasks in which an automated procedure was initiated and monitored to ensure its satisfactory progression. This is a shift in task emphasis which is widely recognised to result from automation in process plants. This also led to a decrease in the workload of the operator as fewer direct control actions were required and the operator was freed to perform other tasks whilst the automated sequence was running. The operators had no such additional task load on the automated units.

The more complex problem solving and decision making tasks were similar for both levels of technology and the operator was still required to bring expertise, skills and knowledge to bear in the optimisation of control of the unit, eg, in making decisions on the most effective combination of mills to use for a particular load demand.

The impact of automation

A degree of automation existed on all the units under study. However, on the VDU touch screen based units, more of the operational tasks were automated. In terms of its impact on the operation of the unit this had a variety of consequences. In general, the operators were subjectively positive towards the automated procedures, primarily because it meant that the unit load could be changed in a much shorter timescale. This therefore made the unit more efficient. Of the operational pressures that existed in the operational context, time was very important as it impacted on the efficiency of the plant and this was rated along with other similar plants on a national level.

As stated, automation impacted on the balance of the tasks that the operator was required to carry out. The operator gained more of a supervisory role, and the task emphasis shifted. Under such conditions the early detection, recognition and analysis of faults was more important. Although on the VDU touch screen based units, the operator was required to monitor the progression of the automated sequences, this also occurred on the panel based units. Here the operator was required to monitor the sequence of events, not as a whole, but as each element of the procedure was carried out. The progression of that element was monitored and its successful completion or achievement of a particular status provided the stimulus for progression onto the next stage of the procedure. Each element also had to be monitored for a fault condition. Rectifying these faults was no less important than in the more automated contexts. The fault management also required similar actions to be taken. Therefore, the primary task change was in the required control inputs and execution of the procedures. Within the automated units there was also more potential for on line decision aids to be included in helping the operator in the more cognitively based tasks.

The use of task analysis for determining display structure and layout

In a VDU based system, one of the prime problems in design is the division of information into display pages. Some information is required constantly by the operator, other information needs to be accessed only occasionally. In such a context, a task based design, rather than a system based approach to the provision of information, is essential. To operate the system effectively and to minimise the opportunities for operator error, the operator must have all the information required for a particular task available. The design of the information must take into account not only the information required to perform the task, but also the information required should a fault occur. In normal operation the information may simply be an indication to the operator that the system is carrying out required functions. However, in the case of a fault, if fault management is not automated, then the operator will require much more detailed information on the nature of the fault and its impact on system functioning.

The proposed method of task analysis allows the information requirements for each task to be specified at all levels of the hierarchy. It makes relationships between tasks and the information required to perform those tasks explicit. This provides guidance to the designer for the structuring of the system, both into display pages, and into the content of information that should be included on each display. Such information can be similarly applied to the design of panel displays where the total layout of the panel needs to incorporate decisions on the way in which the information will be used and the related task flows.

The use of task analysis for the evaluation and design of process based VDU displays

In the development of the enhanced method of task analysis for the design and evaluation of VDU based process displays, recommendations are made as to potentially optimal display formats for different process task types. The recommendations for display formats are derived from display formats that are commonly found on existing process plants and that are reported in the literature. However, the displays currently in use at Didcot did not conform to 'conventional' process display formats. The displays were primarily graphical and in some cases 'mimicked' the dials and other displays found on the control panels. Such mimicking in the Didcot environment helped in the transfer of operators between the different technologies, at the same time however, it may be that more optimal use could be made of the particular attributes of the VDU display media which are not offered by panel type displays.

The system at Didcot offered an unusual problem in that the touch screen technology meant that displays had to be combined with the means of control in the same medium. Therefore, it would have been both difficult and inappropriate to use the more conventional process displays. In the context of this project, the display formats themselves could not be evaluated other than in the extent to which they conformed to ergonomics criteria for display design. However, the analysis could be applied to the specification of the required information flows and the grouping of information into coherent units. As previously stated, this could not easily be carried out for the tasks studied, in isolation of other tasks which the system was to be used to perform. This is particularly the case in VDU based systems, where all the information available is not displayed simultaneously to the operator (as with panel based displays) but must be divided into display 'pages' a limited number of which can be accessed by the operator at any one time.

However, it became evident that the extended HTA method could provide a useful framework in which decisions could be made about the information required by the operator and the relationships between the information and the tasks it was to be used to perform. Such information could be applied equally to the design and the evaluation of display formats. One problem which directly relates to this specification of information requirements also arose in the context of this study. In a context where operators are highly familiar with the system under study and have a high degree of skill and knowledge that relates to the system, elicitation of information requirements can be difficult. This is because the operators describe and perform the task with the information available. Information that is not required in performing the task can be identified, but it can be difficult to identify requirements for information that is not available. Therefore it is essential in any study where highly skilled operators are to be used as a source of task information to ensure that this information is collected as systematically and thoroughly as possible.

Problems and issues arising in the study

At an overall level within this study, it was difficult to make recommendations for information design within the plant for several reasons. Within the time available for study of the plant, only a sample of tasks could be examined. At the outset of the study this was not felt to be a problem and tasks that were both representative and critical to plant operation were selected. However, as the study progressed it became evident that the highly skilled operators used the totality of their plant knowledge, where appropriate, in carrying out the tasks and it was difficult both to elicit this knowledge and to document it within the analysis of the tasks sampled. The result of this was that any recommendations arising from the study have to be considered within the limitations of the scope of the analysis.

Usually in the design or evaluation of the tasks and information flows of a system the operator's tasks would be examined as a whole and the issues arising from this study serve to highlight the importance of this. To gain an effective and complete view of the task context and its associated information requirements, the full range of tasks relating to an operator must be examined and their inter-relationships analysed. This provides a basis from which all the information required for a particular task can be grouped and recommendations for display design derived.

Detailed recommendations were not produced for the plant as a result of this study as their usefulness would be limited by the scope of the work. As the display surface used was also the control medium, their format was unique to the plant. As the displays did not follow any conventional process display formats, information gained from the relationships between tasks and display formats could not be used to feed into the recommendations for display types and task types given in chapter 11. However, the study provided a useful insight into the way custom designed graphical displays could be used to display process information.

All the other aims as outlined in the introduction were achieved as a result of the study. The analysis was able to examine information requirements in a context where the control medium and the medium for information display were the same. The differing technology of the four units in the control room provided the opportunity to examine the way in which tasks and information requirements may change as technology is updated within a plant. The study showed that if an analysis is carried out systematically, then the analytical information will remain valid and not require modification, as long as the functions of the system and the human's role within it do not change. However, such an analysis may require iteration if the technology that is used to achieve those functions changes, for example increased automation, as was indicated by the changes in the operator's tasks on unit 4 when compared to the units with older technology.

Conclusions

The developed method of HTA proved to be effective, when judged according to criteria outlined in previous chapters. This application was for a continuous process plant, which provided a utility rather than a product, and which had to respond to frequent changes in output demand.

Eliciting the information requirements of tasks from highly skilled and trained operators can be problematic and requires a systematic and through approach with a high investment of time for information collection.

The study underlined the need to document the skills and knowledge required of the operators in carrying out task operations. This is especially so, as on this particular plant operators held much of the information required for task performance in memory.

In automation of the plant, it was usually the highly proceduralised tasks that were automated. This impacted on the nature of the operator's task, which consequently had much less of a procedural element and involved a higher degree of monitoring and fault detection.

If there is a change in the allocation of function between the human and the system the analysis can often be updated and iterated to accommodate the required changes.

An analysis of tasks and information requirements as outlined in this study aims to be independent of the media by which the information is presented. It should therefore remain valid with changes in the technology by which the information is presented provided that the functionality of the system and the functions required of the human do not change.

In its current format the analysis defines the information requirements of a task operation. If the analysis is to be used for the evaluation of an existing system then it would be useful to include details of the current locations of each item of information, this would allow the layout of information within the workspace to be assessed.

CHAPTER 11
A TASK ANALYSIS TOOL TO DETERMINE PROCESS CONTROL OPERATOR INFORMATION NEEDS AND PRELIMINARY DISPLAY GUIDELINES

OVERVIEW

Within the discipline of ergonomics, task analysis is a fundamental methodology in approaching the design and evaluation of a system. Whilst task analysis provides a means of studying tasks in detail there are no "tools" that exist for translating the derived task information into design recommendations for process control displays. A process control context provides the possibility of providing concrete guidelines for the design of displays . This is because there is a degree of commonality in the display types that are currently used or could be potentially used within a process context. Furthermore, there is also a degree of commonality in the types of tasks which process operators are required to perform and a classification of these tasks is proposed. This chapter draws on the theoretical and empirical work carried out for display design in a process control context. Preliminary guidelines and recommendations for translating these task types into display design guidelines and recommendations are described and the different display types discussed.

11.1 DERIVATION OF DISPLAY GUIDELINES FROM HTA

Task analysis is viewed as an essential part of an ergonomist's repertoire of "tools". It provides the human factors specialist with a means of breaking down a task for a range of applications such as design and evaluation. Whilst task analysis can be carried out to analyse the task that a human has to perform in using displays and information, and there are guidelines on display design available, the only method of translating information obtained by analysis into display design criteria, is by the use of human factors knowledge and expert judgment. There is no formal method for deriving display design guidance from an analysis. In addition, whilst there are a number of volumes of guidelines on display design (for example, Smith and Mosier, 1974), there are none published which deal explicitly with process control display design. This has two implications for the design of process based displays. Firstly, it increases the likelihood that inconsistencies will occur in the display design recommendations offered by different analysts, or human factors specialists, even if there was consistency in analysis.

Secondly, in the plants visited throughout the course of the study, engineers and designers were becoming increasingly involved in the application of human factors techniques within systems design. Whilst they were able to apply the analysis methods with some training, it was not possible for them to derive even simple, concrete recommendations and guidance for design.

From this it was evident that more than a detailed task analysis was required to provide a useful "tool" for display design, and that guidance on display design should be available to the analyst as a result of the analysis. Following case studies 1, 2 and 3 the analyses carried out indicated that, within a process control context, the tasks that an operator would be required to carry out fell into a limited number of categories. These categories are described in the classification scheme in figure 11.1. Furthermore, taking the state-of-the-art in process control display design into account, there are a limited number of display formats offered by the manufacturers of process systems. Whilst the manufacturers could offer customised display types, plant designers tended towards the commonly used formats such as mimic displays. Although in some of the plants visited customised plant displays were used, these tended to fall into a specific range of display types, such graphical representations of plant equipment.

Given that both the display formats and the task types formed a limited set, it was decided to produce a method which allowed display guidelines to be derived from the extended version of HTA. The display information produced would be in the form of guidelines rather than a detailed specification of the displays. This is because the tasks and displays used in process control, whilst they share commonality at a general level, are very plant specific, even between plants which perform identical functions (for example, case study 1). So, for the guidelines to be generally applicable it was necessary to limit the information to general guidelines on display formats. So the classification scheme was developed to describe the range of task types encountered in process control. A review of the literature and plant visits were used to define the displays available for use in a process control environment. The detailed information content of each display is outlined in the task analysis for each task component. This also makes explicit the relationships between tasks.

There are many task analysis techniques available which aim at a taxonomic approach to the breakdown of tasks. Some of the taxonomies are well known, for example, Gagné (1972) and Miller (1967). It is an approach which allows specific problem areas to be addressed, and classification schemes have been developed for both tasks and displays. Display classifications have been used for a variety of purposes. Different classification schemes stress different display attributes, for example, some emphasise the medium of communication, whilst others stress the system purpose such as command or control.

At a high level, attempts have been made to allow systems to be configurable and managed to suit operator information needs, for example Kanawsky (1983). Many of the classificatory or taxonomic schemes which function effectively in the literature are rigorous. For a classification to be rigorous it must have terms which are mutually exclusive and exhaustive, no one term should contain elements of another. According to Miller (1967) a rigorous taxonomy is only possible when it quantifies, ie, is based on some kind of count. In the behavioural sciences this is often not a feasible approach, categories cannot always be so clearly defined. One approach suggested by Miller is to identify the fundamental underlying elements or sets of building blocks, this would allow behaviour to be categorised and quantified. The attributes of such a taxonomy are given below:

1. Categories should be easily learnt and applied.
2. Categories should parallel the segmentation of training into part tasks. *(Note Miller's own taxonomy was devised for a training context)*
3. Possible types of error should be anticipated.
4. Levels of analysis reflect the level at which predictions are better than random observations.

11.2 DEVELOPMENT OF A 'TOOL' FOR DISPLAY DESIGN

The approach taken to the development of a 'tool' for display design was to consider the information produced at each level of the analysis, developed as a result of the theoretical part of the research and evolved through the case studies, and how this could be translated into design guidance. The HTA provides detailed information on the individual operations involved in carrying out the task, and indicates where the human must interface with the system. This shows where display information will be required, given the analysis in its existing format. The extension to HTA makes explicit the information flows to and from the interface and the information content of these flows. This indicates the content of the displayed information that is required for each task, and the aids, skill and training that the operator is expected to have to allow him or her to perform the task. The classification of each task operation into its task type, or types, provides the means by which display formats can be selected for tasks. The classification scheme was developed to organise the task analysis information into units in a way that could be used in design. In this study, the classification scheme is used to produce display design guidelines, however, it is intended to be sufficiently general to have other applications within a process control context.

11.3 THE CLASSIFICATION SCHEME

In the development of a classification scheme of task types for process control, a variety of approaches were considered, encompassing both skills, task attributes and psychological processes. Previous classification schemes such as those by Fleishman (1972) and Farina (1973) were reviewed to gain an insight into methods that had been used before and possible approaches.

The initial scheme that was developed was amended following its application in case study 1, as it was found that some of the categories were too general to be effective, and that from a practical viewpoint a slightly different scheme would be easier to use. The classification scheme that was developed and that is used to derive the display design guidelines is described in figure 11.1. The classification scheme is not intended to be mutually exclusive and exhaustive. Within the task context under study this would prove too restrictive as some of the tasks may include elements of one or more of the task categories. A totally rigorous approach was not the goal. As the classification scheme stands, any overlap between categories allows certain implications to be drawn for task and display design. For example if a task involves elements of both monitoring and fault detection, as is often the case, then the display design would need to make explicit not only the system status but also help the operator to spot deviations from the norm.

Whilst the taxonomy does not aim to have mutually exclusive categories and be exhaustive, it does provide a framework for looking at operator information needs in the context of the process control tasks to be performed. The scope of the taxonomy aims to cover 'any task, in the context of process control interface design in the control room, involving the exchange of information.'

TASK TYPE	DEFINITION
Monitoring	Sampling information to determine the correct states of variables of importance. This includes the identification of deviations and manipulation of the information to determine changes in system states.
Fault Detection	Perception of a fault having occurred or being imminent.
Prediction	Judgment of likely future system states.
Problem Solving	Process of resolving uncertainty about system states.
(Fault Diagnosis	*A specific kind of problem solving task involving identification of the root causes of a fault)*
Decision Making	Choosing between alternative responses on the basis of available information.
Procedural	Following a pre-determined sequence of events.
Motor Tasks	Any operator action upon system state or configuration.
Communication	Accurate transmission of information without any processing of the information from transmission to reception by the individual or group who will use it.

Figure 11.1 A taxonomy of process operator tasks

11.4 THE 'MAPPING' OF THE CLASSIFICATION SCHEME TO DISPLAY DESIGN RECOMMENDATIONS

In developing a 'mapping' from the task classification to recommendations for display types, the aim was to provide a means of translating one into the other. It was insufficient simply to state that for one task type such a display format was optimal. Task situations were insufficiently uniform for the recommendations to be provided at this level. So the the aim was to develop an approach where the classification of a task, along with the specific task attributes, could be used to suggest possible formats for display of the information.

The psychological attributes approach

Initially the first scheme to be considered was one based on a paper by Easterby (1984), where tasks were defined in terms of their primary and secondary psychological attributes. These psychological attributes were the psychological functions required in the performance of each task type. The primary attributes were those that were dominant and essential in the performance of the task. The secondary were those that were not used in all cases of task performance, but nevertheless were characteristic of the task in question. Having determined the psychological attributes of each task type, the aim was to recommend display types which were particularly suited to specific attributes or combinations of attributes. Figure 11.2 outlines the list which was used in the classification of task types into their psychological attributes.

However, the scheme was found to be very difficult and complex to use. It also required considerable expert knowledge and subjective judgment in its applications. Moreover, given the limited research that has been carried out specifically into process control displays, for some display types there was little experimental information available on which to base details of the psychological attributes. The guidelines were to be based on the literature and other information available on display types. This was because within the timescales of the study, it was not possible to carry out detailed experimentation to compare the effectiveness of different formats for different task types (although a study was carried out to compare loop and deviation displays within the context of the European Coal and Steel Community Project, case study 1).

Detection	Discrimination
Identification	Recognition
Comprehension	Sorting
Searching	Classifying
Labelling	Integration
Judgment	Selecting
Scanning	

Figure 11.2 The psychological attributes involved in process control tasks (after Easterby, 1984)

The task variables approach

The alternative approach adopted was based on consideration of the task variables that were important in the selection of a display format for a particular task type. For any task type within the classification, there are a number of display alternatives. For each there are key variables which influence the display type that is most suited to the task. By identifying these key variables and considering each individual task in terms of these variables, recommendations for display formats can be made. This approach allows tradeoffs between tasks and display types to be considered. Some display formats may be recommended for more than one task type on the basis of their approach to the presentation of the information. The following sections describe the range of most commonly used process control displays and the display guidelines for each task type given in the classification.

11.5 DISPLAY FORMATS FOR PROCESS CONTROL

To provide a context for the application for the display design guidelines the display formats themselves must firstly be described. As previously stated, there is a limited range of display types commonly used in process plants, although plants may have one or more 'customised' displays, for example a pictorial display of an item of plant equipment.

Mimic Displays

Mimic displays offer a graphical representation of the plant. The plant items or systems to be controlled are indicated on the display and connected by lines indicating the flow between them. The items displayed usually include vessels, valves, pumps, stirrers etc; along with the values of relevant sensors (for example for temperature) which are displayed in association with the plant equipment they relate to. Figures 11.3 and 11.4 provide an illustration of an example of functional and geographic mimic display representations of the same plant. Mimic displays can reflect either the *functional* or *topographical* (geographical) layout of the plant. Whilst research (Vermeulen, 1987), has indicated that neither is more effective than the other in operational performance terms, many process displays that are used for more than one task opt for the functional presentation. It is held to help the operator to visualise the functional relationships between plant items, especially under fault conditions. However, the effectiveness of such displays is highly dependent on the training of the operators and their knowledge of the plant. For example if the operator has been trained on the plant before moving into the control room, then it may be the case that geographical mimic displays reflect more accurately his or her mental model of the structure of the plant and of relationships between plant items.

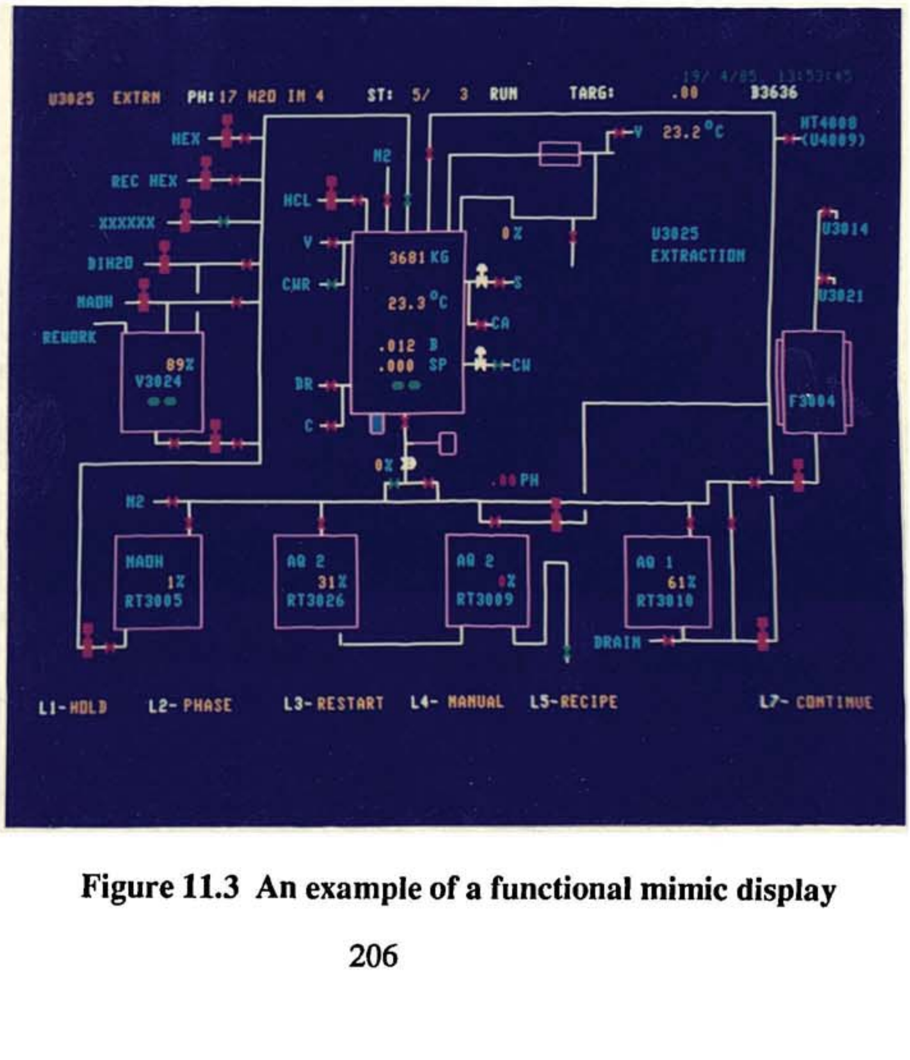


Figure 11.3 An example of a functional mimic display

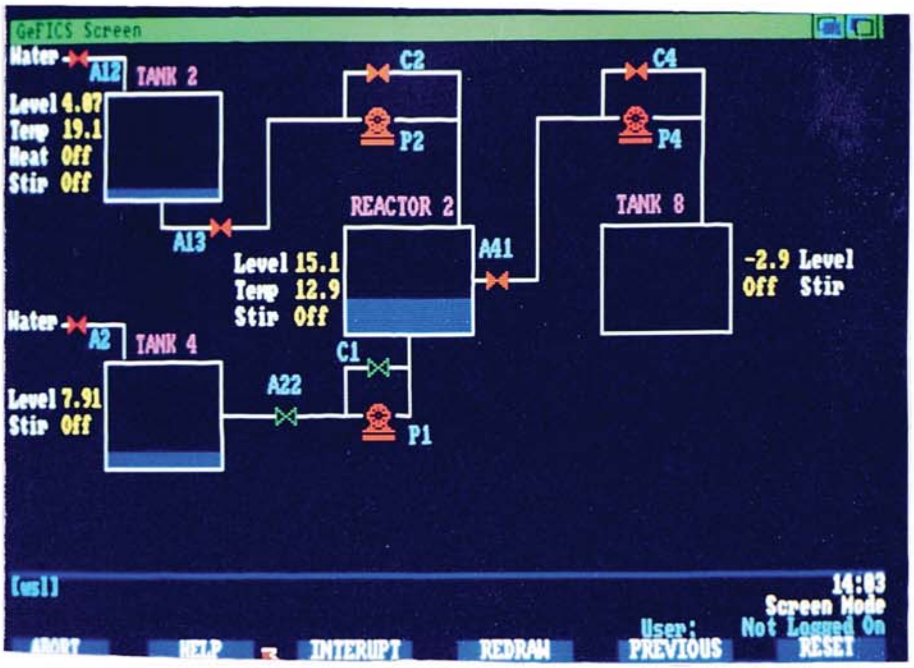


Figure 11.4 An example of a topographical mimic display

Mimic displays are used for a wide variety of operator tasks both in the plants outlined in the context of this research and on other plants visited. These include procedural tasks, monitoring and fault diagnosis.

Sequence displays

In process control environments the control of the process will often take the form of a predetermined sequence of operations, often in the form of a procedure. Such sequences can be displayed in a format that specifically reflects this sequence of operations and so guides the operator through the process. Sequence displays can be formatted in a variety of ways, for example for simple sequences it can take the form of *textual lists* (for example, figure 11.5) whilst other more complex sequences can be displayed in a graphical form such as a *flow chart* or a *network*. Research undertaken at Warren Spring Laboratory (Visick and Simpson, 1986) indicates that graphical networks are preferable for sequence displays both from a performance viewpoint and from the subjective preferences expressed by users. The advantages of this format of display become apparent when the sequences become complex and could not be adequately represented in a textual format.

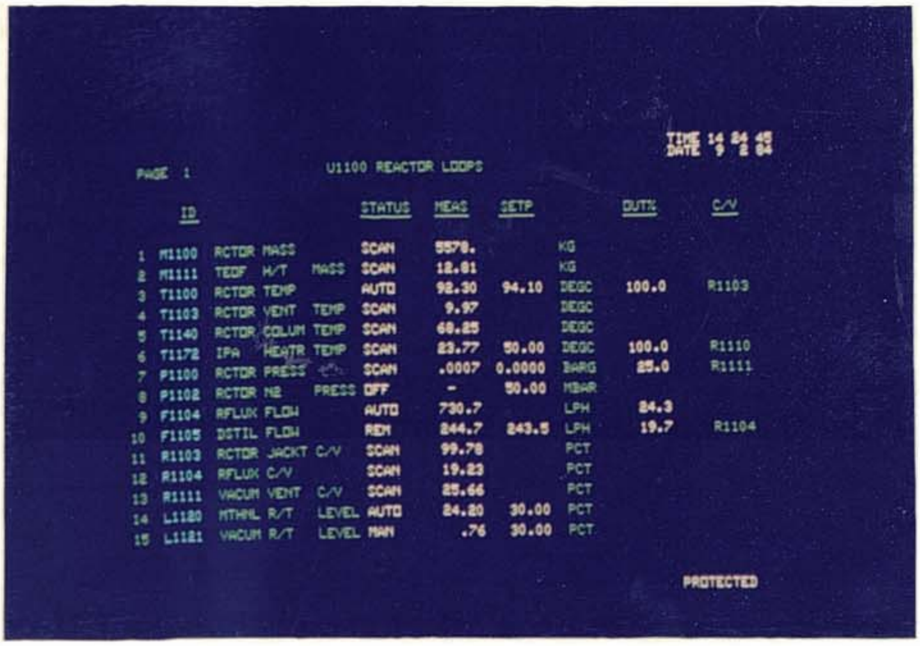


Figure 11.5 A textual sequence display, also used for monitoring and fault detection tasks

The recommendations given for such display formats by Visick and Simpson are briefly:

- Use one line of text for each step in the sequence (where text is used to represent the sequence)
- Highlight the current step, preferably by using a different or brighter colour for the relevant line of text.
- Use the same terminology and item identification as found on related displays.

Command displays

Command displays are normally used for predictive tasks within control systems. The exact format of the display is system and task specific. It is based on the principle that a trajectory for future system states for a task can be predicted, usually in relation to just one variable. The trajectory is computed and deviations from this are shown as errors. These are displayed so that the operator can detect deviations before they would normally be observed.

Alpha-numeric display formats

Alpha-numeric display formats offer a multitude of possible formats, from help pages with text in natural language, to lists of numerals representing process parameters. Within the human factors display literature, there is much research available on the formatting of alpha-numeric displays for different tasks such as text entry. In the guidelines given for choice of display formats, it is assumed that such human factors principles will be observed. Alpha-numeric formats are most useful when there is the need in a process situation for detailed and accurate information, for example in a fault diagnosis situation, where detailed information is required on the plant equipment, functioning and status.

The displays often take the form of lists, which can be static or dynamic. Examples of static type list displays include the display of procedural steps, process steps (as for example in a batch process) and static system parameters. In these instances the information is displayed in a fixed format on the screen, and cannot be altered by the operator. Dynamic list displays are most commonly used for alarm displays, or for complex processes, where there is a significant number of elements in the process (more than one CRT screen full). Dynamic displays cannot usually be altered by the operator, but contain information relating directly to the status of the plant. The displays often scroll (upwards or downwards), new items of information being added to the screen as appropriate or as they become available. The third type of alpha-numeric display format found in process situations is that of an interactive type of textual or numeric display. These displays require the operator to input information in response to certain parameters displayed on the screen. Examples might include a process set-up screen, where the fundamental parameters of the process are entered and defined before start up, or a computerised log, where the operator is required to fill in an on-line "form" giving information about plant status.

In addition to 'pure' alpha-numeric displays, there are many hybrid display formats, where other display formats have a section that is purely alpha-numeric. For example, a mimic display where a process variable can be selected and detailed process information in an alpha-numeric form given at the bottom of the screen (this does not include displays where text and numerals are used for labelling, or to give numeric process information).

Pictorial/graphical display formats

CRT displays can offer graphics displays that are not possible with conventional displays. This flexibility means that plants can make use of pictorial displays and high resolution graphics to represent information in a way that is easily understood and used by the operator. The main advantage of such display formats is that they are not constrained by convention and can be tailored to suit the task. For example, in the fourth case study, the temperature of different parts of an item of equipment needed to be monitored. In such a situation, a pictorial display of the equipment with the temperature indicated on the display, may be easier to monitor than a textual list of the measures of the different temperature variables. A simpler example is the loading of the rail wagons with prepared coal, from case study 1. In one of the plants studied a simple graphical representation of the wagon was used, with the level of 'coal' rising in the wagon as it filled up. Detailed guidelines for formatting of pictorial displays cannot be given, as the displays will be dependent on specific plant features and the operators' information needs. However, situations where such displays might be useful include:

- situations where a general qualitative overview is needed of plant items which can be backed up with digital information.
- where a pictorial representation of a complex plant item helps an operator to relate problems and operation to the equipment on plant more readily (mimic displays do not usually give detailed information about individual items of equipment).
- where representation of the information is difficult in pre-defined display formats such as loop displays and a graphical or pictorial format can be devised.
- where a pictorial representation offers more information in an integrated way than other display formats can.

Object orientated displays/polar co-ordinate displays

Object orientated or polar co-ordinate displays (also known as integrated or shape displays), aim at the integration of information from multiple channels to enhance performance in recognition of total system state (see figure 11.6). The displays are usually based on geometric shapes, with variables indicated as the points on a geometric object. Each angle of the object, or point on the circumference of a circle, reflects a variable. The axes of each variable pass through each point and meet centrally. The axes may have different scales; however, it is usual for these to be normalised so that when the system is functioning normally the display will appear in the expected format. However, deviations in system functioning will lead to deviations in the shape of the character. Operators should then be able to recognise system states by the different shapes formed, and familiar system states will form familiar patterns, such as at start up, shut down and system change over periods. Likewise fault conditions should form identifiable patterns.

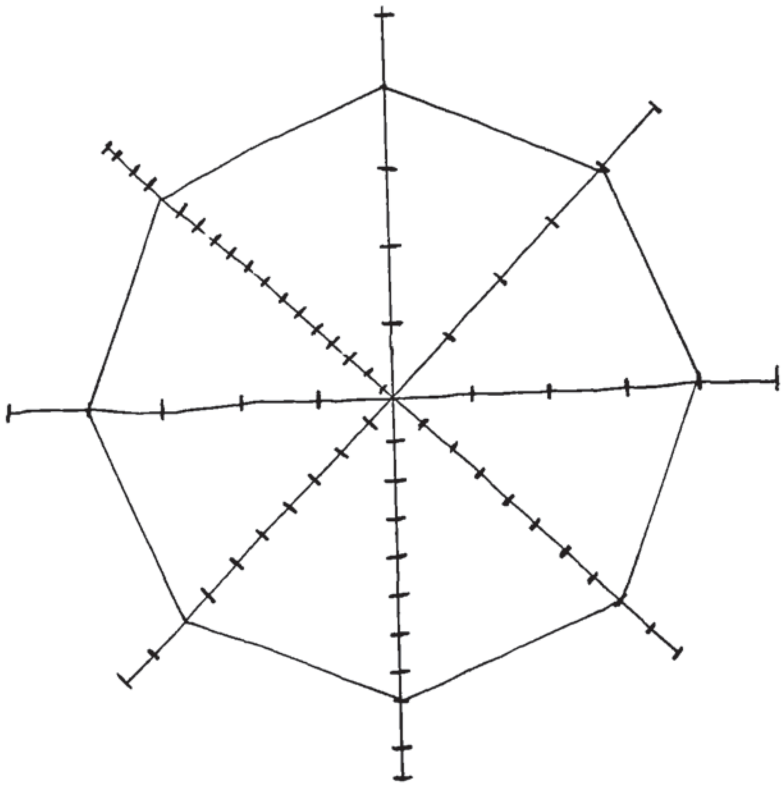


Figure 11.6 An example of an object orientated display format

The aim of such displays is to allow rapid monitoring of system states. It is based on the ideas of Gestalt psychology that humans will look for form in shapes and that the processing of such integrated information takes up less cognitive capacity than processing information about individual variables. A study by Munson and Horst (1986) indicates that the perceptual demands of the task are relatively low, and increased reaction time does not appear to increase in line with the number of parameters to be processed. The idea of object orientated displays was originally proposed by Coekin (1969) and has been considered further by Wickens (1986) and Goodstein (1981). In principle, any geometric format can be used, although experimental studies have used triangles, rectangles and polygons. Wickens (1986) reports on some of the tasks that the displays have been used for, both in his own and other research. These include monitoring, identification of system states, tracking, fault detection, fault diagnosis. Overall, the attributes of the display make it especially suited to general monitoring and the rapid detection of total system state.

Loop displays

Loop displays are frequently found in process plants as a "traditional" way of displaying process variable status. This is because they present the control information for each process variable in a way that relates to the controller, ie, in the form of a setpoint, measured value and where applicable output (or power). These can be grouped functionally, often by system to give group loop displays. These were the principal displays in use at the Rawdon Coal Preparation Plant (Case Study 1). Loop displays show each process variable in the format of a three point controller. The displays are based on a transfer to VDU displays of the faceplate displays of three *term controllers,* and so may have originally been designed to facilitate the transition to the use of VDU displays. The most commonly used format for loop displays is that of a comparative bar chart where each of the three values is represented by a bar on a common axis.

Whilst the analogue display provides a general indication of the relationship between the setpoint, measured value and output, the operator may need to know the absolute value for the task he or she has to perform. So the analogue display may be supplemented by a digital form. However this has been shown to reduce the effectiveness of the analogue display (Astley et al., 1988). Also such displays often contain extraneous information, the output information is usually used only by engineers and may detract from the easy reference bar graph format. In addition, if group loop displays are used, the displays cannot be normalised (reduced to a common scale) and so comparison is difficult and there will be variation in the points (in relative terms) at which the displays move out of acceptable ranges.

Deviation displays

Deviation displays are used principally for monitoring and fault detection tasks. They indicate when a variable deviates outside of accepted threshold values which are preset. In its simplest format the display comprises a horizontal line which represents a setpoint with a small vertical line indicating the magnitude of the deviation from it. It is more usual for the display format to take the form of a horizontal bar with the deviations illustrated in the form of bars. The deviation display can indicate deviations in both positive and negative directions (ie, above and below the horizontal bar) or in one direction only. Figure 11.7 illustrates a commonly used format for a deviation display.

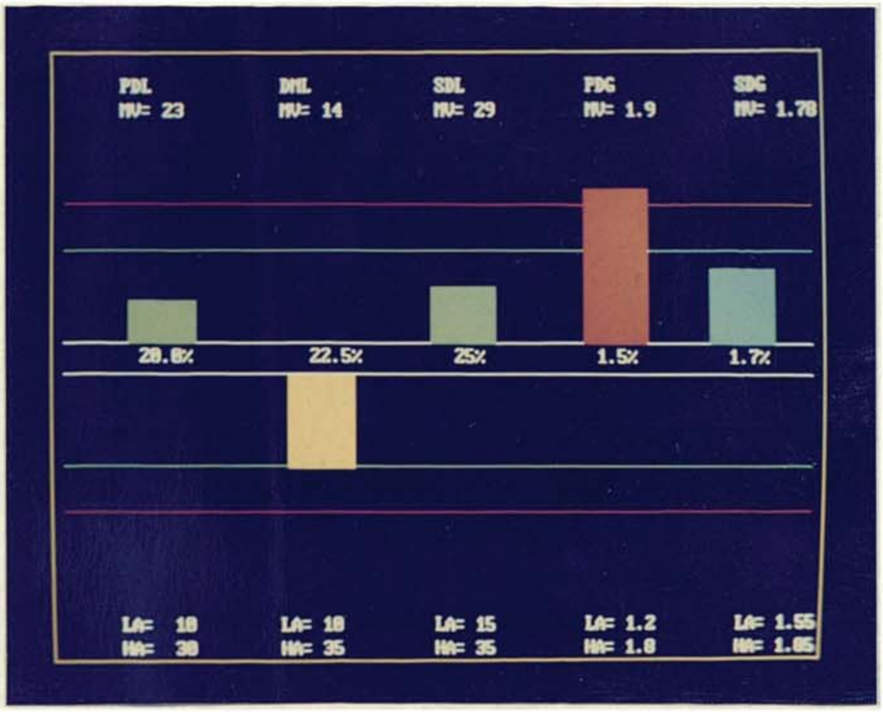


Figure 11.7 A deviation display format

The advantage of using deviation displays is that for a monitoring task, deviations from the accepted range of system values can be quickly detected on the display, and so prompt action taken. However, the number of points or variables that can be displayed is limited. No research was found to indicate the threshold values for the number of points to be used on such a display. However, this is likely to be plant and task specific as it will depend on the integration of information and the relationship between adjacent variables. For deviation displays, it is hypothesised that if the operator is able to integrate several points into familiar patterns of system functioning, then more points can be displayed than when individual points on the deviation display have to be considered on an individual basis.

In addition, the data points on deviation displays are normalised so that all values move out of the acceptable range of specified values at the same point on the display. This makes detection of faults and abnormal plant conditions easier. Digital and absolute values can also be incorporated into the display .

Graphical/trend displays

Graphical displays may be used for a variety of purposes within a system. However, within process control, their main use is for displaying trend information on one or more plant variables. This trend information may be used as historical plant data to give information about plant functioning and performance. It may be used to help diagnose current plant fault conditions and it may be used as a predictive tool to anticipate future system states or to evaluate future alternatives. No evidence was found in the literature for detailed trend information being presented in other than a graphical format. The display of graphs on a CRT display is limited by both the size and resolution of the display screen. The size limits the size of the graph that can be displayed and the resolution limits the number of possible data points and the size of the scale on the axes. In the literature the following recommendations on the design of graphical and trend displays for CRTs were found:

- A maximum of 4-6 charts should be used on the screen at any one time (Jervis, 1971).
- Recommended layouts for the graphs include:

  1. An independent y and time axis
  2. An independent y and common time axis
  3. Common time and y axes.

The latter is particularly helpful when several trends need to be compared on the same screen.

11.6 DISPLAY DESIGN GUIDELINES

The guidelines are intended for use by those responsible for producing display designs and process information system and display recommendations using task analyses and related information as a basis for design. The approach adopted was deliberately pragmatic and intended to present a starting point for consideration of the issues in display design rather than a specification of information display. The guidelines that are presented were produced as a result of both the theoretical and empirical work carried out for the present thesis and are intended to present a possible approach for using task analysis directly in the design process.

The guidelines are intended to be used in conjunction with the extended version of HTA. However, any method of task analysis could be used, if it provides the required information input into the guidelines and was produced in a format that allowed the tasks to be classified according to the task taxonomy. From the analysis, each task is considered not only in terms of its task type, but in terms of the important parameters that need to be displayed and their variation within the task. For example, within trend displays, the temporal parameter is very important. It determines the nature of the display, and whether historical, predictive or current system information is given. Likewise for each task or group of tasks, the important variables need to be compared to the critical variables outlined in the guidelines, and tradeoffs made for a decision to be reached on the choice of display format. The variables given in the guidelines are either parameters that are critical to task performance, or parameters which form the principal differences between alternative display types.

The data for the guidelines were drawn primarily from the literature, current industry practice and from the knowledge of professional human factors specialists.

To help translate the task information into display selection, the guidelines have been devised to enable selection of an applicable display format for each task. Once these have been identified at all levels of the task, the analyst and designer then have a basis on which to make decisions and judgments for the design of the display system. Within the context of this project, the guidelines only deal with the state-of-the art computer based CRT formats. This particular area was addressed for the following reasons:

1. Most new plants that are built, or modifications that are carried out, use display systems of this kind.
2. Most of the manufacturers have a set range of display types. Although these can be combined in to hybrid displays, most process display systems are designed around these basic formats.
3. Whilst guidelines for the physical characteristics of CRT displays are well established from an ergonomics viewpoint, for example scan rate, and resolution, the use of display formats in process control is documented to a far lesser extent.

It is assumed that in the use of the guidelines to select display formats the following will be considered and the appropriate tradeoffs made and compromises reached:

1. All personnel who will use the system and their tasks, are considered in the selection of the guidelines. The selection will take into account their relative use of the displays.

2. The formats will be considered in the context of the task analysis and the skills and knowledge that the operator is assumed to have.
3. The formats will consider the relationships between tasks and task elements as described in the task analysis.
4. The variables used to select the displays from the guidelines will be based on the task analysis, or other systematically derived task information.
5. The content of the displays will be derived from the same analysis, to ensure that the breakdown of tasks and relationships between items of information is based on the same source and so can be used consistently throughout.

In the following section the guidelines are given in a tabular format, accompanied by descriptive text considering the issues concerned with display formats for each particular task type. The table comprises four columns. Use of the guidelines should begin with reference to the second column. This outlines the variables that are used to differentiate between the different display formats for a given task type. For example for most tasks, time is a key variable which impacts on the choice of display. Each of these variables can be divided into criteria which differentiate between the displays in relation to this variable. For time, these criteria might include short, medium and long term operation. These criteria are given in the third column. The first column offers a description of each variable and the criteria. The final column indicates the different display types that are most commonly used for that task type, and indicates where a display format is suitable in relation to particular variables and the criteria within them.

11.6.1 MONITORING

Sampling information to determine the correct states of variables of importance.

Monitoring is probably the most prevalent operator task in modern process control systems. In systems where control is centralised, monitoring will usually account for a large part of the operator's task. Monitoring involves a continuous checking of system status with a twofold purpose. Firstly, to ensure that the process is running smoothly and as expected, and secondly to ensure rapid detection of faults. As automation increases, so the role of the operator as a supervisor and monitor of the automatic system is more prevalent. Whilst the problems of maintaining vigilance and attention in such situations are well known, automating the monitoring task itself may not be a possible or be a practical solution. If operators are unaware of current system status and a fault occurs, it may be difficult for them to react to the fault in appropriate ways. Firstly, because, as the system is highly automated, they may have little experience in actual plant operation. Secondly, because it may take time before the current system status and events leading to the fault are assimilated by operators. The problems with automation are well documented by Bainbridge in her paper "The ironies of automation" (1983).

The prevalence of monitoring tasks has led to a range of observations on the effect of monitoring in relation to the arousal of operators. In his classic study, Mackworth (1949), found that a performance decrement occurred over 2 hours in both experienced and unexperienced operators in a monitoring task. Such tasks can lead to under arousal, resulting in boredom and reduced levels of attention. Under such conditions the operator may fail to note important pointers toward system status. Hockey (1983) distinguishes between boredom resulting from monotony and boredom as a result of task content. The task and arousal of the process operator can be affected by both.

Brouwers (1984) found that the type of monitoring to be carried out related to the degree and type of automation on the plant, and the impact of this relates to the frequency and objectives of the monitoring. Brouwers outlines three degrees of automation:

Level 1. Intensive monitoring
: Here displays are under continuous observation. Information available relates to control of the systems.

Level 2. Active monitoring
: The aim of monitoring is a regular inspection of process conditions and operations, control actions can result.

Level 3. Survey monitoring
: Surveying process conditions and related trends. Often the monitoring is related to prescribed administrative work. This seldom leads to control actions.

It is generally true that, as the level of plant automation increases, so the proportion of the operator's task devoted to monitoring increases.

Critical variables in monitoring tasks include the number of channels to be monitored and the number of levels per channel. Kanarick and Peterson (1969) found that monitoring 6-10 channels produced fewer performance errors than monitoring 10 or more channels. It is for this reasons that many displays which offer arrays of variables for monitoring, aim to integrate the information in a way that both aids the task and reduces the perceptual loading on the operator, for example object orientated displays (Wickens, 1986). A study by Gould and Shaffer (1966) indicated that when many channels are displayed to the operator, the strategy of the operator usually involves monitoring the first four for indications of overall system status. Generally, if the operator is overloaded some selectivity occurs in processing.

A further important variable is that of the rate of information change and the frequency of the signal. A longer updating time may help the operator with "keeping track" behaviour (Kanarick and Peterson, 1969), whilst uncertain and irregular signals can increase reaction time (Loeb and Alluisi, 1970). It has been noted that in addition to these variables, the patterns formed by the information can aid monitoring behaviour.
The variables should also be presented at the level of accuracy and detail required by the operator.

The display formats that can be used to provide information for monitoring tasks are varied. Almost all the display types described in section 11.5 can be used for the purposes of monitoring. Often the formats used for monitoring tasks are mulit-functional and are used for other tasks such as start up and operational tasks. The relationship of the monitoring task with other tasks that occur in conjunction with it, impacts on the choice of a display format. For example, the monitoring of the system during an automatic start up sequence may be better represented by a mimic or sequence type display, which shows the relationship between elements in the system, rather than a loop display, which gives detailed information on the individual variables. If the system is small, then the multiple use of one format for several tasks can be a viable solution.

Monitoring tasks also relate closely to fault detection, in that monitoring may be carried out for the purpose of identifying abnormal system states. It may also involve an element of prediction as the operator may be required to anticipate future system states. Therefore when applying the guidelines given in figure 11.8.1 account should also be taken of the guidelines given for fault detection and prediction tasks when appropriate.

Figure II.8.1.a. DISPLAY GUIDELINES FOR MONITORING TASKS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
Level at which monitoring is required	The level at which the system variables and their deviation from the required values are to be monitored. This can vary from an overview of total system status to the level of individual sensor values	Overview of system	✓	✓	✓			✓			✓	
		Overview of main functional variables	✓	✓	✓			✓			✓	
		Key variables in detail	—	✓	✓				✓			
		All system variables	✓	—	—				✓			
Number of variables to be monitored	This refers to the number of variables that the operator is required to monitor. If there are a wide range to be monitored then the numbers refer to the number of variables that can be given on a "page" of information for that particular display type.	Less than 6	✓	✓	✓							
		6 - 10	✓									
		More than 10	✓									
Number of levels per variable	The number of different levels that can be displayed for a given variable This may only be relevant where certain display types are used (eg histograms to display variables) If the variables are given in digital or analogue format where the exact value of a variable is given, then this parameter will not be relevant	16 or more levels	✓	—	—				✓			
		Less than 16 levels	✓	✓	✓					✓	✓	
Rate of change of information	The rate at which the system updates the process information used for monitoring	Rapidly changing (more than 2.5 changes per second)	✓	✓				✓	✓			✓
		Medium rate of change (seconds)	✓	✓	✓			✓	✓		✓	
		Slow rate of change (minutes)	✓	✓	✓			✓		✓	✓	

✓ Recommended format

— Possible format

Figure11.8.1.b. DISPLAY GUIDELINES FOR MONITORING TASKS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical. Trend	Object oriented	Dedicated alarms
Type of monitoring task	The reson for monitoring system behaviour may vary both between and within systems. The purpose of the monitoring impacts on the most suitable display type for the task	Monitoring to optimise system operation	✓	✓							✓	
		Monitoring to predict future out of spec conditions	✓							✓	✓	
		Monitoring to detect unacceptable but not critical system conditions	✓	✓	✓						✓	
		Monitoring to gain feedback information on the results of control actions	✓	✓					✓	✓		
Frequency of scanning variables	The frequency with which variables are monitored and scanned	All scanned within a strategy	✓	✓	✓				✓		✓	
		Mostly scanning of important variables, others irregularly	✓	✓	✓						✓	
		Scanning primarily of important variables		✓	✓					✓	✓	
		Some scanned all of the time	✓								✓	
Allocation of the monitoring function	The extent to which the monitoring of the system is automated or carried out by the operators	All human	✓		✓						✓	
		Mostly human some automatic	✓		✓						✓	
		Mostly automatic the human may be required to detect faults in the automatic system	✓		✓				✓			
Temporal nature of monitoring information	The relationship in time of the information available for monitoring as compared to the current system status For example historical information may be used to monitor the variation in a variable over time, or simply the current status of a variable may be given.	Current variable values only displayed	✓	✓	✓				—		✓	
		Historical variable information/trends						✓	✓	✓		
		Predictive information	✓					✓	✓	✓		
		Rate of change information						✓	✓	✓		

11.6.2 FAULT DETECTION

Perception of a fault having occurred or being imminent.
Many process systems allow an operator to detect that a fault has occurred in the system by means of alarms. These may have different priorities or levels to promote the correct response and sequence of actions on the part of an operator. In the majority of the plants studied, the alarms were treated by the operators in a reactive way. That is, that operators responded only when an alarm or similar display indicated a fault condition. Sometimes this response was merely to press the cancel alarm button, if the problem was not perceived to need immediate attention.

However, a more optimal situation is for the operators to be trained in fault detection as a proactive task. Where anticipation of future fault states occurs, it is usually closely allied to the monitoring of system status. The type of information required for fault detection is task and plant dependent, and relates to the overall system philosophy, ie whether the operator is to aim to prevent faults or to react to mitigate the consequences of faults. In some plants, the operator's role is to detect the presence of a fault and to pass on the information up the chain of responsibility for all but the smallest faults. In other plants the operator is a system expert, and requires access to detailed fault information to allow him or her to progress onto the task of fault diagnosis, should it be appropriate. In these two cases the fault detection task is very similar, to detect the presence of a fault and to register its significance and impact on system functioning and safety. However, the task which follows may be very different and this will impact on the choice of displays.

In many instances the task may form part of the overall monitoring task. However, there will be fault conditions which need to be channelled into alarms and warnings, to ensure early and prompt detection. For such conditions, the thresholds at which the alarms are triggered need to be carefully set. Firstly, not too low to ensure that the alarms are not triggered too frequently and so lead to the "cry wolf" syndrome. Secondly, not too high so that an alarm gives an indication that the fault condition has already progressed considerably, and may not be triggered when necessary. Faults themselves, especially in large and complex systems, can be divided into primary, those with an impact on system safety or integrity, and secondary, those it is important to be aware of, but which may not require the immediate attention of the operator. In addition to this approach to the display of faults, other possibilities include:

- a scheme where all faults are displayed even at a minor level of detail.
- a scheme where an overview of the main systems is given with faults indicated at system level, with further details available if requested.
- a scheme where only the important variables for system functioning are monitored for faults automatically.

With respect to fault detection and fault diagnosis tasks, the allocation of function between the human and automatics has a large impact on how the task is performed. Detection may be highly automated, offering the operator detailed alarms and warnings. Alternatively, in smaller systems, the operator may have greater responsibility for detecting fault conditions, either for single variables or for collections of variables. In addition to greater or lesser automation of detection, the immediate response that is required for a fault may or may not be automated. If the response to a fault is critical both in terms of time, and system integrity and safety, then an automatic safety system may be installed which is designed to bring the system to a particular status. Such a system may even inhibit human intervention for a period of time. The effect of such a system is to allow the operator to become familiar with the current system status, without suffering the immediate time pressures of making decisions on the measures which must be taken as quickly as possible. The allocation of both the functions of detection and immediate responses to fault conditions, affects the display format which is most appropriate to the task. However, if the automatic system is not sufficiently well designed, problems can occur. For example, in one of the plants studied, there was a problem with alarms occurring during system states such as start up. These were not *alarms*, but occurred because the condition of the system during this phase of system functioning was not considered in the design of the alarms.

Whilst the format of the display is highly task and situation dependent, the basic information required by the operator regarding faults is very similar between different tasks. This includes basic parameters, such as the part of the system in which the fault occurred, the time of occurrence and type of fault. In addition, information may be given, or may be available at a more detailed level of display, on the exact item of equipment, the sequence in which faults occurred, and current status of the system in comparison to the status at the time of failure.

However, the general consensus is that in all systems, at least one dedicated display is required for alarms (Goodstein, 1981). This should usually be supplemented by an auditory alarm, and by display of the fault on the other process displays, wherever the system or equipment related to the fault condition is shown (see figures 11.8,2 a and b).

Figure11.8.2.a DISPLAY GUIDELINES FOR FAULT DETECTION TASKS

DISPLAY FORMATS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
Level at which fault detection required	The level at which the system variables and their deviation from the required levels is to be detected and interpreted as a fault	Overview of system variables	✓	—	—			✓	—		✓	✓
	There may be a range of displays giving the different levels of fault detection required.This may include an overview of the main plant area in which a fault has occurred or detection at the level of individual process variables	Overview of main functional variables	✓	✓	✓			✓	—		✓	✓
		Key variables in detail	✓	✓	✓			—	✓	✓		✓
		All system variables (At an individual level)	—	✓	✓			—	—	✓		✓
Number of variables to be monitored	The number of variables which are required to be monitored to note the occurrence of a fault	Less than 6	✓	✓	✓			✓	—	✓	✓	✓
		6 - 10	✓	✓	✓			✓	—		✓	✓
		More than 10	✓	—	—			—	—		—	—
Rate of change of information	The rate at which information on system variables is updated Whilst some alarms occur at a certain threshold level, others may go through several levels of alarm. If the latter is the case then the rate of change of system information may be an important variable	Rapidly changing (more then 2.5 changes per sec)	✓	✓	✓				✓		✓	✓
		Medium rate of change (minutes)	✓	✓	✓				—		✓	✓
		Slowly changing (over several minutes or hours)	✓	—	✓				—	✓	✓	✓
Type of fault detection task	The way in which fault detection is carried out as a task may vary depending on the system culture. For example the operator may be required to respond to alarms in one system, whilst in another the aim may be for him to continously monitor for faults and in another to try and anticipate them before they occur.	Detection of faults when they occur at all levels of the system	✓	✓	—				✓	—		✓
		Detection of faults at a system overview level	✓	—	✓			✓	✓	✓	✓	✓
		Monitoring to predict likely faults	✓	✓	✓			✓	—	✓	✓	
		Detection of priority faults (eg for critical systems)	—	—	✓				✓	✓	✓	✓

Figure 11.8.2.b DISPLAY GUIDELINES FOR FAULT DETECTION TASKS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
			DISPLAY FORMATS									
Frequency of scanning variables	The frequency with which the operator is able to scan the variables for which faults are to be detected	All scanned within a strategy	✓	✓	✓				✓		✓	✓
		Mostly important variables, others irregularly	✓	✓	✓			✓	—	✓	✓	✓
		Some all of the time	✓		✓				—	—	✓	✓
		Important variables are regularly scanned	✓					✓	✓	✓	✓	✓
Allocation of the fault dectection function	The extent to which the fault detection function is automated and human detection of faults is required	All human	✓	—	✓			✓	✓	✓	✓	✓
		Mostly human some automatic	✓	—	✓				✓	✓	✓	✓
		Mostly automatic the operator is required to detect only minor system faults	✓	—	—			✓	✓	—		✓
		Mostly automatic the human responds to only major and high level faults	✓	✓	✓			✓	✓	✓	✓	✓
Frequency of occurrence of unacceptable plant conditions	The frequency with which fault detection is required, for example the level at which alarms occur. This parameter is highly dependant on the system culture and the level at which alarm thresholds are set	Regular pattern of known events	✓	✓	✓			✓	—	✓	✓	—
		Regular minor faults Irregular major plant faults	✓	✓	✓				—	—	✓	✓
	In some systems personnel other the operator eg. maintenance may deal directly with the minor system faults	Operator only required to deal with detection of major plant faults	✓	—	✓			✓	✓	✓	✓	✓

11.6.3 DECISION MAKING

Choosing between alternative responses on the basis of available information.

Decision making is an activity that is prevalent in many of the tasks carried out in modern process environments. It can occur either in a static or dynamic processing environment. The process of decision making will be dependent on many variables including operator knowledge, training and experience in operation of the system. Information about earlier decisions will affect current decisions. Furthermore, the format and content of the currently displayed information will also impact considerably on decision making behaviour. Too much detail, ie redundant information, may cloud or confuse the issue, whilst too little may lead the operator to make a wrong decision.

Approaches to decision making are dependent on the information available to the operator concerning the system and the environment. All the information that an operator needs should be available in a form he or she can use. In a static environment, decision making is an easier task for the operator as outcomes are more easily assessed. Decision making can be viewed at one level as a simple form of problem solving, that of the selection between alternative courses of action. However, aids that will be used in a decision making task will be different from those used for problem solving. For decision making the aim of the aids will be to simply present the options available to the operator with some evaluative information. Both decision making and problem solving may involve the operator in consideration of "what if " scenarios.

Aids for decision making need to evaluate what current displays offer and if this can be used to aid decision making, or if alternative displays need to be provided. The most useful information for decision making includes cost, probabilities and payoffs. The weighting and choice between alternatives may be influenced by such factors as management style and the safety risk associated with the system. However, in a dynamic environment, especially where conditions can change rapidly, it is not always easy to apply probabilistic information processing systems. Aids can take different forms, for example, one approach is the "divide and conquer" principle (Slovik et al., 1977). Here, by decomposing a problems into manageable chunks, judgment is improved. Alternatively there are also probabilistic aids.

Decision making in a system is often a key function, particularly where it is a flexible function and cannot yet be automated. In some plants, where safety critical states can develop rapidly, it may be better if safety systems are triggered automatically, to avoid compromising plant integrity by a hesitant decision.

Training, system knowledge and the displayed information, also determine the operator's sensitivity to the plant in taking decisions and establishes his or her criteria for decision making. The strategies adopted are mostly dependent on training. Montgomery (1975) showed that decision makers consider firstly the most important dimension when selecting between a pair of alternatives. If the difference between the two is greater than a minimum difference, then the most attractive is chosen. If not, then another dimension is selected and the process repeated. Lindsay and Norman (1977) outline two possible approaches to the comparison of dimensions. There is an overall impression of the relative attributes of the dimensions, usually by giving them a rating, and a comparison dimensions by dimension. They state:

> "It is a very difficult task to compare several courses of action and select one...if the alternatives are complex ones then there is no clear way to do the comparison, even if the several choices could all be laid out one in front of the other."

Other models of decision making also suggest a component wise evaluation of alternatives. However, this difference in values is relative and perceived rather than actual. So displays should aid differentiation on the basis of important dimensions.

Decision theory itself has two facets, normative and descriptive. Normative relates to the prescription of courses of decision making actions and descriptive theory outlines the beliefs and values individuals use to reach decisions. Fjellman (1977) states that most decision making theories deal with the way people should make decisions, which does not necessarily relate to the way that they do. For example, a procedure may prescribe courses of actions and the outcomes of decisions for the operator, but if it is badly designed it may not be followed.

The only real evidence that a decision exists, is its outcome. With a decision making task, it is the display that helps the operator to achieve this outcome or goal. However, the decision made can only be as effective as the information, coupled with the operator's knowledge about the system and system functioning, allows. The display of information must be considered in relation to this knowledge. Rasmussen and Goodstein (1985) state:

> "An important basis for prediction of responses of the system to control inputs in supervisory control decisions is knowledge about functional relations at each of the levels in the hierarchy."

Displays that can be used for decision making are again highly task dependent. Text displays can offer probabilistic information. This may be the outcome of a simulation or computer modelling, and can offer textual information, for example help pages. Decision aids can also be in the form of graphs, giving information about system functioning either historically or about current plant functioning. The operator may be aided by giving functional and other related information in a neutral way. If certain system configurations give rise to certain patterns which will facilitate decision making, then object orientated displays may be an option. Other display types include mimics, which make the functional relationships of the system explicit and displays which give detailed information on individual variables, should that level of detail be required (see figure 11.8.3).

Figure11.8.3. DISPLAY GUIDELINES FOR DECISION MAKING TASKS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
Complexity of required decision	The complexity of the required decision is dependant on factors such as the number of variables and potential/possible outcomes. For example it may be a simple yes/no decision or choice between 2 alternatives (binary) or a much more complex decision making situation	Binary	✓	✓		—		✓	✓	✓		
		Choice between multiple variables	✓	✓		—		✓	✓	✓		
		Complex	✓	—				✓	—	—		
Time available for decision making	The time pressures and constraints that exist on the task, for example rapid decisions to be made concerning overall system states versus long term decisions over static plant variables (eg set points)	Short and constrained (minutes)	✓	—		—		✓	✓	—		
		Medium term decisions (minutes to hours)	✓	✓		—		✓	✓	✓		
		Long term decisions (hours to days)	✓	✓		✓		✓	✓	✓		
Overall system criteria influencing decision making	The organisational , management and operational structures and philosophies influencing plant operation and the way in which this impacts on the criteria used in the decision making environment	Least risk option/ maximise safety	✓	✓				✓	✓	—		
		System optimisation	✓					✓	✓	✓	✓	
	(Note: this is a highly plant dependant variable and the criteria only give typical examples of common approaches)	Minimise down time	✓		—			✓	✓	—	✓	
Type of decision making environment	The nature of the decision making environment i.e are the relevant plant parameters changing over the period in which the decision must be made or do they remain static or change little?	Dynamic	✓	✓						✓	✓	
		Static	✓	✓				✓	✓			
Type of decision making	Is the decision one which involves the operator's subjective judgement, a decision based on qunatitative values or one based on the probabilites relating to outcomes (Note it is accepted that for complex decisions there may be several of these elements but for the purposes of these recommendations these issues have been treated as separate elements in the decision making situation)	Functional/ Qualitative	✓					✓				
		Mathematical/ Quantitiative	✓						✓	✓		
		Probabalistic							✓	✓		

11.6.4 PROBLEM SOLVING AND FAULT DIAGNOSIS

Process of resolving uncertainty about system states.

As a category, problem solving is perhaps one of the more prevalent activities of process operators in systems. In particular, it occurs where operators are given a level of responsibility which involves control over a wide range of plant attributes under normal and abnormal operating conditions. In other plants, an operator will have very little problem solving responsibility (for example, as in case study 1) and will simply act as a focal point for the exchange of information between individuals on the plant.

The kinds of problem solving that operators are required to carry out will vary depending on their experience, training and understanding of the plant. Hence, the display formats to be used are system and task specific. It is, however, possible to give some general guidelines to the display types that may be used. Plants rarely have displays that are aimed to provide information to the operators in a way that is specific to problem solving situations, rather, information is given in addition to other display formats.

Murphy (1984) identifies the cognitive attributes of the human and relates five of these attributes as being particularly relevant to problem solving, these are:

- Constrained problem solving
- Strategic problem solving
- Inflexible representation in problem solving
- Presentation dependent problem solving
- Stress induced problem solving

The choice of problem solving strategy by an operator is dependent on a range of factors. These include the training and the approach to system operation that the operator has. This may also be influenced by overall company policy, the operator's knowledge and previous experience.

In a process control environment problem solving can occur at a variety of levels:

1. At its simplest level, operators will receive a stimulus and this will invoke the knowledge that a specific action must be taken or procedure used. The decision involves selection of the correct response. This is akin to decision making.

2. At the next level, operators must select one from a limited range of possibilities, all of which provide the means of achieving the goal. For example, selecting a start up procedure in which several processes could be carried out in parallel or sequentially, would involve operators choosing the procedure they felt gave the most effective timing, efficiency and safety tradeoffs.

3. When no predetermined approaches or procedures are available for a problem. Here the operators can break the problem down into elements where previous approaches and procedures can be applied. The operators must then synthesise an approach from their previous experience and the procedures they have in their repertoires.

4. At the most complex level, operators may encounter a problem to which none of the known procedures or operational repertoire can be applied. In such a situation, they must evaluate and assess the situation before considering appropriate action.

The important considerations when selecting a display for problem solving include, the characteristics of operators and the level of responsibility they have. These characteristics include skills, knowledge and training. These will determine the approach of operators and their understanding of the system, which in turn determines their problem solving capabilities, with respect to the system. The company philosophy and management and organisational structure will influence the responsibility of the operators and allocation of functions amongst personnel. In some systems (for example, in the coal preparation plants outlined in case study 1), the operators have no demanding problem solving tasks. Those occurring during normal system operation are highly proceduralised or else automated and required only decision making skills. Should a fault occur then this is reported to the plant management or else referred to a highly specialised technical team. This approach is not only reserved for plants processing high bulk product or with less safety critical systems. In the United States at least one nuclear utility employs this approach (EPRI, 1981).

Displays for problem solving tasks can be based on the formats used for other tasks. For example, mimic displays give information about the functional relationships between plant items. If the problem solving activity occurs during normal plant operation this may be the most viable option, and can be supplemented with problem solving aids. Displays can also show the choices available to operators, outlining the best option, the least risk approach and allowing operators to explore "what if" scenarios. Overall to aid diagnostic strategies, the aim of the displays should be to relieve some of the cognitive load on the operators. Suitable display formats are suggested in figure 11.8.4..

Figure 11.8.4.a. DISPLAY GUIDELINES FOR PROBLEM SOLVING TASKS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
Type of problem	The nature of the problem to be solved and its complexity	Simple (for example a problem where there is a very limted choice of outcomes)	✓	✓					✓		✓	–
		Familiar /repetitive problem	✓	✓							✓	–
		Complex functional problem	✓					✓	–			
		Jud gement based problem	✓						✓	✓		
Level of operator problem solving responsibility	The extent to which the operator is able to progress with the problem solving task and take action without reference to management or supervision	Determing nature of problem	✓		✓			–	✓	✓	✓	–
		Deciding on action relevant to problem	✓	–				✓	✓			
		Passing on problem related information	✓	✓				–	✓	–		–
		Implementing action	✓	✓				–	✓			
Type of information required to aid operator in problem solving	This variable is dependant on the approach taken to operation in the plant and the skills and knowledge of the operator. These determine which different kinds of informaiton to aid problem solving will be appropriate.	To try outcomes of different options	✓	–					✓	✓		
		Probabalistic information	–	–				–	✓	✓		
		Trend information						–	–	✓		
		Plant history, or other histroical information	–	–					–	✓		

Figure 11.8.4.b. DISPLAY GUIDELINES FOR PROBLEM SOLVING TASKS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
			DISPLAY FORMATS									
Objective of problem solving	The reson why the problem solving task is to be carried out	Diagnosing why an event occurred	✓	—	—			✓	—	✓		✓
		Predicting what is likley to happen given a series of events	✓	—					—	✓		
		Assessing alternatives to find most acceptable outome (see also decision making)	✓	—				✓	—	✓		
Type of problem solving required	Is the problem solving constrained by the problem solving environment to meet a particular need or is to be used in a strategic fashion to optimise system operation?	Strategic	✓									
		Constrained	✓	✓							✓	✓
		Past solutions	✓					✓	✓	—		
Time available for problem solving	The time constraints that exist in the problem solving environment	Short term (0 - 20/30 mins)	✓	—					✓	—	—	—
		Medium term (30- mins - several hours)	✓	—					✓	✓		✓
		Long term (hours -days)	✓	—					✓	✓		✓

FAULT DIAGNOSIS

A specific kind of problem solving task involving the identification of the root causes of a fault.

Fault diagnosis is a specific kind of problem solving activity essential to the safety and efficient operation of process systems. In some systems the diagnosis task will not be the responsibility of the operator, in others when a major problem occurs, the operator will form part of a team working towards a solution for the fault. As it is a form of problem solving, separate guidelines for fault diagnosis have not been specified. However some of the issues which relate to fault diagnosis tasks are discussed in this section to enable issues that are particularly relevant to the design of displays for fault diagnosis to be highlighted.

With the range of displays that are possible, the display type hinges on the type of problem that is presented. As such it may be possible to find specific display types that provide a unique representation of the problem for a given system or task.

The display should help the operator to resolve the uncertainty that exists about system states. In the fault diagnosis process, the operator needs to firstly determine the current system state, and to act to make that safe and to avoid further linked failures. Then diagnosis can occur, determining, how, where and when the fault occurred and the underlying causes. Following this, the actions that need to be taken to bring the system into an optimal state can be decided. So the displays must help the operator in resolving uncertainties and in making decisions about future system operation, states and system actions.

The displays should help the operator wherever possible, by prioritising alarms, helping to sort out common mode failures and aiding judgment. These aids are dependent on the assumed level of operator knowledge. Many provide the operator with probabilistic or trend information, and may even offer the opportunity to test outcomes.

The scope of the problem can vary, it may be a simple binary decision regarding a fault, or a repetitive problem which leads to a routine solution. Alternatively, the fault diagnosis problem may be complex and functional, requiring detailed plant information, or else requiring judgmental ability. As with problem solving, the responsibility of the operator may involve determining the problem or deciding on an action or both. Supervisors and other personnel are likely to use the same display system and information in diagnosis. So displays will need to provide the information required by all users. This applies to all the display formats. If a fault has occurred before, then it is useful if the information on actions taken and their success is available to the operator, perhaps in the form of on-line diagnostic aids. It has been shown that simple repetition of the problem content with immediate feedback of results was not adequate in aiding performance.

To provide optimal operator support, the displays should give the operator all the appropriate information and an appreciation of the situation, whilst leaving the decision making to the operator. The data should be reduced to an assimilable format and be compatible with existing procedures. Humans tend to generate diagnoses one at a time and to accept the first which appears to make sense, they then tend to seek confirmatory information, rather than continuing to test alternative hypotheses. In addition, humans tend to err towards the conservative solutions. Offering displays which allocate probabilities and define the risk can help. Edwards (1963) showed that whilst humans tend to be good at estimating the probabilities of individual items, this is not the case for aggregated items. Fault diagnosis may involve more demanding problem solving of the operator than other such tasks. Particular constraints are imposed on the problem solving activity, for example, such tasks are usually carried out under time constraints in a stressful situation.

Whilst the displays needed for this particular task type may be used only infrequently, especially if they are dedicated fault diagnosis displays, they are essential to ensure that when faults occur, the system integrity and safety is maintained, and that the operator is given the required information and aids to carry out the task effectively.

11.6.5 PREDICTION

Judgment of likely future system states

Current trends in computer science and information technology mean that intelligent knowledge based systems are becoming more widely applied. In addition, modelling and simulation can be used to provide aids to predict future system states.

Predictive tasks often take the form of "what if " scenarios, where operators use predictive aids to aid in making decisions or solving problems. However, unlike the decision making or problem solving tasks, the aim is not to consider the solution in terms of present system status, but to examine future system states. Prediction is very much concerned with factors such as future alternatives and eventual outcomes of modes of operation. Operators use predictive displays and aids to test hypotheses and so make decisions.

The aim is to reduce uncertainty about the system and its future status. This uncertainty may relate to the system or the human, and it is important which areas of uncertainty relate to which. If there is uncertainty about the system, operator skill is all the more important. However, if the system is rigidly defined, then the uncertainty belongs to the operator and is easier to aid.

Studies have shown that humans can be trained for prediction. It can be be considered how degraded the environment would have to be for an ideal operator to perform at the same level as an ordinary operator. It has also been found that for simple binary events, subjects can be infallibly trained to predict sequences. Goldsmith and Schrameveldt (1981) found that if a system relationship is learned and understood, then the predictive ability of the operator improves, although, it was more difficult to combine information that was linear and non configural. They examined three kinds of display; bar graphs, rectangles and triangles (with and without radii and in an object orientated display type format). They found that for configural information the triangle led to better performance and they conclude:

> "Substantial improvements in decisions performance should be possible by displaying information in a more holistic fashion"

Usually predictive displays offer absolute information based on current and recent plant history or they offer the option of testing out courses of action to evaluate their effects. The temporal criteria for the displays is an essential one. Prediction is especially important in situations where there are rapidly changing variables, as it can help the operator to check the status of the system. Prediction can also be used for longer term planning tasks, for example, planning ahead for production over a weekly or monthly period. The displays used in this instance may be quite different to those used in short term modelling for prediction. However, with predictive displays the predictions are based on current and previous system status and in utilising these for prediction, it may be difficult to account for the impact of any control actions by the operator on this future system state (Kelley, 1968). Umbers (1975) states the operators tend to exhibit two kinds of predictive behaviour:

1. Predicting a future system state.
2 Predicting the effect of a possible control action on the state of the system.

The display formats used for predictive displays may be stand-alone dedicated formats, or the predictive information may be incorporated into existing formats. The formats may be selected on the basis of such variables as the allocation of responsibility for prediction, the time over which prediction is required and the training of the operator. The kinds of formats that can be used include graphs and trend displays, object orientated displays and alpha-numeric displays (figure 11.8.5.).

Figure11.8.5.a. DISPLAY GUIDELINES FOR PREDICTIVE TASKS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
System states	The overall nature of the operation and functioning of the system	Repetitive or cyclical	—		—		✓	✓		✓	✓	
		Unpredictable	✓		✓						—	
		Vary according to key variables	—		—		✓	✓		✓	✓	
System complexity	The complexity of the system as it relates to operator understanding of the system etc.	Simple	✓	—	—		✓	✓	✓	✓	✓	
		Complex	✓				✓	✓	✓		✓	
		Simple with several complex variables/ system functions	✓	—	—		✓	✓	✓	✓	✓	
Number of variables which predicition is to be based on	The number of variables which need to be considered in conjunction with one another to provide a basis for prediction. This is important as some display types limit the number of variables that can be displayed at one time.	Single variable	—	—	—		✓	—	✓	✓		
		Small number of variables (2 - 6)	✓	—	—		✓	✓	✓	✓	✓	
		Large number of var iables	✓					✓	✓	✓	✓	
Type of relationship between variables on which prediction is to be based	The relationship between the variables impacts on the choice of display, allocation of function (i.e. what is automated)	Simple eg. linear/additive	✓	✓	—			—	✓	✓	✓	
		Intermediate can be learnt without training	✓	✓	—			✓	✓	✓	✓	
		Complex requires considerable skill to interpret	—					✓	✓	✓	✓	
Timescales for execution of predicitve function	The time available for making predictions and utilising the predictive information	Short (minutes, for example in fault situations)	✓	—	—		✓	✓	✓	✓	✓	
		Intermediate (eg. 30 mins- several hours)	✓	✓	—		✓	✓	✓	✓	✓	
		Long (usually as a planning or forecasting task can be days or weeks)	—	✓	✓		—	✓	✓	✓	—	

Figure 11.8.5.b. DISPLAY GUIDELINES FOR PREDICTIVE TASKS

			DISPLAY FORMATS									
VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
Allocation of predictive function	The allocation of responsibiltiy for prediction and the extent of automation	Predictive tasks carried out exclusively by the operator	✓	✓	—		✓	✓	✓	✓	—	
		Predictive tasks carried out by machine	✓	✓				✓	✓	✓		
		Flexible allocation of prediction task	✓	—				✓	✓	✓		
Accurracy/Detail of predictive informaiton required	Whether the predictive task requires detailed exact process values or more qualitative information	Qualitiative	✓	✓	✓			✓	✓	✓	✓	
		Quantitative proababistic (eg. least risk)	✓					—	✓	✓		
		Quantitative Accurate and absolute data	✓	✓					✓	✓		
Data and information available for prediction	The data and facilities available for prediction for which information can be displayed	Historical information over a period of time							✓	✓		
		Historical information for a single point in time	✓	✓						✓		
		Modelling of system functio ning	✓					✓	—	—		
		Simulation of system behaviour	✓					✓	✓	✓		
		On line manipulation of data (eg real time what if scenarios)	✓	✓				✓	—	✓		
Aim of prediction	The aim of the predictive task	To predict future system states	✓		—			✓	—	✓	✓	
		To predict the effect of control actions on system states	✓	✓				✓	—	—	—	

11.6.6 PROCEDURAL

Following a predetermined sequence of events.

Almost without exception, process plants will have operating procedures which determine personnel roles in system operation. These procedures are usually developed as the system is designed and may be informally or formally adapted as the system is modified or as it evolves.

The requirement on the operator to follow procedures stringently is dependent on the level of system safety that is acceptable and the operator's perception of risk. Both are influenced by training and the management and organisational structures of the plant. If the safety criteria of the system result in the inclusion of elements in the procedure which are there purely for safety purposes, then the operators must be fully aware of the reasons for inclusion and the operating environment must encourage safe working practices. Otherwise operators may be encouraged to circumvent the procedures, especially if external pressures such as time constraints exist.

In some plants the procedural tasks are often those parts of the operator's role to be automated. This is usually because, in order to automate a task, its elements must be well defined and the rules of execution understood. For tasks where procedures exist, this is already achieved and so automation is simplified. If such tasks are automated, an operator may be required to intervene should a fault or an "out of '*spec*'" incident occur. The function of the displays is then to give the operator procedural information for a task that, whilst it may involve some procedural elements, will generally require problem solving, decision making and predictive skills. Such displays will be in a different format to those used to guide an operator through a procedure that must be carried out.

In considering general guidelines for displays for procedural tasks, the following considerations apply. Firstly the initiating and terminating events or functions should be clearly marked for feedback to the operator. In the selection of displays the required length of history, prediction should be considered. The requirements of information for a procedural task include, step by step guidance at an appropriate level for the operator, showing clearly the following and preceding steps (including those which are automatic and those which are manual) and the current stage reached and the status of the relevant system.

The availability of items in the sequence should be made explicit and feedback given as the sequence progresses, showing when the procedure starts, when it is complete, indicating progress and drawing to the attention of the operator any failure or problem. Displays which can be used for procedural tasks include sequence displays, textual lists and flow diagrams (figure 11.8.6)..

Figure 11.8.6. DISPLAY GUIDELINES FOR PROCEDURAL TASKS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
Size of procedure	The number of steps in the procedure and the number of pages or screens required to display the information	Information will fit onto one page/screen	✓			✓			✓			
		There is nore than one page/screen of information	✓			✓			✓			
Complexity of procedure	The procedure may be a simple sequence, it may be have several decision points or it may be complex with a wide variety of decision alternatives	Simple - all steps follow on sequentially	✓			✓			✓			
		Simple with some decision points	✓			✓			✓			
		Complex with many and varied decision points	✓			✓			—			
Level of automation of sequence or procedural task	The task may be a completely manual procedural task operated from the VDU or there may be varying degrees of automation of part or all of the task sequence	All manual	✓			✓			—			
		All automated	✓			✓			—			
		Both manual and automated stages	✓			✓			—			
Detail of information to be supplied on the sequence	This is the amount of detail concerning the sequence required by the operator to perform his task. If the sequence is simple and familiar to the operator this may simply be the current, preceeding and following steps in the sequence. In other cases more detailed procedural information is required such as all the options and decision points available to the operator, alternatively the most optimal option can be displayed	Current, previous and future steps only	—			✓			✓			
		All stages in procedure (Whole procedure)	—			✓			✓			
		All options available	✓			✓			—			
		Optimal option	—			✓			✓			

Figure11.8.6.b. DISPLAY GUIDELINES FOR PROCEDURAL TASKS

VARIABLE	DESCRIPTION	CRITERIA	Mimic	Loop	Deviation	Sequence	Command	Pictorial	Alpha-numeric	Graphical Trend	Object oriented	Dedicated alarms
Level of skill and operator training	The nature of the use of displayed procedural information in a process context is highly dependant on the skills and training of the operator A highly skilled operator will use displays as an aid to carrying out a procedure. Less skilled operators may require displays to guide them through the different procedural steps	Highly trained in plant operations and knowledge of operating procedures	✓			✓			✓			
		Needs guideance or aid in carrying out procedures	—			✓			—			

11.6.7 MOTOR SKILLS

Any operator action upon the system state or configuration.
In the context of this project the aim is to offer guidelines for display formats, and so guidelines for the selection of control devices for different tasks are not outlined. The main recommendations for the use of control devices, as relevant to different task types can be derived principally from two reviews of the area, Carey (1985) and Milner (1988). The former relates specifically to process control tasks, whilst the latter addresses the issues of input devices for human computer interaction in a general way.

The motor skills required of a process control operator mainly comprise the input and control operations that are required to run the system. The physical elements of the input such as the pressing of a button or manipulation of a joystick are likely to be found at lower levels of analysis, being superseded at higher levels of analysis by the cognitive tasks that are used in control. These involve the tasks which determine what control is to be used and how, and also involve the feedback that is given once a control has been manipulated.

This is relevant, as the feedback is usually offered in a display format, it can also be auditory or tactile. The displays that give feedback are usually those used for the task associated with the control action. However, the effectiveness of such feedback is dependent on the display type. For example, on a loop display, if the data is only updated every few minutes, then feedback may prove too slow to aid the operator in controlling a rapidly developing plant situation.

In the same way as a mapping has been developed to specify the suitability of different display types for different tasks, so a similar approach could be taken to the specification of control devices. However, this is considered to be outside the scope of the present research and could provide a basis for potential further work.

11.6.8 COMMUNICATION

Accurate transmission of information without any processing of the information before it is received.
In this classification the communication tasks of the operator are defined as those where there is no processing of the information into another format before it is received (excluding, of course, the means of transmission). In this category is included the

transmission of information by intercom and telephone. Displays usually involve the coding of information in some way, for example into a symbolic format. The only display formats that relate to this task type are the use of VDU monitors as CCTVs to visually monitor the plant.

Communication tasks usually involve the transmission of information between plant personnel or passing information externally out of the plant. Communications could occur via VDU terminals. Given current technology, however, this would most likely be text that is typed in at one terminal and displayed in the same format at another. Most commonly the means of communication within a plant that are available to the operator include verbal communication via links such as intercom, radio, telephone, tannoy and visually usually via a CCTV or similar system.

11.7 DISCUSSION

The guidelines in this section have been based on information reported in the literature and on experience of the use of displays within empirical process control contexts. Within the timescales of the thesis it was not possible to carry out work to examine the applications of the guidelines to different plant contexts and systems and this is an area for potential future work. It is intended that the guidelines be expanded, updated and amended as necessary to incorporate new developments in display design. However, in their current format the guidelines present a means of linking a task analysis to display design which has not previously been explored and they offer an initial attempt at moving from simply providing methods of analysis to utilising such methods as tools for design.

This chapter represents a drawing together of the research carried out, with the aim of providing the elements of a useful tool for information and display design in process control contexts. The method described presents an approach which evolved throughout the case studies and it has yet to be applied to an empirical context. However, the structure of the methodology offers an approach to providing a 'design tool' for human factors, which bridges the gap between analysis and design, and presents a systematic and documented method for the analysis of information requirements.

CHAPTER 12
DISCUSSION

12.1 INTRODUCTION

The thesis describes research and case studies which offer original perspectives and approaches to the use of task analysis in a process control context. An examination of the theory surrounding the concepts of tasks and task analysis indicated that there was no central theory relating to tasks; therefore definitions of the concepts have been proposed for task analysis, description and synthesis and a working definition of a task has been given. The theory and exploration of the issues relating to task analysis provided criteria which would ideally be met by a method of analysis for identifying operator information needs in a process control context. These criteria were developed as a result of an extensive literature review, where methods which could be potentially used for this purpose identified. In the context of the case studies, a method of task analysis was evolved from Hierarchical Task Analysis and applied to four differing contexts.

The method developed during the studies offers an approach to the specification of information flows as they relate to tasks in a process situation. The method presents an original approach for several reasons:

- It allows the information flows to be described as they relate to each individual task element at all levels of analytical detail.
- The information flows are intended to be described in a way that relates to the task to be performed and not to the particular control context. It should be possible therefore for decisions to be made on the most appropriate means of transmitting the information. Further, the information requirements should remain constant as they relate to the task. The analysis will be usable until the task content itself changes (unless there is a change in allocation of function and tasks are automated or automated tasks revert to human operation).
- Each task element is classified into a task type. These task types aim to help the analyst make decisions concerning the design and selection of appropriate display formats.

- A preliminary outline of a task analysis tool for use in directly obtaining display design information from the analysis is given. This is proposed with the aim of overcoming the problem that, whilst a task analysis details how to carry out a task, there is no information or standard approach on how to derive design information from an analysis.
- The analysis provides documentation of all the information and communication flows that are required for a task, and not just those needed for the design of the displays.
- It is recognised that the requirements of the task will vary according to the training and skills, knowledge and abilities of the operator. These attributes must allow effective operation of the system with the tasks as described and the related information flows. If the task and displays are designed for a naive user and the system will be operated by a highly trained expert, then more information than is required may be displayed or the operator may become frustrated with the system. Conversely, the operator may be assumed to have more knowledge or skill than is the case and so problems in operating the system on the basis of the information provided may ensue. For this reason the analysis includes documentation of the assumptions that are made concerning the skills and knowledge of the operators. If too little information is given, or if there is excessive redundancy, then this can be identified. This part of the analysis also helps in the decisions that are to be made concerning training and selection of the system operators.
- HTA was subjected to a series of studies to identify the problems in achieving consistency amongst analysts, and to identify if an acceptable level of consistency could be reached. These studies, along with previous applications of HTA reported in the literature, helped to establish a face validity for the method.

The theory and concepts of task analysis

The research and consideration of task analysis is based on an extensive literature review of task analysis methods that can be utilised in a process control context. There is no central theory in the human factors literature or research which relates to the idea of a task, and no consistent approach to the concept of a task. Therefore different assumptions have been made in the development of the range of methods in the literature. The available definitions and models of the concepts are sparse. The needs of ergonomics practitioners have given rise to a vast array of methods which meet the needs of analysing a task in a particular context, rather than starting from a general consideration of the nature of tasks and progressing to the specific context. This thesis proposes definitions which aim to have a general process control application. These have formed the basis for the development of a technique and for the assumptions made throughout the work.

The development of the method considers the requirements of task analysis from a general viewpoint and recognises that the information given in an analysis must be flexible to provide an effective approach. A task analysis is a resource intensive activity in terms of time and manpower, although it can be carried out with minimal equipment. It is also an information intensive activity. The aim of a method is to provide a framework to document and describe tasks accurately which allows their assessment and analysis. This information may be used in a myriad of ways, not only by human factors specialists but also by engineers, designers and other system personnel. Therefore, to be effective the analysis needs to document the task clearly and to provide a form of system documentation of human functions and activity. If the analysis can be used as a common resource to form a basis for decisions concerning the human operator, then it provides a useful tool in the human factors design of the system. The potential uses of a task analysis are considerable, so a common approach helps to ensure that there are consistent assumptions made about the human in the system. Many methods of task analysis only address very specific issues in system design, for example training, and do not provide information that is easily usable for wider applications. The method of task analysis developed in this thesis aims to provide a more general framework. Any task information not provided in the analysis can be annotated systematically by extension of the analysis, for example, by adding an extra column. Alternatively, the analysis can be used as a basis for the use of a technique to address a specific issue, for example, it could provide the basis for a link analysis to evaluate control room layout.

The case studies

The research and case studies offered a pragmatic approach to evolving a method of task analysis which analysed operator information needs. The approach allowed both the theoretical basis for the analysis to be explored alongside its effectiveness in different practical applications. As a follow on to the theoretical consideration of the development of a technique, the evolution of a method in a practical environment provided a technique that was shown to be usable and useful in complex control situations. The four case studies offered very different plant situations which allowed application of the method to a range of different process contexts and information environments.

The Coal Preparation Plant study provided the context for the development of a method and its preliminary evaluation. Coal Preparation is a continuous process, with several plants in the UK being semi-automated. The automation is complemented by operators controlling the plant locally. A total of three plants, which had the same basic process, but variations in the level of automation, display design and operational philosophy were studied. Methods of task analysis considered to be potentially suitable for the documentation of information flows, were compared on a representative task selected from Rawdon CPP. From this assessment, HTA was selected as a basis for the development of a method, as no one existing method met all the criteria outlined. A methodology was developed and applied to the three plants it was possible to study within the project timescale. The methodology allowed the development of a generic task analysis to describe the tasks common to all three plants. This analysis provided a basis for display design which could be consistently applied throughout CPPs with VDU based display systems. As a result of the applications, the task classification scheme was updated and a column to specify assumptions concerning knowledge and operational skill added.

The Boots Ibuprofen plant provided a highly automated batch plant for the second case study. In contrast to the processing of coal, the plant produced a high cost, low bulk pharmaceutical product. The control room was also very rich in a wide variety of communication and information flows. The plant gave a different context for the evaluation of the method and showed that the method could be applied to the full range of information flows relating to the control room operator's task and not solely to the analysis of information flows for the design of VDU display formats. In addition, the case study provided an input into the evolution of the task classification scheme.

The third case study evaluated the use of the developed method for task synthesis, and assessed its use comparatively with the method used by the plant design team, FAST. The process was continuous and the plant itself was part of a national network. Therefore the required output of the plant was coordinated nationally, and so the process had to adapt to meet the process demands of the national network.

The case study showed that the modified HTA provided the ideal approach to the synthesis of tasks in a system undergoing design, but this was only where the task goals themselves had been defined, and the functions allocated between the human and the system. FAST provided the approach to achieving this. Rather than being evaluated comparatively for task synthesis in a complex systems environment, the two methods were complementary. FAST can be applied at the early stages of design to aid in decisions concerning task feasibility, automation and allocation of function. HTA can then provide the ideal means of gathering this information together into coherent tasks and detailing all the required information about the tasks.

The second part of the case study involved the application of the method to the analysis of information on the plant's electrical services panel. Whilst the method was effective at documenting the information required by the operator to carry out the tasks, the information in the analysis was used in different ways to derive design guidelines, rather than as it would be for VDU process displays. For example, on a panel display **all** the information required by the operator is on display at any one time, so although the problem of breaking the information into pages does not occur, the problem of making the relationships between items of information clear is more evident, even when an item of information is used for several tasks. However, there are guidelines available on the design of panel displays and it is well documented in the literature. The different use of the task information however, means that the mapping methodology developed at the end of this research could not be applied in its current format to the design of panel displays, although it could conceivably be extended to do this.

The final case study was on a plant with many similarities to that studied in the third case study. The process was continuous and operation was carried out to meet a demand for the product that varied throughout each shift. However, the plant was selected as the control room comprised four control units with identical functions. The technology in the control and interface design of the units varied. Therefore the study examined the task and information content for two of the units, one of which had a highly automated VDU based touch screen interface, and the other which had a similar console configuration but which was primarily a panel based unit. The study compared the use of the method in an analysis where the task and information requirements were essentially the same, but where the media of presentation differed. The method was able to show the information requirements independently of the means of transmission, and so could be used to transfer task information from an existing task situation to a context where the task remained constant, but the technology was updated.

Overall, the case studies allowed the evolution and development of a method of task analysis which was able to document the communications and information flows related to tasks in a complex control situation. This included not only displayed information, but also the full range of communication flows that are involved in the operation of a plant such as verbal communication, logs and records, and maintenance information. The case studies approach allowed issues such as this to be explored within the time constraints of the study, and also to consider the full range of variables that could impact on task performance in a real world situation. This would not have been possible in the context of a laboratory study. The variety of the plants selected for the case studies enabled the method to be evaluated in a representative range of process situations which included :

- Batch and continuous plants.
- Highly automated and centralised processes versus less automated processes which were more dependent on the operators on the plant.
- Operators with little operational responsibility and operators who were responsible for all aspects of plant operation under normal and emergency conditions.
- Plants where product demand varied little and others where it varied from day to day.
- Operational environments with complex and more simple information systems.

The final output of the theoretical work and the applications of the case studies was to propose a method of task analysis that could be used as a tool for process display design. The approach is suggested in chapter 6. The outline of the tool in the context of this thesis is only preliminary. Nevertheless, it provides a significant development in the way in which such task analyses can be used and applied within a systems context. Increasingly, as the importance of task analysis is recognised, engineers, designers and other personnel are being called on to carry out and to implement analysis. A method which is more of a human factors tool can only help the use of task analysis, although it is recognised that human factors specialists have the particular skills required to implement display design. In addition, guidelines help to standardise the output of an analysis, and this increases the potential for the validation of the method. Finally, the guidelines are presented in such a format that they too can be updated and expanded to incorporate new technologies and displays as they are developed.

12.2 TASK ANALYSIS IN AN INFORMATION CONTEXT

The thesis has aimed to examine the use of task analysis in process control, but in particular the flows of information and communications. Information flows are critical in the context of complex control room situations. These are not only the flows of information between the humans and the system, which form the basis for effective task performance, but also the information flows between members of the operational team. It is unusual to find a control room manned by a single operator

There are also the information flows with external organisations, for example, the suppliers of raw materials, and between the management and operators and between operations and maintenance personnel. All these flows need to be documented and analysed if the tasks are to be studied in their totality. The extended method of HTA aims to do this.

Means of transmission of the information

The evaluation of tasks and their related information requirements is often carried out in the context of a system where there are existing task structures and displays on which the analysis, at least in part, is based. In such an analysis, the information required needs to be documented independently of the existing system to allow effective evaluation of what currently exists, against an ideal. The method of HTA proposed provides a framework in which this can be achieved. The case studies showed that it was important that all information in the control room context was analysed and not only that to be provided in the format of displays on the interface. This is because there may be information that is required by the operator in carrying out the control task, that is currently transmitted in another format (ie, not via the displays) or that is not currently available to the operator. This may need to be included on the interface. Alternatively, there may be information which is currently displayed at the interface but which could more optimally be transmitted in another format (eg. verbally or via a written format). It is not always practicable to analyse the whole task, but all related items of information should be considered.

Once these information flows are documented, then decisions can be made on the mode of transmission of that information. This must optimally match the tasks it is to be used for and so enhance operator performance. Such modes of transmission may include VDU displays, panel and other supplementary hardwired displays, verbal communications (eg, intercoms or the telephone), written communications such as logs and operating procedures. Although recommendations were not given in the research on the most appropriate forms of transmitting different types of information to operators, it is a potential area for further study. It is possible that the method of HTA used could form a base from which such recommendations could be derived.

However, one problem which became evident in the case studies in the elicitation of information concerning tasks, was that it can be extremely difficult to gain an independent view of the information required, especially where operators are highly skilled. In such situations, the human factors specialist has to use as many sources of task information as possible and to be aware of the potential problems.

In a task synthesis situation, the problems which may arise are of a different nature. Assumptions concerning the equipment that could be used for information transmission in the control room are often made at an early stage of system design. The analyst therefore needs to be able to specify what might be required and be able to present arguments for items of equipment which might otherwise not be considered. The advantage of a task synthesis situation is that previous designs do not impinge on the information design in the form that they do in a task analysis situation.

Flow of information

In the design of VDU and other displays, a designer needs to be able to track the flow of items of information through the system and the relationship of these information flows to the tasks to be performed. Just as task elements are related to each other and one task element may form part of several tasks, so elements of information are related to each other and may be used for several different purposes. Therefore, within an analysis, it may be useful to track where and how items of information are used within a task hierarchy. This aids consideration of issues such as redundancy and the allocation of items to VDU display pages in display design.

Two approaches to including this information in the analysis can be suggested. Neither of these were actually employed in the case studies, but arose as a possible aid to problems that can be encountered in display design. Firstly, the task analysis could be annotated in some way to indicate the task elements for which a particular item, or group of items of information are used. This could be carried out at a particular level of task detail or at all levels of the hierarchy.

Another option would be to track an item or group of items of information through the hierarchy. One possible approach to this would be to use a system similar to that employed in petri-nets (Petri, 1976). Tokens (ie, markers to indicate the flow of the task) are used on the analytic diagram to give a more dynamic quality to the static information. In HTA, this may mean the use of tokens in the plans as well as the task operations. In petri-nets the tokens indicate task flow, in HTA they could indicate the use of information through the hierarchy. The item of information could be first 'tagged' at the highest level it appears in the hierarchy. This tagging then continues at each level of the hierarchy where each task element that uses the information is tagged. To ensure thoroughness, it may be more appropriate to begin by documenting the information use at the most detailed level of the hierarchy, then follow the flow up through the hierarchy. As a checking measure it should be possible to follow the flows down the hierarchy, to ensure that all information routes are documented. This should enable the display design to account for all the uses of a particular item of information and for the most appropriate way of displaying that information to be selected.

12.3 APPROACHES TO ANALYSIS

Top down versus bottom up

In any analysis of tasks where varying levels of task detail exist, one of two methods is employed to organise the task data. One commences at the most detailed level of analysis and works towards a more general description of the tasks. The other begins with the top level task and gradually decomposes it. When a bottom up approach is used, the task elements must have been identified in a systematic way to ensure that all aspects of the task are covered and that the more general levels of analysis give a detailed representation of the task. For example, TAKD (Johnson et al., 1986) takes a bottom up approach to task analysis once the fundamental elements for task description have been identified. The formality of this method, and other similar bottom up approaches, means that a structure is imposed on the way in which task description and analysis occurs.

A top down analysis offers a greater flexibility and adaptability in the analytic structure. Top level goals can be further decomposed to accommodate new or more detailed task information. This is difficult in a bottom up approach, as the detail precedes the more general task information and so the whole analysis may have to be changed to accommodate the additional information. A top down approach also allows each task element to be considered repeatedly to see if it can decomposed further. Within HTA the completeness of the redescription of each of the task operation is ensured by the rule that the subordinate operations and the plan must completely redescribe the superordinate operation.

A top down approach also allows the analyst to have flexibility in the level of detail used. This can be increased or decreased according to the context. Whilst a bottom up approach begins with the most detailed level of analysis and this is then fixed. Given these considerations, a top down approach was adopted in this thesis, although using a bottom up approach once the analysis is complete can provide a further check on its thoroughness. The logic of an analysis and the relationships of the task elements need to be checked with the overall system mission and goals of the task in mind.

A further issue which can relate to bottom up approaches is the definition of what constitutes the most detailed level of analysis. Is this flexible or should it always be fixed? The bottom most level of task elements are often referred to as task primitives. These task primitives could be individual button presses, or at an even more detailed level, individual muscle movements. Clearly the level of detail that is appropriate will vary from context to context, and may differ within an analysis. For example, a task that is critical to safety may need to be described in more detail than a simple and frequently performed procedure. In bottom up approaches the task primitives are the starting point and are uniform and fixed throughout the analysis. However, within top down approaches boundaries are required to determine when analysis is complete. In HTA, these take the form of stopping rules. These rules are generally applicable to allow the level of detail to vary within an analysis, and to determine when an appropriate level of detail has been achieved.

Thoroughness

Consideration of whether to adopt a top down or bottom up approach has already touched on the issue of ensuring the thoroughness of an analysis. Any analysis can only be as accurate as the information input to it. However, the framework provided by the task analysis technique can impose a structured approach to the analysis.

The third case study illustrated that for a task synthesis, HTA was more effective if all the points at which the human contributed to system functioning were firstly identified using a functional approach to analysis.

12.4 THE TASK CONTEXT

The management and organisational context

The influence of the overall task context on the way in which tasks are carried out should not be underestimated. The management of plant and the organisational philosophy has a significant impact on the plant operational context. This is illustrated in the case studies. For example, in the CPP case studies the organisational hierarchy was structured so that responsibilities were very explicitly defined and the operator had very little flexibility. By contrast, the operating environment at Didcot was such that the operators had a high degree of responsibility for operation under normal and emergency conditions.

A number of factors have to be considered to take these issues into account when carrying out an analysis. The first stage is to ensure that all assumptions about the allocation of responsibility and the management of the plant are stated. This is important as the task may remain constant but the management philosophy of the plant can change. In such a situation, the task analysis may not remain valid. In order for the analysis to remain up to date, the impact of such changes should be considered. If a task analysis is carried out on one plant and this is then to be used on a comparative plant, then the overall task context should be considered. The analysis can then be modified to take account of any differences in management or organisational structure to ensure an accurate analysis.

Normal and emergency operating conditions

Most analytical methods offer an analysis of the tasks to be performed by the operator under normal system operating conditions. The role of the operator includes tasks such as planning, problem solving, and fault detection and diagnosis. However, analysis may not address the operation of the system under abnormal system conditions, or even the tasks involved in commonly occurring faults. Yet as systems become increasingly automated, so the role of the operator in controlling the plant under emergency and abnormal system operating conditions is critical. Whilst the system may have many built in safety features, all the possible combinations of failure and emergency conditions are difficult to predict, especially in a complex system. One of the primary advantages of humans over machines is that of flexibility and adaptability. They have the ability to deal with unforeseen system states.

Whilst many systems, especially plants with hazardous processes or products, have automatic safety systems, in many emergency situations humans are required to completely recover the system to a normal mode of operation. This may involve the use of specialist teams or it may be the responsibility of the operating team. However, unless some approach is made to defining the demands that are likely to be made of an operator in such situations, there will be no systematic basis for decisions to be made. In any system, consideration is given in the engineering analysis to possible fault scenarios and these can be used as a basis for considering tasks that may need to be performed, the likely demands on the operators and the environment in which task performance is required. For example, pressures that are not normally encountered such as time constraints may need consideration, or even changes in the physical environment, such as a hazardous release restricting access to operating panels will need attention.

One approach that is effective is to consider the tasks required for a range of emergency scenarios from a small fault to the worst design basis accident. This should provide an indication of the types of operational situation that may be encountered. From this, decisions can be made concerning the level of skills and training required by the operator. For example, more detailed training or use of simulation may be required than would be for normal operation. Consideration will have to be given as to whether the control room operators will be the most appropriate personnel to carry out the tasks. Emergency operating procedures can also be based on such analyses. Decisions can be made concerning the human interaction with safety systems and the level of manual intervention required. The variations of this can be illustrated by three of the plants studied. One plant allocated no responsibility to the operator in any fault situation other than to report the fault information to the plant manager. Another employed a high level of automatic safety systems, such that no operator intervention was permitted for a period of half an hour following an emergency condition. A third allocated responsibility for fault detection, diagnosis and recovery to the operator.

In the context of the case studies, there was insufficient time available to examine tasks under emergency scenarios in detail. Primarily this was because of the additional information collection and plant familiarisation that would be required. This would be a profitable area for further study and may highlight a different set of issues that may be encountered in the documentation of operator information requirements under such situations.

12.5 FORMAL METHODS

Recently there has been the emergence of more formal methods and approaches to task analysis. These are primarily in the format of task grammars, for example, TAKD. Such methods aim to achieve a high degree of consistency and repeatability in the way in which tasks are described. The grammars usually cover a defined task area, for example, a particular kind of human computer interaction task, and once developed, can be applied to a wide range of tasks in that field. The way in which the grammar is applied is clearly defined. The methods also aim to address the cognitive content of tasks. TAKD (Johnson et al., 1986) is one such method considered in the context of this study which describes the knowledge required for a particular task.

A formalised approach to the analysis of tasks was not adopted in this study for a variety of reasons. Firstly, in describing the information that an operator requires to perform a task, natural language was felt to be a more appropriate media as it allows the more accurate communication of the required content of the information. A more formalised grammar would not allow the exact content of the displays, or other method of communication, to be defined in detail. Secondly, the formal methods often adopt a bottom up approach, which, as discussed earlier, can be problematic and does not provide a useful framework for task synthesis. The analysis method outlined in the thesis provides a resource and common basis on which other analysis can be based. This allows a suite of inter-related analyses to be formed, for example, a time line diagram or analysis of selection criteria. This could not easily be achieved from a formal analysis of the tasks. Finally, formal methods are defined in their structure and cannot easily be updated or expanded to accommodate further task information as a system is modified or as it progresses through the design cycle.

12.6 TASK SYNTHESIS

The issue of task synthesis and the use of the developed method for such an application is described in detail in the third case study. As a result of the case study an approach to synthesis emerged which provides a context for the development of a task structure and the study of tasks in a complex systems environment. The role of the human in the system needs to be identified in a systematic way before tasks can be synthesised and formed into a coherent structure, from which decisions can be made concerning issues such as interface design, training and operating procedures.

Such a preliminary analysis ideally coincides with a system centred engineering analysis, that identifies the functionality of the system. This permits decisions to be made concerning automation and allocation of function that cannot be made from a human centred analysis of operational and functional requirements. It also allows a rigorous identification of all the points in the system where a human input is required. As with a task analysis, if emergency and fault conditions are to be effectively designed for, then the analysis will encompass functionality under fault scenarios and allow the human role in such situations to be identified. FAST is a method of functional analysis that has been applied extensively within the plant described in the third case study and which provided information in a format that could be readily utilised in the modified HTA method. Further work could consider the uses of functional analysis as a precursor to a detailed task synthesis.

12.7 REDUNDANCY

The redundancy of information is an essential feature of the design of any display system, that is, the same information presented more than once in the same or different formats in the same information system, and which is supplementary to the minimum information required. However, the extent and nature of its use is dependent on the specific characteristics of the system. For example, a system with a large number of VDU displays is more likely to require the redundancy of information than a panel display based system. There is also the experience and training of operators. Highly experienced operators will require less redundancy of the information as a task aid, surplus information can actually be a hindrance for frequently executed tasks.

The proposed method of analysis described in this thesis highlights the information which is surplus to that actually required to perform the task. Sometimes this may indicate redundancy, it may also indicate that the information is irrelevant or not directly used in task performance. The method also helps decisions to be made within the context of the task structure as to whether or not redundancy is a desirable feature in the information design for a particular task. Conversely, the method of analysis also highlights tasks where the information provided is inadequate in terms of what the operator requires to perform the task, thus allowing such problems to be rectified at an early stage of design before change becomes too costly.

The method also helps the analyst and designer to trace, by use of the HTA, where items of information are used for more than one task, although this is not made directly explicit in the analysis. This is an important factor, as information may be required in different formats for different parts of a task. So the format in which it is displayed has to be considered in the total context. For example, if a task element requires an item of information which should ideally be displayed in a particular format, that same item of information may also be used in a completely different task context where a different format is required. A decision has to be made reaching a compromise which best meets the needs of both task elements. For this to be effective, the designer has to be fully informed about all the ways in which an item of information will be used and the context of this use. The proposed method of task analysis facilitates such decisions by highlighting for which task operations a particular item of information will be used and the types of task it is to be used for.

12.8 VALIDITY

There is little evidence in the literature of studies undertaken to validate techniques of task analysis. Fleishman and his co-workers (1975) carried out studies to validate the abilities requirements scales by evaluating the consistency in applying the scales by different analysts. In the course of examining HTA for use in this thesis three short studies were carried out on different groups of likely users. This was to evaluate the consistency reached in analysing a task from common information and to identify problem areas within HTA that might hinder the repeatability of an analysis. These studies are outlined in a paper by the author (Astley, 1988).

Inter-rater reliability is commonly cited as an approach to evaluating the validity of a technique. However, in the use of methods such as HTA the flexibility offered by the use of natural language in analysis means that any two analyses of the same task are very unlikely to be identical in content. The problem then arises of how two analyses can be judged to have equivalent content and to describe a task in the same way. Without imposing a formal structure or grammar on the analysis it is unlikely that this can be done systematically and such an assessment would ultimately have a considerable subjective content.

To truly measure the validity of a method, that is the extent to which a method can produce a predicted output, a measure of the expected output of analysis would have to be defined. Two issues of validity were outlined in the theoretical section of the thesis;. they were that a valid theoretical basis for the analysis, and its validity in application would both need to be considered. As there is no accepted theory surrounding the idea of a task, the theoretical grounding for an analysis would have to be justified on the basis of definitions of the concepts and on the research carried out into human performance and other relevant issues. As most analytic methods provide a framework in which to structure the task information, the validation could consider the use of the framework and the rules governing its construction. An alternative approach is to consider the use of the method in its anticipated application to the design or evaluation of the system. Again this would involve value judgments as to what constitutes a *good* human factors design. For example, if the required output of an analysis could be defined in terms of the display design it is predicted to produce, or an operating procedure that has already been defined and tested on the system, then the extent to which the analysis meets these design criteria could then be assessed. However, the problem then arises of the appropriate measures to use in assessing the compliance of the analysis.

The subjectiveness of task analysis techniques is a major problem, as it can lead to a wide variation in content. The output of an analysis is also highly dependent on the quality of information input, and this is not always under the control of the person carrying out the analysis. Although the latter could be partially overcome by stating the problems in information collection as part of the analysis.

At the present time the *face* validity of a method provides the most accessible form of validation. HTA can be judged to have a high face validity through its use and successful application to a wide variety of contexts as reported in the human factors literature. Although this face validity applies primarily to process control contexts, and in particular to training applications. Whilst the problems which surround the validation of task analysis techniques are evident, it is undoubtedly an issue which merits further consideration and work.

12.9 TASK ANALYSIS AS A TOOL

One of the issues addressed in this thesis is the use of task analysis methods to form more complete human factors tools for use in the design of systems. Preliminary ideas have been put forward to the use of the extended method of HTA as a tool for display design in process control. As task analysis becomes accepted as an essential stage in the design of systems, then guidelines on how to apply the resultant information are important to ensure a consistent approach and to overcome some of the problems resulting from subjectivity and expert judgment. This is especially so in complex systems where the human aspects of the system must be systematically studied in some detail. This is particularly important when elements of the system are analysed by a series of analysts who must then combine the resulting information into a coherent approach.

In process control contexts, there is little available to guide the analyst or designer in using the task information in design. Often it will not be the analyst who translates the task analysis into its application. Therefore, a prescribed approach to design or evaluation can help non-human factors experts to use the information. At present as methods do not present a tool for design, human factors specialists must be involved to provide all the specialist knowledge in translating the analysis into design criteria.

The other issue which arises in the use of task analysis as a tool, is the use of several methods to analyse different aspects of the task. In a complex system no one method can provide all the information required. More comprehensive tools can be provided by the use of batteries of task analysis methods selected to complement one another. This is discussed further in the following section.

12.10 BATTERIES OF TASK ANALYSIS METHODS

The review of the literature revealed that the majority of methods aim to address a specific issue in design; for example, training or interface design; the analysis of a specific task issues, for example, learning tasks; or else aim to offer a general approach. Where the latter approach applies, the analyses may be too general to be of use for particular design applications as greater detail is required.

In a complex system there are many facets to the tasks to be analysed, to which no one method can offer optimal approaches to all these facets. Some methods (eg, Farina and Wheaton, 1971) are comprised of several progressive analyses, each offering an examination of a different aspect of the task such as timing, skills requirements and operational procedures. It must be recognised that the needs of each system to be analysed will be different and that this will be dependent on factors such as the level of automation, the operating environment and the personnel of the plant. To meet these varying needs, an analyst needs to be able to use a range of methods of task analysis. Currently in systems that have been examined this occurs in an ad hoc fashion, in the sense that the methods used have not been designed to be used in conjunction with one another and no guidelines exist for the selection of suites of methods of task analysis.

Task analysis is a time and personnel intensive activity, so for the analyses to be carried out as effectively as possible, the analyses should ideally make use of common information. To avoid unnecessary repetition of analytic effort, they should also have minimal overlap in the information they provide as an output of the analysis. To achieve this, batteries of task analysis techniques could be constructed using existing or developed methods of analysis which complement each other and which are interlinked. Carrying out analysis in this way also helps to ensure that all the analyses are based on common assumptions and on common and coherent approaches to analysis. It also allows analyses to be carried out in parallel without the risk that the information produced will conflict or lead to problems in the use of the different analyses in design.

The approach taken to analysis in this thesis provides the basis for such a battery of techniques. It has already been demonstrated that FAST provides a useful basis for the functional analysis of the human's role in the system which can then be used and structured by the developed method of HTA. The HTA provides the basis for the design of the interface, displays and communications in the system. The structure of the task information in the HTA also provides a base for many other aspects of the system design. In constructing a battery, it would appear useful to have a core method such as HTA which provides the reference point for the other analyses, and from which the basic information can be derived. Such a method provides most of the task information, and the other methods in the battery may often be more simple and address specific issues. For example, a time line analysis could be constructed from the information in the HTA to show the concurrency of tasks and workload. HTA itself has been used extensively for training applications and for interface design. Additionally, the adapted method of task analysis can provide information to form the basis for an analysis of selection needs and the requirements of skills and knowledge of the operators. The HTA can also form a basis for decisions on the allocation of the tasks to members of an operational team.

The formulation of such batteries for complex control situations and other applications is an area which requires further consideration, HTA provides just one suggested approach. However, it would also appear to be a critical area if task analysis is to be used and applied as an effective tool for systems design and evaluation. There are such a variety of methods available, that it would also make efficient use of the resources that are already available to ergonomists.

12.11 GENERIC TASK ANALYSIS

For many large companies in the process control field, there are often two or more plants within the company which have a high degree of similarity and which provide the same product or service. Experience of process plants has shown that often the design of these plants is carried out in a localised fashion, including the human factors aspects of the design. Whilst there may be some centralisation of resources, for example, of experienced design personnel, the commonalities in the process may not lead to commonalities in the design approaches. This is often evident in the design of the human machine interfaces and the operating philosophies of the plant, which can be quite different from one another.

It would seem evident that if commonalities and differences could be identified, then common approaches to design could be adopted and centralised and so design effort reduced. This provides not only economic benefits, but also greater potential for the transfer of technology and personnel between plants. It also impacts on modifications and upgrades which could be carried out more consistently, with reduced effort.

A generic task analysis approach was adopted in the first case study. Coal preparation plants have many common factors, such as equipment and operating philosophies, yet the plants were very diverse and there was no common approach to the design of the human machine interfaces. Task analyses were carried out of three representative plants and from these a common task analysis constructed. This task analysis represented the tasks of the operators to a level of detail that was common to all the plants as far as practicable. Whilst HTA was used in this instance, there are other methods reported in the literature such as Overview Task Analysis (Patrick et al., 1980) which could also be employed for such applications. Design recommendations were then derived based on these common tasks. These recommendations provided the potential to apply common technologies in display design and common formats across the plants. Whilst the results of the study were not applied during the period of this research the benefits of such an approach are evident.

However, there are certain factors which must be taken into account when considering whether or not such an approach is viable in a particular context. Firstly, there is the question of whether or not the process and items of plant equipment share sufficient commonality and that the operation of them is functionally the same. Secondly, the operational environment, operating philosophies and the management of the plant must be considered. Variations in management, for example, can mean that tasks which appear to be similar, are in fact carried out in very different ways. Finally, the level of automation on the plant and the coincident allocation of function between the human and machines may impact on the task structure. This is not always the case and tasks which are included in the analysis may be automated in such a way that a common analysis can still be used in the plant. This would be the case for example, if one of the tasks of the operator was automated in its entirety. However, automation can impact on the way in which tasks are grouped into jobs and then allocated amongst the operational personnel. In situations where there are commonalities, however, a profitable approach to analysis can be a help in making optimal use of the resources available.

12.12 DIFFICULTIES AND PROBLEMS

In any situation where a complex problem is the subject of research, problems will be encountered in carrying out that research. This study was no exception.

Variety of analysts

In the context of the case studies, it was not possible to have several analysts working on the same task. Therefore within the context of the thesis the only situations in which inter-rater reliability could be assessed were the training courses and study described in Chapter 5. In order to attempt to fully assess the method, different analysts would ideally be trained in the use of the method, and their results in applying the method to the same task compared. It would also be useful to carry out trials on the use of the method with analysts of different backgrounds to allow an appraisal of the differences and difficulties encountered. For example, it may that engineers find the concept of describing tasks in a textual format difficult, or alternatively all groups that may use the method could find the concept of plans difficult.

By carrying out studies to identify these problems, training in the use of the method could be modified appropriately and the manuals and instructions on the use of the method used to give particular emphasis to problem areas.

Time constraints

Access to the plants on which the case studies were carried out was kindly permitted by the companies involved. However, carrying out any analysis, in general, and especially the collection of information for analysis, is time consuming not only for the analyst. It will also make use of the resources on the plant such as access to operational personnel. For this reason the time spent on the plants was limited. There were also time constraints imposed by the timescale in which the studies could be carried out. External constraints also applied in some situations, for example, access to the Coal Preparation Plants was limited due to the Miner's Strike. Time spent on plants also involved time taken for plant familiarisation, an essential step before analysis could be effectively carried out.

Comprehensiveness of analysis

Within the timescales of the analysis it was not feasible to carry out a comprehensive analysis of all the tasks involved in the operation of a particular system. Therefore representative tasks, or tasks that were particularly critical to system operation, were selected for study. In some of the case studies the tasks were selected by the design team to contribute to design activities that were occurring at that time.

12.13 FUTURE WORK

The preceding sections have outlined a variety of possible areas for future work. In the future there must be a drawing together and optimising of the work carried out. As new technologies emerge, then new methods of task analysis will be developed to complement them. However, the fundamental characteristics of humans and their approaches to tasks do not change. Rather, it is their role in systems that has undergone a metamorphosis. Existing methods of task analysis provide the framework, structures and approaches required for the study of human work. These should be fully utilised and adapted to take account of the evolution of systems and technologies.

The next decade may see further methods being developed to address the cognitive issues relating to task performance. However, the need is not only for methods to analyse the increasingly large cognitive task component in process systems, but also to address the analysis of tasks in large scale systems, such as those found in process control. Future work could usefully include the development of batteries of techniques which can be combined to allow the analysis of the many facets of human involvement in such systems.

Computer based task analysis has received some attention during the 1970s and 1980s. Existing software packages have been used to provide a computerised base for carrying out task analysis. Such methods usually provide a framework in which to structure the task analysis information (for example, as a hierarchy). Others check for consistency in the links, inputs and outputs between task elements. The primary advantage of these computer based tools lies in the automatic generation of the analysis diagrams or representation, which consequently allows easy updating of the information. Future work could incorporate further advancement of such tools. One example might be the use of an Intelligent Knowledge Based System (IKBS) to facilitate the information gathering and structuring for analysis, in addition to providing the framework for an analysis.

The plethora of task analysis methods available means that methods have been developed to suit almost all purposes. However, further attention could be paid to the development of manuals detailing how methods can be carried out, and also for aids to the selection of appropriate methods for different contexts. This would enable better use to be made of the methods that exist. Few attempts have been made to validate task analysis techniques. If task analysis is to be fully accepted as a technique for use in systems design, studies to examine issues such as consistency and inter-rater reliability would give a useful starting point to provide a validation of methods. Future work could also address the development of tools to enable task analysis and the task information it provides to be more readily incorporated into design by ergonomists and other system designers alike. In conclusion, future work in the context of task analysis for industrial process control would be most usefully concentrated, not on the development of new methods of task analysis, but on the full utilisation of existing methods, adapting and evolving them to meet the demands of changes in technology. Such methods may form the basis for tools to facilitate design, for example, as the tool proposed in this thesis, and may also provide a basis for the computerisation and validation of task analysis.

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APPENDICES

APPENDIX A

METHODS REVIEWED: TASK ANALYSIS METHODS FOR APPLICATION TO PROCESS CONTROL CONTEXTS

1. AET
2. Job Process Charts
3. Hierarchical Task Analysis
4. Link analysis (Frequency counting)
5. Abilities requirements approach (Fleishman)

6. Berliner, Angel and Shearer : a task taxonomy
7. Operational Sequence Diagrams
8. Petri-nets
9. FAST
10. Management Oversight Risk Trees (MORT)

11. HAZOP (Hazard and Operability studies)
12. Signal Flow Graphs
13. GOMS (Goals, Operations and Methods)
14. Cognitive Task Analysis (Barnard)
15. Rasmussen, cognitive task analysis

16. Cotterman's task analysis method
17. Farina and Wheaton's task analysis method
18. Position Analysis Questionnaire (PAQ)
19. Functional Job Analysis
20. Overview Task Analysis

21. Occupational Analysis inventory
22. Task Action Grammars (TAG)
23. User programmes
24. Block Interaction Methodology (BIM)
25. Task Analysis for Knowledge Descriptions (TAKD)

26. Miller (Task strategies approach)
27. Command Language Grammar
28. External-Internal Task Mapping
29. BNF grammar
30. Analysis of menu systems

31. Strategies of user interaction model
32. Task analysis for information structure description
33. Bainbridge and Beishon methodology
34. Flow charts
35. Information Decision Action Diagrams

36. Decision flow diagrams
37. Job Evaluation Methodology
38. Task Network Scheduling (TANES)
39. Simon (Protocol Analysis)
40. Time Line diagrams

41. State transition diagrams
42. Finite State Analysis
43. PERT charts
44. Critical Path Analysis
45. Burger and De Jong's method

46. Alluisi's method
47. Bennett's method
48. Carroll's method
49. Folley's method
50. Gilbreth (Therbligs)

51. Taylor's method
52. Miller, Galanter and Pribram (TOTE)
53. Meister's method
54. Melton's method
55. Manoeuvre task analysis

56. Sternberg's method
57. Silverman's method
58. N^2 charts
59. Willis' method
60. Eason and Harker's task analysis

61. Personalised Task Representation (PTR)
62. Fault trees
63. Withheld information
64. Repertory grids
65. Responsibility charts

66. Information and controls analysis
67. Checklists
68. Process inventory
69. Operator action event trees
70. Job component inventories

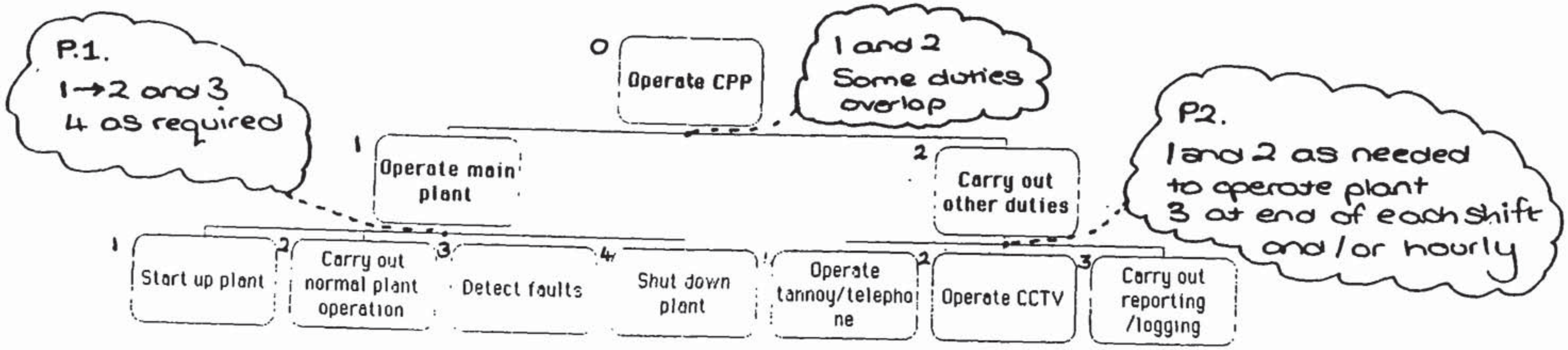
71. Task decomposition
72. SAINT
73. Murphy diagrams
74. Task analysis profiling system (TAPS)
75. Critical Incident technique

76. Verdier's method
77. Burgy's method
78. Singleton's taxonomy
79. Cognitive task analysis (Scandura)
80. Cuny : task analysis in terms of messages and signs

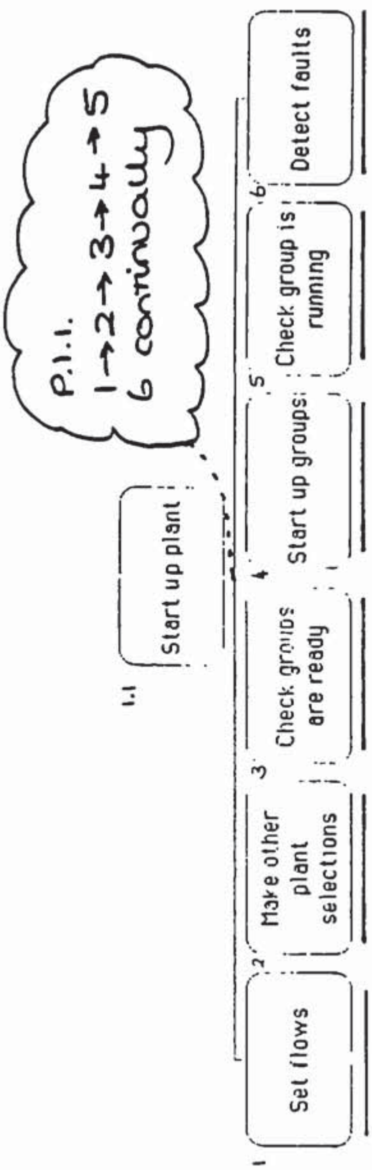
81. Johanssen's method
82. Barrier analysis

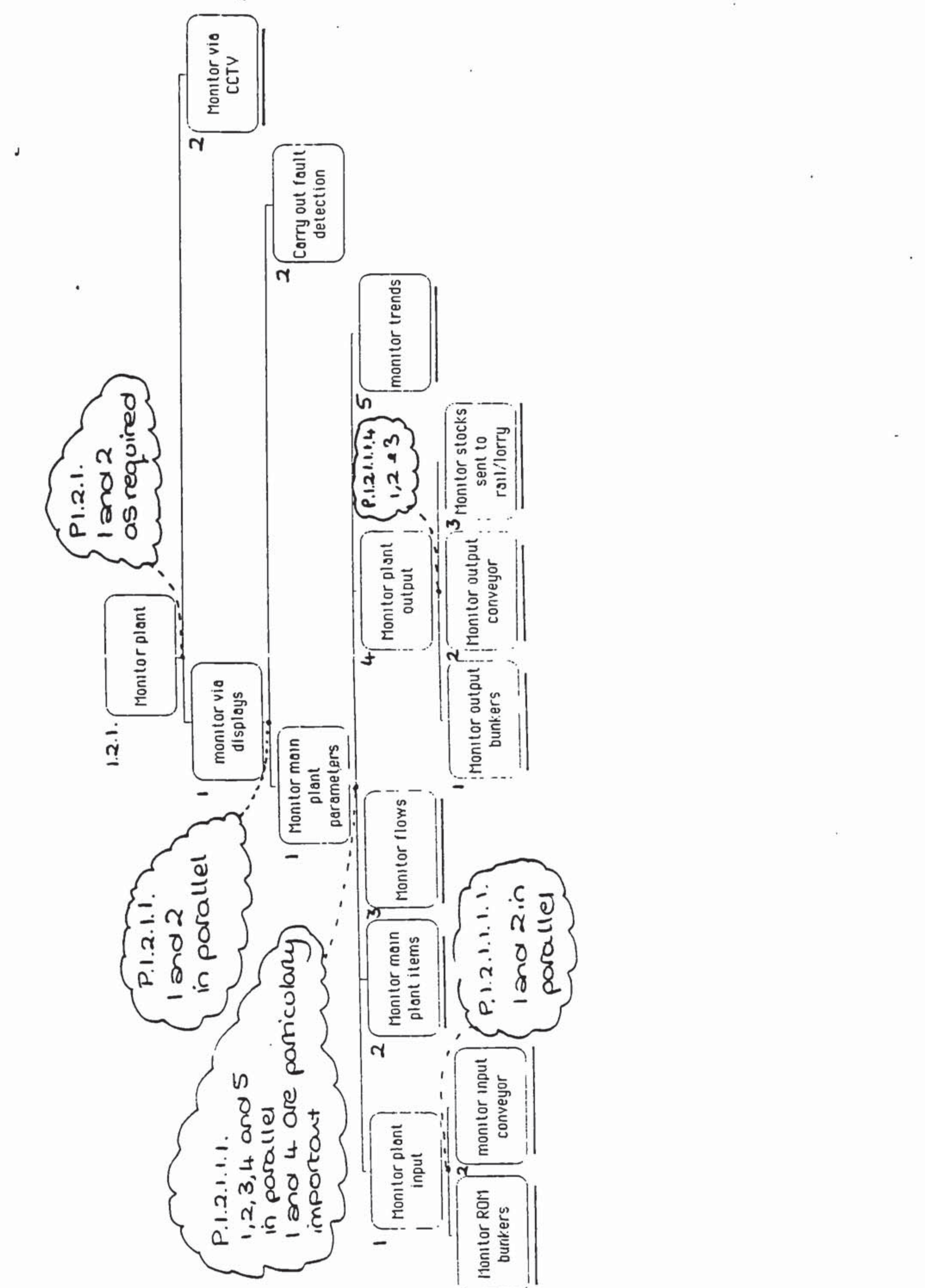
APPENDIX B

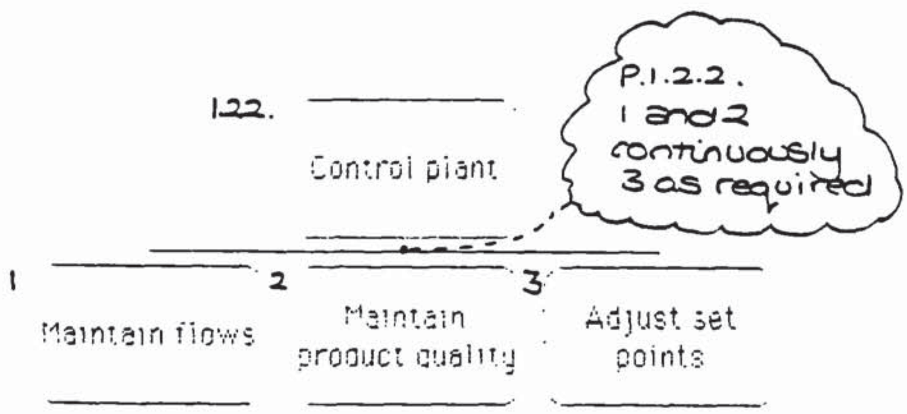
The Coal Preparation Plant Task Analyses



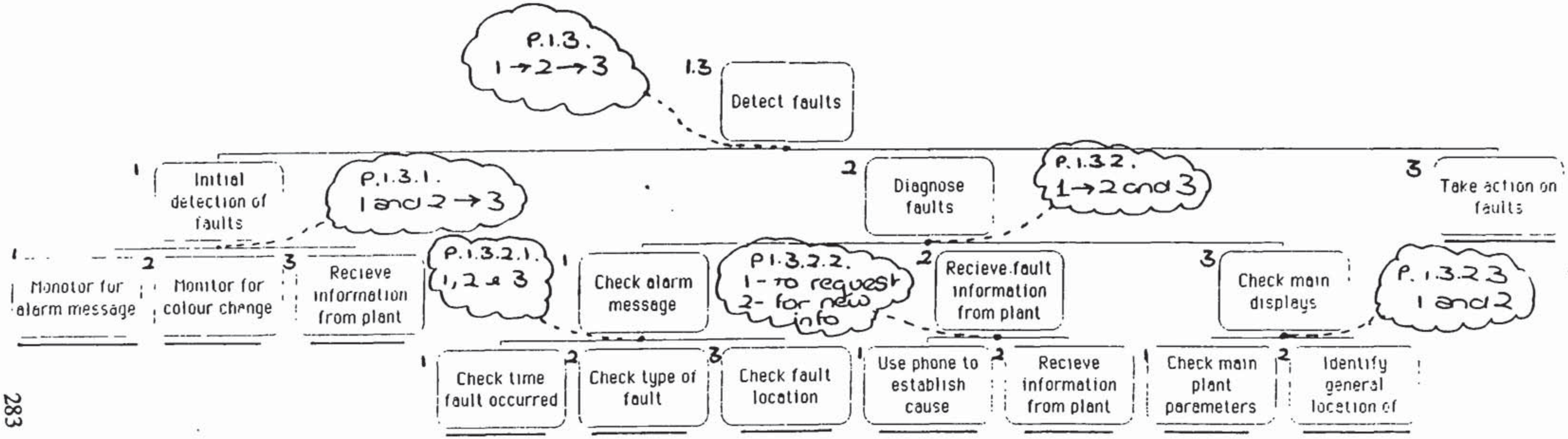
COMMON TASK ANALYSIS

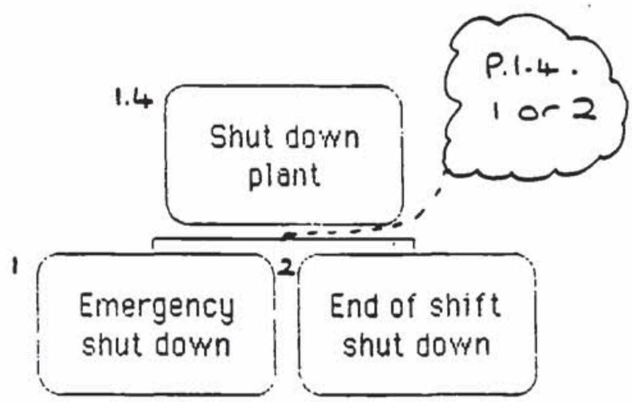

1.1
Start up plant
P.1.1.
1→2→3→4→5
6 continually
1
Set flows
2
Make other plant selections
3
Check groups are ready
4
Start up groups
5
Check group is running
6
Detect faults


1.2.1.
Monitor plant
P1.2.1.
1 and 2
as required
monitor via displays
Monitor via CCTV
P.1.2.1.1.
1 and 2
in parallel
Monitor main plant parameters
Carry out fault detection
P.1.2.1.1.1.
1,2,3,4 and 5
in parallel
1 and 4 are particularly
important
Monitor plant input
Monitor main plant items
Monitor flows
Monitor plant output
monitor trends
Monitor ROM bunkers
monitor input conveyor
P.1.2.1.1.1.1.
1 and 2 in
parallel
Monitor output bunkers
Monitor output conveyor
Monitor stocks sent to rail/lorry
P.1.2.1.1.1.4
1,2 & 3



1.2.2.
Control plant
P.1.2.2.
1 and 2
continuously
3 as required
1
Maintain flows
2
Maintain
product quality
3
Adjust set
points


P.1.3.
1→2→3
1.3
Detect faults
1
Initial detection of faults
P.1.3.1.
1 and 2→3
2
Diagnose faults
P.1.3.2.
1→2 and 3
3
Take action on faults
1
Monotor for alarm message
2
Monitor for colour change
3
Recieve information from plant
P.1.3.2.1.
1,2 & 3
1
Check alarm message
P.1.3.2.2.
1 - to request
2 - for new info
2
Recieve fault information from plant
3
Check main displays
P.1.3.2.3
1 and 2
1
Check time fault occurred
2
Check type of fault
3
Check fault location
1
Use phone to establish cause
2
Recieve information from plant
1
Check main plant paremeters
2
Identify general location of


1.4
Shut down plant
P.1.4.
1 or 2
1
Emergency shut down
2
End of shift shut down

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
0. Operate Coal Preparation	1 and 2 Some duties overlap	1. Operate main plant	← main plant status and parameters	Operator has the knowledge and skill to operate the plant	Operational	1 and 2 may be allocated to each of the operators on a shift (if there is more than one operator).
		2. Carry out other duties	← other plant and related information		Operational	
1. Operate Main Plant	1→2 and 3→4 as required	1. Start up plant	← start up information → start up operations	Knowledge of start up procedure	Procedural	
		2. Carry out normal plant operation	← plant operational information → plant control information	Knowledge of operation procedures and plant parameters and functioning	Operational Procedural	
		3. Detect faults	← faults occurring or predicted	Some fault knowledge	Fault detection	
		4. Shut down plant	← shut down information	Shut down procedure	Procedural	

COMMON TASK ANALYSIS

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
1.1 Start up Plant	1→2→3→4→5 6 continually whilst carrying out other operations	1. Set flows //	← current flow parameters and defaults → required flow parameters	Knowledge of flows required and setting flows procedure	Decision making Procedural	
		2. Make other plant selections //	← plant parameters and selection available → selections required	Understanding of how the plant should be configured and the effect of different parameters	Operational Procedural Decision making	
		3. Check groups are ready //	← status of plant groups	Understanding of the indications of group status	Procedural	
		4. Start up groups //	→ group start	Knowledge of start procedure	Procedural	
		5. Check group is running //	← plant group status	Understanding of displayed indications	Procedural	
		6. Detect faults	← faults	Some knowledge of faults	Fault detection	Redescribed under operation 1.3.
1.2 Carry out normal plant operation	1. Continously	1. Monitor plant	← status of plant parameters	Knowledge of how and what to monitor	Monitoring	
	2. When required	2. Control plant	→ changes in plant parameters	Knowledge of how and what to control and when	Operational	

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
1.2.1. Monitor Plant	1 and 2 as required	1. Monitor via displays	← current status of plant parameters	Knowledge of Important and minor plant parameters	Monitoring	
		2. Monitor via CCTV //	← direct visual feed-back on plant status	Which parameters have the most Impact on the plant	Monitoring	
1.2.1.1. Monitor via displays	1 and 2 in parallel	1. Monitor main plant parameters	← main plant parameters status	Understanding of how the main parameters relate functionally to the plant	Monitoring	
		2. Carry out fault detection	← faults occuring ← information on the limits and trends of the parameters being monitored	An undertstanding of the relevant importance of faults and how they affect the plant	Fault detection	
1.2.1.1.1. Monitor main plant parameters	1, 2, 3, 4 and 5 in parallel, 1 and 4 are particularly important	1. Monitor plant input	← status of plant input parameters	Knowledge of limits of parameters and the effect of faults on overall running of the plant		
		2. Monitor main plant items //	← status of main plant items	Knowledge of limits of parameters and the effect of faults on overall running of the plant	Monitoring	The major plant items vary from plant to plant but would include the washing parameters, grading etc.
		3. Monitor flows //	← Flow information	Knowledge of limits of parameters and the effect of faults on overall running of the plant	Monitoring	Flows are especially important (a) to ensure the plant is running at its optimum efficiency

CIA 3

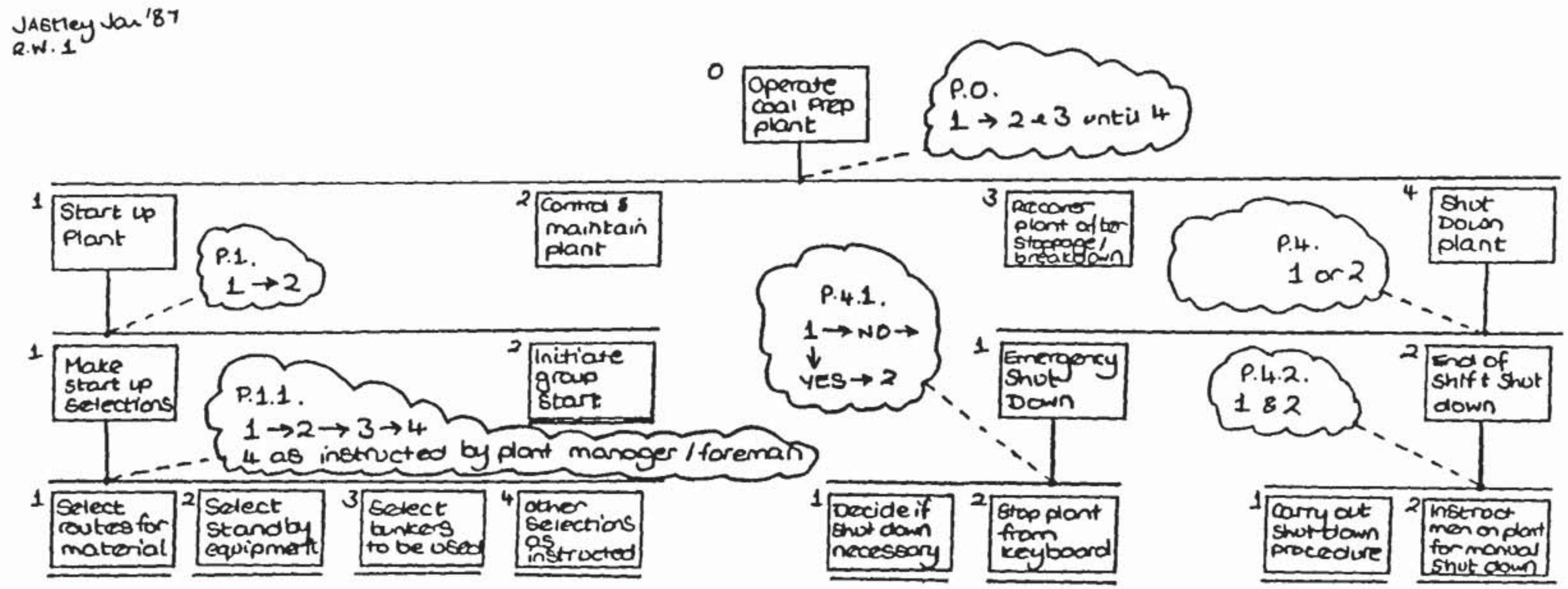
Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
1.2.1.1.1 (cont.)		4. Monitor plant output	← output information	Knowledge of limits of parameters and the effect of faults on overall running of the plant	Monitoring	(b) In the event of a fault rerouted, plant flows could avoid production lost through plant down time
		5. Monitor trends //	← trend information on critical and other plant parameters	Ability to interpret and use trend information for the early detection of faults	Monitoring Fault detection	Trends are important in helping to anticipate and avoid faults that may occur
1.2.1.1.1.1. Monitor plant input	1 and 2 in parallel	1. Monitor ROM bunkers //	← bunker levels and flows in and out of bunker	Knowledge of correct levels and flows and what the parameter limits are	Monitoring	Input flows information must also be related to level of stockpile and the rate of delivery of coal, as this may decide whether the plant runs at optimum capacity or not
		2. Monitor input conveyor //	← flows onto, off conveyor and tonnage per hour	Knowledge of correct levels and flows and what the parameter limits are	Monitoring	
1.2.1.1.1.4. Monitor plant output	1, 2 and 3 in parallel	1. Monitor output bunkers //	← flows, bunker levels and tonnage per hour ← quality of coal going out of plant (especially ash content)	Knowledge of correct levels and flows for current plant status	Monitoring	The quality of the output can give indications of problems in the process
		2. Monitor output conveyor //	← flows and tonnage per hour	Procedures for interacting with men on plant – for quality control and co-ordinating stocks to rail and lorry	Monitoring Procedural	The output needs to be co-ordinated to some extent with the number of trains arriving to deliver stock to customers
		3. Monitor stocks sent to rail/lorry //	← stocks sent to rail/lorry			

CTA 4

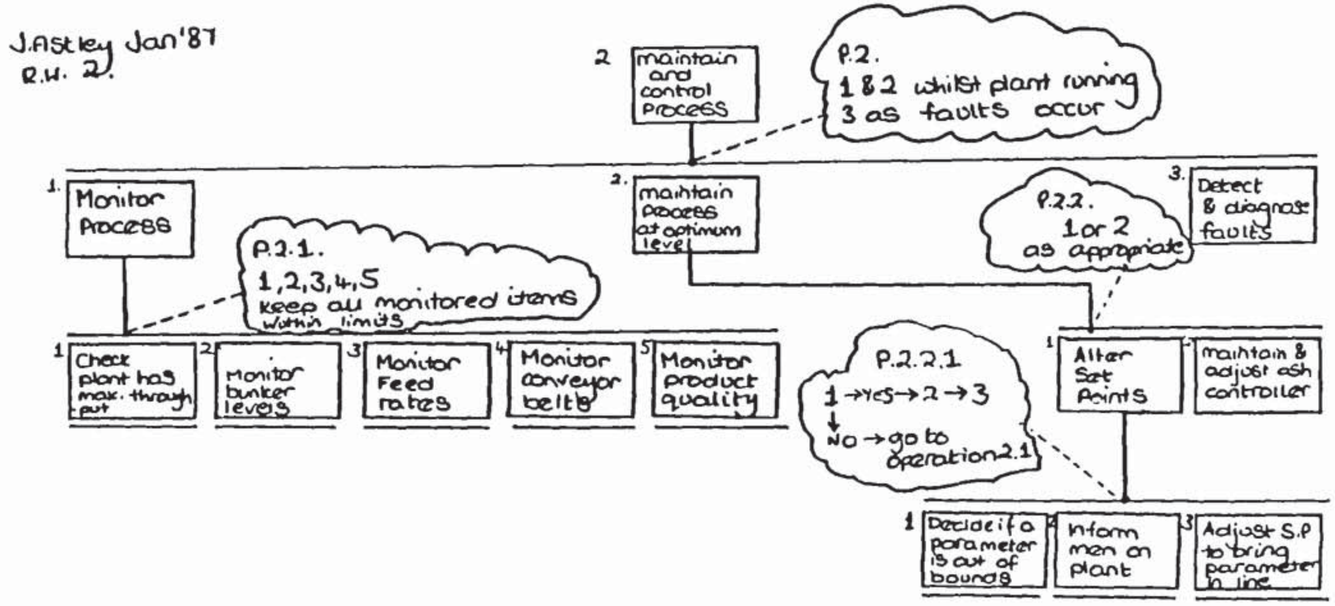
Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
1.2.2 Control plant	1 and 3 continuously 3 as it is required according to current and expected future plant status	1. Maintain flows //	← information on current status and trends	The correct status for the system under likely operating conditions	Monitoring Operational	
		2. Maintain product quality //	← information on current quality – e.g. size, ash content etc.	Factors affecting product quality and how they are controlled	Monitoring Operational	
		3. Adjust set points //	← current set points → changes in set points	Knowledge of procedure for changing set points and acceptable boundaries for set points	Operational	
1.3. Detect faults	1→2→3 2 and 3 with co-operation of shift foreman, managers and men on plant	1. Initial detection of faults	← occurrence of fault	Operator understands fault indications	Fault detection	
		2. Diagnose faults	← detailed fault information			
		3. Take action on fault //	→ action to alleviate or remove cause of fault	Operator has sufficient plant experience to be able to evaluate alternative courses of action	Problem solving Operational	As the possible causes of faults and actions were not examined in detail as part of the study, the analysis finishes at this general level

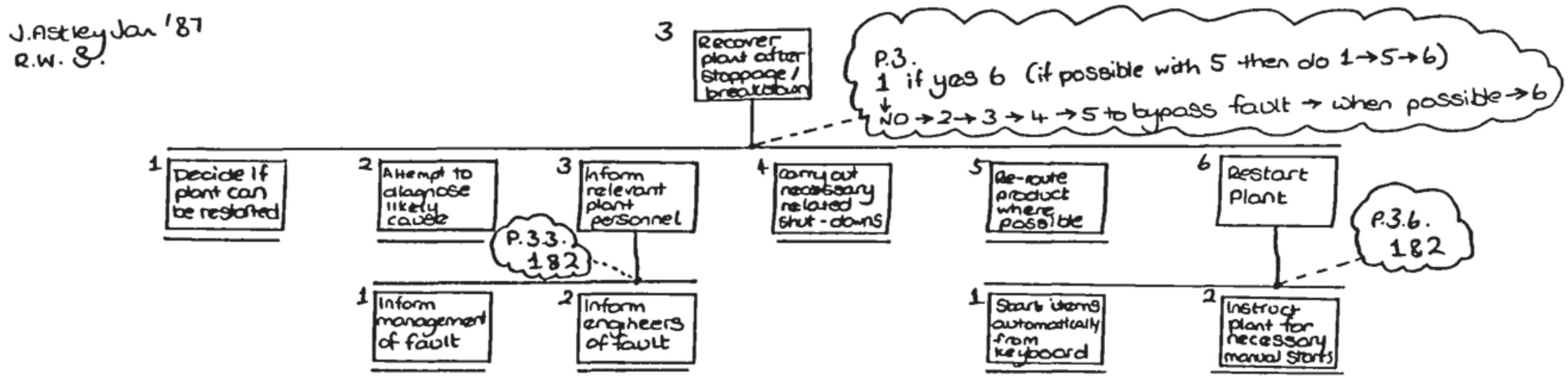
Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
1.3.1. Initial detection of faults	1 and 2 → 3 (3 may need to be requested)	1. Monitor for alarm message //	← alarm message	Understanding of message	Monitoring Fault detection	
		2. Monitor for colour change //	← change in colour of plant item displayed	Understanding of message	Monitoring Fault detection	
		3. Receive information from plant //				Information given by telephone or tannoy
1.3.2. Diagnose faults	1 → 2 and 3 as necessary	1. Check alarm message //	← details of fault	Ability to interpret fault message	Fault diagnosis	
		2. Receive fault information from plant			Fault diagnosis	Further fault information as it becomes available is recieved via telephone or intercom system
		3. Check main displays for fault information	← fault information shown on main displays	Operator is able to understand where faults have occured	Fault diagnosis	Displays may help to indicate common m de faults
1.3.2.1. Check alarm message	1, 2 and 3	1. Check time fault occurred //	← time of occurrence of fault	Understanding of fault messages	Procedural	
		2. Check type of fault //	← nature of fault	Understanding of different fault types	Fault diagnosis Procedural	
		3. Check location of fault //	← location of fault	Knowledge of location of plant items on plant	Fault diagnosis Procedural	

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
2. Carry out other duties	1 and 2 as needed to operate plant 3 at end of each shift and hourly if required	1. Operate tannoy/ telephone		How to operate tannoy/telephone	Operational	Operator uses telephone /tannoy to communicate with men on plant and to gain plant information not given on the displays. CCTV used to visually monitor parts of plant not shown on screen or that are problematic
		2. Operate CCTV //	← direct visual plant information	How to operate CCTV and items of plant to monitor	Procedural Operational	
		3. Carry out reporting/logging	← parameters that need to be reported or logged	Logging procedure	Procedural	
2.1 Operate tannoy/ telephone	1 and 3 or 2	1. Operator requests information from plant //	→ information required	How to request information	Procedural	
		2. Give information to plant //	→ request information required ← information required	How to assess information needed	Decision making Procedural Operational	
		3. Receive information from plant //	← plant information	How to integrate information with information from displays	Problem solving Procedural	
2.3. Carry out reporting/ logging	1→2 and 3	1. Collect data	← data needed → request data	Procedure for collecting data	Procedural	
		2. Log data	→ input data to log	Logging procedure	Procedural	
		3. Report information	→ report information logged to plant and/ or shift foreman	Reporting procedure	Procedural	

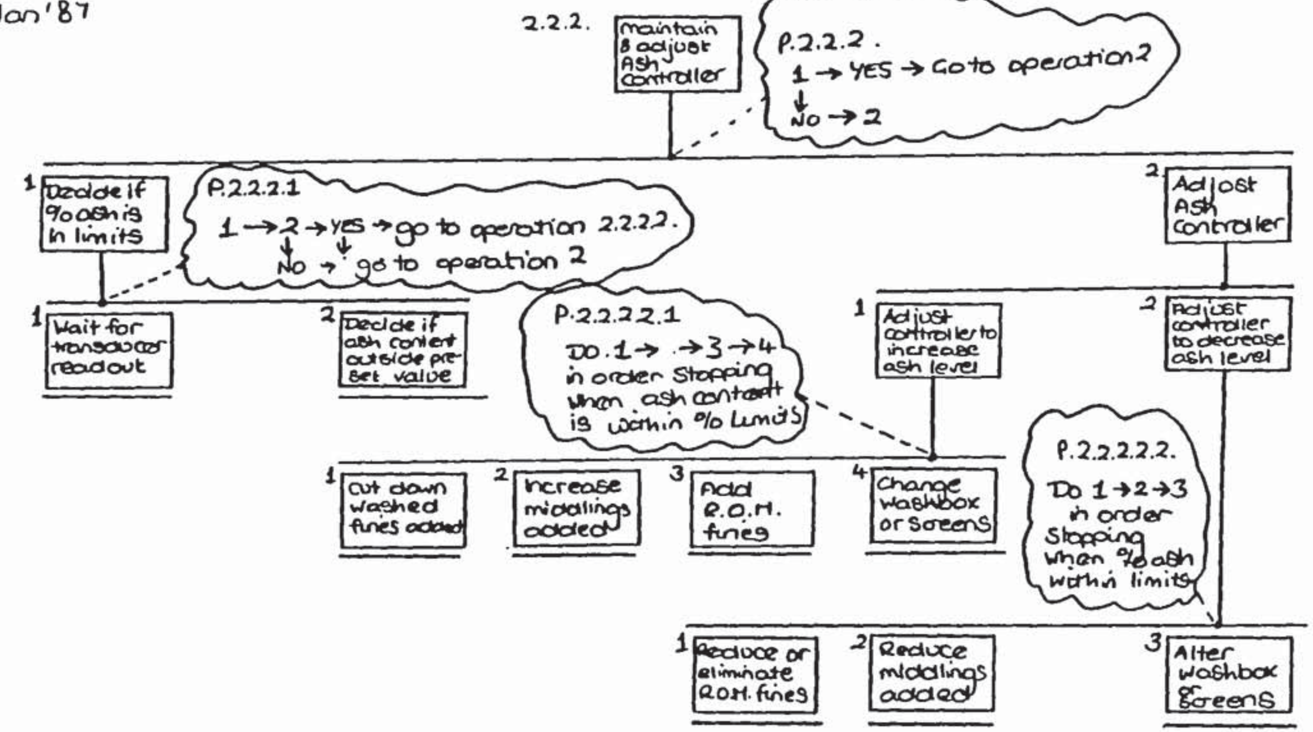


RAWDON CPP TASK ANALYSIS

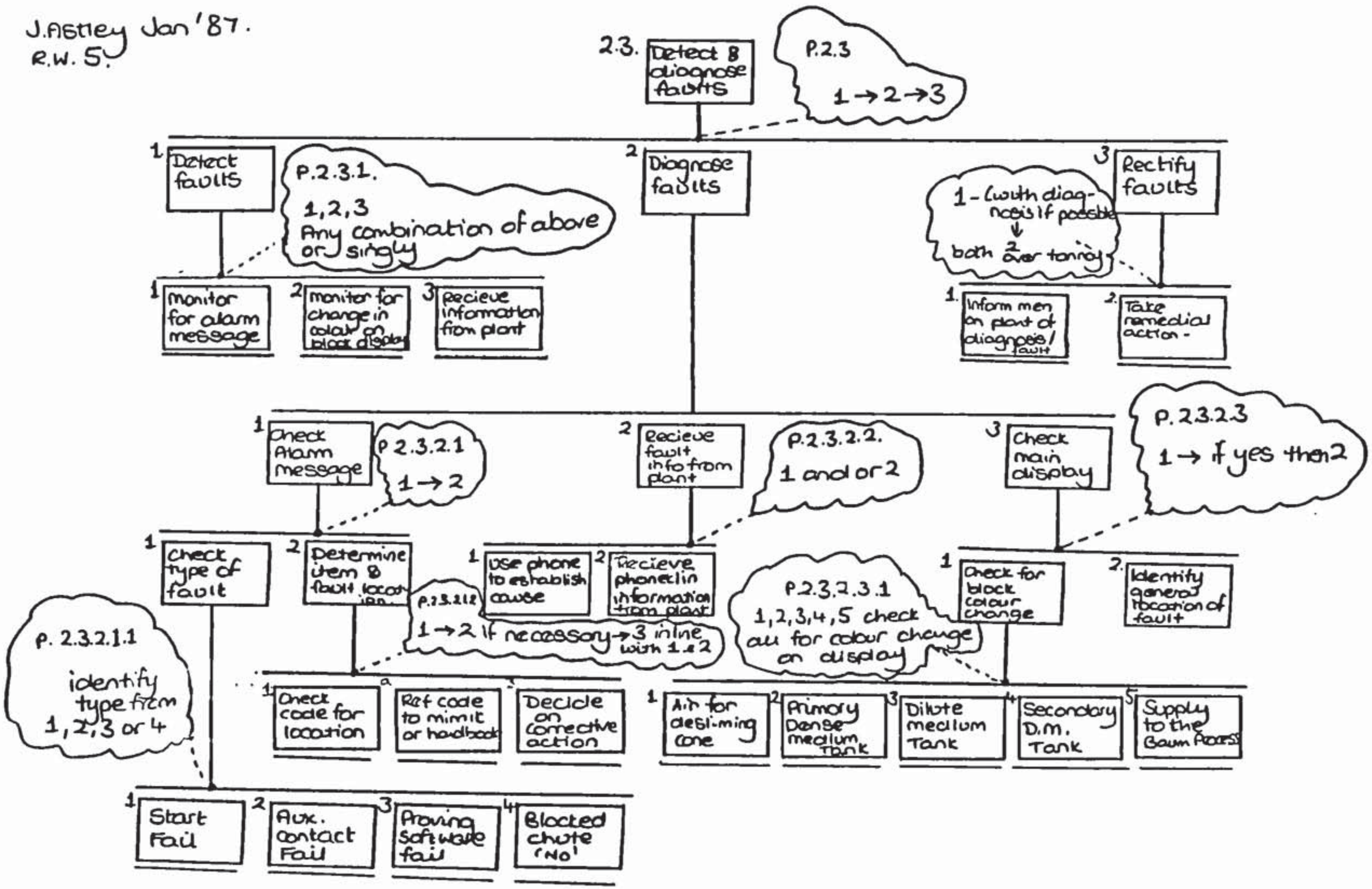

J.Astley Jan'87
R.H. 2.
2 maintain and control Process
P.2.
1 & 2 whilst plant running
3 as faults occur
1. Monitor Process
2. maintain process at optimum level
3. Detect & diagnose faults
P.2.1.
1,2,3,4,5
keep all monitored items within limits
1 Check plant has max. through put
2 Monitor bunker levels
3 Monitor Feed rates
4 Monitor conveyor belts
5 Monitor product quality
P.2.2.
1 or 2
as appropriate
1 Alter Set Points
2 maintain & adjust ash controller
P.2.2.1
1 → YES → 2 → 3
NO → go to operation 2.1
1 Decide if a parameter is out of bounds
2 Inform men on plant
3 Adjust S.P to bring parameter in line

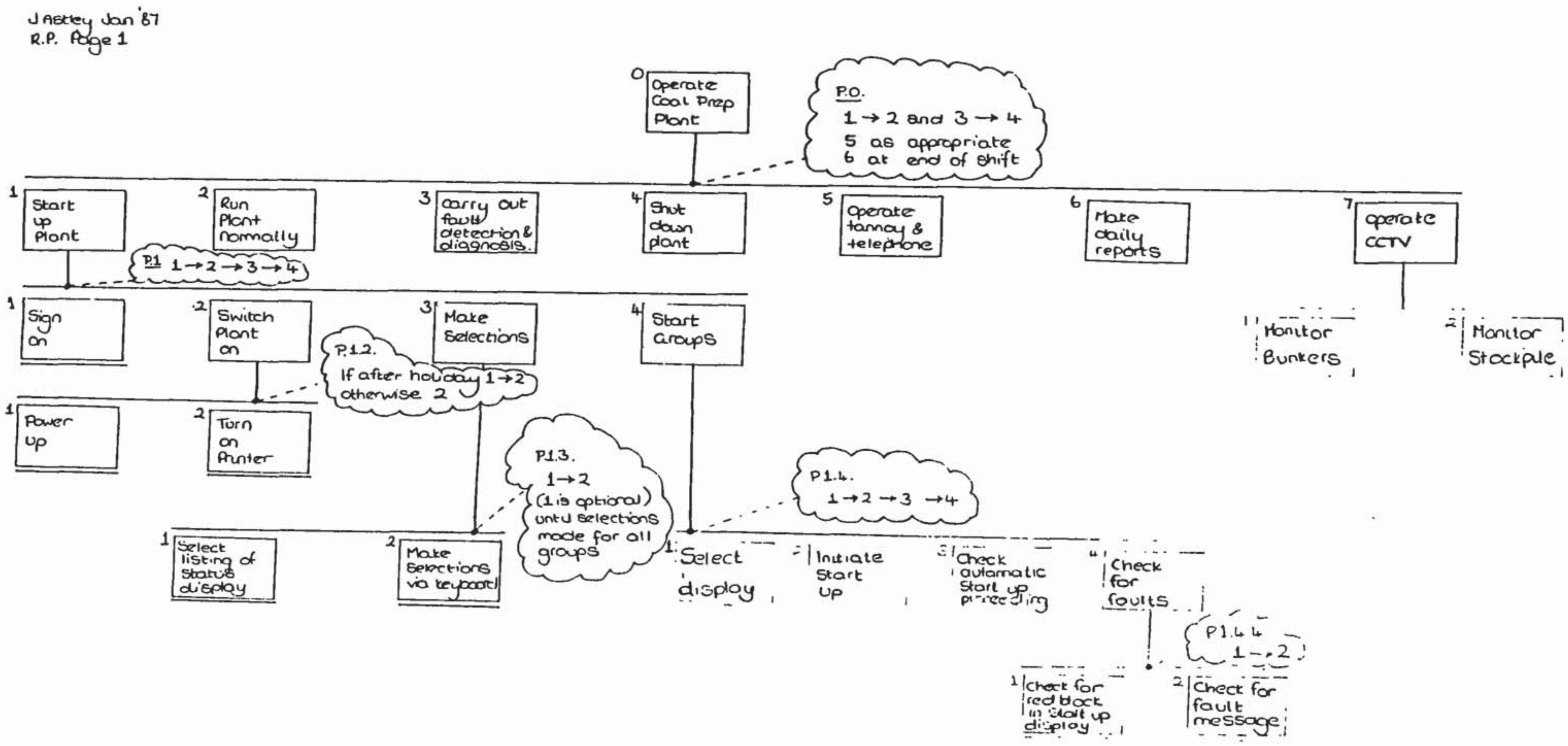

J.Astley Jan '87
R.W. 3.
3 Recover plant after stoppage / breakdown
P.3.
1 if yes 6 (if possible with 5 then do 1→5→6)
NO→2→3→4→5 to bypass fault → when possible→6
1 Decide if plant can be restarted
2 Attempt to diagnose likely cause
3 Inform relevant plant personnel
4 Carry out necessary related shut-downs
5 Re-route product where possible
6 Restart Plant
P.3.3. 1&2
1 Inform management of fault
2 Inform engineers of fault
P.3.6. 1&2
1 Starts items automatically from keyboard
2 Instruct plant for necessary manual starts

J.Ashley Jan '87
R.W.4.



J.Astley Jan '87.
R.W.5.





RENISHAW PARK CPP TASK ANALYSIS

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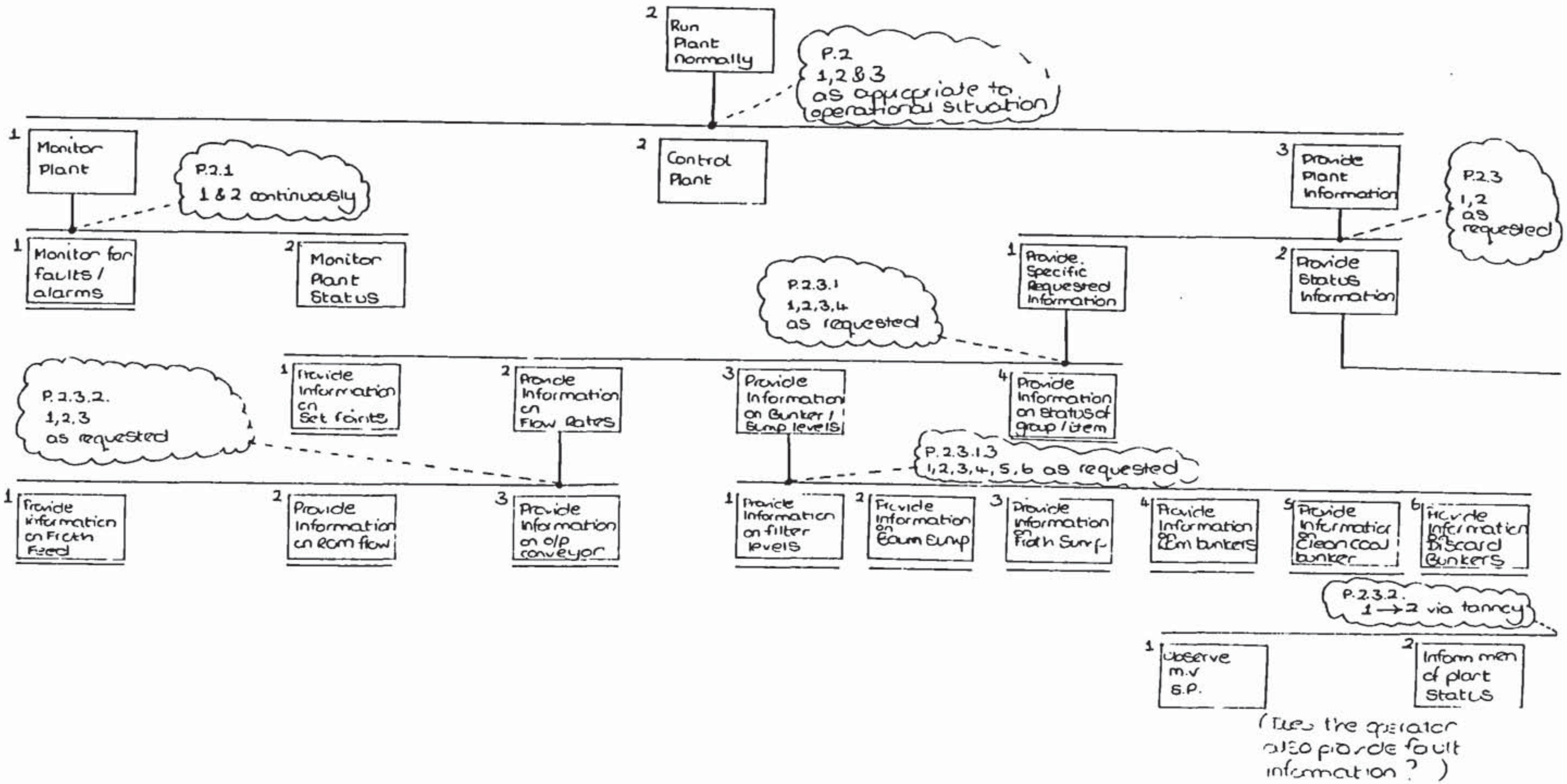
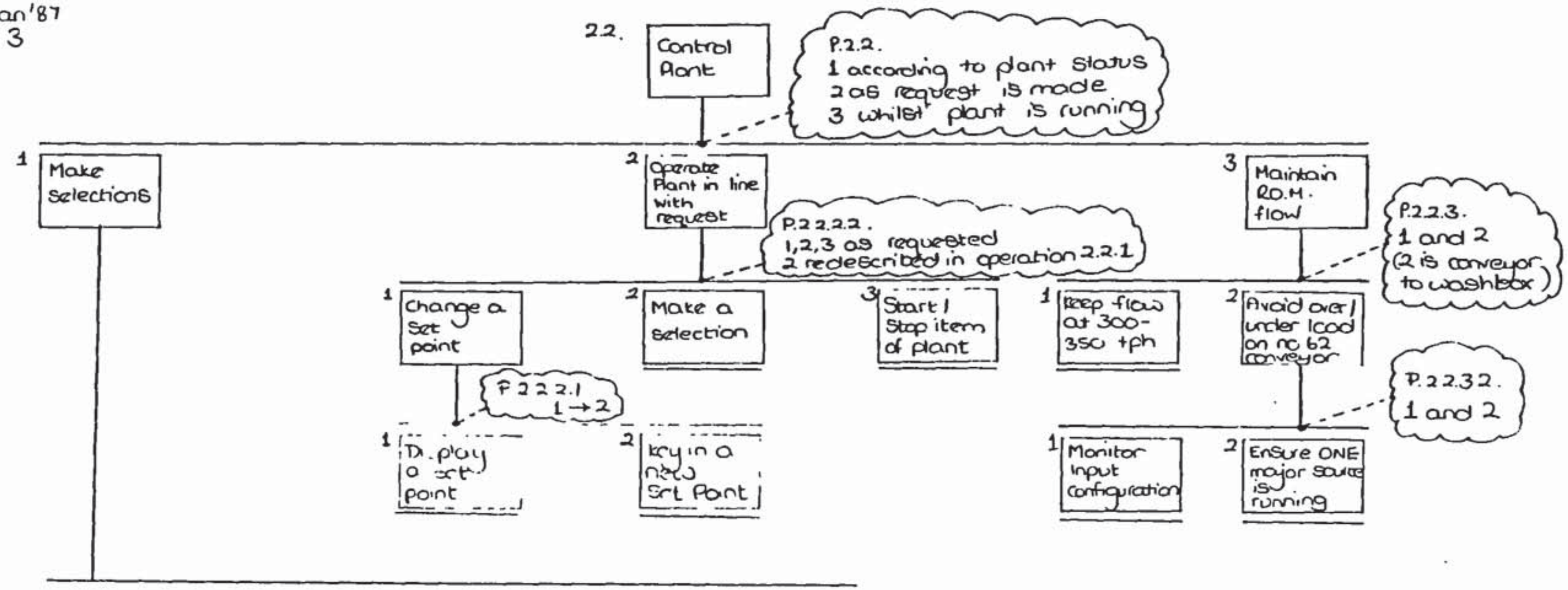
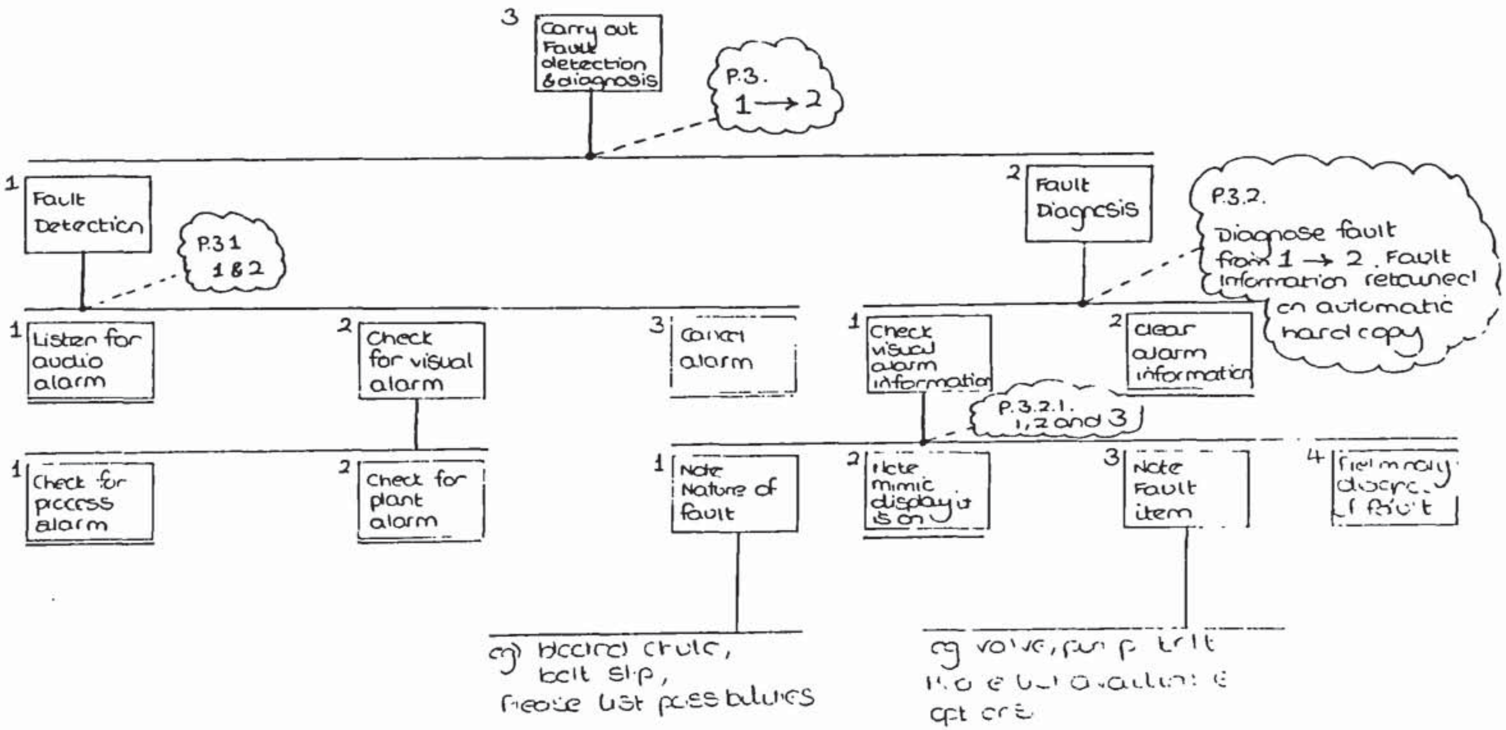
RP. Page 2



J.Astley Jan'87
R.P. Page 3

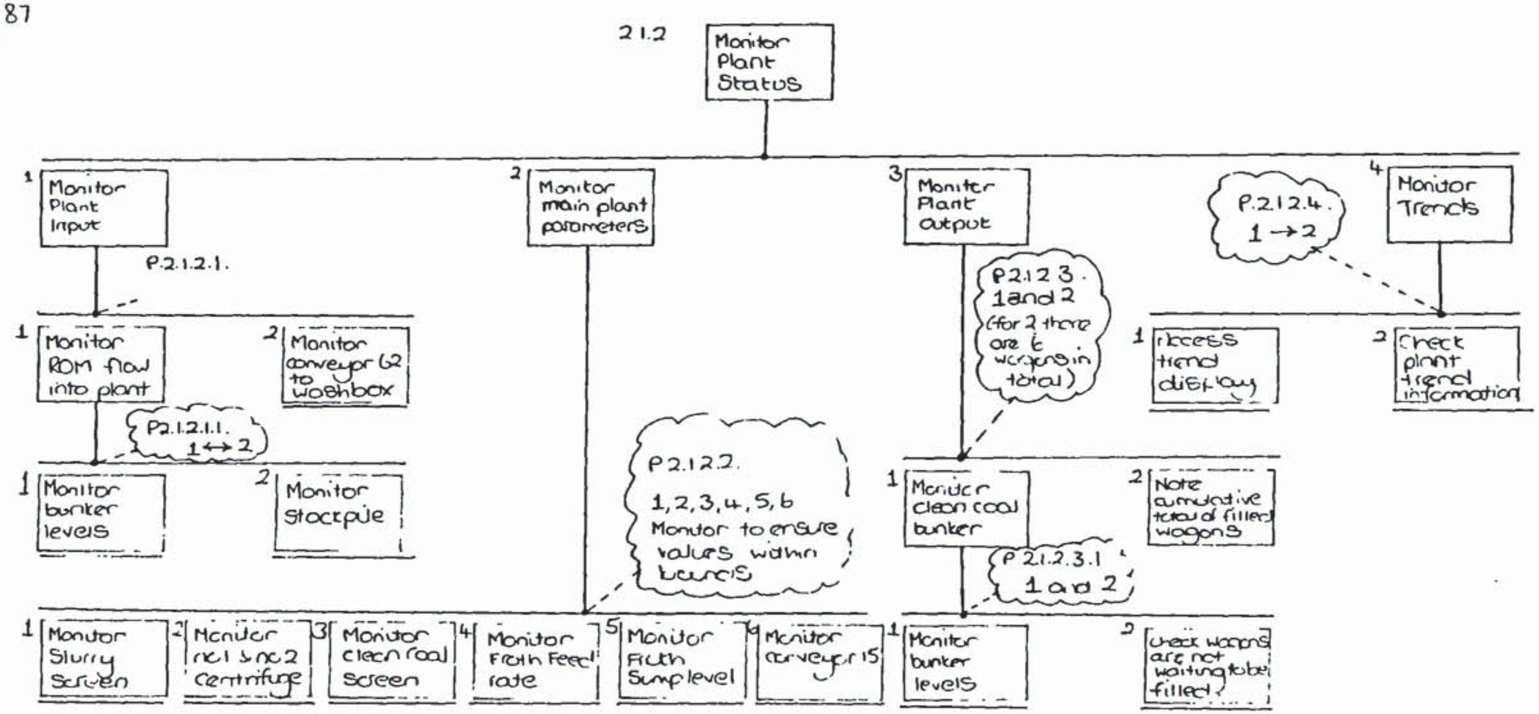


J.Astley Jan '87
R.P. Page 4.



Is fault information passed to

JAstley Jan 87
R.P Page 5



Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
1.2 Switch Plant On	If after holiday 1 → 2 otherwise 2	1. Power up //	→ power up system ← power on/off	Power up procedure	Procedural	
		2. Turn on printer //	––	How to turn printer on	Operational	
1.3 Make Selections	1 → 2 (1 is optional) until selections made for all groups	1. Select listing of status display //	→ select display ← status information	How to select display understanding (or means of) status information	Operational	
		2. Make selections via keyboard //	→ status selections ← selections made	How to make selections – appropriate selections for operational situation	Procedural Decision Making	
1.4 Start Groups	1 → 2 → 3 → 4	1. Select display //	→ display wanted ← change in display	How to select display Appropriate display	Operational	
		2. Initiate start up //	→ start up initiation ← start up commenced	How to initiate start up and feed-back expected	Procedural	
		3. Check automatic start up proceding //	← start up proceding			
		4. Check for faults	← faults occuring	Fault detection procedures	Fault detection	
1.4.4 Check for faults	1 → 2	1. Check for red block in start up display //	← red block in start up display	When red block indicates a fault	Fault detection	
		2. Check for fault message //	← fault message	Knowledge of fault messages relevant to above	Fault detection	

J.A.
R.P.2

RENISHAW PARK CPP TASK ANALYSIS

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
2. Run Plant normally	1, 2 & 3 as appropriate to operational situation	1. Monitor plant 2. Control plant 3. Provide plant information	← plant status information → control actions → display of information requested ← information requested	Important areas for monitoring, normal plant status and what constitutes a deviation How to interrogate interface for required information	Monitoring Operational Procedural	Information is usually requested from an external source, and provided via the tannoy
2.1 Monitor Plant	1 & 2 continuously	1. Monitor for faults/alarms // 2. Monitor plant status	← faults occurring ← plant status	Relative importance of alarms – when alarms are expected Normal and abnormal plant status	Monitoring Monitoring	
2.3 Provide Plant Information	1, 2 as requested	1. Provide specific requested information 2. Provide status information	← specific information requested ← plant status	How to access relevant information The important items of plant status information	Procedural Procedural	
2.3.2 Provide Status Information	1 → 2 via tannoy	1. Observe S.P., M.V. // 2. Inform men of plant status //	← set points & measured values (are they out of limits?)	Normal operating/status limits	Decision Making Operational	

J.A.
R.P.3

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
2.3.1 Provide Specific Requested Information	1, 2, 3, 4 as requested	1. Provide information on set points //	← set points	How to access relevant S.P.'s	Procedural	Changing of S.P.'s has to be authorised by manager or foreman Information can be communicated over the tannoy or face to face
		2. Provide information on flow rates	← flow rates	How to access relevant flow rates	Procedural	
		3. Provide information on bunker/sump levels	← bunker/sump levels	How to access relevant bunker/sump levels	Procedural	
		4. Provide information on the status of a group or item //	← status of group/item	How to access status information	Procedural	
2.3.1.2 Provide Information on flow rates	1, 2, 3 as requested	1. Provide information on froth feed //	← froth feed flow rate	Relevant display and position of information	Procedural	
		2. Provide information on R.O.M. flow //	← R.O.M. flow rate	Relevant display and position of information	Procedural	
		3. Provide information on output conveyor //	← O/P conveyor flow rate	Relevant display and position of information	Procedural	

J.A
R.P.4

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
2.3.1.3. Provide Information on bunker sump levels	1, 2, 3, 4, 5, 6 as requested	1. Provide information on filter levels	← filter levels	How to access specific item of information	Procedural & Decision Making	
		2. Provide information of baum sump	← baum sump parameters	How to access specific item of information	Procedural & Decision Making	
		3. Provide information on froth sump	← froth sump parameters	How to access specific item of information	Procedural & Decision Making	
		4. Provide information on R.O.M. bunkers	← R.O.M. bunker levels	How to access specific item of information	Procedural & Decision Making	Rate of change information may be useful here
		5. Provide information on clean coal bunker	← clean coal bunker level	How to access specific item of information	Procedural & Decision Making	
		6. Provide information on discard bunkers	← discard bunker level	How to access specific item of information	Procedural & Decision Making	
2.2 Control Plant	1 According to plant status 2 As request is made	1. Make selections //	← selections existing/ available → selections ← new selections	Configurations of selections appropriate to plant	Decision Making, procedural	
	3 Whilst plant is running	2. Operate plant in line with request	→ (control activity)		Operational	
		3. Maintain R.O.M. flow	← existing R.O.M. flow → necessary changes in flow	Correct R.O.M. flows, and means of adjustment	Decision Making Operational	

J.A.
R P 5

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
2.2.2. Operate Plant in line with request	1, 2, 3 as requested 2 redescribed in operation 2.2.1.	1. Change a set point 2. Make a selection // 3. Start/Stop item of plant //	← set point → desired change ← new set point → selection made ← selection carried out → start/stop item ← item running/ stopped	Procedure for changing set points known Procedure for making selection known Control procedure known	Procedural Procedural Procedural	
2.2.2.1. Change a set point	1 → 2	1. Display a set point // 2. Key in a new set point //	→ request a set point ← set point → key in set point	How to request set points	Procedural Operational	
2.2.3 Maintain R.O.M. flow	1 and 2 (2 is conveyor to washbox)	1. Keep flow at 300–350 tph // 2. Avoid over/under load on no. 62 conveyor	← existing flow rate ← load on no. 62 conveyor	How to maintain flow at optimal level How to avoid over/ under load	Decision Making, Monitoring, Operational Decision Making, Monitoring Operational	
2.2.3.2. Avoid over/under load on no. 62 conveyor	1 and 2	1. Monitor input configuration // 2. Ensure one major SOURCE is running (one only) //	← input configuration ← sources feeding onto no. 62 conveyor	What input configurations limits are Classification of sources into major and minor	Monitoring Monitoring	

J.A.
R.P.6

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
3. Carry out Fault detection & diagnosis	1 → 2	1. Fault detection	← faults/alarms	Operator knows how to access fault information/when a fault has occurred/ is about to occur	Fault detection	
		2. Fault diagnosis	← nature, location type of fault	Operator understands relationships between plant items & faults	Fault diagnosis	All available information on fault that is usable by the operator, could be centrally collected in the control room, for disemination as appropriate
3.1 Fault detection	1 & 2 → 3	1. Listen for audio alarm	← fault alarm	Operator can recognise audio signal as an alarm	Fault detection	
		2. Check for visual alarm	← fault alarm	Visual alarms can be located and recognised	Fault detection	
		3. Cancel alarm	→ cancel alarm ← alarm cancelled			
3.1.2. Check for visual alarm	1 → 2	1. Check for process alarm	← type of alarm process/ or plant	Operator can distinguish between process and plant alarms	Fault detection	
		2. Check for plant alarm	← type of alarm process/ or plant			

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
3.2. Fault Diagnosis	Diagnose fault from 1 → 2	1. Check visual alarm information 2. Clear alarm information //	← visual alarm information → clear alarm ← alarm cleared	Operator can access alarm information Procedure for alarm clearing	Fault diagnosis Procedural	Fault information is retained on a hard copy
3.2.1. Check visual alarm information	1, 2 and 3 → 4	1. Note nature of fault // 2. Note mimic it is displayed on // 3. Note fault item // 4. Preliminary diagnosis of fault //	← nature of fault ← location of fault group number ← fault item ← all information related to the fault that is relevant	Operator can understand implications of fault information or is aware of the procedure for informing appropriate personnel	Fault diagnosis Fault diagnosis Fault diagnosis Fault diagnosis, Decision Making, Problem solving	
2.1.2. Monitor Plant Status	1, 2 and 3 regularly 4 as appropriate to the operational situation	1. Monitor plant input 2. Monitor main plant parameters 3. Monitor plant output 4. Monitor trends	← plant input ← main plant parameters ← plant output ← trend information	Plant input parameters Limits of main parameters Plant output parameters Likely effects of trends	Monitoring Monitoring Monitoring Monitoring	

J.A
R.P.8

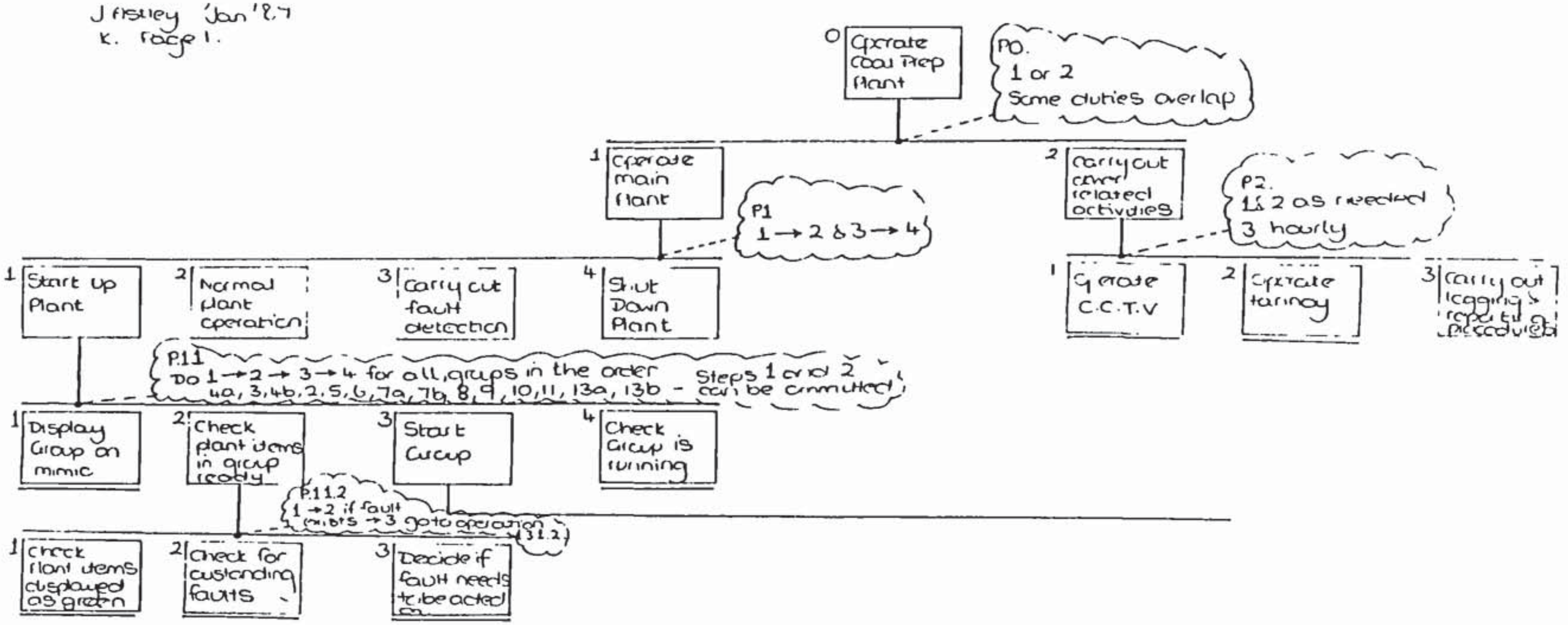
Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
2.1.2.1. Monitor Plant Input	1 and 2	1. Monitor R.O.M. flow into plant	← R.O.M. flow into plant	R.O.M. flow parameters understood	Monitoring	
		2. Monitor conveyor 62 to washbox //	← conveyor 62 load/flow	Conveyor input parameters understood	Monitoring	
2.1.2.1.1. Monitor R.O.M. flow into plant	1 ⇌ 2	1. Monitor bunkers levels //	← bunker levels	Limits of bunker levels and effects of changes in levels	Monitoring	
		2. Monitor stockpile //	← stockpile levels	Operator understands use of stockpile	Monitoring	
2.1.2.2. Monitor Main Plant parameters	1, 2, 3, 4, 5, 6 Monitor to ensure values within bounds	1. Monitor slurry screen //	← slurry screen parameters	Parameter limits	Monitoring	
		2. Monitor no. 1 & no. 2 // centrifuge	← centrifuge parameters	Parameter limits	Monitoring	
		3. Monitor clean coal screen //	← clean coal screen parameters	Parameter limits	Monitoring	
		4. Monitor froth feed rate //	← froth feed rate	Parameter limits	Monitoring	
		5. Monitor froth sump level //	← froth sump level	Parameter limits	Monitoring	
		6. Monitor conveyor 15 //	← conveyor 15 parameters	Parameter limits	Monitoring	

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
2.1.2.3. Monitor Plant Output	1 and 2 (for 2 there are 6 wagons in total)	1. Monitor clean coal bunker 2. Note cumulative total of wagons filled	← clean coal bunker level ← total of wagons filled	Operator understands procedures for filling/emptying bunkers	Monitoring Monitoring	
2.1.2.3.1. Monitor Clean Coal Bunkers	1 and 2	1. Monitor bunker levels // 2. Check wagons not waiting to be filled //	← bunker levels ← if a wagon is present ← if filling is occuring		Monitoring Monitoring	At present wagons not shown on displays but can be monitored by C.C.T.V.
2.1.2.4. Monitor Trends	1 → 2	1. Access trend display // 2. Check plant trend information //	→ request trend display ← trend information	How to access trend display Significance of different trend patterns	Operational Monitoring	

J.A.
R.P.10

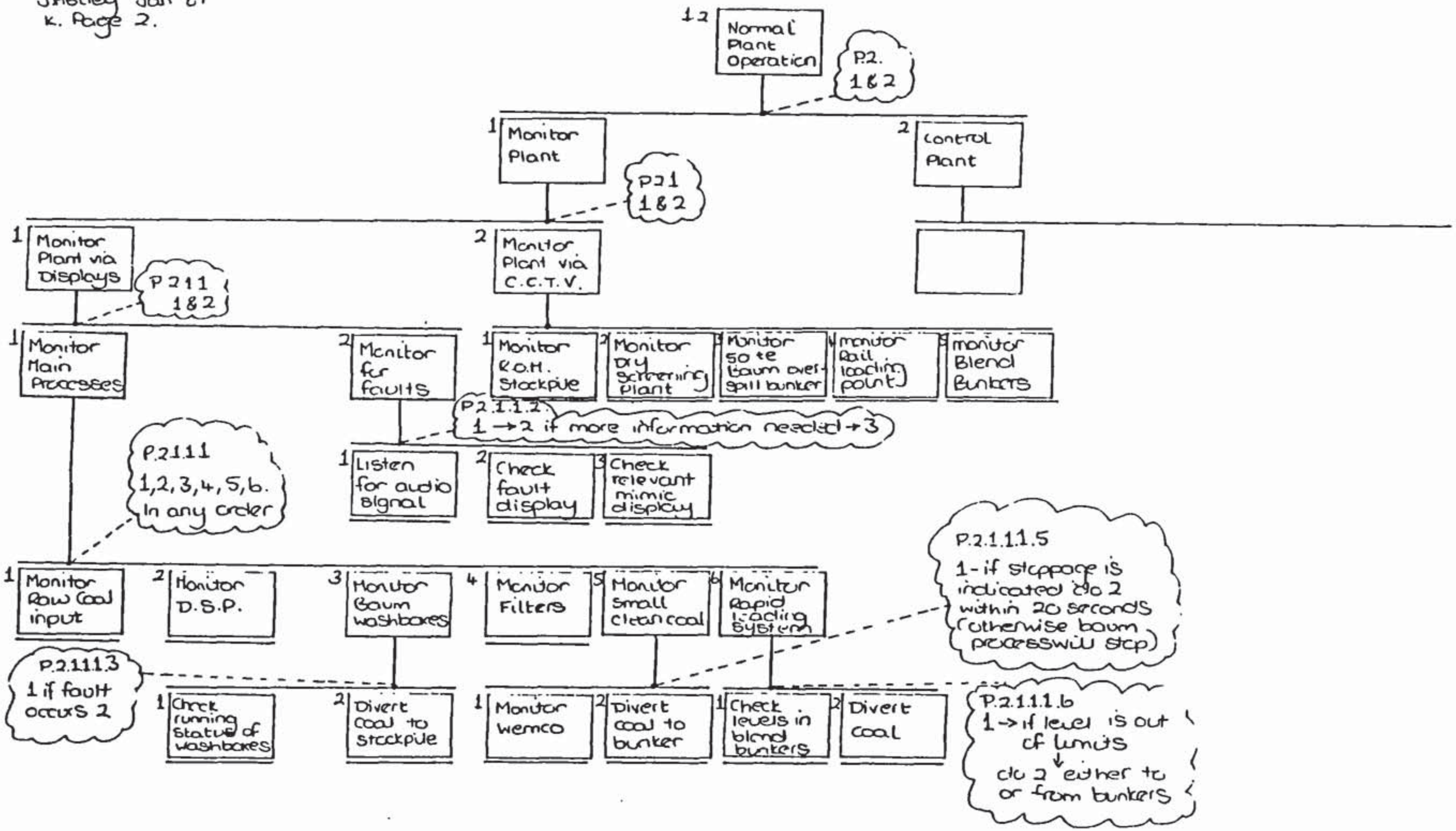
Kellingley
HTA

J Astley Jan '87
K. Page 1.



KELLINGLEY CPP TASK ANALYSIS

JAsley Jan '87
K. Page 2.



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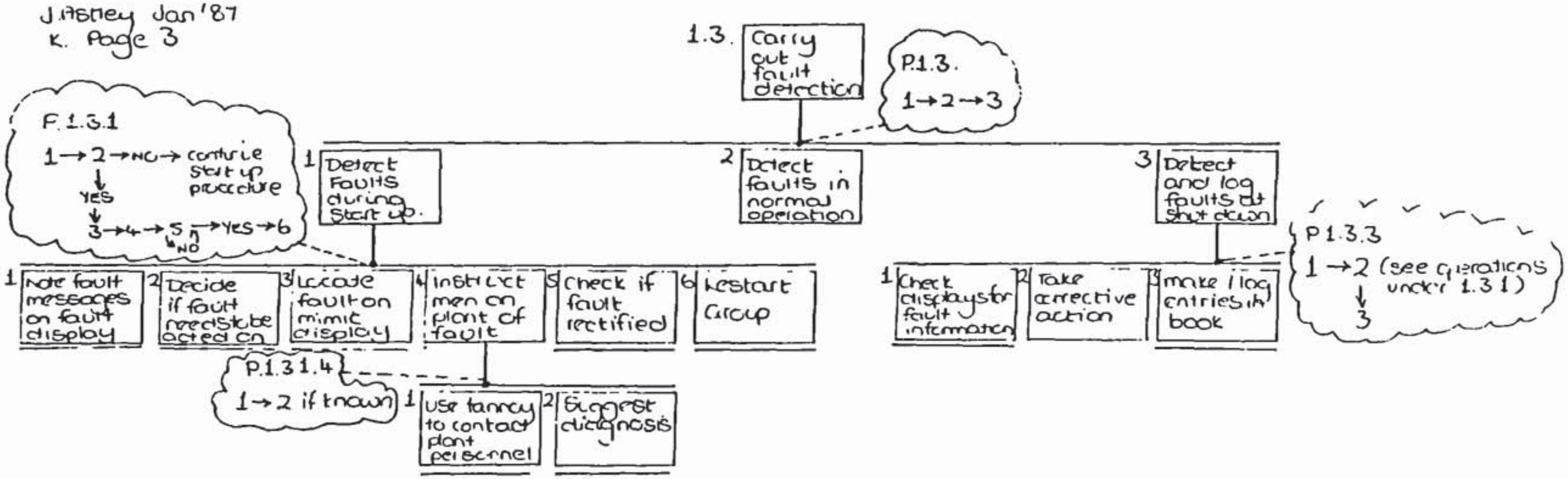
K. Page 3



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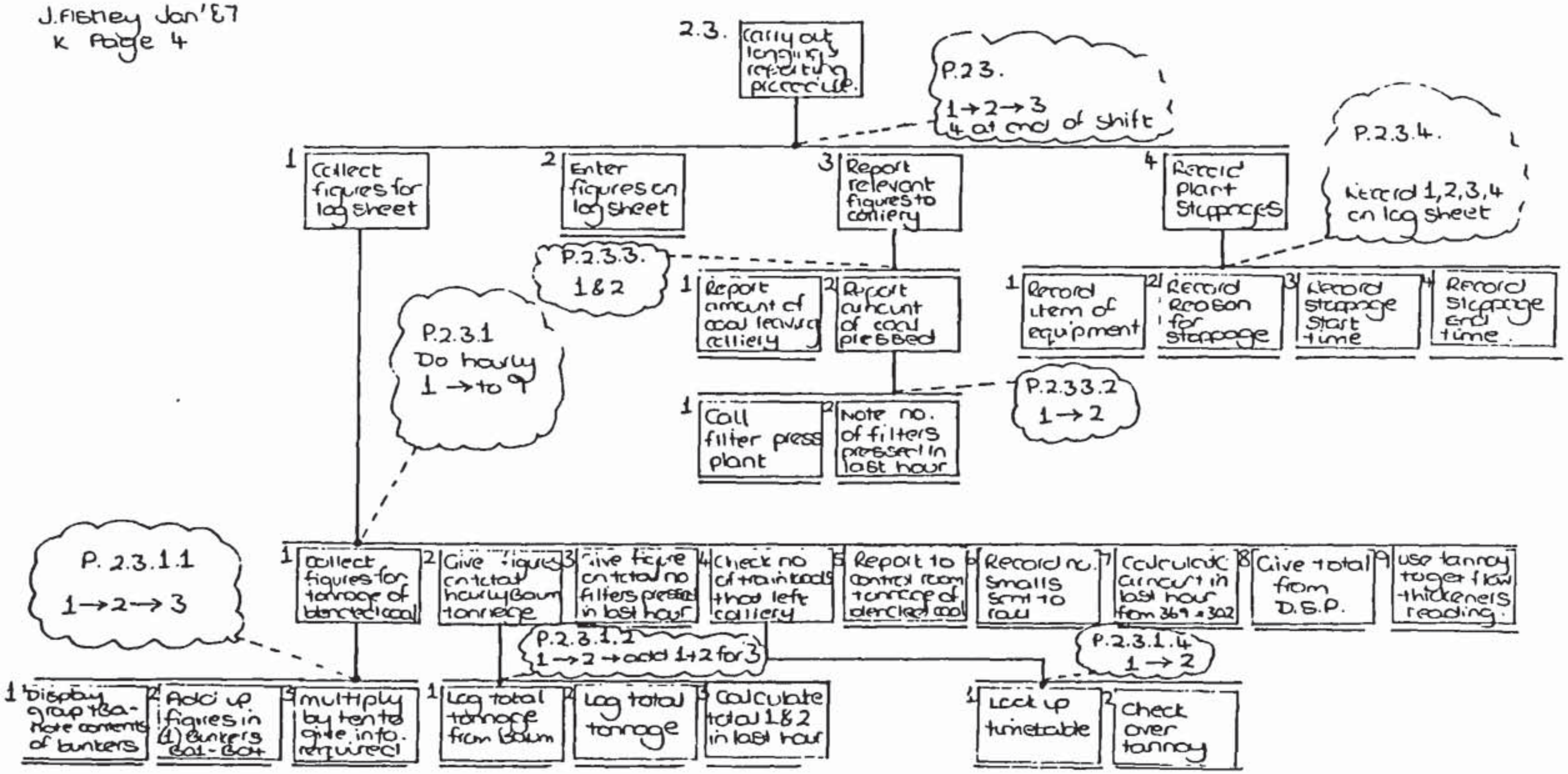
K Page 4



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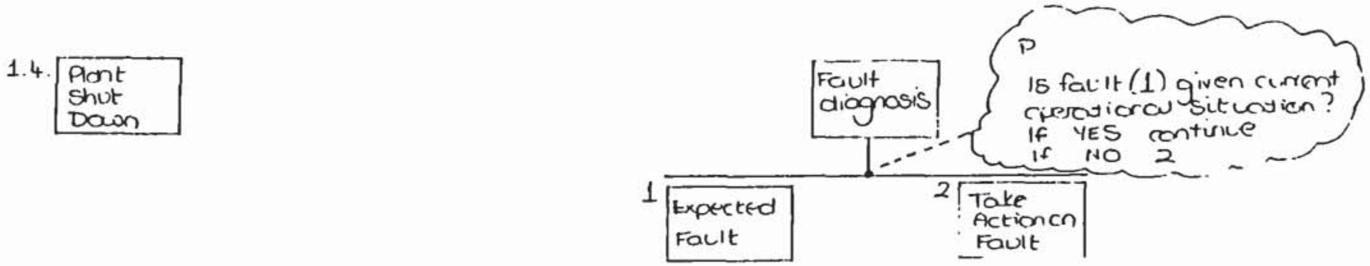

Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
0. Operate Coal Preparation Plant	1 or 2 Some duties overlap	1. Operate main plant 2. Carry out other related activities	← main plant status & operational information ← other plant & related information	Operate has knowledge to operate plant	Operational Operational	1 and 2 usually allocated to each of the 2 operators on shift
1. Operate Main Plant	1 → 2 & 3 → 4	1. Start up plant 2. Normal plant operation 3. Carry out fault detection 4. Shut down plant	← start up information ← plant operational information ← faults ← shut down information	Start up procedure Operation procedures Some fault knowledge Shut down procedure	Procedural Operational Procedural Fault detection Procedural	
1.1 Start up Plant	Do 1 → 2 → 3 → 4 for all groups in the order 4a, 3, 4b, 2, 5, 6, 7a, 7b, 8, 9, 10, 11, 13a, 13b, (steps 1 & 2 can be omitted)	1. Display group on mimic 2. Check plant items in group ready 3. Start group 4. Check group is running	→ display group ← group displayed ← plant items ready → start group ← group started ← group running/ not running	Control sequence Checking procedure Start group procedure Checking procedure	Operational Procedural Procedural Procedural	

KELLINGLEY CPP TASK ANALYSIS

J.A.
K.1

Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
1.1.2. Check Plant Items in group ready	1 → 2 if fault exists go to operation 1.3.1.2.	1. Check plant items displayed as green 2. Check for outstanding faults	← plant items ← outstanding faults	Green indicates ready state in plant Items Access to fault information	Procedural Fault detection/ procedural	
1.2. Normal Plant Operation	1 & 2	1. Monitor plant 2. Control plant	← plant status information → control actions	How to access plant status information Control activities /skills needed to operate plant	Monitoring Operational	
1.2.1 Monitor Plant	1 & 2	1. Monitor plant via displays 2. Monitor plant via C.C.T.V.	← displayed plant status information ← visual direct plant status information	Access plant status information Ability to interpret visual direct plant information	Monitoring Monitoring	
1.2.1.1. Monitor Plant via displays	1 & 2	1. Monitor main processes 2. Monitor for faults	← main processes status ← fault status	Limits of main processes Significance of faults in relation to main processes	Monitoring Monitoring fault detection	

Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
1.2.1.1.1. Monitor Main Processes	1, 2, 3, 4, 5, 6, in any order	1. Monitor raw coal input //	← raw coal input	Knowledge of parameters limits	Monitoring	
		2. Monitor D.S.P. //	← D.S.P. parameters	Knowledge of parameter limits	Monitoring	
		3. Monitor Baum washboxes	← washbox parameters	Knowledge of parameter limits	Monitoring	
		4. Monitor filters //	← Filter parameters	Knowledge of parameter limits	Monitoring	
		5. Monitor small clean coal	← small clean coal parameters	Knowledge of parameter limits	Monitoring	
		6. Monitor rapid loading system	← rapid loading system parameters	Knowledge of parameter limits	Monitoring	
1.2.1.1.1.3. Monitor Baum Washboxes	1 if fault occurs 2	1. Check running status of washboxes	← status of washboxes	Knowledge of washbox parameters	Monitoring Fault detection	
		2. Divert coal to stockpile	→ divert coal to stockpile ← coal diverted		Operational	
1.2.1.1.1.5. Monitor Small Clean Coal	1 – if stoppage is indicated do 2 within 20 seconds (otherwise Baum process will stop)	1. Monitor Wemco	← Wemco parameters	Wemco limits	Monitoring Fault Detection	
		2. Divert coal to bunker	→ divert coal ← coal diverted			

J.A.
K.3

Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
1.2.1.1.1.6. Monitor Rapid Loading System	1 → if level is out of limits do 2 either to or from bunkers	1. Check levels in blend bunkers //	← blend bunker levels	Correct levels and tolerable limits	Monitor	
		2. Divert coal //	→ divert coal ← coal diverted	Diversion procedure	Procedure	
1.2.1.1.2. Monitor for faults	1 → 2 if more information needed 3	1. Listen for audio signal //	← audio signal for fault	Know which audio signal indicates a fault	Fault detection	
		2. Check fault display //	← fault information	Display access to faults	Fault detection & Fault diagnosis	
		3. Check relevant mimic display //	← faults in relation to other plant items	Which mimic display(s) shows fault		
1.2.1.2. Monitor Plant via C.C.T.V.	1, 2, 3, 4, 5, as appropriate to plant operation	1. Monitor R.O.M. stockpile	← R.O.M. stockpile status	Ability to interpret the visual cues on the status of items	Monitoring	
		2. Monitor dry screening plant	← D.S.P. status	Ability to interpret the visual cues on the status of items	Monitoring	
		3. Monitor 50 te Baum overspill bunker	← Baum overspill bunker status	Ability to interpret the visual cues on the status of items	Monitoring	
		4. Monitor rail loading point	← rail loading point status	Ability to interpret the visual cues on the status of items	Monitoring	
		5. Monitor blend bunkers	← blend bunker status	Ability to interpret the visual cues on the status of items	Monitoring	

Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
1.3. Carry Out Fault Detection	1 → 2 → 3	1. Detect faults during start up	← faults occuring	Ability to recognise fault Indications	Fault detection	
		2. Detect faults during normal operation	← faults occuring	Ability to recognise fault Indications	Fault detection	
		3. Detect and log faults at shut down	← faults occuring	Ability to recognise fault Indications Knowledge of logging procedure	Fault detection Procedural	
1.3.1. Detect Faults during Start up	1 → 2 → NO → continue start up procedure ↓ YES ↓ 3 NO 6 ↓ ↓ ↑ ↑ 4 → 5 → YES	1. Note messages on fault display //	← fault messages	Meaning of messages	Fault detection	
		2. Decide if fault needs to be acted on //	← fault message, plant status relevant to fault	Knowledge of base decision on or decision making aid	Decision making	
		3. Locate fault on mimic display //	← mimic indicating fault	Which mimic to access	Procedural Fault detection	
		4. Instruct men on plant of fault	→ fault detected	Instruction procedure	Procedural	
		5. Check if fault rectified //	← fault rectified	Checking procedure.	Monitoring Procedural	
		6. Restart group //	→ Initiate start ← group restarted	Restart procedure	Procedural	

J.A.
K.5

Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
1.3.1.4. Instruct Men on Plant of Fault	1 → 2 if known	1. Use tannoy to contact plant personnel // 2. Suggest diagnosis //	→ tannoy information to personnel	Tannoy operation understood Information on interpretation of fault messages available	Operational Fault diagnosis	
1.3.3. Detect and Log Faults at Shut down	1 → 2 (see operations under 1.3.1) ↓ 3	1. Check displays for fault information 2. Take corrective action 3. Log faults	← faults/alarms → fault correction → log faults	Location of fault Corrective action relative to fault Fault logging procedure	Monitoring Fault detection Fault diagnosis/ operation Procedural	Fault correction is dependant on operators knowledge of the system and fault disgnostic skills
1.3.2. Detect Faults in Normal Operation	Is fault '1' given current operational situation? If YES decide if '3' is appropriate else '2'	1. Detect expected fault 2. Take action on fault 3. Ignore fault	← fault → action related to fault → fault to be ignored	Knowledge of which faults are expected in which operational situations Action needed Criteria for ignoring fault	Fault detection Decision making Operational Decision making	In this particular operational situation, faults often occur (especially during start up/shut down) which can be ignored. This is not the ideal situation.

Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
2.3 Carry Out Logging & Reporting Procedure	1 → 2 → 3 4 at end of shift	1. Collect figures for log sheets	← figures relevant to log sheet	Operator knows figures needed & location	Procedural	
		2. Enter figures on log sheet //	—	Logging procedure is known	Procedural	At present log sheet is hard copy
		3. Report relevant figures to colliery	(to colliery) → figures relevant to colliery	Which are the relevant figures	Operational	
		4. Record plant stoppages	—	—	Operational	
2.3.1. Collect Figures for Log Sheet	Do hourly 1 to 9 (for redescription of '3' see operation 2.3.3.2.)	1. Collect figures for tonnage of blended coal	← tonnage of blended coal	Where figures are located	Procedural	
		2. Collect figures on total hourly Baum tonnage	← total hourly Baum tonnage	Where figures are located	Procedural	
		3. Give figure on total number of filters pressed in last hour //	← No. filters pressed in last hour	Where figures are located	Procedural	
		4. Check number of train loads that have left colliery	← No. of train loads that left colliery in last hour	Where figures are located	Procedural	
		5. Report to control room tonnage of blended coal //	(to colliery control room) → tonnage of blended coal	Where figures are located	Operational	

J.A.
K.7

Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
2.3.1 continued	Do hourly 1 to 9	6. Record no. of smalls sent to rail //	→ no. smalls sent to rail	Recording procedure known	Procedural	(At present recording is on paper and not via the CRT display)
		7. Calculate amount in last hour from 369 and 302	← amount from 369 & 302	Location of information known	Procedural, Problem solving	
		8. Give total from D.S.P. //	← total from D.S.P.	Location of information known	Procedural	
		9. Use tannoy to get flow thickeners reading //	→ request information ← flow thickener's reading	Procedure known	Procedural	
2.3.1.1 Collect Figures for Tonnage of Blended Coal	1 → 2 → 3	1. Dispaly group 13a – note contents bunkers //	← group 13a bunker contents	Display group 13 a is on	Procedural	
		2. Add up figures in '1' bunkers B01 – B04 //	← figures for bunkers B01 – B04	Location of figures/ bunkers on display	Procedural	
		3. Multiply by ten to give information required //	——	——	Procedural	

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Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
2.3.1.2. Give Figures on Total Hourly Baum Tonnage	1 → 2 → add 1 + 2 for 3	1. Log total tonnage from Baum //	← total baum tonnage	How to access information	Procedural	
		2. Log total tonnage //	← total tonnage	How to access information	Procedural	
		3. Calculate total of 1 + 2 in last hour //	——	——	Problem Solving Procedural	
2.3.1.4. Check Number of Train Loads that left Colliery	1 → 2	1. Look up timetable //	← train timetable	How to use timetable	Procedural	
		2. Check over tannoy //	→ request train information ← number of train loads	How to use tannoy	Operational	
2.3.3 Report Relevant Figures to Colliery	1 & 2	1. Report amount of coal leaving colliery //	→ figures for coal leaving colliery	Reporting procedure	Procedural	
		2. Report amount of coal pressed	→ amount of coal pressed	Reporting procedure	Procedural	
2.3.3.2 Report Amount of Coal Pressed	1 → 2	1. Call filter press plant	——	Calling procedure	Operational	
		2. Note number of filters pressed in last hour	← number of filters pressed in last hour	——	Procedural	

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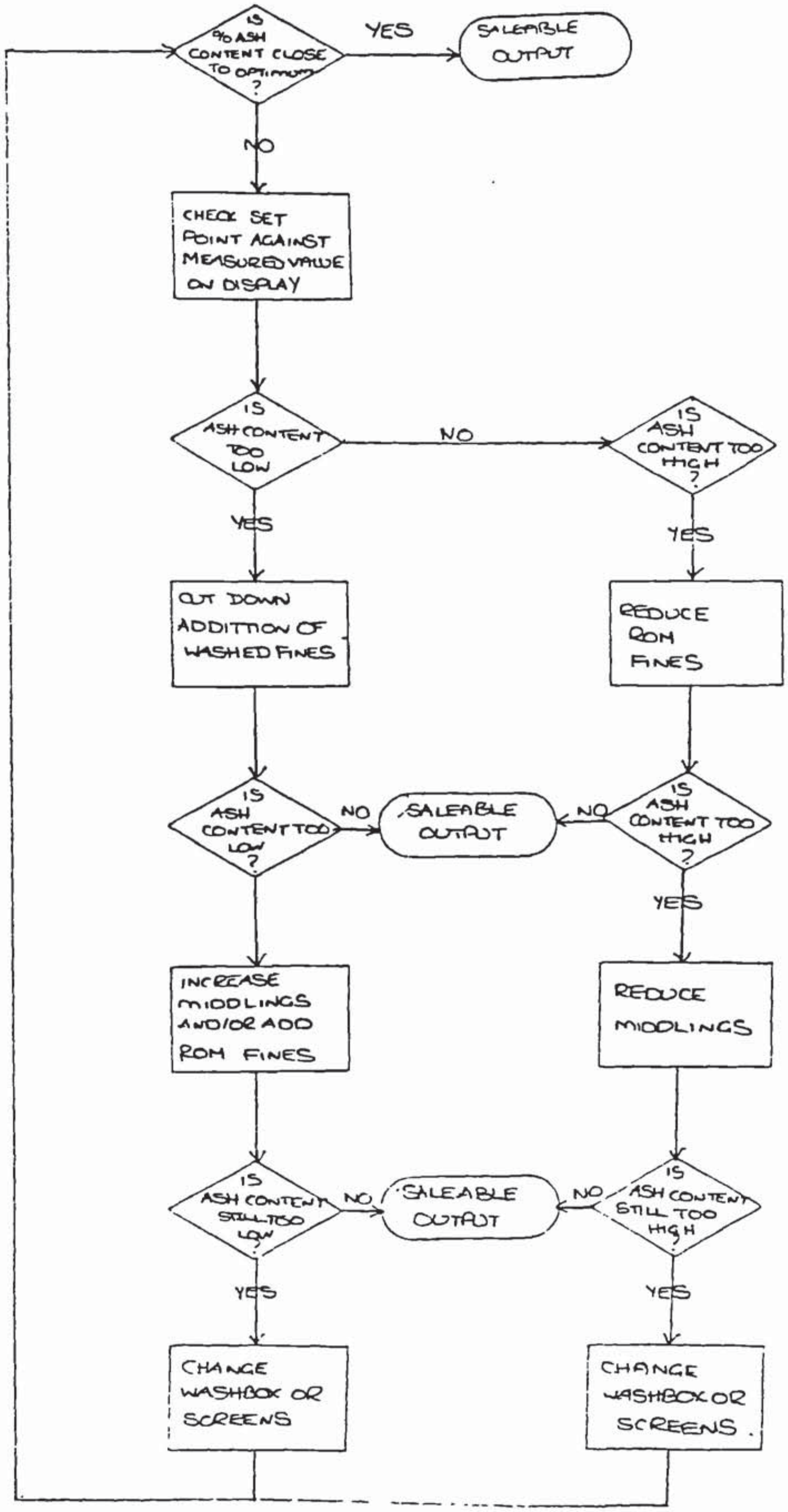
K.9

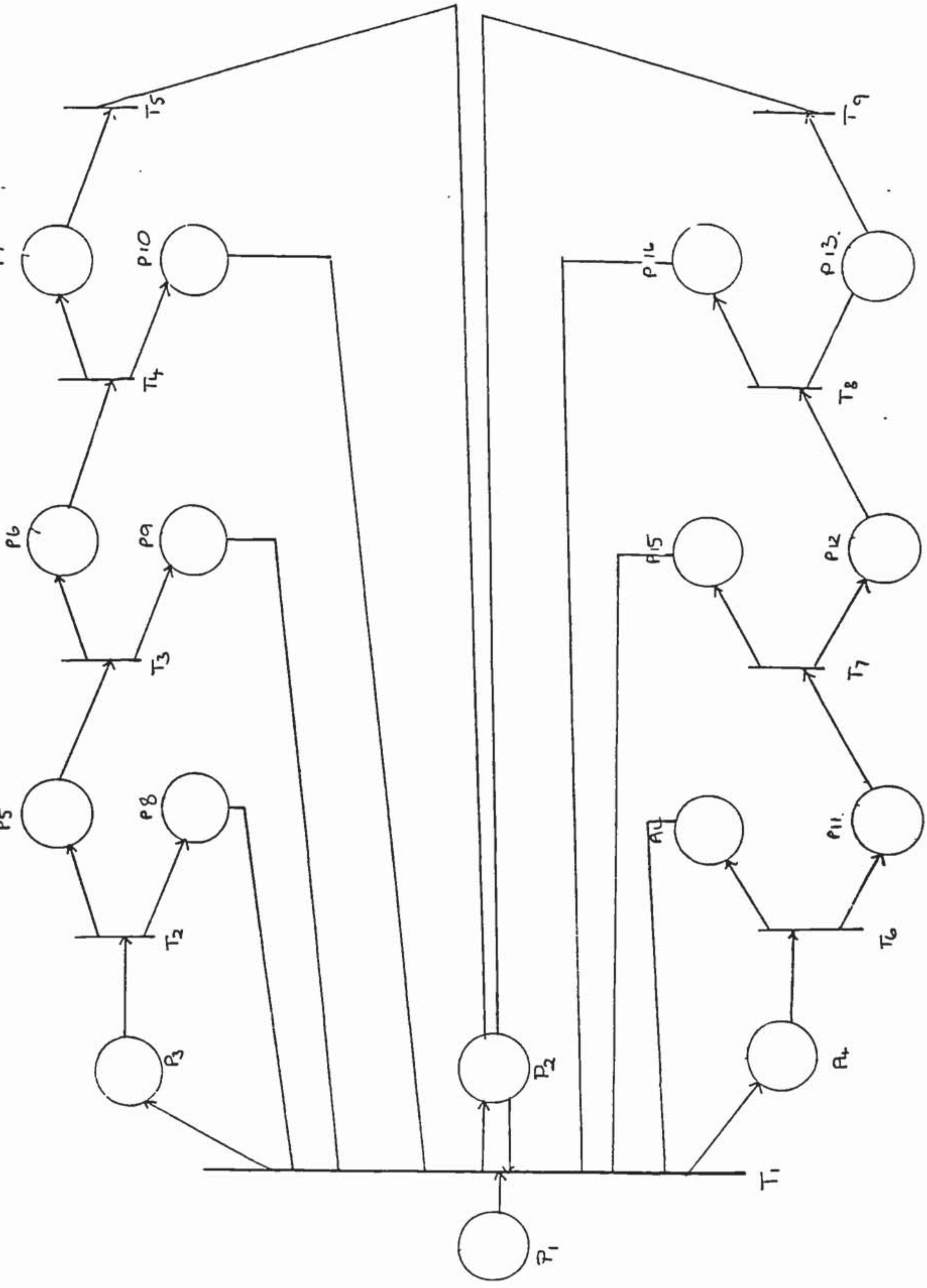
Superordinate	Plan	Operations	Information flow across information	Information assumed	Task classification	Notes
2.3.4. Record Plant Stoppages	Record 1, 2, 3, 4 on log sheet	1. Record item of equipment //	← item of equipment	Operate can locate information	Procedural	
		2. Record reason for stoppage //	← reason for stoppage	Operate is able to deduce or find information from plant on cause of stoppage	Fault diagnosis Problem solving Procedural	This information at present is not given directly via the interface
		3. Record stoppage time //	← stoppage time	Operator can locate information	Procedural	
		4. Record stoppage end time //	← stoppage end time	Operator can locate information	Procedural	
2.4 Plant Shut Down						More information needed

APPENDIX C

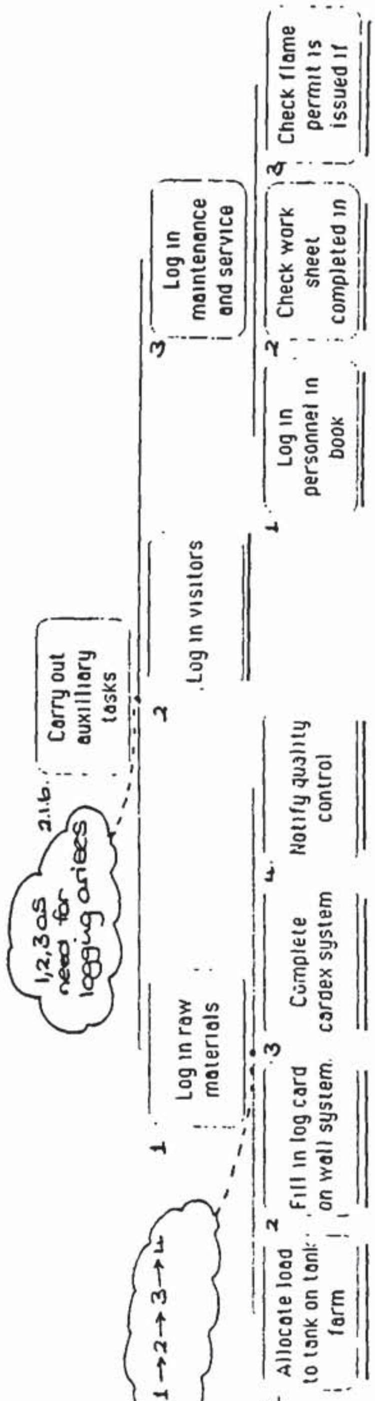
Example Task Analyses from the methods, applied to the CPP Ash Controller Task



FLOW CHART OF ASH CONTROLLER MONITORING PROCESS

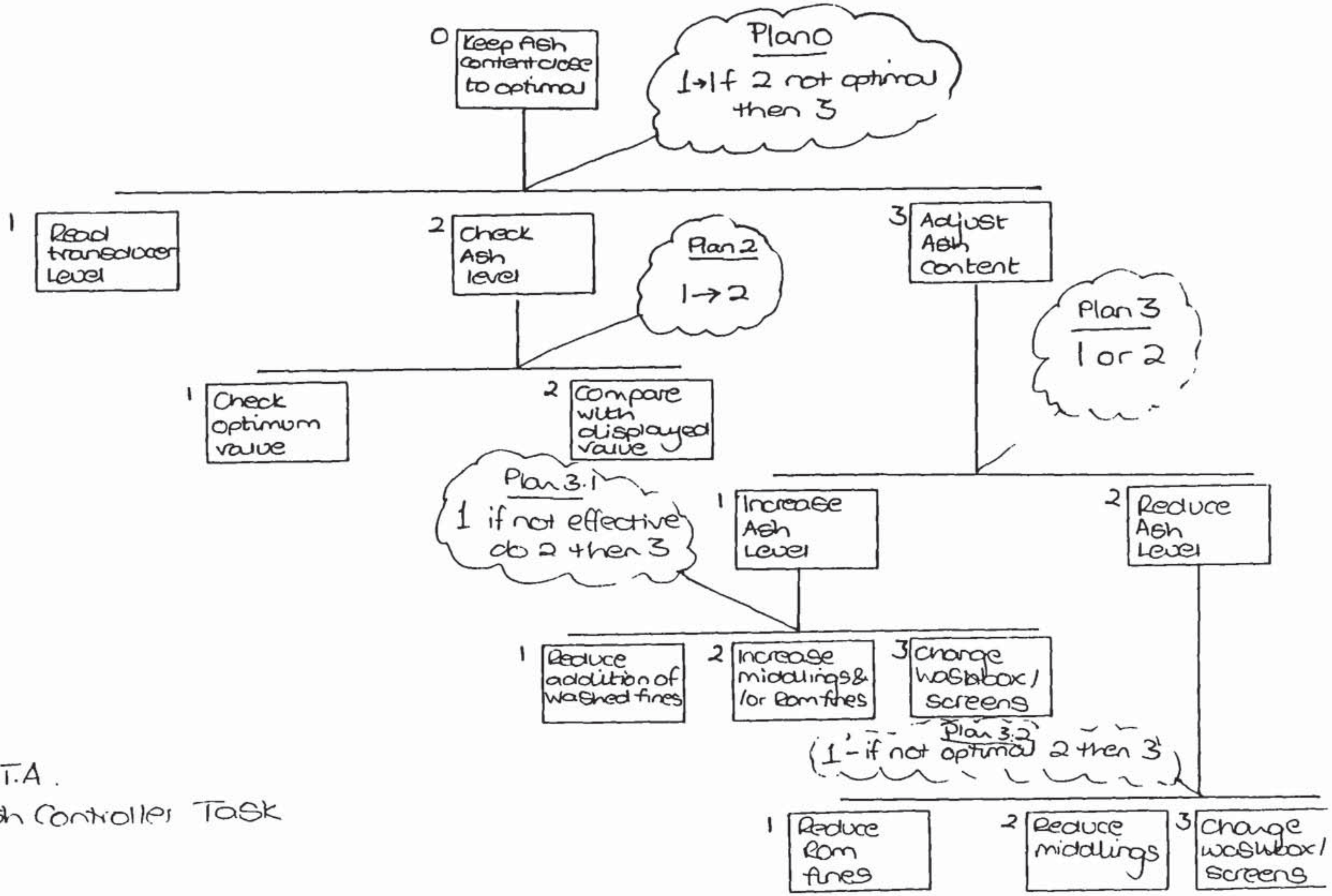


Petri-Net to indicate Ash Controller Task.

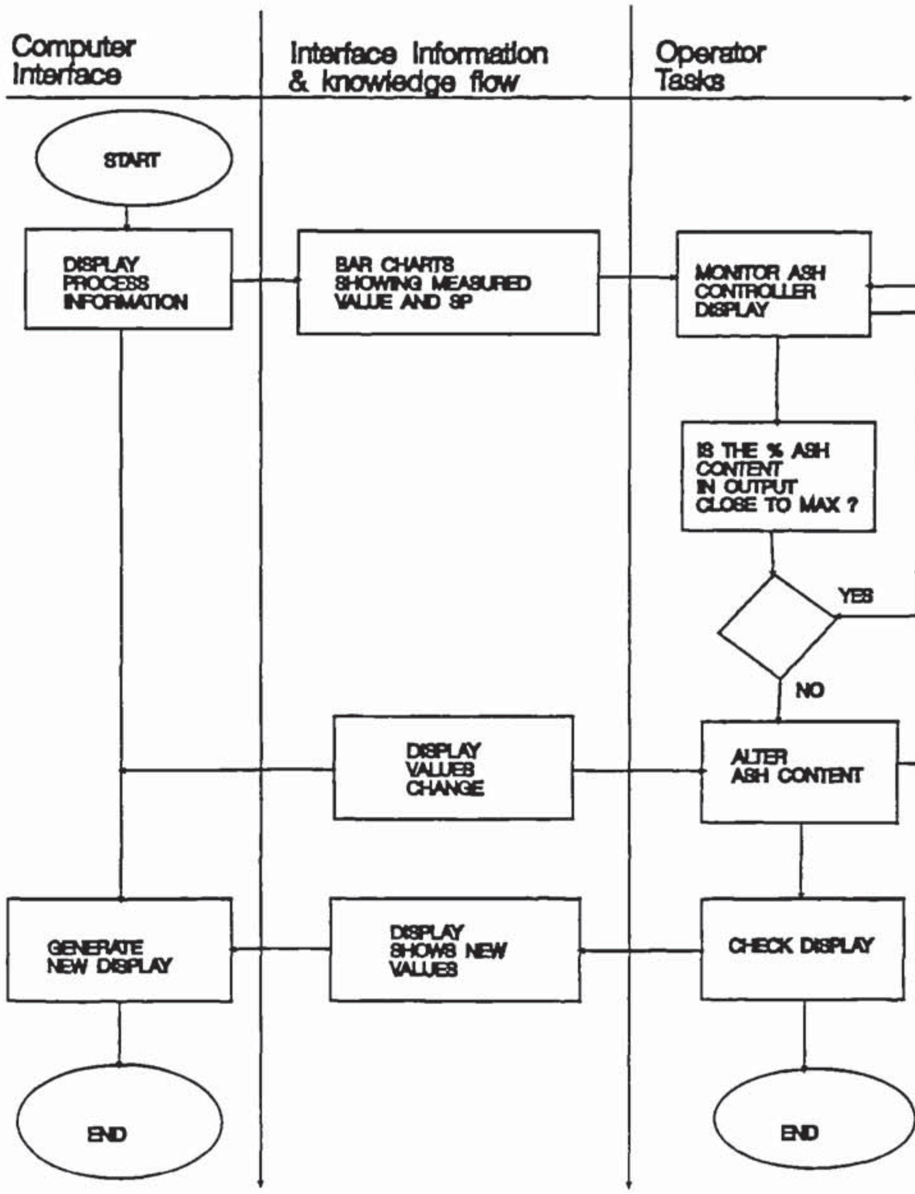

2.1.6.
Carry out auxilliary tasks
1,2,3 as need for logging arises
1
Log in raw materials
2
Log in visitors
3
Log in maintenance and service
1 → 2 → 3 → 4
1
Allocate load to tank on tank farm
2
Fill in log card on wall system.
3
Complete cardex system
4
Notify quality control
1
Log in personnel in book
2
Check work sheet completed in
3
Check flame permit is issued if

Superordinate	Plan	Operations	Information flow across interface	Information assumed	Task classification	Notes
1.3.2.2. Receive fault information from plant	1→to request information	1. Use phone to establish cause of fault //				Faults are currently diagnosed by means of interactive communication with the men on the plant
	2→to gain new fault information as it is available	2. Receive information from the plant //				
1.3.2.3. Check main displays	1 and 2 as needed for diagnosis	1. Check main plant parameters //	← main plant parameters status	Operator is able to interpret and use fault information given on main displays for diagnosis	Fault diagnosis	
		2. Identify general location of fault //	← fault location information on main displays		Fault diagnosis	
1.4. Shut down plant	1 or 2	1. Emergency shut down //	← plant needs to be shut down due to an emergency	Operator is able to interpret the need for emergency shut down and has knowledge of emergency shut down procedure	Procedural	Exact shut down procedure varies from plant to plant so details are not given here
		2. End of shift shut down //	← shut down information	Knowledge of shut down procedure	Procedural	

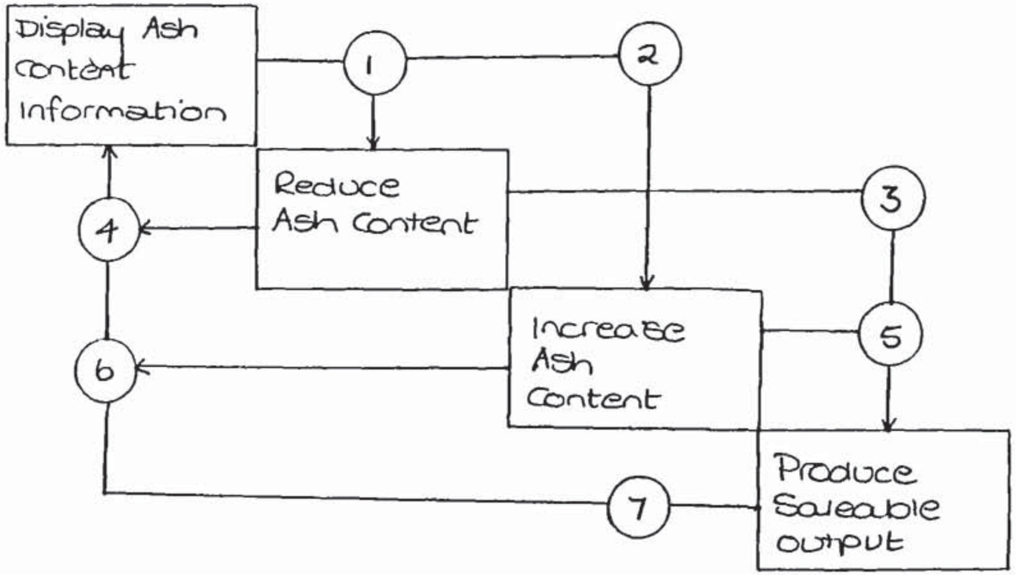
P_1 Information displayed on ash content	T_1 Compare displayed value and optimal value
P_2 Ash content close to optimal	T_2 Reduce ROM fines
P_3 Ash content > than optimal	T_3 Reduce middlings
	T_4 Change washbox
P_4 Ash content < than optimal	T_5 Change screens
P_5 " "	T_6 Cut down addition of washed fines
P_6 " "	
P_7 " "	T_7 Increase middlings and add ROM fines
P_8 Ash content close to optimal	T_8 Change washbox
	T_9 Change screens
P_9 " "	
P_{10} " "	
P_{11} Ash content > than optimal	
P_{12} " "	
P_{13} " "	
P_{14} Ash content close to optimal	
P_{15} " "	
P_{16} " "	



H.T.A.
Ash Controller Task



A Job Process Chart
Ash Controller Task

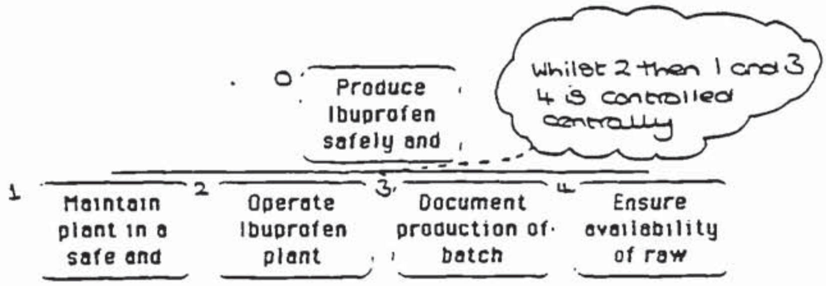


1 Ash Content too high
2 Ash content too low
3 Reduced Rom fines etc
5 Increased Rom fines etc
4 Reduce middlings
change washbox /screens
Reduce Rom fines
6 Increase middlings
Increase Rom fines
Change washbox /screens
7 Percentage ash is
correctly adjusted

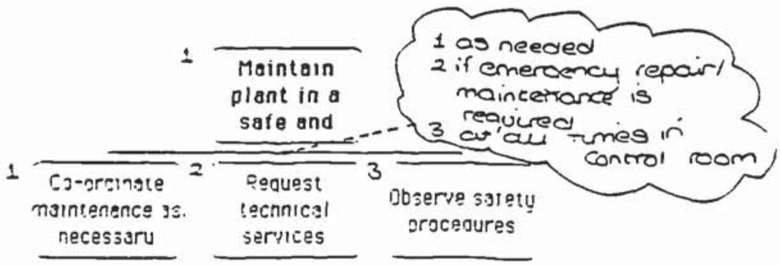
N^2 chart indicating Ash Controller Task

APPENDIX D

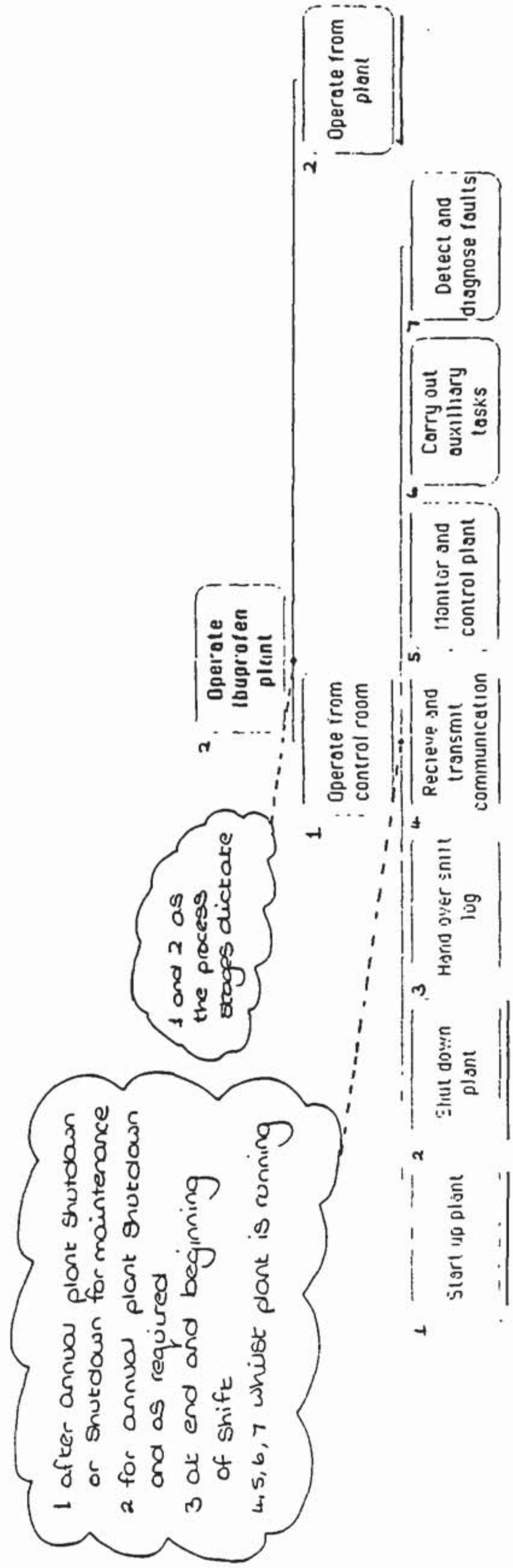
The Boots Ibuprofen Plant
Task Analysis

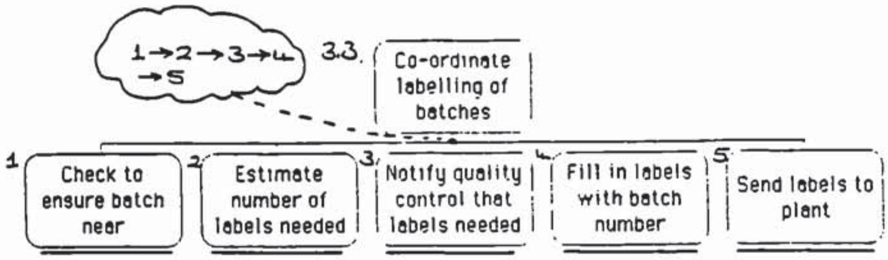


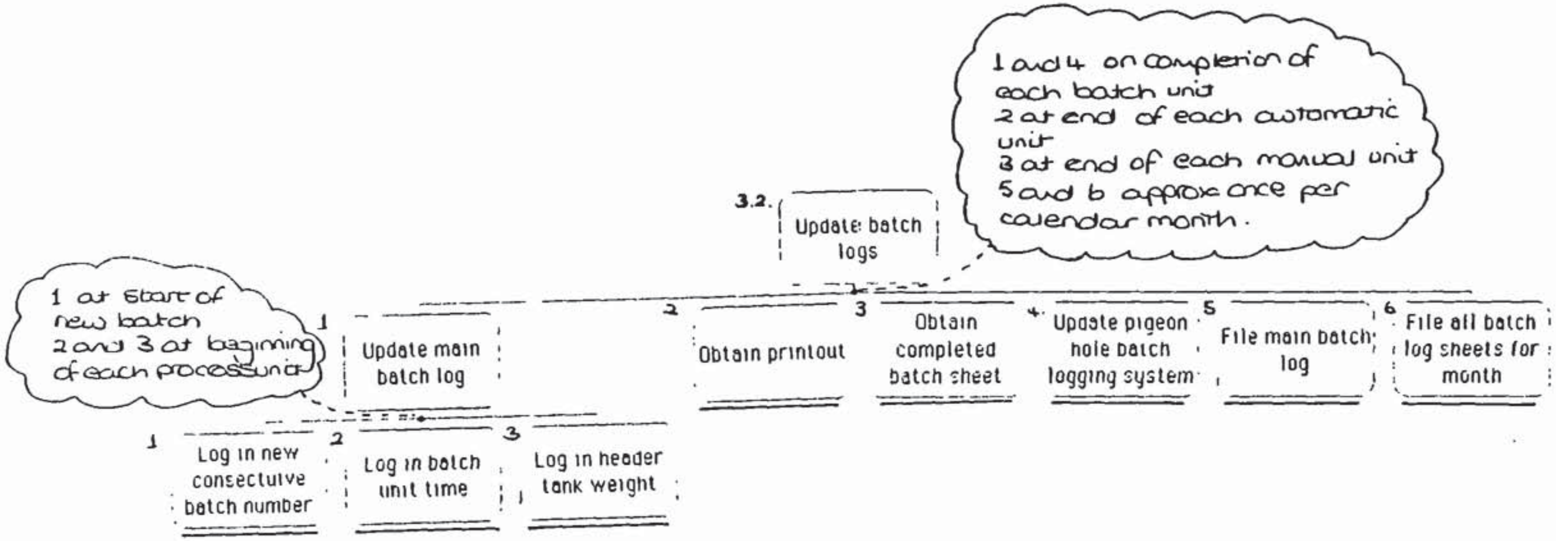
0 Produce Ibuprofen safely and
Whilst 2 then 1 and 3
4 is controlled centrally
1 Maintain plant in a safe and
2 Operate Ibuprofen plant
3 Document production of batch
4 Ensure availability of raw

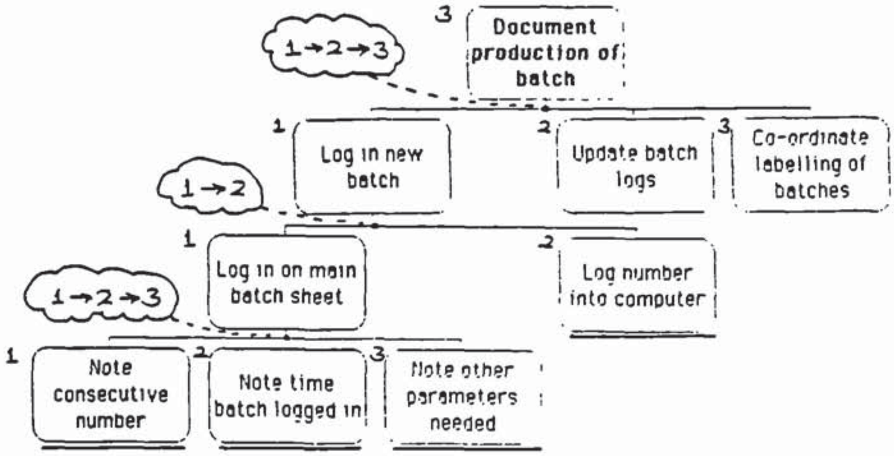


1 Maintain plant in a safe and
1 as needed
2 if emergency repair/ maintenance is required
3 at all times in Control room
1 Co-ordinate maintenence as necessary
2 Request technical services
3 Observe safety procedures

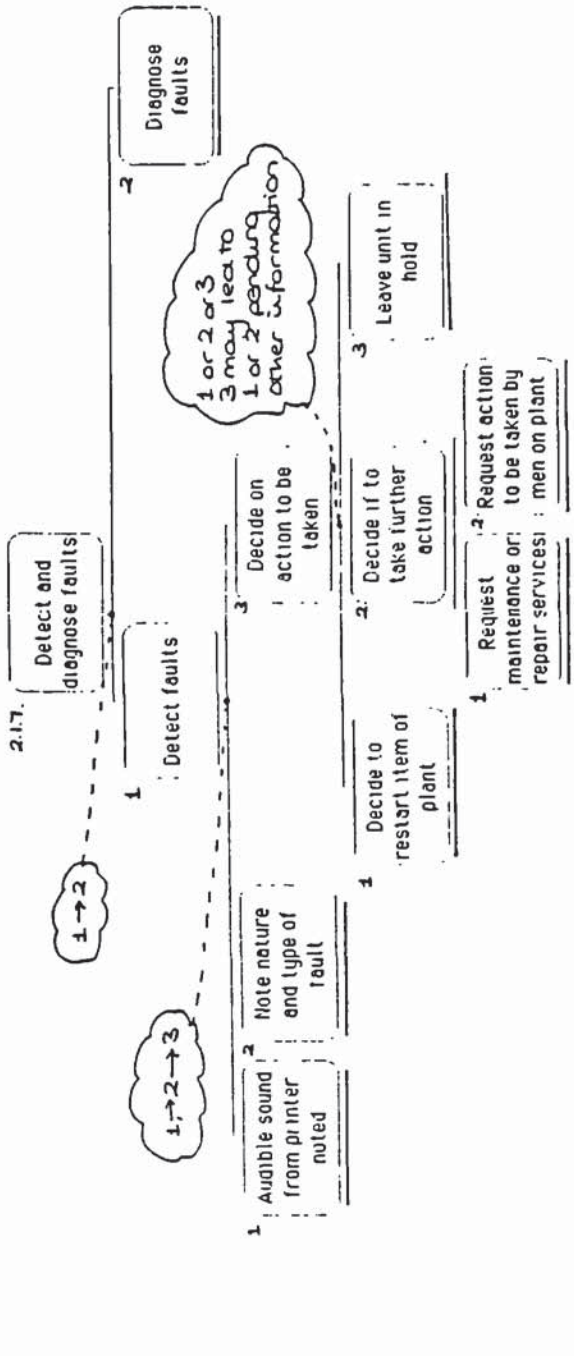

0 Operate Ibuprofen plant
1 Operate from control room
2. Operate from plant
1 Start up plant
2 Shut down plant
3 Hand over shift log
4 Recieve and transmit communication
5. Monitor and control plant
6 Carry out auxiliary tasks
7 Detect and diagnose faults
1 and 2 as the process stages dictate
1 after annual plant shutdown or shutdown for maintenance
2 for annual plant shutdown and as required
3 at end and beginning of shift
4,5,6,7 whilst plant is running

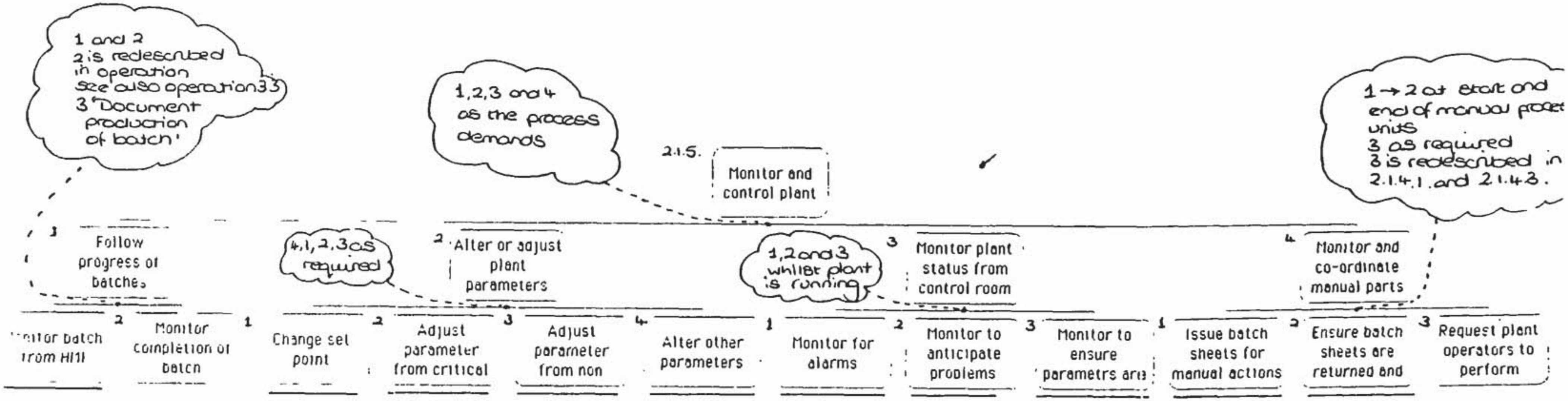

1→2→3→4
→5
3.3. Co-ordinate labelling of batches
1 Check to ensure batch near
2 Estimate number of labels needed
3 Notify quality control that labels needed
4 Fill in labels with batch number
5 Send labels to plant


3.2. Update batch logs
1 and 4 on completion of each batch unit
2 at end of each automatic unit
3 at end of each manual unit
5 and 6 approx once per calendar month.
1 at start of new batch
2 and 3 at beginning of each process unit
1 Update main batch log
1 Log in new consecutive batch number
2 Log in batch unit time
3 Log in header tank weight
2 Obtain printout
3 Obtain completed batch sheet
4 Update pigeon hole batch logging system
5 File main batch log
6 File all batch log sheets for month

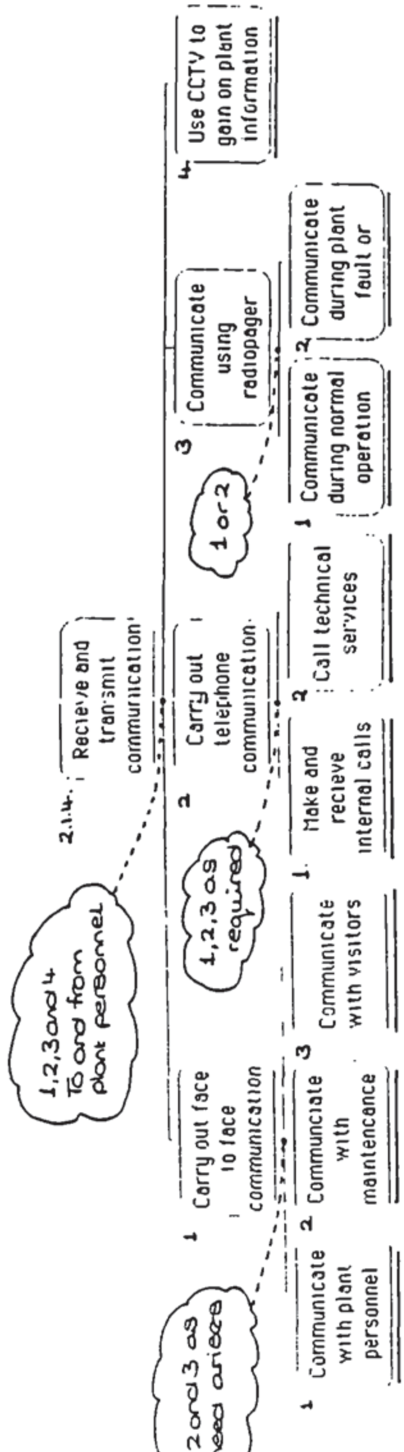


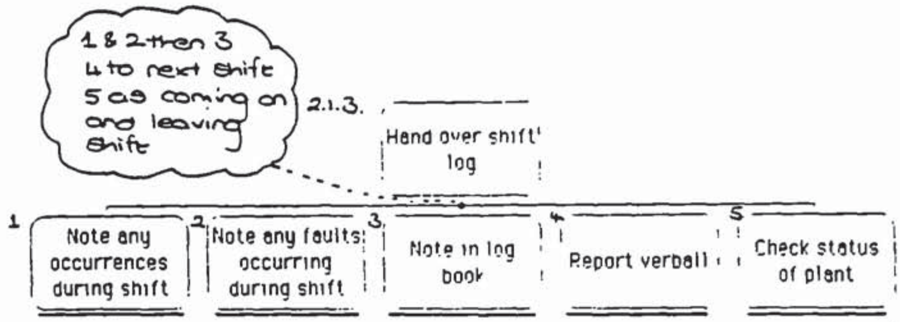
3
Document production of batch
1→2→3
1
Log in new batch
2
Update batch logs
3
Co-ordinate labelling of batches
1→2
1
Log in on main batch sheet
2
Log number into computer
1→2→3
1
Note consecutive number
2
Note time batch logged in
3
Note other parameters needed


2.1.7.
Detect and diagnose faults
1 Detect faults
2 Diagnose faults
1 → 2
1,→2→3
1 Audible sound from printer noted
2 Note nature and type of fault
3 Decide on action to be taken
1 or 2 or 3 may lead to 1 or 2 pending other information
1 Decide to restart item of plant
2 Decide if to take further action
3 Leave unit in hold
1 Request maintenance or repair services
2 Request action to be taken by men on plant



2.1.5.
Monitor and control plant
1 and 2
2 is redescribed in operation
See also operation 3.3
3 'Document production of batch'
1,2,3 and 4 as the process demands
1 → 2 at start and end of manual proce
units
3 as required
3 is redescribed in 2.1.4.1 and 2.1.4.3.
1 Follow progress of batches
2 Alter or adjust plant parameters
3 Monitor plant status from control room
4 Monitor and co-ordinate manual parts
4,1,2,3 as required
1,2 and 3 whilst plant is running
1 Monitor batch from HHI
2 Monitor completion of batch
1 Change set point
2 Adjust parameter from critical
3 Adjust parameter from non
4 Alter other parameters
1 Monitor for alarms
2 Monitor to anticipate problems
3 Monitor to ensure parametrs are
1 Issue batch sheets for manual actions
2 Ensure batch sheets are returned and
3 Request plant operators to perform


2.1.4.
Recieve and transmit communication
1,2,3 and 4 To and from plant personnel
1 Carry out face to face communication
2 Carry out telephone communication
3 Communicate using radiopager
4 Use CCTV to gain on plant information
1,2 and 3 as need arises
1,2,3 as required
1 or 2
1 Communicate with plant personnel
2 Communicate with maintenance
3 Communicate with visitors
1 Make and recieve internal calls
2 Call technical services
1 Communicate during normal operation
2 Communicate during plant fault or


1 & 2 then 3
4 to next shift
5 as coming on and leaving shift
2.1.3.
Hand over shift log
1
Note any occurrences during shift
2
Note any faults occurring during shift
3
Note in log book
4
Report verbal
5
Check status of plant

Page 1

Superordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
Produce ibuprofen safely and economically 0	Whilst 2 then 1 and 3 4 controlled externally	1 maintain plant in a safe and available state. // 2. Operate Ibuprofen plant 3 Document production of batch. 4. Ensure availability of raw materials //	← plant status → maintenance & repair, testing required ← Plant current status → Control actions ← Progress of batch → Documentation of relevant information ← raw materials available → ordering of raw materials ← Timing of arrival of materials	← Status information → Necessary routine testing & maintenance ← current plant status → control actions ← Progress of batches → Documentation of batch parameters ← raw materials available.	Knowledge of maintenance procedures & how to ask for emergency maintenance Plant operating roles Procedures for documentation. How the docs inter-relates Sources of information Relative rates of use	Procedural Operational Procedural Decision making	At present ordering of raw materials is automated centrally & so does not involve the operator.
2. Operate ibuprofen plant	1 and 2 as stage in process dictates	1. Operate from control room 2. Operate from plant //	← plant status → control actions via d.p. system ← plant status → control actions direct to plant	← plant status → control actions ← plant status → direct plant control	The ability to interpret plant status Knowledge of the relationship between cues and appropriate control actions	-operational -procedural -decision making -operational -procedural	1 and 2 occur sequentially in processing a batch. 2 can only occur if instructions are issued from the control room.

ge 2

erordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2 1 perate from ontrol room	1 after annual plant shutdown 7 for annual plant shutdown and as required 2 at end and beggining of shift 3,4,5 & 6 whilst plant is running	1 Start up plant //	→ control actions ← feedback from control actions & change in plant status	Not known	Start up procedure information availiable	Procedural.	The analysis didn't cover starting up the plant from a cold state.
		7. Shutdown plant //	→ control actions ← feedback of change in plant status	Not known	Shut down procedural information availiable	Procedural	As shutdown occurs so rarely it was not covered in the analysis
		2. Hand over shift log	→ shift information to foreman and CRO's of following shift ← Plant status & shift occurrences from previous shift	→ report to foreman any shift incidents ← plant status gained from displays and CRO's on shift	Reporting procedure Incidents & events that need to be noted.	Procedural	
		3. Recieve and transmit communications	→ outgoing communications ← incoming communications	→ outgoing communications ← incoming communications	Knowledge of operation of communication equipment	Operational	

age 3

erordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2.1 continued erate from ntrol room		4. Monitor and control plant	← plant status ← alarms → control actions	← plant status ← alarms → control actions	Knowledge of plant parameters - how to detect faults. General plant operational and control.	- Procedural - operational - fault detection.	
	...	5 Carry out auxilliary tasks	← cue that auxilliary task needs to be carried out → information necessary for task performance	← request for auxilliary task to be carried out → acknowledgement that task is needed precluding task performance	Knowledge of procedures for tasks - Ability to deal with unforseen or unusual situations	Procedural Problem solving.	At present all requests for auxilliary tasks occur on a face to face basis
		6 Detect and diagnose faults	← fault information/alarm → request for information needed ← further fault information	← alarm ← fault information ← alternative displayed fault information	How faults are signalled and reported. Procedures and actions to follow	- Fault detection - fault diagnosis - procedural	

'age ii

...erordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2 1 2 and over ...hift log	1 and 2 then 3 4 to next shift 5 as coming on and leaving shift.	1. Note any occurrences during shift // 2 Note any faults occurring during shift //	← occurrences during shift ← Faults occurring during shift, faults remaining from previous shifts.	← occurrences during shift : ← Faults outstanding (from shift) & previous shifts.	The ability to relate the information to current shift and plant activity and to make appropriate planning decisions.	Decision making Predictive	At present these are all noted in the shift foreman's log book. So the operator has no direct access to documentation, just information via verbal reporting.
		3. Note in log book //	→ information related to 1 and 2	→ information related to 1 and 2.		operational	
		4. Report verbally //	→ information related to 1 and 2	→ information related to 1 and 2		operational - procedural	There is obvious redundancy with 3 and 4 - However the use of 2 sensory channels for information input and the redundancy help to minimise error, (potential error)
		5 Check status of plant //	→ request status information ← Status information	← Status information.	How to access status information for overall view of plant current status		

erordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2.1.3 eciere and ansmit ommunications	1, 2, 3 and 4 to and from plant personnel	1. carry out face to face communications	← information to operator aurally → verbal information to other plant personnel	← aural information to operator → verbal information to plant personnel.	No special skills required it is useful to be able to convey & understand plant information clearly.	-procedural -operational -predictive -decision making -problem solving -fault diagnosis	The type of task is largely dependant on what the content of the communicatio requires the operator to do.
	...	2. Carry out telephone communications	" → control of telephone	" → verbal information to external personnel	" knowledge of use of telephone	"	"
		3. Communicate using the radiopager system	" → control of radiopager	"	"	"	"
		4. use CCTV to gain on plant information //	→ control of CCTV system ← visual plant i...	→ control of CCTV system ← visual plant information	knowledge of how to use CCTV & infor-mation ...	operational monitoring	

ge 6

erordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
1 3 1 rry out face to face communications	1, 2 and 3 as need arises.	1 Communicate with plant personnel //	← aural plant information → verbal plant information	← aural plant information → verbal plant information	An understanding of plant functioning and "jargon" is necessary	'see notes'	Again type of task is dependant upon the content of the communication
		2. Communicate with maintenance/ service personnel //	→ details of work to be carried out ← authorisation of work verbal and documented	← worksheets detailing work if planned. → verbal reports if unplanned work requested → requests for services → work to be carried out and details	Knowledge of plant affected by work, current status of the part of the plant. When work can safely be carried out. Safety & maintenance procedures.		
		3. Communicate with visitors //	→ request information on purpose of visit ← details of proposed visit → Log in visitors	→ request information on purpose of visit ← details of proposed visit → Log in visitors	Knowledge of who is allowed access to plant and security procedures. Knowledge of logging procedures	Procedural	

ay='1

erordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2 1 3.2 Carry out lephone mmunications	1, 2 and 3 as required	1 Make and recieve internal calls //	→ exchange ← of verbal information	→ exchange ← of verbal information.	internal numbers, & how to make internal calls	Procedural 'see notes'	Type of task is dependant upon content of information exchange
		2 Recieve external calls //	← recieve aural information → Give out requested information if appropriate	"	How to respond to external calls	"	"
		3. Call technical services //	→ make call → request service ← service details given	→ make call →request service ← service details given	Procedural for requesting technical services	Procedural	
1 3.3. mmunicate sing clidpager ystem	1 or 2	1 Communicate during normal operation /	→ call plant personnel ← recieve information from plant personnel	→ call plant personnel ← recieve information from plant			

ge 8

erordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2133 ommunicate sing adiopager system cont		2. Communite during plant fault or problems !!	→ details of fault /problem ← details of fault → request for action. ← request control action ⇄ exchange of information	⇄ exchange of information	Knowledge of plant needed and ability to determine as much information about the problem /fault as possible from the interface.	Problem solving Fault detection Fault diagnosis.	This aspect of the task was not observed in detail during the plant visit - as no such task demands were made.
2.1 4 onitor nd control lant	1, 2, 3 and 4 as the process demands.	1. Follow progress of batches	← batch information & current status → requests for information	← batch information → requests for information	Location of relevant batch information and how it relates	Monitoring	Batch information is available from a wide variety of sources.
		2 Alter or adjust plant parameters from control room	← Need to adjust parameter → control action to change parameter	← Plant status/ parameter information → control action to change parameter	Knowledge of procedure to adjust parameter. Understanding of when parameter needs adjusting	Procedural operational Decision making	
		3 monitor plant status from control room	← Plant status information	← plant status information	Knowledge of acceptable plant status	Monitoring	

Page 9

Superordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2.1.4 Monitor and control plant (continued)		4. Monitor and co-ordinate manual parts of process	← current status of manual sections of process → requests for action to be carried out → requests for information → process relevant information ← information on completion of manual stage ← record of batch unit completed	→ requests for action or information ← information as requested ← batch sheet provides record of batch	Knowledge of the functions of the manual inputs of the process and how they relate to the system	monitoring Procedural Decision making	
2.1.4.1 Follow progress of batches	1 and 2 → 3 For 3 documentation is redescribed in 2.1.4.1.1.3.	1. Document batches	→ number batch → Document progress of batch → Document completed batch → Document Raw materials	→ main batch log → unit batch logs → Raw materials logs	How to complete documentation An understanding of the documentation & how it inter-relates is needed.	Operational Procedural	

Superordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2.1.4.1 Follow progress of batches (continued)		2. Monitor batch from H.M.1 //	← batch status information → requests for information	← batch status information → requests for information	The stages in the process, how they inter-relate and trends which indicate problems	Monitoring Predictive	
	...	3. monitor completion of batch	← monitor for when batch nears completion → Prepare packaging for batch ← batch completed → Documentation of completion of batch	← Progress of batch ← Batch completed → Documentation of completed batch	Procedure to be followed for completion of batch	Procedural	
2.1.4.1.1 Document batches	1 → 2 → 3	1. Log in new batch //	→ Batch number	← batch number from documentation → Batch no to computer	How to log in batch number	procedural operational	

ug: 11

Superordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
r 11 Document batches (continued)		2. Update batch logs	← Unit/stage completed of batch → Logging of batch information	← Unit / stage of batch complete → logging of batch information	Knowledge of different logging procedures & the information to be logged.	Procedural.	
		3. Co-ordinate Labelling of batches.	→ Provide labels batches	→ notify q.c that batch labels needed ← batch labels issued → complete labels with batch number → issue labels to plant.	Knowledge of labelling procedure	Procedural	
4.1.1.1. Log in new batch	1→2 (1 redescribed in 4.1.1.2.1)	1. Log in on main batch sheet 2. Log number into computer //	→ Log in batch number → Log in batch number	→ Log in next consecutive number ← Note number → Log in number on computer	Knowledge of how to fill in logs	Procedural	There is scope for human error in transferring batch number between the 2 mediums

Page 1.2

Subordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
1.1.1.1 Log in on main batch sheet	1 → 2 → 3	1. Note consecutive number /	→ Log in consecutive number	→ number	How to use the logging sheet	Procedural	
		2. Note time batch logged in //	→ time	→ time			
		3. Note other parameters needed //	→ other parameters needed	→ header tank weight			'other parameters' are not specified as it is largely dependant on legal and company requirements for batch traceability
1.1.1.2 Update batch logs	1-4 on completion of each batch unit 2 at end of each automatic unit 3 At end of each manual unit	1. Update main batch log	→ batch information to log ← information correct.	→ batch information to log ← information correct.	Procedure to update main batch log.	Procedural	
		2. Obtain printout //	← Printout of log given → check information.	← printout of log given.	How to use printout & where information should be transferred to.	Procedural	
		3. obtain completed batch sheet from plant operator //	← batch log sheet → Ensure sheet correctly completed	← batch log sheet	Knowledge of issuing & filing procedure for manual batch [illegible]	Procedural	

..erordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
..1.1.3 ..-ordinate ..belling of ..atches	1 → 2 → 3 → 4 → 5	1. Check to ensure batch near completion //	← Process information on batch progress	"	Labelling procedure should be familiar	Procedural	
		2. Estimate number of labels needed //	→ Request men on plant to estimate approx no of containers	"	Operator should know how to communicate with quality control.	Procedural	
		3 Notify quality control that labels needed //	→ Request labels from quality control.	"		Procedural	
		4. Fill in labels with batch number //	← batch no on labels	"		Procedural	
		5. Send labels to plant //	→ labels ready, plant notified	"		Procedural	
..4.2 ..lter or ..djust plant ..rameters ..om control ..om	1,2,3 as required	1. change set point //	→ control actions to change SP ← SP changed	→ control action to change SP ← SP changed	Knowledge of situations when parameters can be changed	Procedural operational	
		2. Adjust parameter from critical to non-critical or v.v //	→ check current status → change status ← status changed	→ check current status → change status ← status changed	Knowledge of control procedures	"	
		3. Alter / Adjust other parameters //	→ adjust parameter ← parameter adjusted	→ adjust parameter ← parameter adjusted.		"	

...ge 15

...erordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
.1.4.3 ...onitor ...lant status ...om ...ontrol room	1,2 and 3 whilst plant is running	1 Monitor for alarms // 2 Monitor trends to anticipate problems // 3. Monitor to ensure parameters are within boundaries //	← Plant status ← alarms ← Plant trends ← process parameters moving out of bounds. ← parameters ← boundaries that are acceptable	← Plant status ← alarms ← Plant status information	How to react to and anticipate alarms. How to use trends to anticipate problems	Fault detection	Alarm information is auditory and hard copy as well as displayed.
.1.4.4 ...onitor and ...o-ordinate ...e manual ...nits of the ...rocess	1→2 at start and end of manual process units. 3 as required 3 is redescribed in 2.1.3.1 & 2.1.3.3.	1. Issue batch sheets for manual actions. // 2. Ensure batch sheets are returned and filed // 3. Request plant operators to perform actions	→ issue batch sheet ← Process ready to begin manual unit ← Note completion of manual unit. → Ensure batch sheet returned → request action of plant operator	→ issue batch sheet ← Process ready to begin manual unit. ← Note completion of manual unit → ensure batch sheet returned → request action of plant operator	Knowledge of batch sheet issuing and filing procedure.	Procedural operational	

Superordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2.15.1 Log in raw materials (continued)		3. Complete cardex system //	→ Log information into overall raw materials record	→ Log information into : cardex system			
		4 Notify quality control //	→ notify quality control	→ notify quality control			
2.15 3 Log in maintenance and service personnel	1 → 2 → 3	1 Log in personnel in book //	→ Log in ← Request personnel to fill in details	→ Log in ← Request personnel to fill in details	Knowledge of how to log in staff and how relevant documents - work sheets & flame permits - should be filled in	procedural	
		2. Check work sheet is completed in triplicate //	→ Check work sheet → check details of work & precautions to be taken	→ check work sheet → Check details of work & precautions to be taken		procedural	
		3. Check flame permit is issued if required and authorised by shift chemist //	→ check flame permit	→ check flame permit		procedural	

g= 18

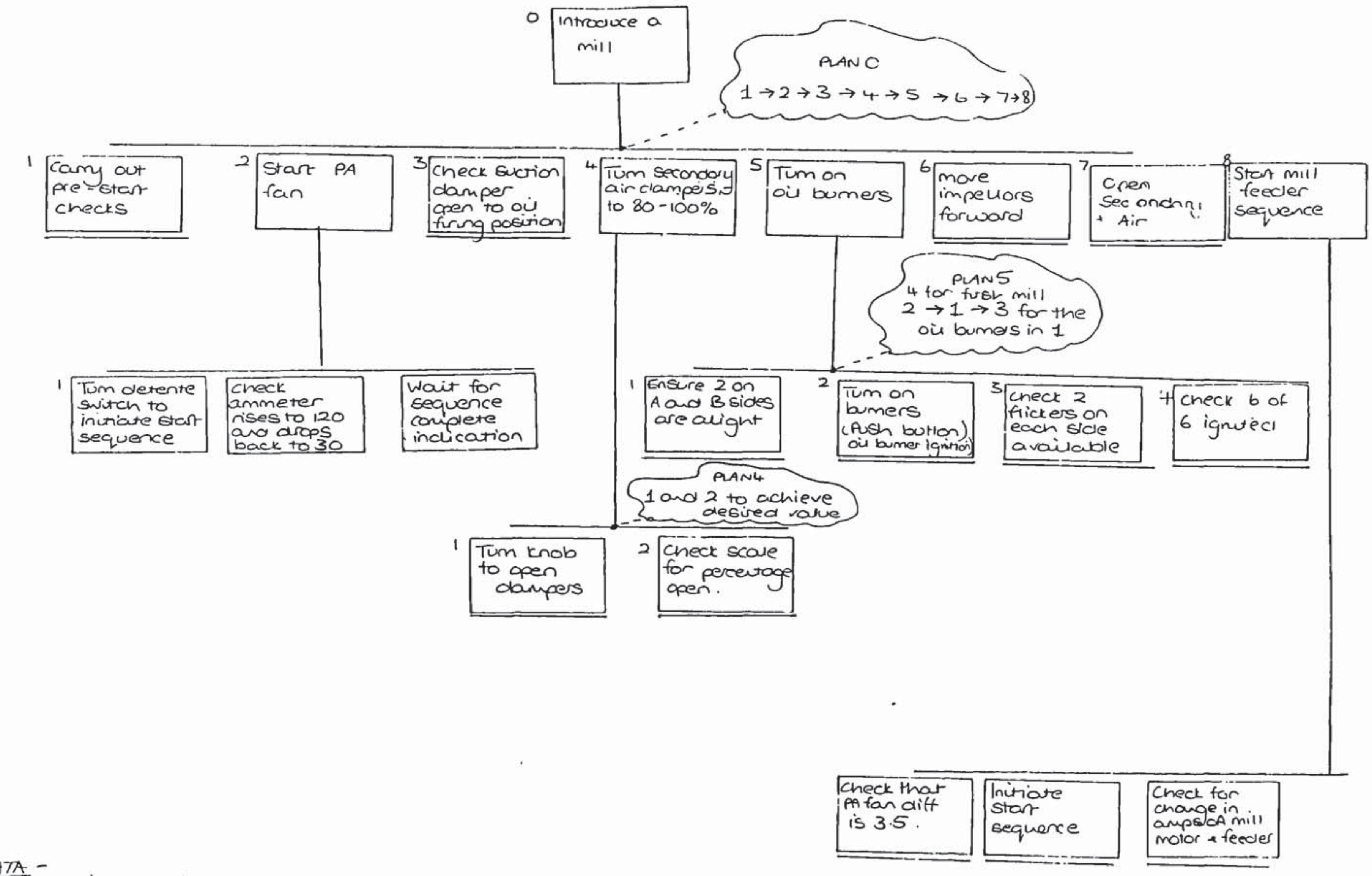
Co-ordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
1.6 rect and gnose ults	1 → 2	1. Detect faults 2. Diagnose faults	← alarm information ← plant status & process information ← relevant fault information.	← hardcopy alarm information ← plant status information ← fault information	Recognition that a fault has occurred Ability to make initial diagnosis of fault situation	Fault detection Fault diagnosis.	
1.6.1 etect aults	1 → 2 → 3 ...	1. Audible sound from printer noted // 2. Note nature and type of fault. // 3 Decide on action to be taken	← audible alarm given ← visual alarm given ← detailed fault information immediately available	← printer makes audible sound ← unit is placed in hold on display ← fault item flashes on display ← Fault information given on printout	Knowledge of how to locate fault and use fault information to minimise plant down time	Fault detection.	
1.6.1.3. ecide on ction to e taken	1 or 2 or 3. 3 may lead to 1 or 2 pending other information	1. Decide to restart item of plant // 2. Decide if to take further action 3 Leave unit,	← Plant information → restart item ← plant information → other action monitor plant situation	← plant information → restart item ← plant information → other action ← plant	Judgemental skills are needed to decide on action appropriate to situation	Decision making Fault Diagnosis monitoring	

Page 19

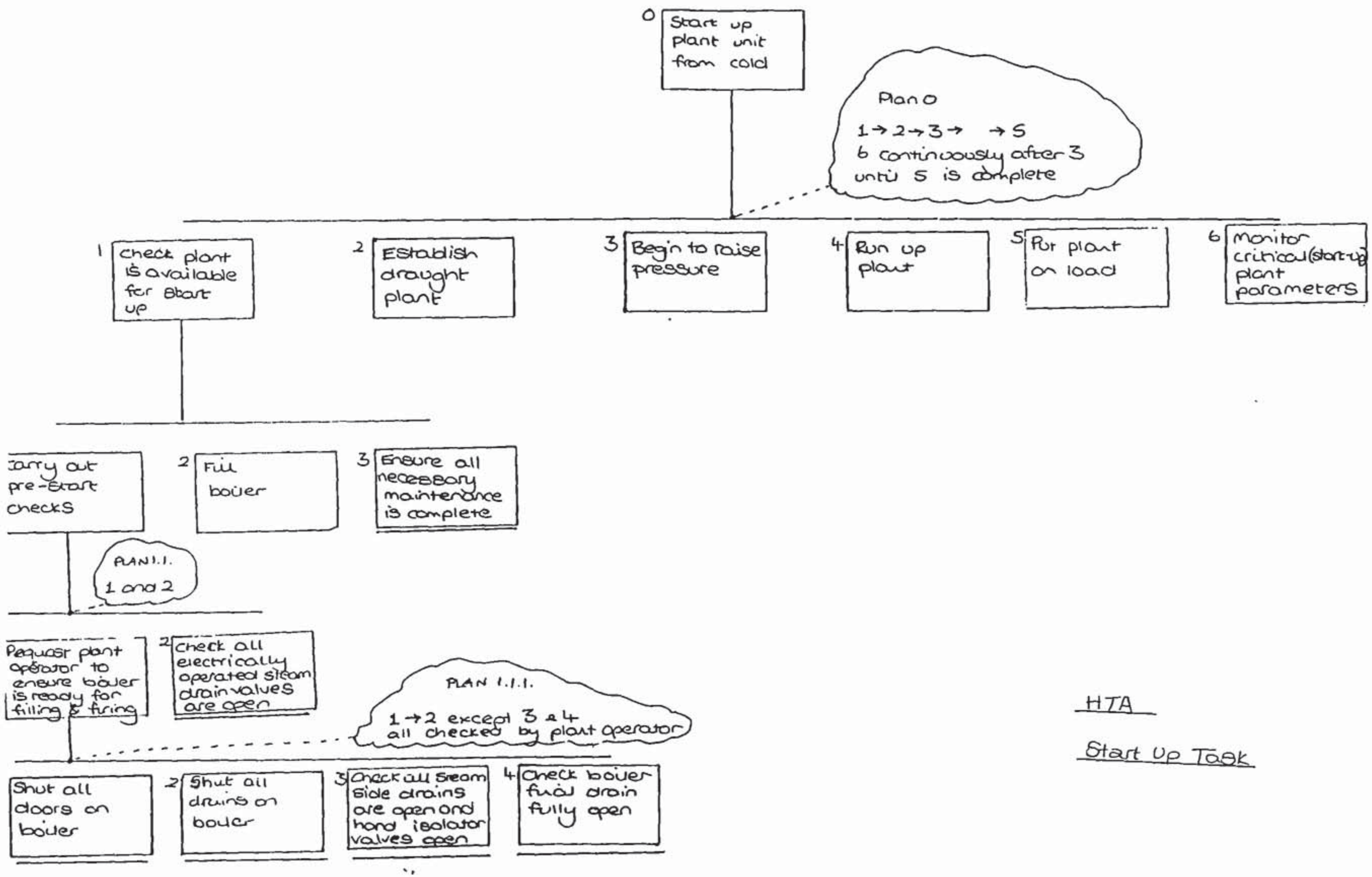
perordinate	Plan	Operation	Information flows assumed	Information flows existing	Knowledge and skills	Type of task	Notes
2.1.6.1 3.2.. Decide if to take further action	1 and/or 2.	1. Request maintenance or repair services 2. Request action to be taken by men on plant.	→ request for maintenance or repair → request action by plant personnel	→ request service from technical services. → request action by plant personnel.	when service aid is needed and the request procedure Knowledge of the process should allow communication of required action relating to fault	Procedural decision making Problem solving operational	

APPENDIX E

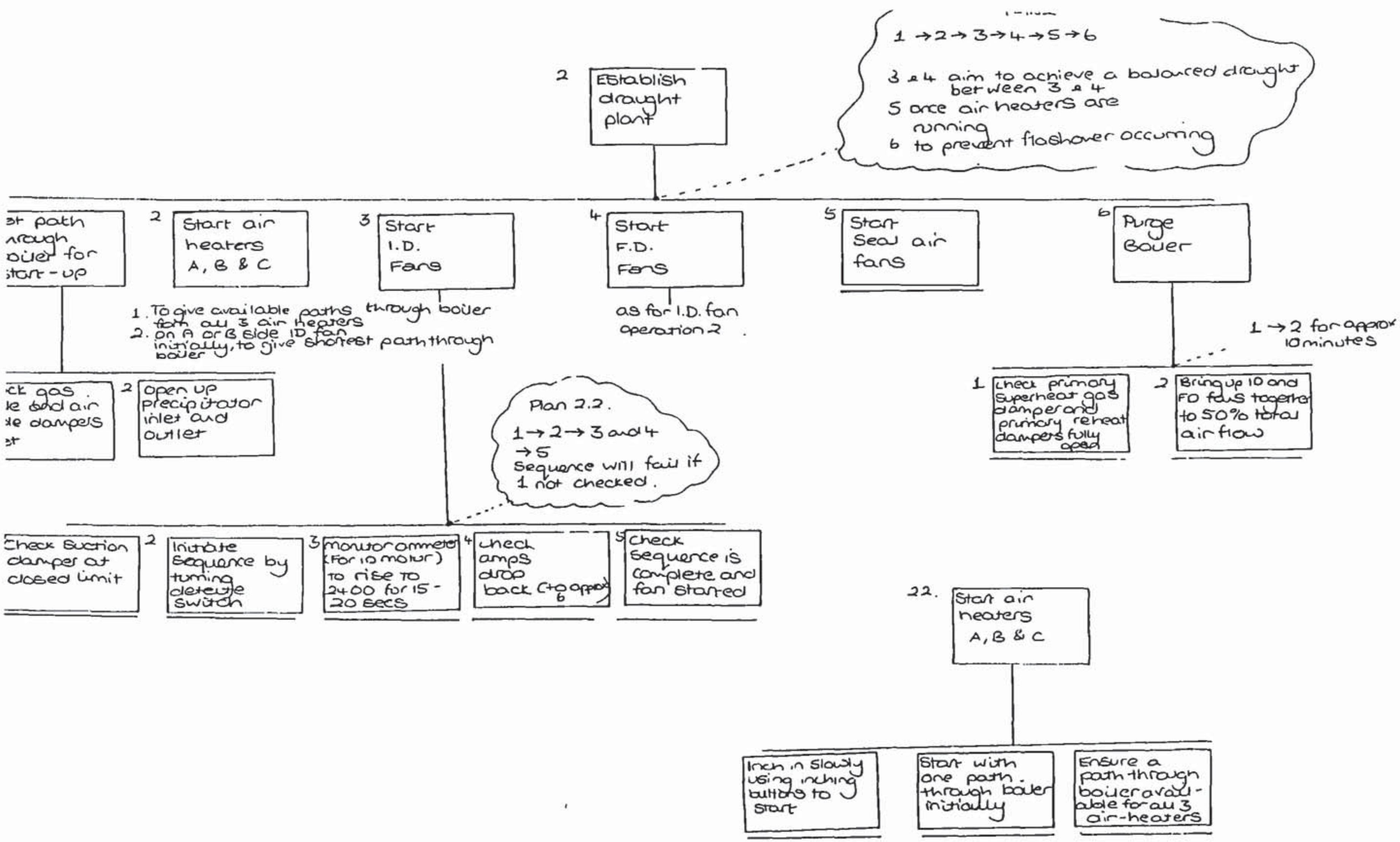
Didcot Power Station
Task Analysis



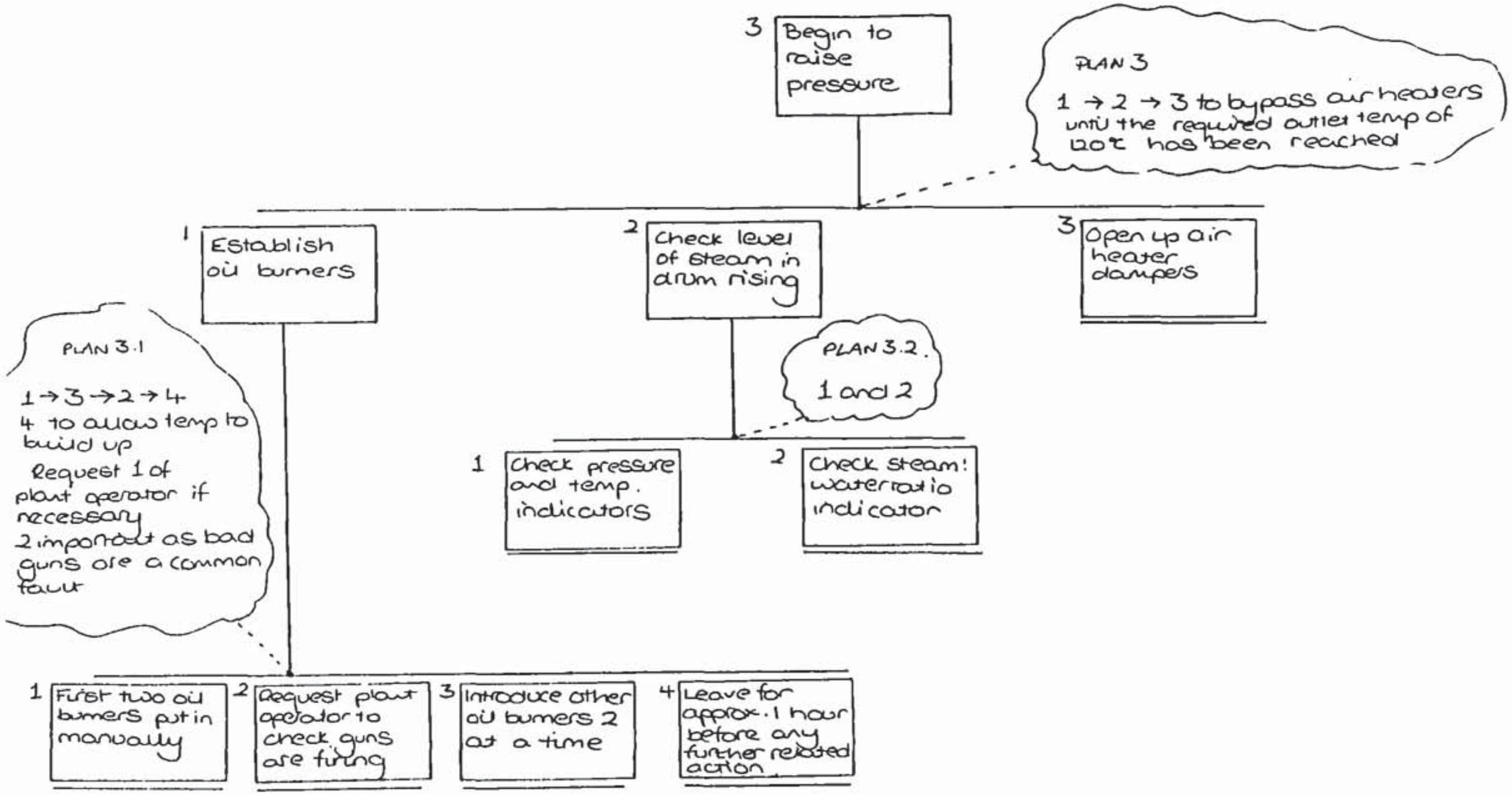
HTA -
Introducing a mill



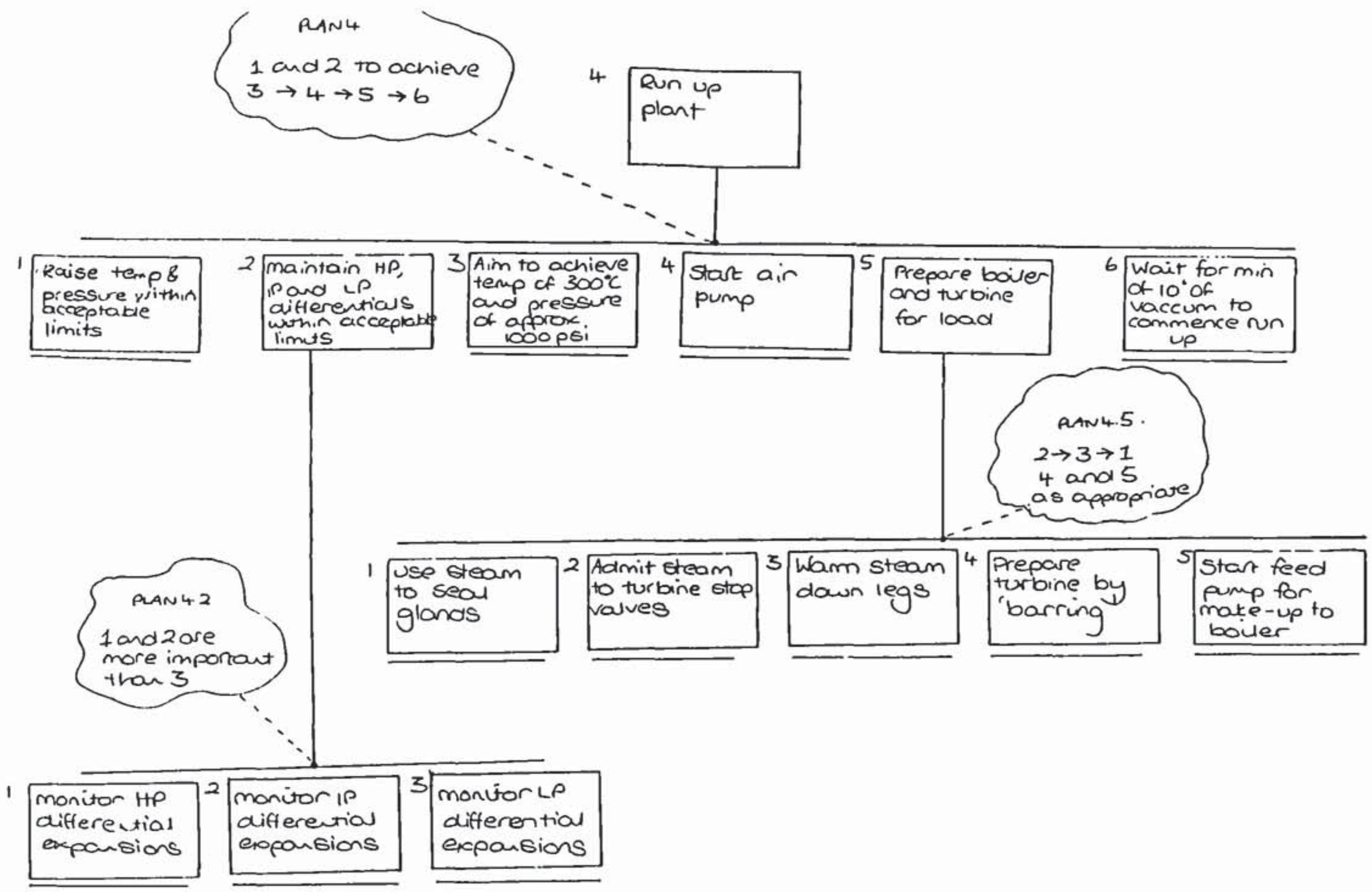
Start-up HTA
Page 1

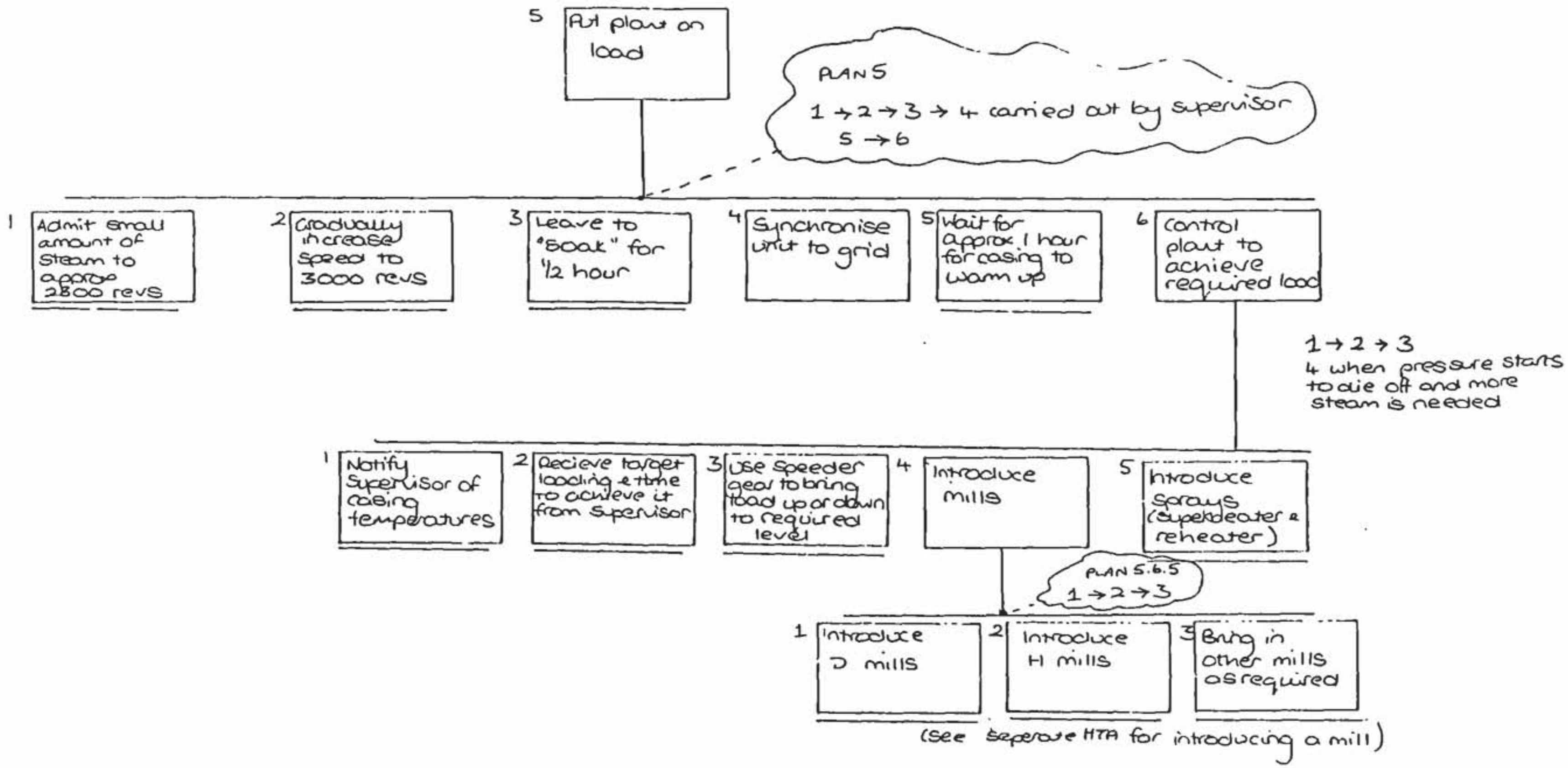


2 Establish draught plant
1 → 2 → 3 → 4 → 5 → 6
3 & 4 aim to achieve a balanced draught between 3 & 4
5 once air heaters are running
6 to prevent flashover occurring
2 Start air heaters A, B & C
3 Start I.D. Fans
4 Start F.D. Fans
5 Start Seal air fans
6 Purge Boiler
1. To give available paths through boiler for all 3 air heaters
2. on A or B side ID fan initially, to give shortest path through boiler
as for I.D. fan operation 2
1 → 2 for approx 10 minutes
2 Open up precipitator inlet and outlet
1 Check primary superheat gas dampers and primary reheat dampers fully open
2 Bring up ID and FD fans together to 50% total air flow
Plan 2.2.
1 → 2 → 3 and 4 → 5
Sequence will fail if 1 not checked.
Check suction damper at closed limit
2 Initiate sequence by turning detente switch
3 Monitor ammeter (for ID motor) to rise to 2400 for 15 - 20 secs
4 Check amps drop back (to approx 6
5 Check sequence is complete and fan started
22. Start air heaters A, B & C
Inch in slowly using inching buttons to start
Start with one path through boiler initially
Ensure a path through boiler available for all 3 air-heaters
Start up HTA

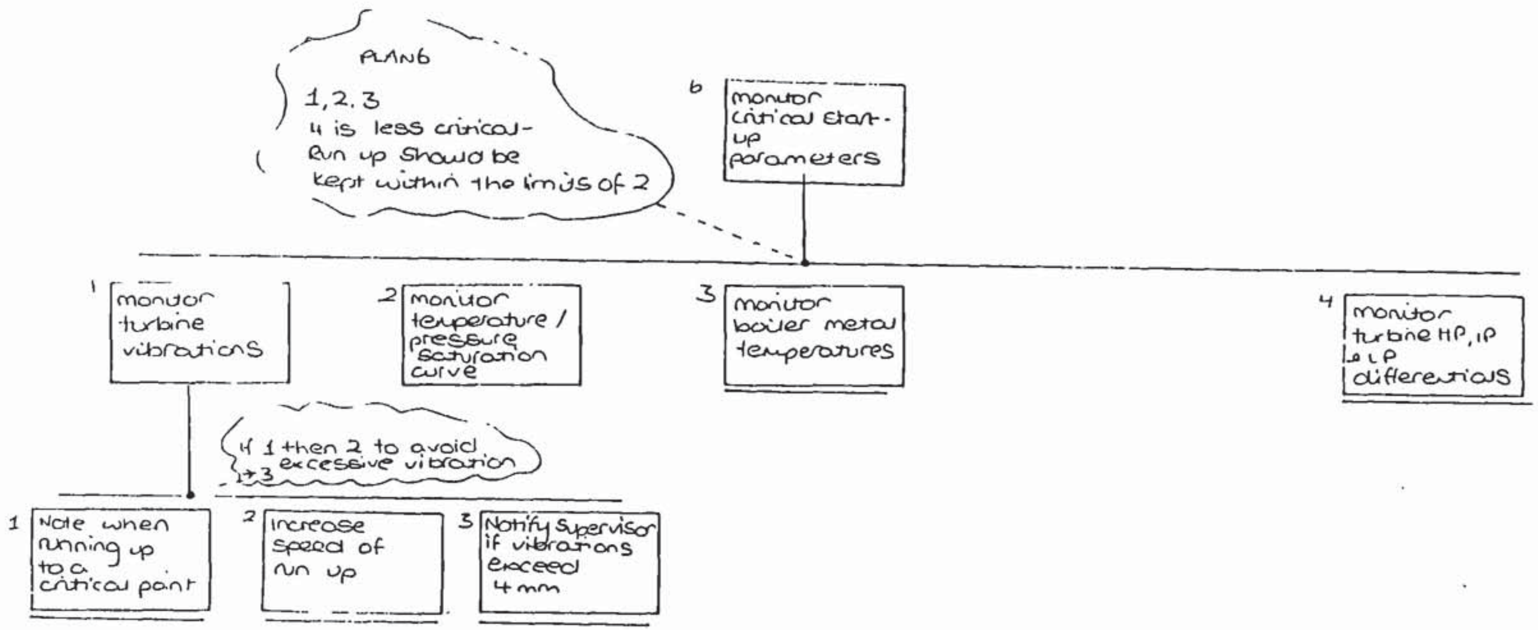

3 Begin to raise pressure
PLAN 3
1 → 2 → 3 to bypass air heaters until the required outlet temp of 120°C has been reached
1 Establish oil burners
2 Check level of steam in drum rising
3 Open up air heater dampers
PLAN 3.1
1 → 3 → 2 → 4
4 to allow temp to build up
Request 1 of plant operator if necessary
2 important as bad guns are a common fault
PLAN 3.2.
1 and 2
1 Check pressure and temp. indicators
2 Check steam: water ratio indicator
1 First two oil burners put in manually
2 Request plant operator to check guns are firing
3 Introduce other oil burners 2 at a time
4 Leave for approx. 1 hour before any further related action

START UP HTA


PLAN 4
1 and 2 TO achieve
3 → 4 → 5 → 6
4 Run up plant
1 Raise temp & pressure within acceptable limits
2 maintain HP, IP and LP differentials within acceptable limits
3 Aim to achieve temp of 300°C and pressure of approx. 1000 psi
4 Start air pump
5 Prepare boiler and turbine for load
6 Wait for min of 10" of vaccum to commence run up
PLAN 4.5.
2 → 3 → 1
4 and 5
as appropriate
1 use steam to seal glands
2 Admit steam to turbine stop valves
3 Warm steam down legs
4 Prepare turbine by 'barring'
5 Start feed pump for make-up to boiler
PLAN 4.2
1 and 2 are more important than 3
1 monitor HP differential expansions
2 monitor IP differential expansions
3 monitor LP differential expansions


5 Put plant on load
PLAN 5
1 → 2 → 3 → 4 carried out by supervisor
5 → 6
1 Admit small amount of steam to approx 2800 revs
2 Gradually increase speed to 3000 revs
3 Leave to "soak" for ½ hour
4 Synchronise unit to grid
5 Wait for approx 1 hour for casing to warm up
6 Control plant to achieve required load
1 → 2 → 3
4 when pressure starts to die off and more steam is needed
1 Notify supervisor of casing temperatures
2 Recieve target loading & time to achieve it from supervisor
3 Use speeder gear to bring load up or down to required level
4 Introduce mills
5 Introduce sprays (superheater & reheater)
PLAN 5.6.5
1 → 2 → 3
1 Introduce D mills
2 Introduce H mills
3 Bring in other mills as required
(See seperate HTA for introducing a mill)

Start up HTA

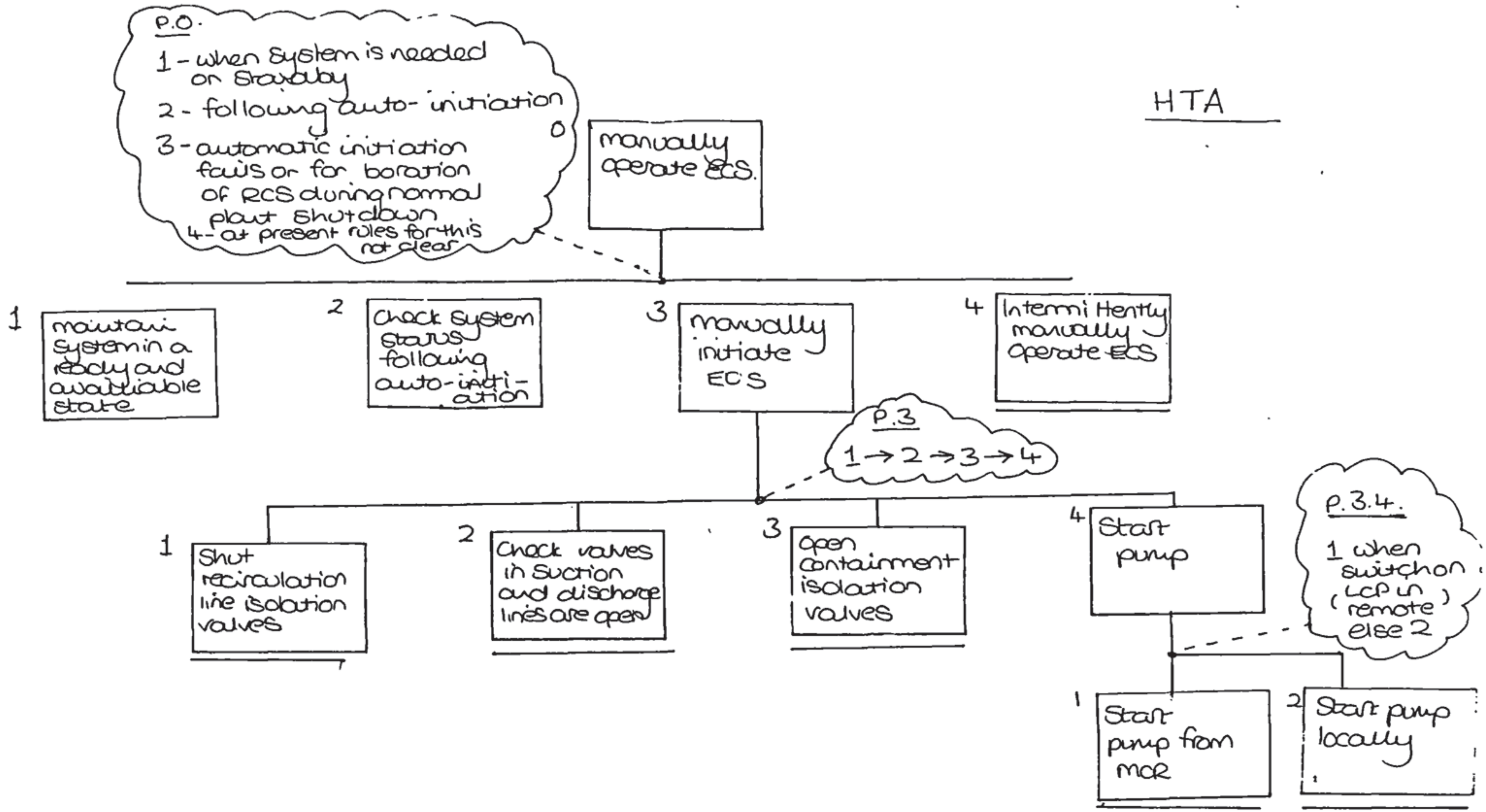


Start up HTA
App 6

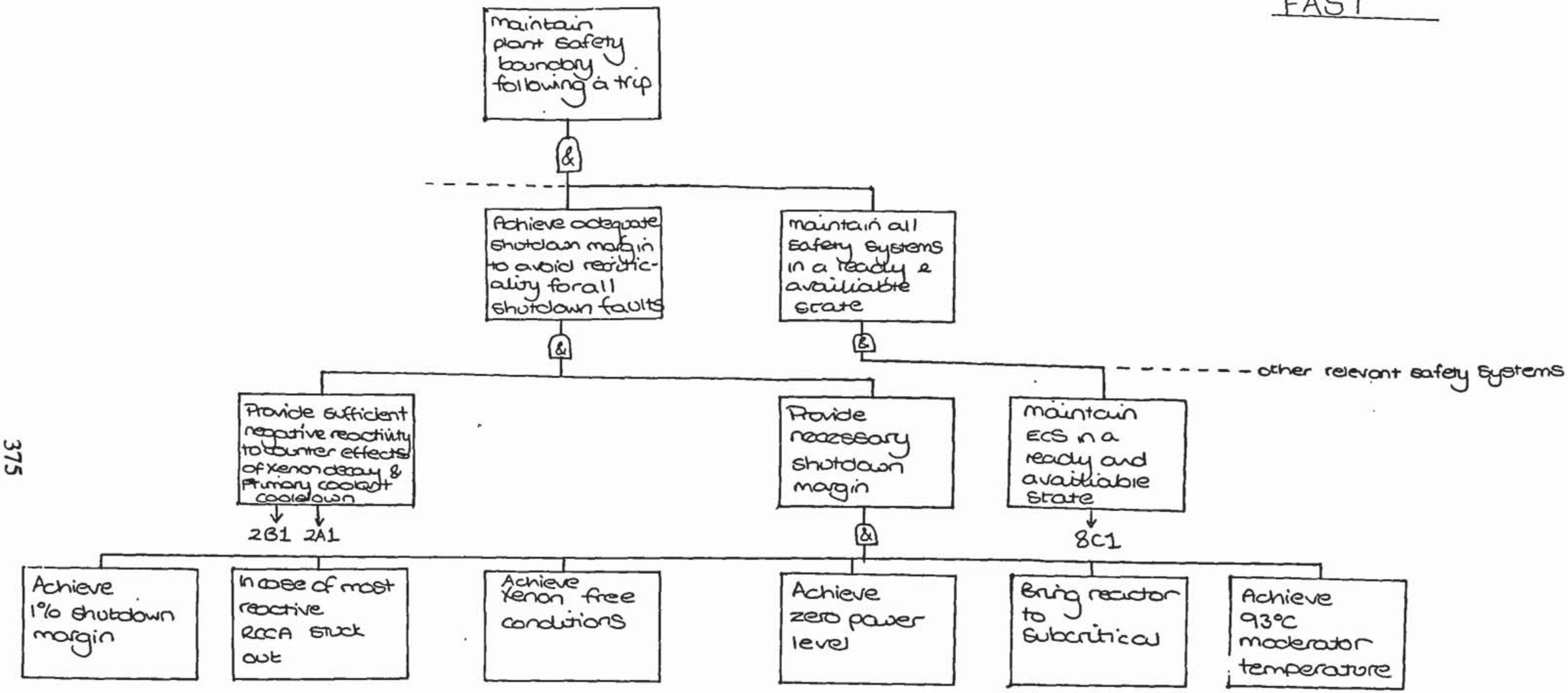
APPENDIX F

Examples taken from the task analysis of a high risk plant

HTA and FAST


HTA
0
manually operate ECS.
P.0.
1 - when system is needed or standby
2 - following auto-initiation
3 - automatic initiation fails or for boration of RCS during normal plant shutdown
4 - at present rules for this not clear
1 maintain system in a ready and available state
2 Check system status following auto-initiation
3 manually initiate ECS
4 Intermittently manually operate ECS
P.3
1 → 2 → 3 → 4
1 Shut recirculation line isolation valves
2 Check valves in suction and discharge lines are open
3 open containment isolation valves
4 Start pump
P.3.4.
1 when switch on LCP in (remote) else 2
1 Start pump from MCR
2 Start pump locally

FAST



maintain plant safety boundary following a trip
&
Achieve adequate shutdown margin to avoid recriticality for all shutdown faults
maintain all safety systems in a ready & availiable state
&
&
- - - - - - other relevant safety systems
Provide sufficient negative reactivity to counter effects of Xenon decay & Primary coolant cooldown
2B1 2A1
Provide necessary shutdown margin
&
maintain ECS in a ready and availiable state
8C1
Achieve 1% shutdown margin
In case of most reactive RCCA stuck out
Achieve Xenon free conditions
Achieve zero power level
Bring reactor to subcritical
Achieve 93°C moderator temperature

APPENDIX G

A GUIDE TO HIERARCHICAL TASK ANALYSIS

The following section comprises a handbook detailing the basic method of Hierarchical Task Analysis (HTA). As the modifications to the analysis carried out in this thesis are described in detail throughout the thesis, the basic ideas and methodology of the method are described here and a step by step guide to using HTA given.
The analyses of the plants studied are detailed in the appendices and provide examples of the application of HTA.

The method is based on Hierarchical Task Analysis (HTA) (Annett et al 1971, Shepherd 1976, 1985) which was developed in the late 1960s and early 1970s and has evolved to meet the changing task demands imposed by modern complex process control tasks.

As its name suggests the task is analysed by breaking it into a hierarchy of task elements, each level being more detailed. For each of these task elements the information and communication flows needed to perform the task are analysed.

A task analysis is:
"A process of sorting out what people actually so when they perform tasks - what actions they carry out; how they respond to different cues in their working environment; how they plan their activities" (Shepherd, 1976)

The technique described here is based on the idea that task performance can be defined in terms of its goals, and that to analyse the task all that has to be done is to state the plans that are needed to achieve these goals.

It is a hierarchical method which means as much or as little detail needed for each application can be included. The analysis begins with a statement about the overall goal of the task, and at each level these goals are analysed in more detail forming a hierarchical structure. This means that the analysis is complete at any one level of the hierarchy.

The representation of the task is easily understood and so can provide a source of information about the task not only to the human factors expert but also to trainers, designers and engineers.

THE METHOD

Operations

The analysis begins by making a statement about what the overall goal of the task is. This statement shows the overall task objective. All task statements like this in the analysis are called OPERATIONS, this is because they involve the human performing an action with something, or to something. Examples of operations are:

"Filter solution until clear"
"Operate process plant"
"Run distillation process"

Throughout the description of the method, the example of the analysis carried out on the Coal Preparation Plants is used. The analysis begins with the overall goal of the operator - to "Operate the Coal Preparation Plant".

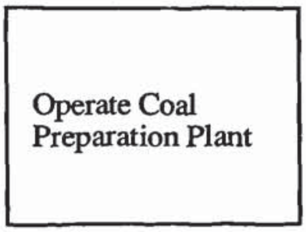


Figure 1 The main task operation

Progressive redescription

The next stage is to take the main operation and break it down into its constituent task goals or SUB-ORDINATE OPERATIONS. There are usually between 2 and 6 of these operations. Together, these operations should form the equivalent of the super-ordinate operation. (Figure 2)

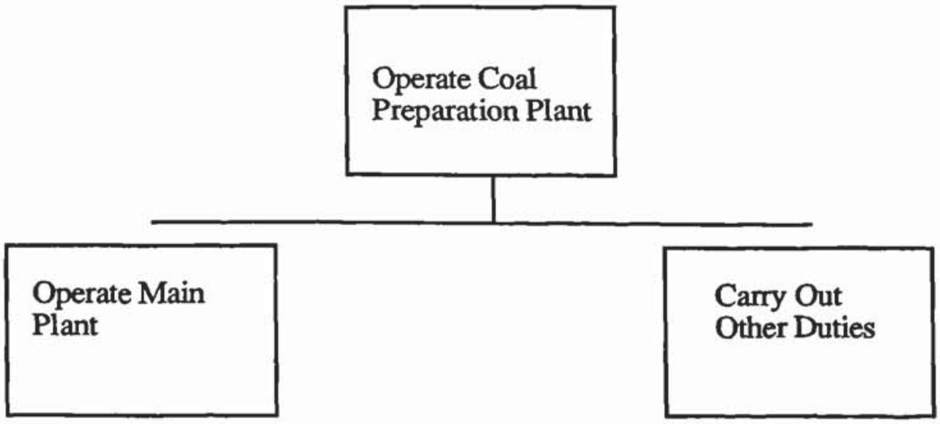


Figure 2 Progressive Redescription

The task is analysed by dividing it into a hierarchy of all its constituent operations. This means at each level of the hierarchy the task is described in greater detail. The first step in developing the hierarchy is as outlined above, the overall task goal is broken down into its constituent task goals. Each of these goals is then in turn broken down into their constituent task goals. This then continues until the required level of detail is reached in the hierarchy. This process of breaking down task goals into their subordinate operations is known as PROGRESSIVE REDESCRIPTION.

Representation

Hierarchical diagram

The representation is the way in which the task information is communicated to the user of the analysis. As the analysis is being carried out it is usually put into the tree type diagram as shown for the example. This type of representation is useful for showing the relationship in the task between all the different operations.

Tabular format

Once this initial analysis has been carried out showing the main task components, the tree diagram must then be translated into a tabular format which gives more detail and additional task information. The table used is outlined below in figure 3.

No.	Task component—operation or plan	Reason for stopping	Remarks
1	*Operate the melting-process* *P* 1. A two-day training programme ' off the job ' 2. Logkeeping 3. Process control 4. Telecommunication 5. Maintenance		
2	*Logkeeping* *P* 2. No training	$P \times C$ acceptable	Explanation by showing the logs ' on the job '

Figure 3 The tabular representation

The tabular format is designed so that the task information can be read across the table from left to right. The use of the different columns, and the task information that they include, is outlined below

Super-ordinate	The number and brief description of the superordinate operation to be described.
Plan	A detailed plan showing conditions under which the operations are carried out
Operations	A list of the operations as they occur under the super-ordinate
Information/ communication flows	Information and communication flows to and from the operator. This is the information the operator needs in task situation in order to be able to effectively perform the task. This includes information from the interface and from other sources such as the men on the plant. This information is independent of any existing interfaces, but identifies the information the operator needs to perform the task given his skills and knowledge.
Information/ communication existing	These are the information and communication flows that exist in the present task situation, it allows comparison with the assumed optimal task information as outlined in the previous column.
Skills and knowledge required	The aim of this column is to identify the skills and knowledge the operator will need to achieve the goal described in the operation, given the information he has at his disposal. The skills and knowledge identified when coupled with the information provided in the task situation, should provide the operator with all the information he needs to perform the task in question.
Type of task	A classification scheme of 8 task types has been identified. This allows the information display to be designed in a way that it most effective for that task type. For example, fault information may best be displayed in an alarm type format, whilst monitoring information is easier to use if a mimic display is used. The task classification used is shown in Figure 4.

TASK TYPE	DEFINITION
Monitoring	Sampling information to determine the correct states of variables of importance. This includes the identification of deviations and manipulation of the information to determine changes in system states.
Fault Detection	Perception of a fault having occurred or being imminent.
Prediction	Judgment of likely future system states.
Problem Solving	Process of resolving uncertainty about system states.
(Fault Diagnosis	*A specific kind of problem solving task involving identification of the root causes of a fault)*
Decision Making	Choosing between alternative responses on the basis of available information.
Procedural	Following a pre-determined sequence of events.
Motor Tasks	Any operator action upon system state or configuration.
Communication	Accurate transmission of information without any processing of the information from transmission to reception by the individual or group who will use it.

Figure 4 Task Classification

The tabular format and the hierarchical format can be used individually or together. The hierarchical diagram makes explicit the structure of the task goals and shows the relationship between operations clearly.

The tabular format allows much greater depth of analysis - but it is not easily able to show the overall structure of the task. The tabular format shown is an extended version to make explicit the task details relating to information and communication flows.

Numbering
All operations are numbered to allow their unique identification in the hierarchy. This is important, as for a complex task the analysis can be quite large and it may be difficult to navigate and to relate the different items of task information. Numbering allows an easy means of overcoming this problem.

Each operation has two numbers, the number in which it occurs under its superordinate operation, and its unique number in the hierarchy. In the tree-like diagram, all the operations with a common super-ordinated are numbered 1 - n, these numbers are used to refer to the operation in the plan. For the tabular format, the operations are numbered according to the position of their super-ordinates in the hierarchy this is illustrated in figure 5. For each level down the hierarchy an operation gains an extra number, so the number of numerals describing an operation indicate its depth in the hierarchy.

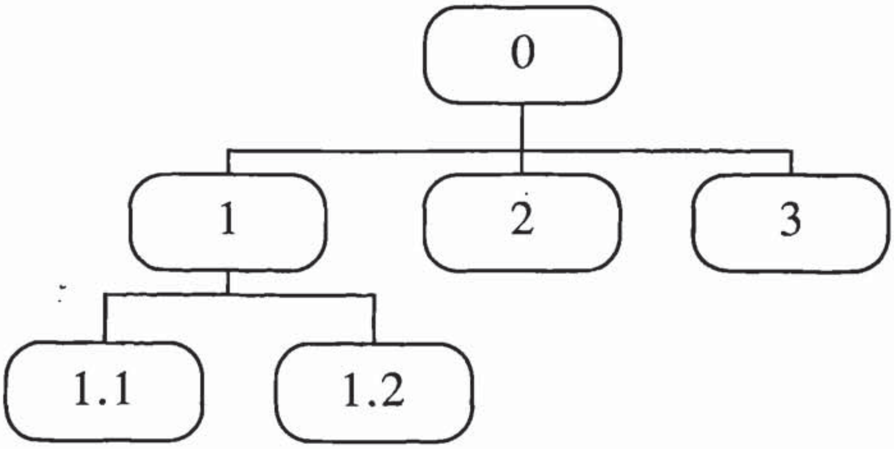


Figure 5 Numbering conventions

Plans
The hierarchical diagram shows clearly the relationships between the different levels of the hierarchy but is unable to show the relationships between the different operations with a common superordinate goal.

There is often the temptation to read the operations in the hierarchy from left to right. There are not always ordered in this manner and there may be conditions or alternatives under which the operations are carried out. These are shown by the use of plans. Plans are annotated on the tree diagram for each superordinate operation within the hierarchy. A superordinate operation is one that is redescribed and has subordinate operations under it.

The plan shows not only the sequencing of the operations in performing the task, but also the conditions, temporal constraints and alternatives in carrying out the operations. An illustration is given below. They can also be used to indicate concurrency of operations or if they are mutually exclusive.

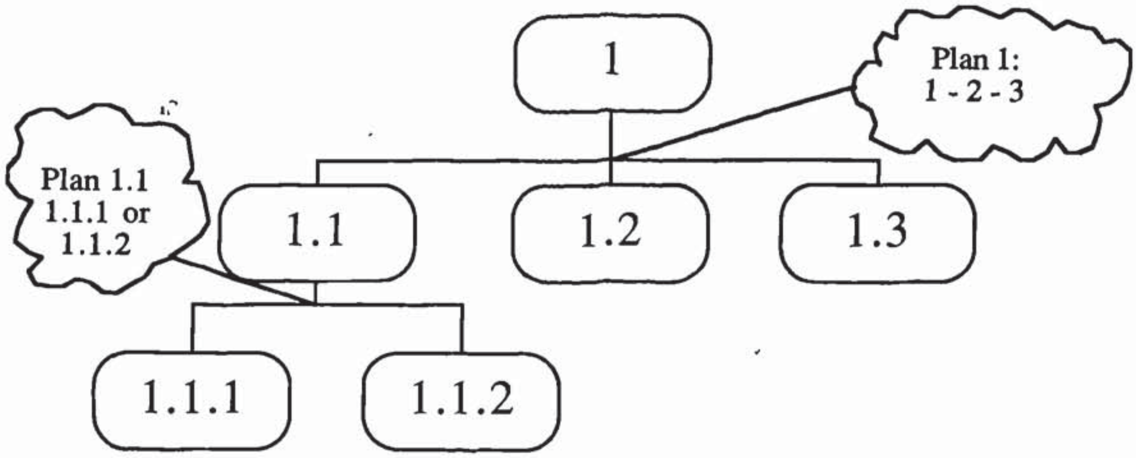


Figure 6 Plans

WHEN TO STOP REDESCRIPTION

Hierarchical Task Analysis is based on the idea that, in principle there are an indefinite number of levels that the analysis and hierarchy could continue to. However such detail is rarely needed and there are various rules which determine when an analysis is to be stopped.

These rules are known as stopping rules. The principle rule that is often applied is known as the P x C rule. Or the probability times cost rule. It is based on the idea that there is enough detail in the analysis if for a given operation at the bottom level of the hierarchy:-

The probability of a human failing to perform that operation (P),

multiplied by ,

The cost to the system if it is not performed or is not performed effectively (C) = P x C.

If this is acceptable then redescription can be stopped. However, although this measure gives an indication of the importance of an operation, the information needed is sometimes difficult to obtain and it may be an impractical measure.

There are other more general guidelines to indicate when the analysis is complete:

- Current performance of that particular operation is satisfactory
- A means to ensuring satisfactory performance can be proposed
  (For example job aids or specific training)
- The same operation has been redescribed elsewhere
  (In this case the analysis need only refer to the other operation)
- No further way of redescribing the operation can be seen.

INFORMATION COLLECTION

To carry out the analysis the analyst must have adequate task information available to begin with. There is a wide variety of methods available to analysts to allow them to collect information about tasks.

However, to carry out an HTA, information is needed about the *steps to be taken in performing* the task (both cognitive and physical) and the information flows. Much of the information needed can be collected from the control room environment by observation of the task or by informal interviews with both the control room operators, and other plant personnel. Examples of information collection methods that could be used in this context include; activity analysis, verbal protocols, interviews and "walk /talk throughs" of the task.

APPENDIX H

Example Coal Preparation Plant display formats

GROUP 1

1	NO. 1 COMP COOLING FAN	ON
3	CLARIFIED WATER PUMP	ON
4	BRACKET FILTER	ON
5	FROTH OIL PUMP	ON
FL	IS STOCK TANK EMPTY	nO
S22	IS 6 FILT AID PUMP SEL'ED	YES
6	NO. 6 FILTER AID PUMP	ON
S23	IS 7 FILT AID PUMP SEL'ED	NO
7	NO. 7 FILTER AID PUMP	OFF
TL	IS REAGENT TANK EMPTY	YES
8	THICKENER REAGENT PUMP	ON
10	FILTER AID MIXING POWER	ON
11	THICKENER AID MIXING	ON
111	CLEAN COAL BKR HYD PUMP	ON
112	DIRT BKR HYRAULIC PUMP	ON
117	AUTO LUBRICATION SYSTEM	ON

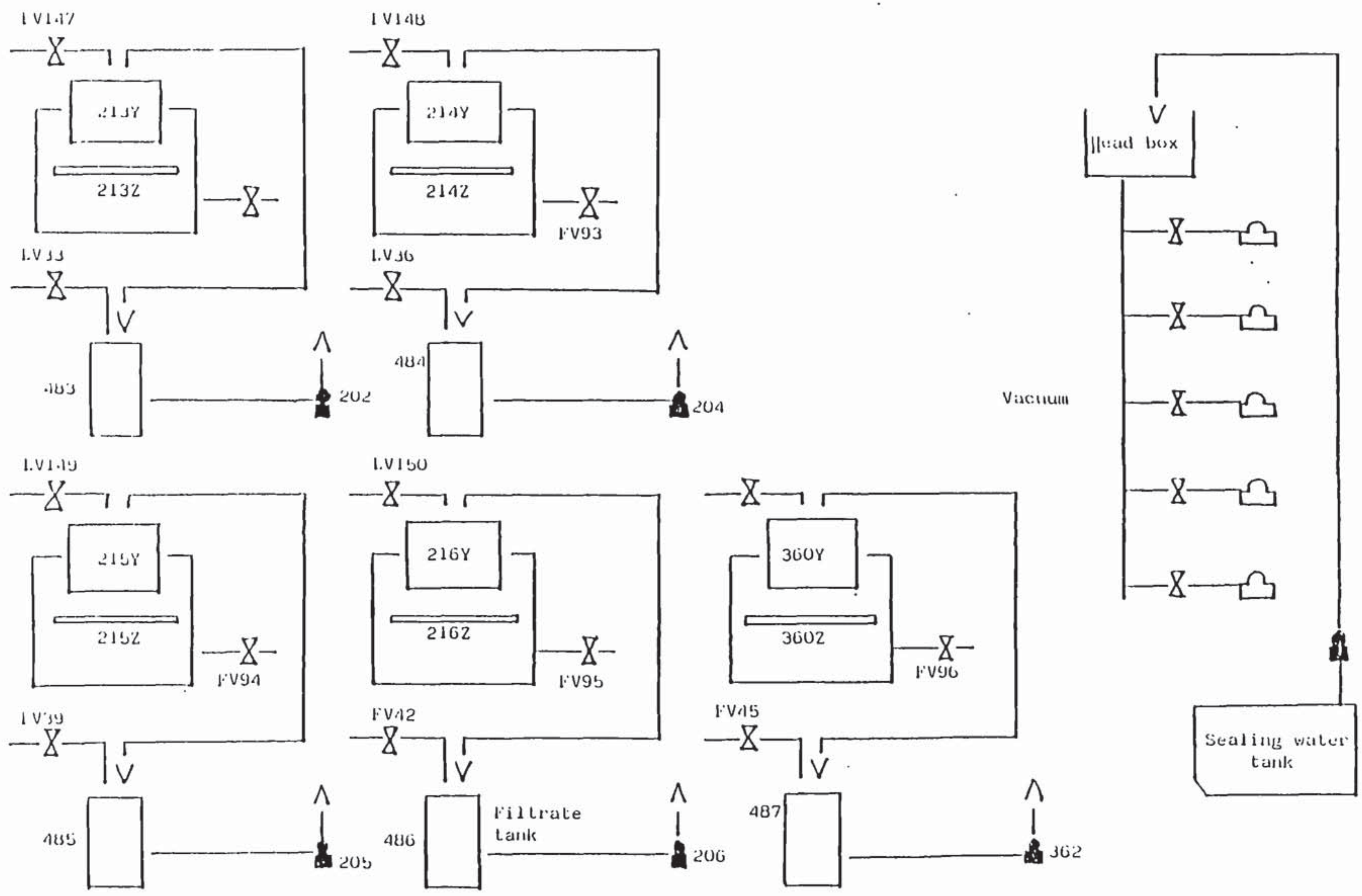
GROUP 1 COMPLETED

GROUP 2

PSA2	PRE START ALARM	NO
P2	COMPRESS AIR AVAILABLE	YES
S1	CLEAN COAL TO STOCK	NO
13	CLEAN COAL TO STOCK C/V	ON
V1	POSITION 'A' OR 'B'	A
12	CLEAN COAL OUTLOAD C/V	ON
9	LINEAR SAMPLER POWER	ON
S2	CLEAN COAL OUTLOAD C/V	YES
14	MIXER	ON
15	CLEAN COAL COLLECT C/V	ON
S3	BLEND RECLAIM SELECTED	YES
L12	CLEAN COAL BUNKER LEVEL	LOW
16	RECLAIM COAL C/V	ON
17	AFC	ON

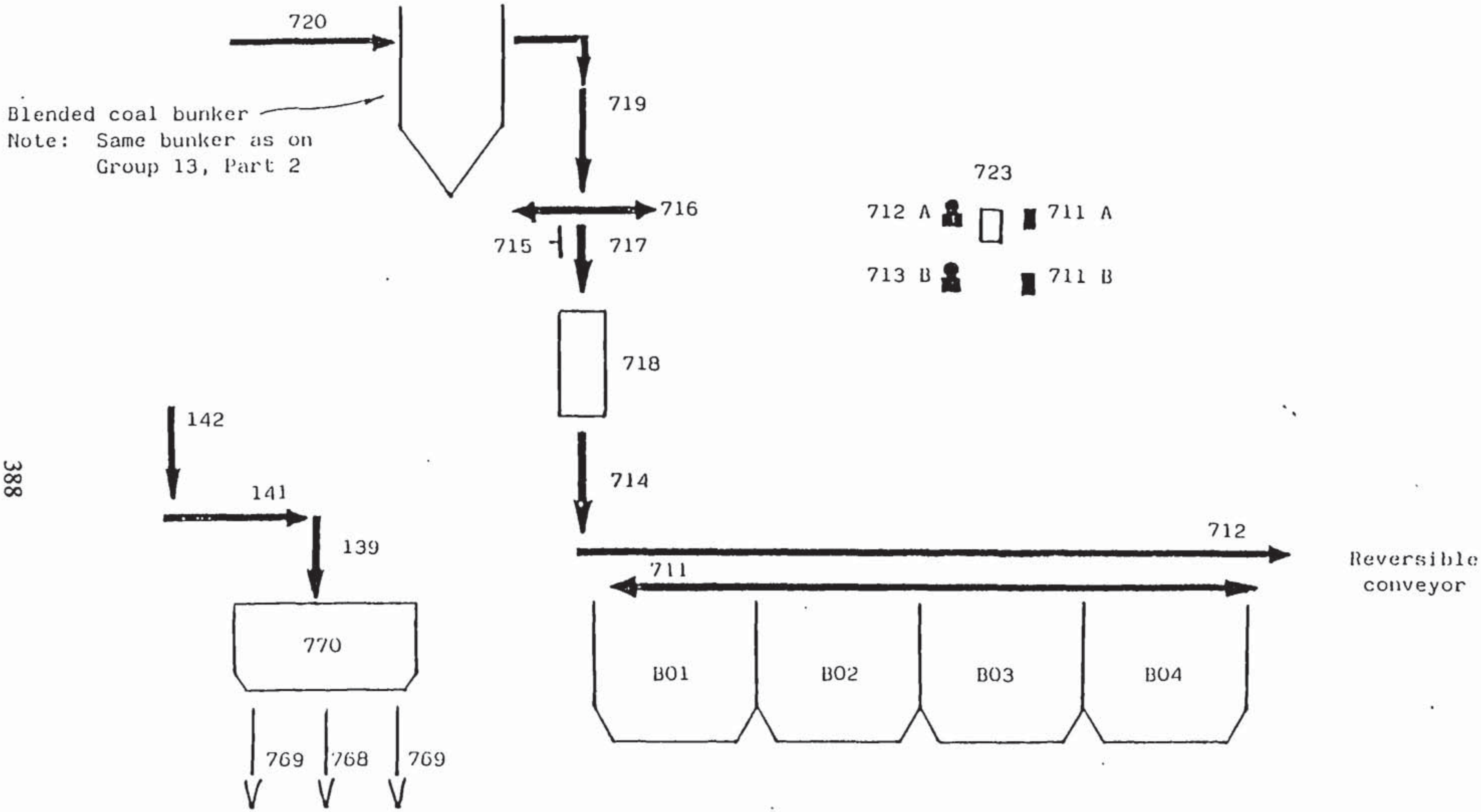
GROUP 2 COMPLETED

Status of Groups 1 and 2



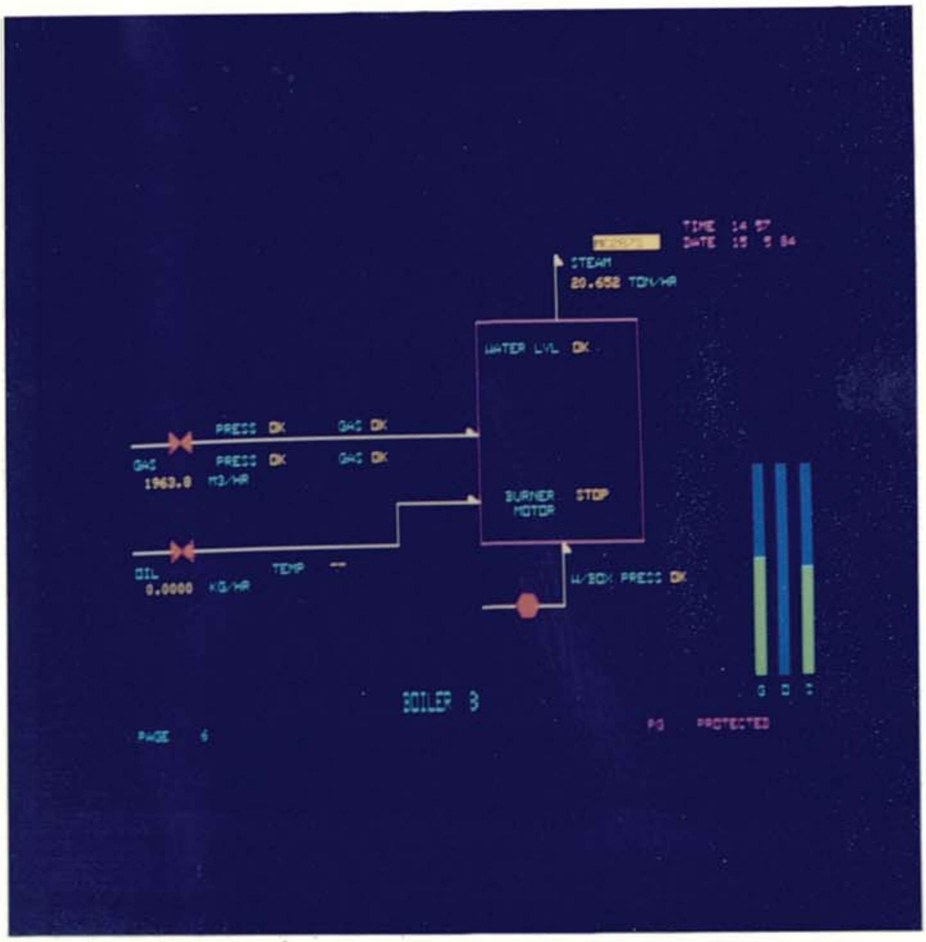
Filters
Group 7 Part 2

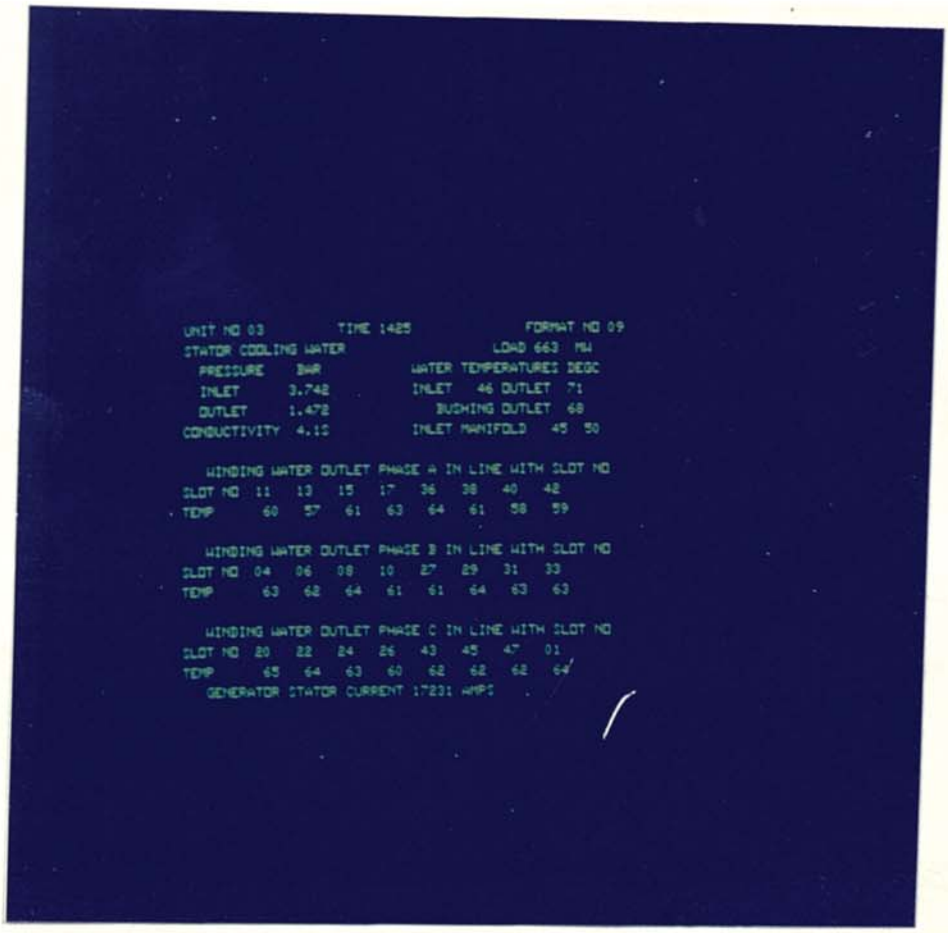
Rapid Loading System
Group 13, Part 1



APPENDIX I

Example Boots VDU display formats


TIME 14 57
DATE 15 5 84
STEAM
20.652 TON/HR
WATER LVL OK
PRESS OK
GAS OK
GAS
PRESS OK
GAS OK
1963.0 M3/HR
BURNER MOTOR
STOP
OIL
0.0000 KG/HR
TEMP --
W/BOX PRESS OK
BOILER 3
PAGE 6
PROTECTED


UNIT NO 03 TIME 1425 FORMAT NO 09
STATOR COOLING WATER LOAD 663 MW
PRESSURE BAR WATER TEMPERATURES DEGC
INLET 3.742 INLET 46 OUTLET 71
OUTLET 1.472 BUSHING OUTLET 68
CONDUCTIVITY 4.12 INLET MANIFOLD 45 50
WINDING WATER OUTLET PHASE A IN LINE WITH SLOT NO
SLOT NO 11 13 15 17 36 38 40 42
TEMP 60 57 61 63 64 61 58 59
WINDING WATER OUTLET PHASE B IN LINE WITH SLOT NO
SLOT NO 04 06 08 10 27 29 31 33
TEMP 63 62 64 61 61 64 63 63
WINDING WATER OUTLET PHASE C IN LINE WITH SLOT NO
SLOT NO 20 22 24 26 43 45 47 01
TEMP 65 64 63 60 62 62 62 64
GENERATOR STATOR CURRENT 17231 AMPS