FACTORS AFFECTING HUMAN RELIABILITY
IN THE
CHEMICAL PROCESS INDUSTRY

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SUMMARY

This research was concerned with identifying factors which may influence human reliability within chemical process plants - these factors are referred to as Performance Shaping Factors (PSFs).

Following a period of familiarization within the industry, a number of case studies were undertaken covering a range of basic influencing factors. Plant records and site 'lost time incident reports' were also used as supporting evidence for identifying and classifying PSFs. In parallel to the investigative research, the available literature appertaining to human reliability assessment and PSFs was considered in relation to the chemical process plant environment.

As a direct result of this work, a PSF classification structure has been produced with an accompanying detailed listing.

Phase two of the research considered the identification of important individual PSFs for specific situations. Based on the experience and data gained during phase one, it emerged that certain generic features of a task influenced PSF relevance. This led to the establishment of a finite set of generic task groups and response types. Similarly, certain PSFs influence some human errors more than others: The result was a set of error type key words, plus the identification and classification of error causes with their underlying error mechanisms. By linking all these aspects together, a comprehensive methodology has been forwarded as the basis of a computerized aid for system designers.

To recapitulate, the major results of this research have been: One the development of a comprehensive PSF listing specifically for the chemical process industries with a classification structure that facilitates future updates; and two a model for identifying relevant PSFs and their order of priority. Future requirements are the evaluation of the PSF listing and the identification method. The latter must be considered both in terms of 'useability' and its success as a design enhancer, in terms of an observable reduction in important human errors.

Keywords : Performamce Shaping Factors, Human Reliability, Human Error, System Reliability, Process Plant Design

DEDICATION

"Onwards and Upwards"
- To the Family

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CHAPTER ONE
INTRODUCTION

1.1 RESEARCH AIMS

The primary aim of the research was to identify a range of system characteristics that could influence human performance, termed Performance Shaping Factors - PSFs, and to produce a comprehensive classification scheme that would encompass these individual PSFs. Once a PSF listing was established a secondary, but equally important, aim was to devise a methodology that would identify the appropriate PSFs in order of priority for a specific scenario, prior to detailed plant design. This was to enable the design engineer to identify causes of human failure, much as an Hazard and Operability study (HAZOP) identifies causes of equipment failure.

1.2 THE IMPORTANCE OF HUMAN PERFORMANCE

As early as the 1940s, when rapid advances occurred in equipment performance due to the demands of the second world war, it was recognised that people were part of systems and that human performance often had as much influence on overall reliability as did the equipment. Acknowledgement of this problem by the Ministry of Defence came in the form of applied research based on three human sciences; anatomy, physiology and psychology. This inter - disciplinary approach was to become known as **Ergonomics** in Europe and **Human Factors Engineering** in the USA.

Human error and human recovery of system faults can respectively, either degrade or enhance overall system reliability. It has also become increasingly apparent that a fully integrated system means that the base line of personnel performance can be influenced by the surrounding environment and interface - not just the individual's internal capabilities and limitations. The first to apply this knowledge to the process industries was the American nuclear industry (Swain, 1969) as a spin-off from the incorporation of human error / reliability figures in nuclear sub-marine reliability assessments. The chemical process industry in the UK has been slower to recognise the importance of human reliability and has in the past been more inclined to place the responsibility for those unsafe incidents and accidents unrelated to equipment, upon individual negligence, incompetence or risk taking*.

Through the sixties and seventies research attempted to produce human reliability data bases, for example the AIR Data Store (Payne & Altman, 1962), SHERB (Rigby, 1967) plus methods for incorporating such data into fault trees and equipment assessments THERP (Swain & Guttmann). As the difficulties with data collection became increasingly apparent alternative methods were considered for supplying human error probabilities. Currently the two main alternatives are Expert Judgement (Embrey, 1982) and, to a lesser extent, simulation techniques first started by Siegel (Siegel et al, 1975).

Swain was the first to recognize the influence of certain system characteristics on error likelihood, these he termed Performance Shaping Factors. If certain PSFs were rated as poor / below standard (during the assessment of existing nuclear power plants) then a weighting factor was applied to the standard error probability for reliability calculations. Note that these error probabilities were themselves a product of extrapolation, interpretation and judgement;

> "The scarcity of objective and quantitative data on human performance in NPPs (*nuclear power plants*) is a serious limitation. Most of the HEPs (*human error probabilities*) in this handbook are what we call derived data. In some cases, they are extrapolations from performance measures, which may be only marginally related. In other cases the HEPs represent our best judgment based on our experience in complex systems and our background in experimental and engineeering psychology. "
>
> Swain & Guttmann, 1983

The THERP (Technique for Human Error Rate Prediction) method has been regularly reviewed over the years with the final report published as recently as 1983. This presents a more extensive selection of PSFs but still relies on the user subjectively assessing which are less than optimum for an existing plant under review. As for new designs, the THERP user would have to estimate whether each design feature will be less than adequate rather than concentrating on ensuring that it will not.

1.3 RESEARCH METHOD

Because of the unavoidable subjectivity of all human reliability data this research has concentrated upon improving system design rather than assessing system fallibility. Based upon the chemical industry, in contrast to the predominant concern with the nuclear industry, the intention was to produce a methodology for assisting detailed system and equipment design from drawing board onwards. PSFs were seen as a route to this end. If PSFs could be used as weighting factors to modify standard error rates, then they could be identified as aspects that required designing to ergonomic standards. This would ensure that no degradation of human performance occured due to poor design. Obviously this would require the formation of a comprehensive and structured set of PSFs plus a method for selecting the most important factors for a specific situation (ie for a particular plant and human task).

In order to accomplish these research aims, the research work was divided into two phases. Phase one concentrated upon producing a PSF classification structure plus a detailed listing of individual PSFs, whilst the second phase considered the identification problem. A number of complementary routes to PSFs had to be explored and ultimately assimilated to produce a balanced methodology. This meant that the theoretical notions of human error and error cause were studied in addition to hierarchical task analysis (HTA), process and instrumentation drawings (P &IDs) and hazard and operability studies (HazOps). The latter group were to provide a means of initiating the technique.

1.4 THE THESIS

The literature review commences with a general overview of system reliability plus the increasing concern of government and more persuasively the general public, in relation to safety standards and the avoidance of such public and widely damaging incidents as witnessed during the 1980's; Bhopal, Challenger Space Shuttle, Chernobyl. . . . .

Within the historical overview both issues of equipment and human reliability are considered. The Human Reliability review is extended during section 2.2, briefly covering analysis (HRA) techniques but more importantly the theoretical issues of **error type** versus **error cause** (section 2.2). Generally these aspects never attain true separation. The background to PSFs is also dealt with in more detail.

As a separate section, the theory of HAZOPs is explored including the reasons for keeping the underlying theory of the PSF identification methodology compatible with the HAZOP principle. The final major section of the literature review introduces models of human performance and the concept of hierarchical task analysis as a necessary preliminary to establishing the specific scenario.

Chapter three considers the methodology that produced the PSF classification structure and the accompanying detailed listing. Reference is made to the familiarization period within the industry and to the major role of the five case studies. Following this, chapter four presents the interim results derived from the case studies and company records.

The resultant PSF classification structure and individual PSFs, including the detailed meaning of each, form chapter five whilst Chapter six assesses the requirements of a PSF identification technique and explains the basic theoretical concepts. This chapter culminates in a description of the resulting methodology.

A major detailed example is provided in chapter seven based on a P&ID and working through a task analysis, ultimately specifying the prominent PSFs for a set of sub-tasks including their importance weightings (currently based on 'frequency of association'). Acknowledging the fact that the technique can only gain credance as a major aid to the design process if interfaced to a design standards data base, the discussion in chapter eight considers methods of accomplishing this priority requirement. Included within the general discussion of the research procedure and results are the research limitations and methodological problems. Suggestions for future assessment, evaluation and improvement are prominent aspects of this chapter.

The final chapter summarises all the issues contained within the thesis and brings this specific research to a close with a suggested schedule of future research .

CHAPTER TWO
LITERATURE REVIEW

2.1 SYSTEM RELIABILITY - An Historical Perspective

Philosophers and writers through the ages have been aware of the fallibility of man-kind; Adam eating the apple from the garden of Eden, Icarus flying too close to the sun, mistaken identity in the Comedy of Errors. To accompany the error scenario there have been an equal plethora of quotations; "to Err is Human", "Experience is the name everyone gives to their mistakes", " the wisest of the wise may err ". . . . . .

Long before equipment faults and reliability were considered important, mankind was considering its own reliability and failure from a purely qualitative perspective. In addition human fascination with risk, luck and gambling could be seen from first documented history onwards - 'what was the chance of throwing three sixes at one throw of three dice'. Gambling or risk taking has always been an integral part of human nature. Every time we perform a new activity we make some estimate of the risk - do the positive factors outweigh the negative factors and how likely are we to succeed? Sometimes this is a highly conscious activity, and at others, a fleeting consideration - acting on impulse.

The real thrust towards consistent assessment of reliability exploded from the second world war, which acted as a catalyst for a rapid increase in the rate of technological development. The 1940s saw the first simple attempts at quantifying equipment reliability and the birth of a new technological discipline - Ergonomics. It was soon realised that now the main limiting factor in system performance was human performance, in contrast to the past when the equipment was inferior. The demands of the new equipment were outstripping the operating abilities of their users. Applied psychology started to categorise human error and engineers studied the reliability of equipment.

Qualitative exploration of reliability continued through the 50s with the chemical process industries considering the cost of alternative designs in relation to possible performance, whilst the nuclear industry explored the implications of the "worst credible incident". Meanwhile Wright Air sponsored the development of a method for man-machine task analysis.

Chemical Engineer	"What increase in quality of performance do we get for an increase in capital cost?"
Nuclear Engineer	"What are the consequences of the worst possible accident?"
Human Engineer	"What are the people actually doing within the system?"

It is interesting to note that from the start engineers designed the equipment within a system largely without considering the role of the operator. People were expected to fill in where equipment was unavailable or couldnot cope. Engineers knew what the equipment was expected to do and were interested in how well it could do it and what could happen when things went wrong. Human Engineers were, in the main, still trying to assess **what** people were expected to do.

The impetus gained force during the 1960s with respect to both equipment and human reliablity assessment. This was still following a deterministic approach with the major concern geared towards limiting the consequences of identified potential risks. It is interesting to note that the forerunners of the modern techniques for risk identification and analysis (HAZOP and HAZAN) were being used.

During this decade several different methods of human error classification were published.

Chapanis (1960) distinquished between systematic and random errors - those that are due to a determinable bias; for example shooting left of a target (one reason could be a visual defect) versus those due to variable ability ie random error; scattered shots around a target (inexperience) or a tight group with one miss (this can for example be due to a disturbance, loss of concentration or physical fatigue). Note the difference between the performance of the inexperienced and that of the expert!

In 1962 Kidd, influenced by the concept of the Information Processing Chain (a cognitive model of the mental stages required to form an action), suggested a set of five error types each associated with one stage at which a block may occur:

failure to detect a signal	------>	stimulus / perception
incorrect identification	------>	comprehension
incorrect weighting	------>	decision
incorrect action selection	------>	plan
commission	------>	response

In contrast, Meister & Rabideau (1965) concentrated upon overt performance discrepancies; failure of performance (No Action), incorrect performance (Wrong Action at right time), out of sequence performance (right action at Wrong Time), man required performance (Unnecessary Action). This was the closest error classification of the time to that of equipment failure.

Alongside these advances in theoretical interpretation and qualitative assessment the mid-1960s saw the start of centralised Reliability Data Banks both for equipment (for example the Swedish Data Bank - Birger, and SYREL the systems reliability service data bank - Ablitt) and human failure data (the AIR data store - Payne & Altman, 1962 and SHERB- Rigby,1967). There were however problems, field data tended to be specific to the actual environmental characteristics under which the equipment was operating.

Electrical components achieved the most rapid advances in data collection, with mechanical components following behind. In contrast the performance of chemical industry process equipment proved very dependent upon environmental characteristics, for example: chemical properties (eg corrosivity, instability, oxidation); operating temperatures and pressures; required flow rates, throughput and vibration; external climate (wind, rain, temperature, humidity) generally related to latitude and season. Due to the problems associated with data of this period a more qualitative approach based on engineering judgement was used to generate reliability figures - ie the envelope or 'boundary approach' (Green, 1969). The system design team would agree a figure that failure rate frequency would not be less than, plus a second higher rate that would not be surpassed (note the similarity to expert judgement used for human reliability data). Even in the 1980's centralised data base information requires informed interpretation accounting for the specific conditions under which the data was collected and those that prevail within the system under review. Many companies, particularly the larger petrochemical companies, collect their own failure rate data.

Returning to the 1960's, even more problems faced the human reliability specialist - data could be collected relating to simple manual tasks, mainly in the laboratory but it was difficult to assess errors within the covert areas of performance such as comprehension, decision making and planning (necessary for monitoring, fault diagnosis, response to plant dynamics, maximization of system performance etc). Tracking tasks (Poulton, 1957) were examined in detail due to their importance to the military and also to air traffic controllers, similarly inspection tasks were studied within the manufacturing industry. Both were shown to be influenced by external motivators or goals, producing a shift in the type and number of errors. Equipment performance and human performance (and hence human errors) are both effected by the environment.

TABLE 2.1 Time Line summarising the Historical Development of interest in Equipment, Human and System Reliability

TIME LINE	IMPORTANT EVENTS
1920s	First consideration of Unit Operations in America, the precursor to Chemical Engineering (forefathers were; chemistry & mechanical engineering)
1942	Lusser & Pieruschka combined engineering judement and statistics : Lusser Product Law of Reliability $R = r_1 r_2 r_3 \ldots$
Early 1940s	First Chemical Engineering department in England, Birmingham University
early 1940s	**realisation that the human element was now the limiting factor in advanced man-machine systems. . . new technology = ERGONOMICS (from psychology, biological sciences & system engineering)**
1946	Wesley Stout study of reliability of American tanks during WWII
1947	**Fitts & Jones error taxonomy for pilots via critical incident analysis**
1950s	Reliability assessments due to consequences of unwelcome events. Cost vs Performance.
1953	**a method for Man - Machine task analysis (Wright Air Devel Center USA)**
1957	WASH 740 idea of the "Credible Accident" a very qualitative assessment.
	Markov Chains
1960s	Farmer; quantified the study of public risk (considered the starting point of HAZAN studies)
	Time of the "deterministic" approach - safety based on 'consequence limiting' equipment also the "maximum credible accident"

TIME LINE	IMPORTANT EVENTS
1960s	**Classification of Human Errors (Chapanis, Kidd, Meister)**
	Development of an human performance taxonomy
	Techniques for evaluating man-machine system design
1962	Munger - index of electronic equipment operability, an evaluation booklet and data store
1962	**paper by Rook - reduction of Human Error in industrial production**
	Meister - the problem of human initiated failures
	Report on the Human Error problem
1963	"Critical Examination Method" forerunner of HAZOP studies
1963	**Swain - method of performing an human error reliability analysis, also comment on human error quantification**
1964	**Methods recorded for predicting human reliability in man - machine systems**
	Irwin, Levitz and Freed, human reliability in the performance of maintenance
	Swain - first suggestion of THERP; Technique for Human Error Rate Prediction
mid 1960s	Start of centralised Reliability Data Banks Data dealt with using the Envelope or 'Boundary Approach'
mid 1960s	**AIR Data store**
1966	**Altman classification of human error**
1967	**Meister development of human reliability indices**
	SHERB - the Sandia human error rate bank
	Symposium on reliability of human performance at work (Wright - Patterson air force base USA)

TIME LINE	IMPORTANT EVENTS
1967	**Check list for plant designers - IEA**
late 1960's	Performance Spectrum Approach Fault Trees presented as an analytical tool Weibull Distribution
1969	**Topmiller USA, mathematical models of human performance in man-machine systems** **Smith, Westland and Blanchard ; TEPPS Technique for establishing Personnel Performance Standards** **Askren and Regulinski - mathematical modelling of human performance errors for reliability analysis of systems** **Siegel and Wolf - computer simulation** **Parker, E. - publication of incidents relating to human errors and mal-operations on UKAEA nuclear reactors for the period 1959 - 67** **Swain (Sandia laboratories) - human reliability assessments in nuclear reactor plants**
1970	**Fleishman and Teichner - taxonomy of human performance**
early 1970's	start of the " Probabilistic" approach - continuation of the Performance Spectrum Approach & Fault Tree Analysis. Combined to estimate correlations between Performance Achievement function Q & performance requirement function H : $R = f(QH)$
1971	**Teichner - preliminary theory of the effects of task and environmental factors on human performance** **Siegel and Federman - developing and testing of human reliability prediction techniques for application in electrical maintenance prediction**
1971	Interconnection of partial solutions of large systems developed from a Topological point of view - dealing with eg nodes,meshes, branches & planes

TIME LINE	IMPORTANT EVENTS
1971	Fault classification; the four character code
	Nielsen - cause consequence diagram method
1972	Potential problem analysis led to Failure mode and effect analysis
	Application of Markov Chains -Lee (outcome of any trial is dependent on the outcome of the directly preceeding trial & not on any other)
	Monte Carlo technique of simulation
1972	**Singleton - techniques for determining causes of error**
	DeGreen - Inputs, Outputs, Decisions
1973	Chemical Engineers showing interest in human performance: ***Kletz** - human error and plant operation* ***Lees** - quantification of man-machine system reliability in process control*
1973	**Johnson - MORT**
mid 1970's	Analytical techniques refined to predict Outcome of postulated accidents but not yet their Likelihood
	Continued collection of failure rate data from Testing, eg accelerated life tests, and field experience
1974	Flixborough disaster, England
1974	**SAINT (systems analysis of an integrated network of tasks)**
	Siegel and Wolf - model for predicting integrated man-machine system reliability; mode logic and description
1975	WASH 1400 published - weighed consequences against anticipated frequency, an exhaustive & analytical study **Swain** - Appendix III human reliability assessment failure data (THERP)
1975	**Markov Chains used to model human behaviour**
	Fox and Dury - human reliability in quality control

TIME LINE	IMPORTANT EVENTS
1976	**Rasmussen model of human decision sequence**
1976	Seveso - toxic dust release, Italy
late 1970's	notion of Common-Mode failures as distinct from independent
1979	Three Mile Island challenged the conclusions and method of WASH 1400 BUT recognised that the TMI accident sequence had been identified - particularly the crucial early stages
	Kemeny Report (independent study), recommended the extended use of PA techniques for assessing Nuclear Power Plant risks & safety decisions
1979	**Kepner Tregoe methodology**
1980	Rogovin Report, second independent study recommending extended use of PA techniques
	Lihou - computer aids for operability studies, chemical process industries
1980	**MORT - management oversight risk trees (updated publication)**
	TESEO - Italian human reliability prediction technique
early 1980s	**Risk Homeostasis Theory**
	HE theory - Absent Minded Errors (slips vs lapses) Norman, Reason, Senders
1981	**Embrey - PSF listing and suggested human reliability assessment technique**
1983	Publication of 22 nuclear power plant Probabilistic Risk Assessment studies.
	Acceptance that quantitative estimates of public risk are less important than the engineering & safety insights gained from the logic and thought processes
	Chemical process industries - CIMAH regulations
1983	**final THERP report**

TIME LINE	IMPORTANT EVENTS
1984	**Embrey - SLIM-MAUD technique (expert judgement)**
	PRA contributed to the understanding & need for continued study, of human error in the context of reactor safety
1984	Bhopal disaster, India
mid 1980s	Technical Safety Audits Process Safety Review
	Software -Safety Analysis using Petri-nets (P-nets developed 1969 Carl Petri) Software Sneak circuit analysis
1985	**Williams - HEART technique**
	SRD - guide to reducing human error in process operation
1986	Rhine pollution, Switzerland
	Chernobyl, nuclear disaster, Russia
1986	**Two day course on human reliability assessment at the London Press Centre**

THE USE OF EXPERT JUDGEMENT FOR HUMAN RELIABILITY PREDICTION CONTINUES

In 1967 the International Ergonomics Association published a checklist for plant designers presenting such questions as;

> "are the characteristics of the hand controls compatible with the forces required to operate them (shape, size, surface) and are the forces acceptable ?"
>
> "is the pointer simple and clear and does it allow the numbers to be read without obstruction ?"

A similar guide, but for visual displays only, was published in 1969 by Meister & Sullivan. Both were produced to help minimize the negative effects of poor system design on human performance. These are relatively easy to use as checklists on existing plant but more difficult to use during design.

Of greatest import to the reliability engineer of the 60s was the first presentation of Fault Trees as an analytical tool. This technique developed through the 1970s to become the basis of probabilistic risk assessment and in 1975 the WASH 1400 report.

The '70s in general saw a shift away from the deterministic to the probabilistic approach to reliability. The emphasis was towards the assessment of large Interdependent systems. Interconnections of part solutions developed from an appreciation of topology and the concept of nodes, meshes, branches and planes. It was also appreciated that the *type* of system fault was important to a reliability assessment. Certain system components could fail in more than one way with specific failure modes having a greater detrimental effect on the system than others. Hence the early 1970s concentrated on fault classification, producing the four character code (Green and Bourne). The first character represented the main effect of the fault, the second which equipment function was effected, the third whether a failure warning is given and the fourth the type of equipment function or facility revealing the fault.

Meanwhile, DeGreen presented yet another method of human error classification, influenced by Kidd but based on the sub-classification of three main error types: Inputs, Outputs and Decisions. What appears to have occured is a fixation on error classification at the expense of an error model. In addition the distinction between Error Type (what went wrong) and Error Cause (why did it go wrong) had been eroded. At this point within the history of system reliability there was still no collaboration between human and equipment reliability engineers - the two strands of system reliability continued to develope in isolation, although certain chemical engineers were showing an interest in human performance, particularly Kletz and Lees. The National Centre for System Reliability (UKAEA) continued to collect both equipment and human error data. Testing eg accelerated life tests proved as important a source of equipment reliability data as field experience. Obviously such methods of information collection would be inappropriate for human error data !

In 1974 the Flixborough disaster rocked the UK chemical industry leading to the realization that **managerial decisions** could have as much influence on accident scenarios as equipment or operator failures. Yet this was still coming as a surprise to people in the mid 1980s. Note the contribution of management to the space shuttle disaster, Chernobyl, Bhopal, Zeebrugger ferry.... The Human Factors in Reliability Group supported by the UKAEA formed a new sub-group the 'human reliability factors in technology management' sub-group, 1985 to address this issue. In the USA Johnson 1973 - 1980 developed MORT, management oversight risk trees, a structured technique for assessing potential or actual managerial contribution to 'accidents'.

A year later WASH 1400 (a safety study that weighed both the consequences and anticipated frequency of a nuclear power plant accident in an exhaustive and analytical manner) was published preceeding Swain & Guttmann's re-introduction and development of the technique for human error rate prediction (THERP) first presented 1964. An interim report was produced 1980 and the final report 1983. This human error prediction technique was produced by the nuclear industry for the nuclear industry with task examples and failure rates based on nuclear power plant process operations and the data was based on laboratory experimentation and expert judgement from many years experience within the industry. For the chemical process industries (of which certain provide a sub-section of the nuclear power industry) these tasks are atypical and any actual tasks for analysis would require **"fitting"** to the most similar scenario presented by THERP, giving an *approximate* reliability figure. What is of interest is that the order of magnitude of the data is varied due to environmental factors (PSFs), particularly Stress. The technique also introduces the concept of certainty levels.

Although the data may be suspect from a predictive point of view, THERP does provide a systematic basis for the comparison of different systems; but does this improve or assist design ? It is one matter to compare designs that exist, whether on paper or built, and yet another to **identify** aspects which are likely to have the most effect on performance for a specific situation. Note that Teichner (1971) advanced a preliminary theory of the effects of Task and Environmental factors on human performance but this was never pursued.

During the same period in time as WASH 1400 and the resurrection of THERP, two performance models were presented; one a method for modelling human behaviour using Markov Chains, the other a predictive model for integrated man-machine system reliability (Siegel & Wolf). Remember that Markov chains are based on the fact that the outcome of any trial is dependent upon the outcome of the directly preceeding trial and no other - a distinctly serial approach to human performance and learning. This model would imply that long term memory was not part of the operational process. Any notion of absent minded or random errors would not be consistent. This would also ignore the principle of error recovery. Markov chains do never the less have their uses, for example modelling a task where the response made during one sub-task influences the choice available during the next. A description of the mathematical modelling associated with these chains is provided by Rouse (1980).

What turned out to be an extremely important model of human decision making was that presented by Rasmussen (1976). This maintained its prominence through the 1980s influencing Embrey (1983), Hollnagel (1980) and others. It extended the model of the information processing chain and overlayed the concept with performance levels; skill based, rule based and decision making.

The Three Mile Island incident 1979 shook both the nuclear and the chemical industry, coming very close to disaster. From a human factors point of view the general confusion and misunderstandings based on faulty mental models of the system were fundamental, exacerbated by poor design, specifically the information overload produced by the 1,600 indicators on one annunciator panel and the unexpected concealment of others (Stephens, 1980).

As far as the engineering reliability fraternity were concerned their immediate response was that WASH 1400 and fault tree analysis had failed - the specific incident had not been predicted. It took the independent Kemeny Report and the Roguin Report to re-establish faith in the probabilistic analysis within the industry. Both recommended the extended use of probabilistic analysis techniques for assessing nuclear power plant risks and forming decisions relating to nuclear safety. When used within WASH 1400 PRA was not at an advanced stage of refinement as an analytical technique, but over the years the technique has been improved. By 1983 PRA was considered more important as a method of gaining safety and engineering insights from the structured logic and thought processes, than for the quantitative estimates of public risk per se. In 1984 PRAs were also contributing to the realisation that there was a need for the continued study of human error in the context of nuclear reactor safety. Sadly the reality of human error still appeared to escape the understanding of engineers, in 1984 Fussell stated that;

> "half the risk to the public from reactor accidents can be related
> to **simple operator error**" What is simple about human error?

The 1980s saw the publication of the final THERP report (Swain and Guttmann, 1983) a purely mechanistic consideration of human tasks, but the most comprehensive coverage based on many years experience within the nuclear industry. TESEO, the Italian answer (Bello and Columbari, 1980) is based on the direct multiplication of five 'K factors':

k1 - the type of activity
k2 - time available
k3 - human operator's characteristics
k4 - operator's emotional state
k5 - environmental ergonomics characteristics

The technique is simple but no reasoning is provided for the relationship, or the choice of k factor weighting.

Norman (1981), Reason (1977, 1982) and Senders (1983) concentrated upon the underlying causes of error rather than providing reliability estimates, whilst Embrey (1985) relied upon expert judgement to manipulate an human reliability model in order to provide error probabilities. Williams (1986) concentrates on presenting a method of manipulating the order of magnitude of failure probabilities dependent upon such aspects as the quality and quantity of system knowledge, response time pressure and the nominal failure figure based on task type. A summary of the state of the art with respect to human **reliability assessment** mid

1980s is presented in the document relating to the two day course on 'human reliability assessment' 1986. This covered such aspects as behavioural models, human error data, performance shaping factors, task analysis, error identification and quantification, human reliability assessment models and sociotechnical aspects. The major emphasis was on providing reliability estimates, though Williams and Bellamy considered the effects of system design on performance through PSFs and 'error producing condition factors' (Williams, 1985).

Despite all the research there was still a need for a technique, geared towards the chemical process industries, to identify the major influencing factors within a specific system for a specific task. This was required, initially to guide the designer and secondly to assist with resource allocation if redesign should be required.

2.2 HUMAN RELIABILITY

2.2.1 Distinguishing Error Type from Error Cause

There are two main approaches to the analysis of human error; one probabilistic typified by Swain & Guttman where error probabilities are defined and combined with equipment error probabilities, the other deterministic which considers the underlying reasons for and types of breakdowns during human information processing: Classically,

Error Types were defined as;

commission - omission
reversible - irreversible

and Error Causes (Kidd 1962);

Failure to detect
Incorrect identification
Incorrect weighting
Incorrect action selection
Commission

In order to assist the engineer with design the most useful approach is the deterministic which gives an insight into what types of error could be expected for a given task and the possible underlying causes. Just as it has been stated that the main benefit of both fault tree analysis and Hazop is the qualitative insight gained from carrying out the technique; if, when examining human failure, some notion of what can go wrong and why it can go wrong has been attained then it is possible to consider methods of *preventing* unwelcome errors.

2.2.1.1 Error Types

Much confusion has occurred over the years when classifying human error, the distinction between error type and error cause has tended to blurr. There is a need to know what can go wrong and separately how this could have happened. It is therefore of interest to look at the type of error classifications that have been suggested.

As previously stated the classical error taxonomy (Singleton, 1974) simply distinguishes between Commission and Omission errors that are either reversible or irreversible.

Commission	------------->	Reversible
and		and
Omission	<------------>	Irreversible

Producing a set of four conditions;

1. Commission and Reversible
   - something extraneous to the required act is performed but can be recovered from.
2. Commission and Irreversible
   - some extraneous act is performed which can not be recovered from.
3. Omission and Reversible
   - the response is not all that it should have been, something was missing, but this can be retrieved
4. Commission and Irreversible
   - the response is incomplete and the result is irretrievable.

For the chemical process industry it was important to identify errors far more specifically. Error Types had to provide qualitative information in their own right.

The second problem with this classical distinction was that certain types of incorrect human performance fell within both main groups:

For example;

'The operator was meant to open valve V2 and instead opened valve V3'

Which generic error type would this be recorded as? Valve V2 was not opened therefore it was an Omission but valve V3 was opened when it shouldnot have been which is commission! Meister and Rabideau (1965) suggested the following scheme:

1. Failure of performance - no action taken
2. Incorrect performance - wrong action at right time
3. Out of sequence performance - right action at wrong time
4. Man required performance - unnecessary action

This provided a more specific classification with the given error example falling within the Incorrect Performance category. However, which category would classify 'part-opening' a valve instead of fully opening a valve ? Once again it would be incorrect performance. What if the valve was over tightened, stripping the threads of a gate valve - Is this also incorrect performance? or would it be an example of Man Required performance? (unnecessary action).

Reason (1977) produced an error classification scheme for Absent-minded actions:

TABLE 2.2.1 The Error Classification Scheme suggested by Reason

A. Discrimination failures (where inputs are misclassified)
1. perceptual confusions : objects are physically similar
2. functional confusions : objects are functionally similar
3. spatial confusions : objects are in close proximity
4. temporal confusions : time misperceived and an inappropriate action initiated

B. Programme Assembly failures
1. behavioural spoonerisms : programme elements reversed
2. confusions between currently active programmes
3. confusions between ongoing and stored programmes

C. Test failures (failure to self-monitor)
1. stop-rule overshoots : actions proceed beyond intended end point
2. stop-rule undershoots : actions terminated early

3. branching errors : initial sequence common to two outcomes and wrong route taken
4. multiple side-tracking : diverted from original intent

D. Sub-routine failures (failure of component actions)
1. insertions - unwanted actions added
2. omissions - necessary actions left out
3. mis-ordering - correct actions in wrong order

E. Storage failures (forgetting, mis-recalling plans/actions)
1. forgetting previous action - lose of place in sequence or mislaying items
2. forgetting discrete items in a plan
3. reverting to earlier plans (when plan should have been changed)
4. forgetting substance of plant (existance of plan forgotten) actions often underway.

This classification was based on reported errors collected during a diary study undertaken by 35 volunteers over a two week period; ie once all the errors had been collated they devised the described classification scheme. The resulting eighteen error types produced a comprehensive listing: **But**, some of the error types bear more resemblence to error causes. Let us re-consider the error of opening valve V3 instead of valve V2, which of the 18 classification types would describe this event?

A1 perceptual confusions - this could have caused valve V2 to be confused with valve V3. That is, both looked the same.

A2 functional confusions - both valves have the same generic purpose.

A3 spatial confusions - valve V3 could have been next to V2.

A4 temporal confusions - the operator intended to open V3 because of mis-reading the time.

B1 behaviour spoonerism - V3 may have required opening after V2 and the operations were reversed.

B2 confusions between currently active programmes - this could have been a cause if the operator had been carrying out two batch processes simultaneously and opened V3 instead of the valve

		for the other batch, V2.
B3 Confusion between on going stored programmes	-	if opening V2 is a highly automated response and the operator was thinking ahead to the next task during which V3 had to be opened, this routine may have become dominant causing V3 to be operated.
C1 stop-rule overshoot	-	not appropriate
C2 stope-rule undershoot	-	not appropriate
C3 branching errors	-	if opening V2 is part of a sequence the first part of which is the same as that prior to opening V3, then the wrong route may be taken resulting in V3 being opened.
C4 multiple side-tracing	-	unlikely
D1 insertions	-	not appropriate
D2 omissions	-	V2 was not opened, however V3 was instead!
D3 misordering	-	not appropriate
E1 forgeting previous actions	-	may think that V2 is already open and progress to V3
E2 forgetting discrete items in a plan	-	not appropriate
E3 reverting to earlier plans	-	perhaps V3 is opened normally but due to the circumstances V2 should have been opened yet the operator reverted to the more familiar response
E4 forgetting substance of plan	-	not appropriate

Apparently the simple error of opening V3 instead of V2 could be classified under 11 of the 18 error types (based on the available information). It is therefore suggested that this classification is of possible **causes** of human error rather than error types.

Rasmussen (1979) compared human errors to "intermittent faults in an electronic system". He stressed the need to consider methods of reducing error or "misfits" by proper design of work conditions. In order to systemmatically approach this aim he recognised the need to classify collected errors in order to search for trends. In

Rasmussen's words "it is necessary to find what went wrong rather than why".

Based on nuclear power plant reports he propounded the following set of error modes:

TABLE 2.2.2 Rasmussen's Error Modes

A	B
1. Absent mindedness	1. omission of functionally isolated act
2. Familiar association	2. omissions - others
3. Alertness low	
C	D
1. manual variability, lack of precision	1. Side effect not adequately considered
2. topographic, spatial orientation weak	2. Latent conditions inadequately considered
E	F
1. Mistakes among alternatives	1. Various
2. Expect, assume - rather than observe	

TOTAL = 12 error modes

Note that Rasmussen himself states that such a classification of reported errors concentrates on those that were **not corrected** since those that were would not have led to an incident report.

Once again certain error modes within this set look suspiciously like error causes. 'Absent mindedness' hardly describes what went wrong but the immediate underlying reason **why**. To try and provide a *simple* error type classification based upon incident reports can be difficult due to the accompanying evidence and description.

Roberts, Golder and Chick (1980) studied pilot attitude towards pilot error -

their cultural conventions and beliefs. Sixty errors known to have occured were chosen and labelled. These were sorted by pilot subjects into order of seriousness and also into similarity of error. Three main groupings of error emerged, each with two sub-divisions:

1. Judgement
   1.1 decision
   1.2 judgement
2. Oversight
   2.1 preflight procedure
   2.2 normal and emergency procedure
3. Skill
   3.1 awareness
   3.2 technique

This method of identifying a comprehensive set of unique errors is very helpful for the assessment of performance and for studying the operation of a system. Unfortunately for the process industries it would be necessary to produce a different set for each operation or plant - a rather impractical pursuit. Based on these six error type groups, the design engineer would be able to consider from what type of task errors could derive but not the effect they may have on the system. An error of judgement may result in many different types of performance deviation.

The classification of Rouse and Rouse (1983) can be considered compatible with the three main error groups described by Roberts et al. In terms of the information processing chain their groups are presented in inverted commas;

(perception -->	comprehension -->	decision -->	plan -->	response)
l	l	l	l	l
"observation of system state"	"choice of hypothesis" "testing of hypothesis"	"choice of goal"	"choice of procedure"	"execution of procedure"

These six groups of pilot error indicated the underlying source of error and provided a total set of thirty one generic error types. Once again from a diagnostic point of view such a specific classification was a very useful tool, however to predict system performance malfunctions and their causes the last group of errors was sufficient - ie Execution of Procedure;

Errors Associated with execution of procedure

1. step omitted
2. step repeated
3. step added
4. steps out of sequence
5. inappropriate timing
6. incorrect discrete position
7. incorrect continuous range
8. incomplete
9. unrelated inappropriate action

By generalizing this group to cover the whole of performance rather than merely procedure execution, a potentially workable classification is provided. Note that in the same year Senders (1983) suggested a four pronged error taxonomy that formed a sub-set of the Rouse and Rouse procedure execution group;

1. omission	2. insertion (commission)
3. repetition	4. substitution

As far back as 1937 Kollarits presented data that showed that almost 70% of errors were **substitution** errors; error classification was important.

For this research project a suitable error type classification had to;
1. cover all unwanted deviations in performance,
2. be simple to apply and determine,
3. suggest possible important failures to the user
AND
4.be based upon accessible terminology - simple language!

In terms of the engineering literature, Martin (1976) suggested categories of typical failure modes grouped by the mechanical engineering element that could have failed. Obviously this form of classification could not describe or be related to human error types.

Of far more practical interest was the literature relating to Hazard and Operability studies (Kletz 1982). Not only does this technique suggest a list of properties but far more importantly a list of **failure mode keywords.** The failure mode keywords (listed in section 2.3) immediately suggested their worth for human error type classification, not only did they easily relate to the procedural error types of Rouse and Rouse but the language was simple and already familiar to the chemical engineer. It was considered that with little modification such a generic list of failures could be used as a generic error type classification. This would allow the reliability engineer to propose or envisage possible important errors in addition to categorising errors that had occurred. Returning to the example error of 'operating V3 instead of V2' this is neatly classified as an **Other Than** error, no other generic type would be suitable. Section 2.3 covers HAZOPs in more detail.

2.2.1.2 Error Causes

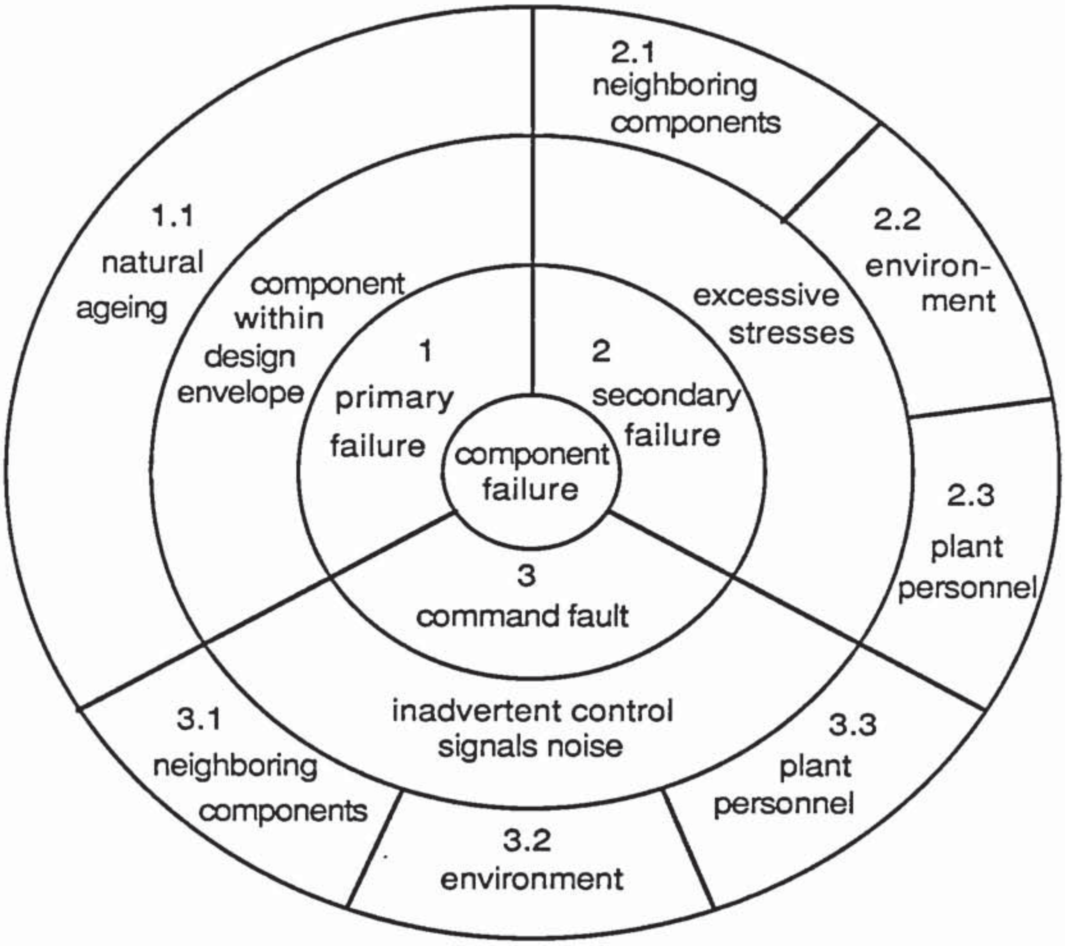
When examining the terminology of the engineer, a fault ie **failure mode** is "what went wrong' with the system or piece of equipment - this equates with the **type** of human error. In extension, a **primary failure** is the 'ultimate reason' for a fault - this equates to error **cause.**

Henley and Kumamoto (1983) demonstrate the electronic engineers interest in identifying failure causes proceeding the recognition of a component deviation. Figure 2.2.1 presents their classification scheme.

Note that 'plant personnel' are cited twice as causes of component failure. As a very simple model the inner circles represent the cause of failure, whereas the outer circle would be the equivalent to human Performance Shaping Factors.

An extension of this diagrammatic representation demonstrates one link between component failure, plant personnel (component PSFs) and in turn personnel PSFs, Figure 2.2.2.

FIGURE 2.2.1 Electronic Failure Cause Classification



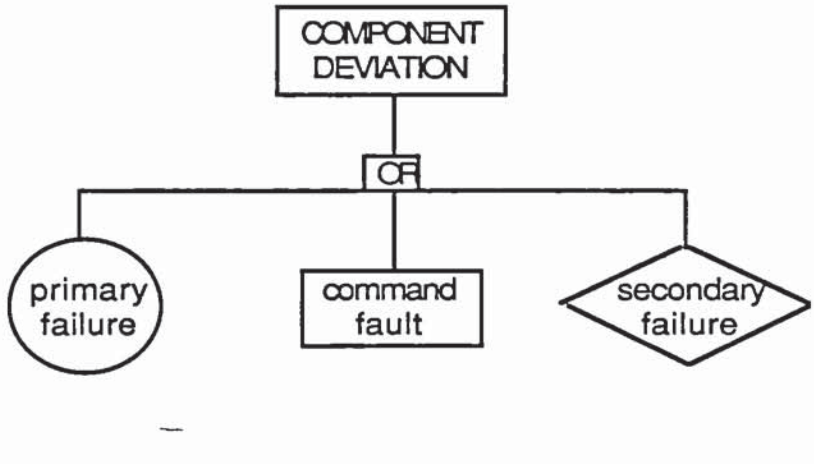
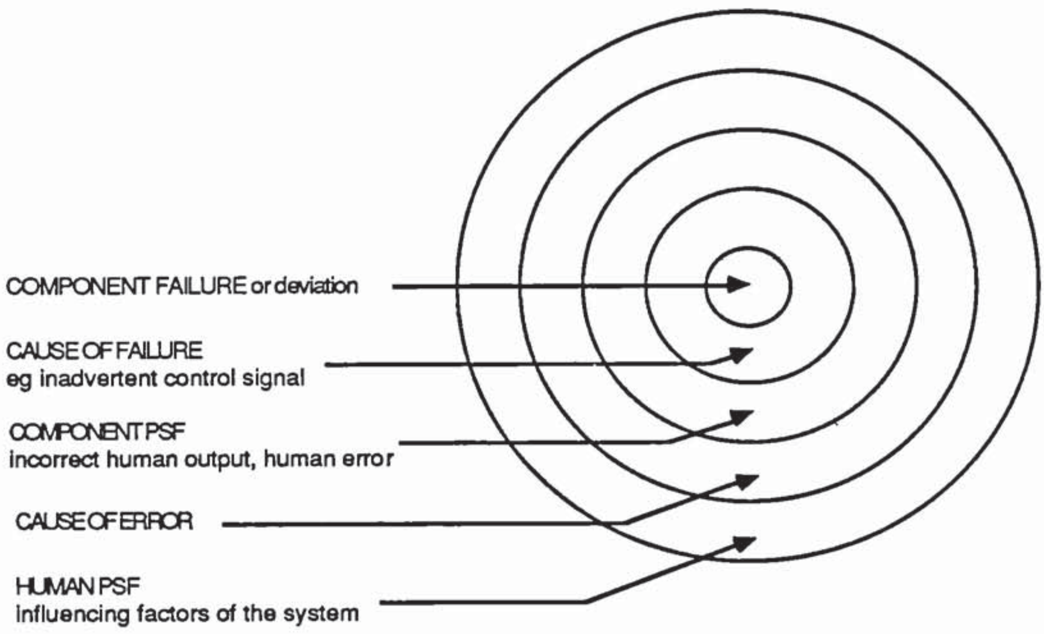


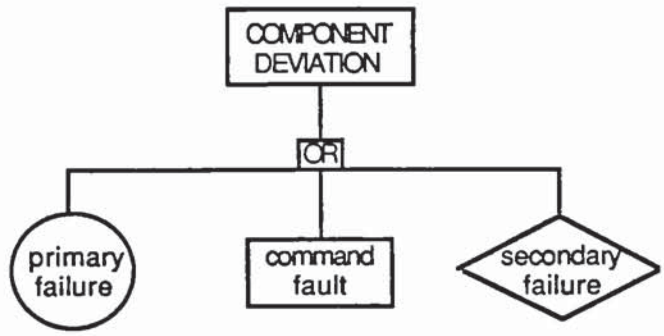
FIGURE 2.2.2 One relationship between human failure and component failure



Hazops, Hazans, Fault Tree analysis, Failure Mode and Effects analysis and Cause Consequence diagrams, all consider the causes of a failure or deviation to some degree.

Although HAZOP keywords have proved a useful basis for error types, the same help is not available for error causes. One interesting aspect shown by Henley and Kumamoto, WASH 1400 and others, is the distinction between primary failure, secondary failure and command faults:

FIGURE 2.2.3 Distinguishing Failure Cause



Primary failure can be considered as due to Internal causes, command faults associated with External causes, whilst secondary failures are due to a mismatch between internal capabilities and external demands. An obvious analogy exists with human error cause.

Many of the proposed sets of error types covered in section 2.2.1 proved a useful start for developing an initial error cause classification. Though the prime consideration was to expand the very 'physical' error types to include the underlying mental component: Overtly experienced error types are predominantly due to covert 'psychological' causes.

To quote Watson (1986) - based on the principle described by Searle during the 1984 Reith lecture -

> "Actions characteristically consist of two components viz:-
> a mental component and a physical component"

Returning to the error 'opening V3 instead of V2' the outward error type based on the HAZOP taxonomy, is a **substitution**. The psychological component of this action was the intention to open a valve (either V2 or V3). Based on this assumption the *cause* of the error could have been Physical - the two valves placed next to each other and the hand going out to the wrong one, ie the intention had been correct, that is to open V2 but during the physical act V3 was opened instead - a Slip (Norman 1981). Alternatively the cause could have been one of many psychological reasons, for example; an incorrect decision (a mistake); habit intrusion; absent mindedness (slips).

Any error cause taxonomy had to include both physical and psychological reasons with a justifiable predominance of 'psychological' causes. Edwards (1981) provides ten error cause examples (table 2.2.3), paired in relation to the stage during the human information processsing chain at which the performance breakdown could have occurred. This demonstrates the importance of considering the **task** in relation to error cause, in addition to the error type. Note the predominance of psychologically related error causes.

TABLE 2.2.3 Examples of error causes (Edwards 1981)

During the late 1970s to date three psychologists in particular have considered the causes of human error; Senders (1983) and Norman (1981) from the USA and Reason (1977,82,87) from the UK. All three have emphasised the role of absent-minded error causes (note the set of "error types" covered by Reason, Section 2.2.1).

To quote Senders (1983):

> "In 1980, with the collaboration of Ann Crichton-Harris, we organised an international conference on the nature and source of human error, the first of its kind to our knowledge. We found many people interested but only two others beside myself who were actually working on the problem,"

In general psychologists use error (along with time) as a performance measure rather than considering the phenomenon in its own right. Rarely are the underlying causes examined in any systemmatic fashion. For example Feggette (1982) places 'error' within a set of symptoms of information overload, interestingly of the other symptoms numbers 3-10 could be considered as causes of error.

Feggette's Symptoms of information overload

1 omission
2 error
3 queueing
4 filtering
5 approximating
6 coning of attention
7 inability to integrate information from various sources
8 regression
9 muscle tension, tremor
10 escape

Even within the reliability world the reason for error has not been considered, only the frequency with which it may happen.

Reason (1978) points out that the outcome of an error is independent of its cause. What might be considered a trivial absent-minded 'slip' at home could have devastating consequences if it was to occur in the control room of a chemical plant. To quote:

> "Whatever further contributions the psychologist may make towards the prevention of accidents, it must surely be predicted upon a better understanding of error-producing mechanisms in general, and of the factors which promote their activity"

In 1987 Reason cites three main origins of error:

1	planning -	mistakes	(the wrong intentions)
2	storage -	lapses ---	} (failure to carry out the intention)
3	execution -	slips ---	

This only accounts for the final stages of task execution, error can also originate during perception, comprehension and decision making. Comprehension and decision making can be grouped with planning but it is less easy to determine the place of the perception / origin of error. What can cause people to misperceive or fail to perceive?

The causes of mistakes could be described as 'failures of expertise' or 'lack of expertise'. Interestingly Reason also relates error causes to task type in terms of Rasmussen's knowledge-based, rule-based and skill-based activities. During knowledge based tasks, personnel often attempt to simplify or reduce the demands by resorting to familiar routines, heuristics and short-cuts. Heuristics are specifically important when resolving conflict due to a lack of information ("match like-with like" and conflict resolution "contextually-appropriate or high frequency"). Reason has moved on to consider other causes of error in addition to absent-minded. He (Reason, 1987b) introduces the idea of **Violations** which are only possible when behaviour is regulated by operating procedures, codes of practice, rules, laws etc. To summarise; Reason suggests that the causes of error are Absent-Mindedness, Violations (risk-taking), Mistakes (irregularities of the performer's mental model) and Psychological task demands.

Norman considers 'action slips' in detail within his paper 'categorisation of action slips' (1981). This suggests that there are three main reasons for slips; Conflict between possible actions or thoughts, Intermixing between components of an action sequence,the selection of an appropriate act but for the Wrong Reasons. Norman states that Freud (1924) believed "that slips resulted from competition among underlying mechanisms, often working in parallel with one another and almost always beneath the conciousness of the owner". In general multiple schema (activity plans) are active at any one time - whilst one mental activity is on-going others are started and completed. Norman explains this concept in terms of driving a car (the parent schema) which triggers all the other associated 'child schemata' (changing gear, stopping at junctions, signalling, complying with road signs etc.), this allows tasks to be undertaken with the minimum of conscious monitoring. It is the human mechanism for reducing information workload. To give an analogy : The background processing tasks carried out by computers, eg the internal clock, garbage collection, screen support, port monitoring - ie all the fundamental tasks that keep a computer operating - represent 'skilled' tasks of an human requiring minimal cognitive control. This allows the user to work efficiently in the foreground; eg programming and data manipulation, the high memory demands and computer processing made of the system for these activities represent human tasks which require a high level of mental processing.

Car driving (the background task)	-->	support functions
Conversation with passenger (foreground task)	-->	programming

It is this method of functioning that makes the human operator prone to absent-minded errors or 'slips'. Norman's classification of slips, based on their source (cause), is given in Table 2.2.4. Note that 'mistakes', errors due to comprehension and decision-making - conscious mental processing - have not been included. Bilcliffe (1986) Figure 2.2.4, follows the work of Norman and extends the classification of slips to incorporate mistakes.

TABLE 2.2.4 Classification of Slips by Presumed Source

1 **Slips resulting from errors in the formation of intentions**
- 1.1 mode errors - erroneous classification of the situation
- 1.2 description errors - ambiguous or incomplete specification of intention

2 **Slips that result from faulty activation of schema** (problems in starting schema)
- 2.1 Unintentional Activation
  - i capture errors - a similar sequence is more frequently used or better learnt and may capture control
  - ii data-driven activation - external events activate schema
  - iii associative activation - a currently active schema activates others associated with it
- 2.2 Loss of Activation
  - i forgetting an intention (but continuing with action sequence)
  - ii misordering components of an action sequence
  - iii skipping steps in an action sequence
  - iv repeating steps in an action sequence

3 **Slips that result from faulty triggering of active schema** (problems occurring once the schema is underway)
- 3.1 False Triggering
  - i spoonerisms - reversal of event components
  - ii blends - combination of components from competing schema
  - iii thoughts leading to actions - a schemata triggered which was meant to be thought
  - iv premature triggering

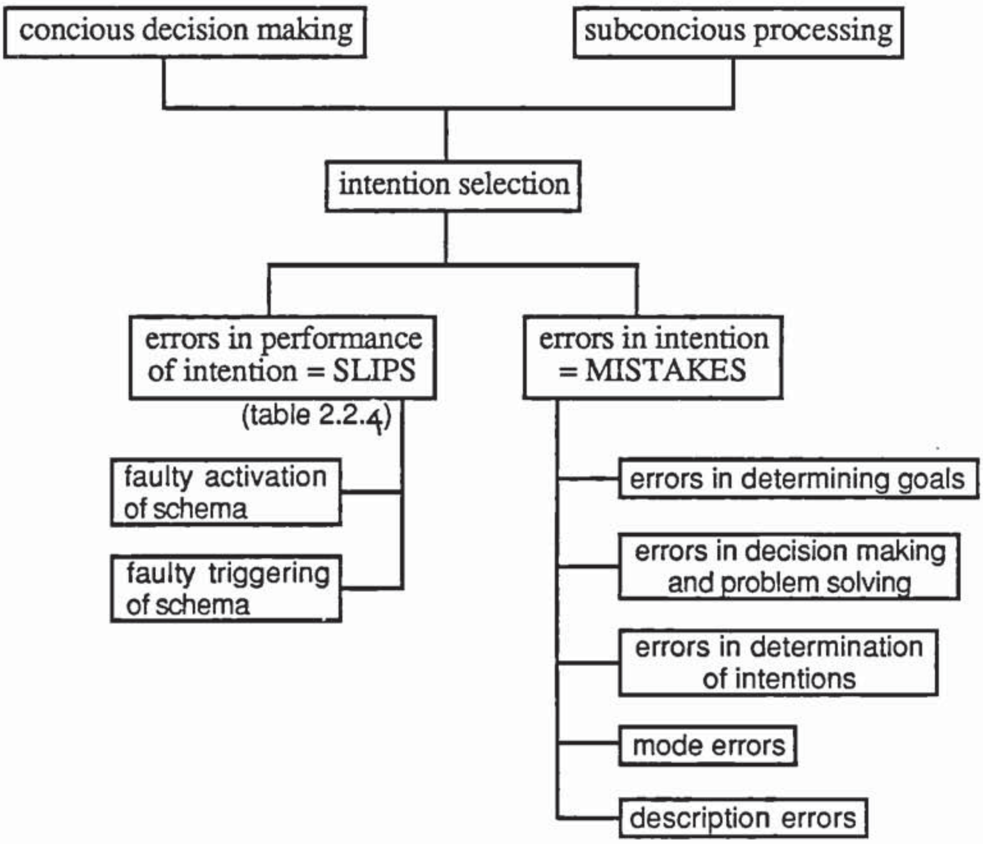
3.2 Failure to Trigger

i action pre-empted by competing schema

ii insufficient activation - forgetting or initial level too low

iii failure of trigger action to match

FIGURE 2.2.4 Slips and Mistakes



The work by Senders remained unknown until late within the research project. His paper "On the nature and source of human error" (1983) was found to vindicate the notion of internal and external sources of error using the same terminology, that is describing internal mechanisms as **endogeneous** and external mechanisms as **exogenous**. Senders focuses on three strands towards error analysis:

1. The Internal PROCESSES resulting in error
    1.1 execution errors
    1.2 intention errors
    1.3 perceptual errors

This identifies the point of error occurence during the information processing chain , rather than providing a statement of error cause.

2. The Primary LOCUS of error
    2.1 internal - endogenous
    2.1 external - exogenous

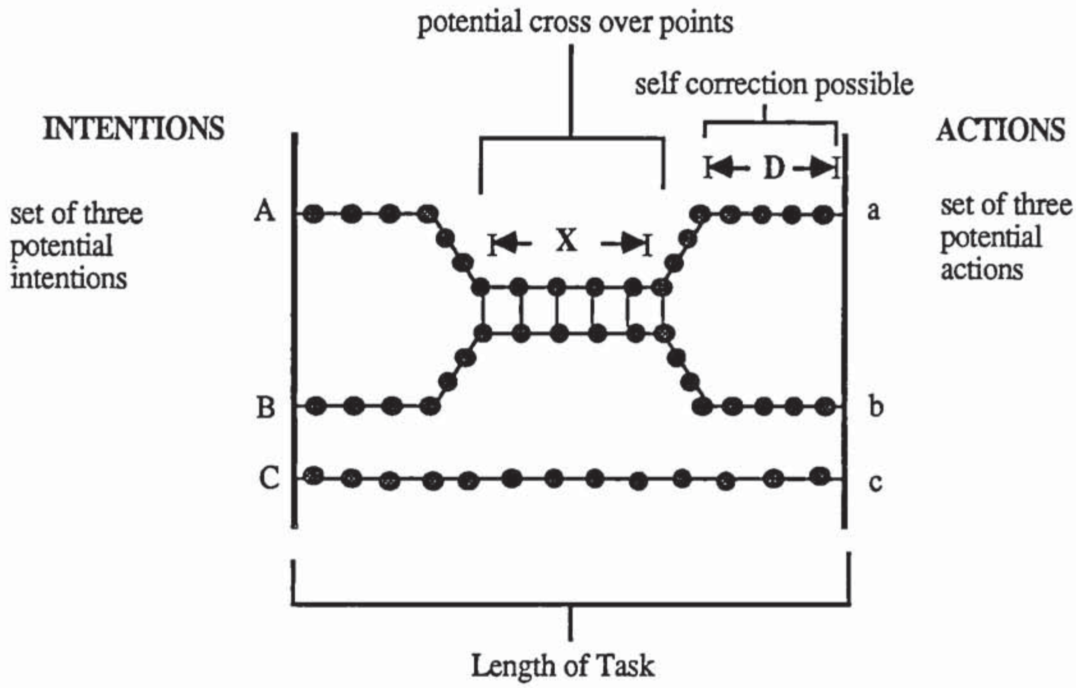
Note that Senders does not consider the combination of the two.

3. Error TYPE taxonomy
    3.1 omission
    3.2 repetition
    3.3 insertion
    3.4 substitution

Having found that the majority of errors are substitution errors, Senders (figure 2.2.5) hypothesises a model of cross-overs from one schema to another, usually better known. Based on this model, the system designer must consider the effect on the task currently being assessed, of similar tasks and tasks with similar sub-tasks in order to identify error prone situations.

To summarise; few psychologists had concerned themselves with the issue of error cause, therefore the literature appertaining towards this subject was sparse. The few taxonomies that did exist were dominated by the notion of absent minded errors, synonymously 'slips'. Therefore no comprehensive error cause taxonomy was available to assist with PSF identification. This required rectification.

FIGURE 2.2.5 Sender's hypothesised cause of human errors



2.2.1.3 Error Dynamics

If there is interest in the performance of those working with an existing process plant, it is likely that their errors will have been documented. In this case it is possible to consider the dynamics of the errors or the '**error profile**'. The three classical patterns (Rigby, 1971) are;

1. Systematic errors
2. Random errors
3. Spurious errors

If all the error records show a similar performance discrepancy, ie the same error is repeated, then the error profile is said to be **systematic.** This means that the cause of the errors is a permanent feature of the system, whether internal or external to the task performer. If the same error consistently occurs *independently* of who performs the task, then the designer / manager knows that the fault is due to external factors and can look at such factors as the environment, the interface, the job demands etc. Conversely if the errors are dependent upon the performer, then internal aspects should be considered, for example; training, mental model, experience, personality, ability.

However, if the errors are frequent and of no consistent type this suggests a truely **random** pattern of errors. This is characteristic of the novice and is due to a lack of experience or training.

Finally a more refined group of random errors are those that occur intermittently for no immediately apparent reason, the **spurious** error. Generally performance is perfect with the occasional inconsistent deviation. This is the form most common to the expert and is the most difficult to prevent. The designer needs to know what can trigger these errors (eg disturbance, sudden noise, schema cross overs, stereotype contravention) and how to design to keep these to a minimum or to counter-act their threat.

This consideration of error dynamics is useful for correcting existing systems, providing insights for the manager and design engineer.

2.2.2 Performance Shaping Factors

> "In conclusion, while the major factor that turned this incident into a serious accident was inappropriate operator action, many factors contributed to the action of the operators. Such as deficiencies in their training, lack of clarity in their operating procedures, failure of organisations to learn the proper lessons from previous incidents and deficiencies in the design of the control room. "
>
> Three Mile Island -
> (the report of the president's commission)

Even before Three Mile Island it was recognised that merely admonishing individuals to 'be careful' was unlikely to produce any significant drop in accidents (and by implication human error). The only change it may make would be to reduce the level of reporting.

Swain (1984) published "The Human Element in Systems Safety - a guide for modern management", this was a training manual for delegates attending a two day seminar. The central philosophy was that:

> "Designing safety features into systems (the work situation approach) is a more effective way to reduce accidents than campaigning to make people more careful (the motivational approach). It is believed that reduction of hazards through design action can be permanent, whereas reduction by modifying people is limited and requires considerable reinforcement. "

Included within this publication is a list of performance shaping factors (Table 2.2.5) first presented by Swain (1972). These were for use in evaluative exercises of tasks performed on existing plants but there was no mention yet of considering such factors during initial design. Despite the belief that design is the most efficient method of reducing accidents, these analysis techniques are retrospective. Design factors acting as negative PSFs should be prevented from occurring in the first place rather than be being corrected afterwards.

Swain can be seen as the godfather of PSFs. It was his work during the late 1960s, early 1970s that saw the start of a specific group of factors termed Performance Shaping Factors, although most ergonomists / human factors engineers would state that this was ergonomics. This initial list remains virtually unchanged from 1972 to 1983 (Swain, 1983). In 1983 Swain still emphasised the requirement of reliability assessors to judge which PSFs exist within a workplace and which could adversely affect performance, producing a weighting factor by which to reduce the reliability figure. Interestingly a report refered to by Kletz (1976) published by Payne et al (1964) introduces the concept of factors, now called PSFs, being used to estimate failure rates for electronic equipment operators. The factors quoted all related to interface design, ie size of push button, push button arrangement, number of push buttons, distance between buttons, whether the button remains depressed and clarity of labelling.These have always been the easiest aspects for ergonomists to assess. For example, an early but most useful guide to engineering visual displays from an human perspective was published by Meister and Sullivan (1969). Kletz points out that the interface design is not the whole story, his example related to personally pushing buttons on a drink dispenser and he quoted a much lower level of reliability than would have been suggested by the multiplication of the interface reliability figures.

TABLE 2.2.5 The PSFS presented by Swain

Extra - Individual

Situational Characteristics

temperature, humidity, air quality
noise and vibration
degree of general cleanliness
manning parameters
work hours / work breaks
availability / adequacy of supplies
actions by supervisors
actions by co - workers and peers
actions by union representatives
rewards, recognition, benefits
organizational structure (eg authority, responsibility, communication channels)

Task and Equipment characteristics

perceptual requirements
anticipatory requirements
motor requirements (speed, strength, precision)
interpretation and decision making
complexity (information load)
long and short term memor
frequency and repetitiveness
continuity (discrete versus continuous)
feedback (knowledge of results)
task criticality
narrowness of task
team structure
man - machine interface factors:
design of prime equipment, job aids, tools, fixtures

Job Instructions

procedures required
verbal or written communications
cautions and warnings
work methods
shop practices

Psychological Stresses

task speed
task load
high jeopardy risk
threats (of failure, loss of job)
monotonous, degrading, or meaningless work
long, uneventful vigilance periods
conflicts of motives about job performance
reinforcement absent or negative
sensory deprivation
distractions (noise, glare, movement, flicker, colour)
inconsistent cueing

Physiological Stresses

fatigue
pain or discomfort
hunger or thirst
temperature extremes
G - force extremes
atmospheric pressure extremes
oxygen insufficiency
vibration
movement constriction
lack of physical exercise

Intra -Individual

Individual (organismic) Factors

previous training / experience
state of current practice or skill
personality and intelligence variables
motivation and attitudes
knowledge of required performance standards
physical condition
influence of family and other outside persons or agencies
group identification

The following quote (Kletz, 1976), indicates the factors that he immediately considered as possible influences:

> "Perhaps I do not have my mind on the job, perhaps I am talking to someone or am under stress - factors which are not taken into account in this rather simple method of calculation"

The second important message of this paper is that it is the situation in which one finds oneself that turns a simple error into an accident. We are regularly making mistakes but it is only at a particular time and place that this matters:

> "A similar mistake to the one with the coffee machine has caused a serious fire in another country in which several men were killed and many injured"

The final message, and one that is fundamental to this research was the answer to the question; 'how can we prevent people making such mistakes'.

> "We cannot prevent men making mistakes like this. We can make mistakes less likely by putting the buttons further apart and by using bigger labels but an occasional mistake will still happen. We should never get into a situation where this sort of mistake has such serious consequences. "

Designers need to know what causes error, they need to determine when mistakes are important and, depending upon the possible reasons for the error occurrence, the contributing PSFs. The identification of relevant PSFs prior to design means that it is possible to ensure good design.

Embrey also recognised the role of PSFs within human reliability assessment techniques. His first reference to PSFs (1979) came when describing a proposed technique for reliability assessors consisting of three stages:

1 identification of goals
2 logical analysis, eg fault tree logic diagrams
3 application of performance shaping factors

The quoted performance shaping factors divide into three groups:

Task Factors -

"the optimal combination of PSFs necessary to minimise error can be specified for each sub-task"

Individual Factors -

"the task analysis . . . can provide a specification of the skill necessary to attain a low probability of failure"

Environmental factors -

including organisational, managerial and procedural factors.

Embrey stated that by applying these PSFs at this stage in design, it is possible to establish the conditions necessary to keep errors to a minimum. Embrey continued to view PSFs as having a predominant importance in human reliability assessment but moved towards the use of these factors in quantification techniques based upon expert judgement (1983) ie the Success Likelihood Index Method (SLIM) and Multi-Attribute Utility Decomposition (MAUD).

During the SlimMaud technique a set of up to eight tasks are assessed as a group. The computer program asks for the assessors to enter PSFS that they consider to be the major influences on human reliability. After entering what they consider to be the critical factors, the judges then have to numerically rate the quality of each PSF for each task. Based on these inputs a numerical index is produced that indicates the position of each task on a scale of "likelihood of success". Embrey states that this not only assists the calibration of a probability assessment scale but can also be used to provide design recommendations.

> "It is possible to identify which design factor has the greatest effect on the overall probability of success for a particular set of tasks"

The problems that emerge from such a technique are due to the total dependence on expert judgement both for suggesting important PSFs in the first place and secondly for ranking these for each task. For example, if training was considered to be important the assessor would then have to rank the tasks according to dependence on good/bad training. There is no guarantee that the assessor would correctly identify the importance of a PSF or even that all the relevant PSFs were included. It would prove very difficult to ensure an acceptable level of consistency between assessors, the same assessor at different times, or for the comparison of task groups. By 1986 the assessor was being asked to indicate the **ideal** point on the self-selected PSF scale.

A second technique presented by Embrey (1986) was SHERPA (Systematic Human Error Reduction and Prediction Approach). The purpose of this technique was to assess the human component of risk in major hazard situations. SHERPA commences with hierarchical task analysis whose stages are then taken through a human error analysis, very similar to the approach suggested by Whalley (1983). Unfortunately SHERPA does not seem to distinguish between task requirement (expected performance) and task error (unwanted performance), both are considered as tasks for quantification. It appears that it is still up to the assessor to suggest methods of error reduction, ie the PSFs applicable to the situation.

Williams (1985) presents a different philosophy towards PSFs. This technique concentrates upon providing engineers with knowledge relating to error-likely situations, the types of errors which may occur and the strength of the effect of the different influencing factors. Thirty eight 'error producing conditions' (or PSFs, Table 2.2.6) are described along with the amount of influence they are likely to have on a situation; error producing condition number one is viewed as having the most potentitial effect with the other 37 conditions arranged in rank order from the most influential to the least. In addition, remedial measures are considered for each condition and extensive information is presented referring to experimental evidence and the literature. These error producing conditions are used to manipulate the major determinants of 'failure orders of magnitude', ie the quantity and quality of system knowledge, response time pressure and poor / ambiguous feedback and the 'nominal human unreliability figures' for the generic task types of which he suggests nine dependent upon task complexity. From the PSF perspective it is interesting to note that no classification scheme has been attempted and that the 38 error conditions are predominantly centered around psychological factors. These are by reputation difficult influencing factors to judge, therefore such a hierarchy of effect would prove a useful addition to a design aid. It would still be necessary to include a more comprehensive range of PSFs than that used with this model.

Seminara and Parsons (1982) presented results from a set of case studies

TABLE 2.2.6 Williams's 38 Error-Producing Conditions

A. Major Error-Producing Conditions

1. Unfamiliar or Novel situations
2. Time Shortage
3. Low signal to noise ratio
4. Easy suppression of information
5. No method to convey easilly understood spatial & fuctional information
6. Mismatch between operators and designers model
7. No obvious means to reverse unintended action
8. Channel capacity overload
9. Opposing philosophy of a new technique

10. Transference of knowledge between tasks without loss
11. Ambiquity of required performance standards
12. Mismatch between real and perceived risk
13. Poor Feedback
14. Poor system confirmation of intended action
15. Operator inexperience
16. Poor quality of information in procedures or passed between people
17. Little or no independent checking or testing of output

B. Secondary Error-Producing Conditions

18. Conflict between short and long term objectives
19. No diversity of information for checks
20. Mismatch between individuals education and task demands

21. Incentives to use more dangerous procedures
22. Little exercise of body and mind outside immediate confines of the job
23. Unreliable instrumentation
24. Need for absolute judgements beyond capability or experience of personnel
25. Unclear allocation of function and responsibility
26. No method to keep track of progress during an activity
27. Danger of exceeding physical capability
28. Little meaning contained within a task
29. Emotional Stress
30. Ill Health, especially fever

31. Low workforce morale
32. Inconsistency of meaning of display and procedures
33. Poor or hostile environment
34. Prolonged inactivity or highly repetitive tasks of low mental workload
35. Disruption of normal work-sleep cycle
36. Task pacing dependent on others
37. Additional team members above those necessary to perform the task
38. Age of Personnel performing perceptual tasks

relating to maintenance problems at five nuclear power plants. Their study findings were presented in a disciplined and pictorial manner under major headings. These headings facilitated the extrication of the Performance Shaping Factors that applied to these case studies (Table 2.2.7) as well as providing evidence of PSF influence on performance and human reliability during maintenance tasks. This report showed the benefits that could be derived from case studies in terms of information acquisition.

With respect to the specific PSFs that should be incorporated into a PSF classification structure and detailed listing both Hunns (1982) and Bellamy (1983,4,5,6) provide evidence of the influence of socio-technical factors, particularly communication.

A summary of one study undertaken by Bellamy (1985) looked at the pattern of performance shaping factors within a sample of ten accidents taken from the process industries. This demonstrated the frequent interplay of sociotechnical factors, figure 2.2.6. Unfortunately it is these factors that are the hardest to assess and understand and hence they have received the least attention over the years. It is however clear that these aspects must be incorporated into any PSF classification and taxonomy.

FIGURE 2.2.6 The influence of sociotechnical factors

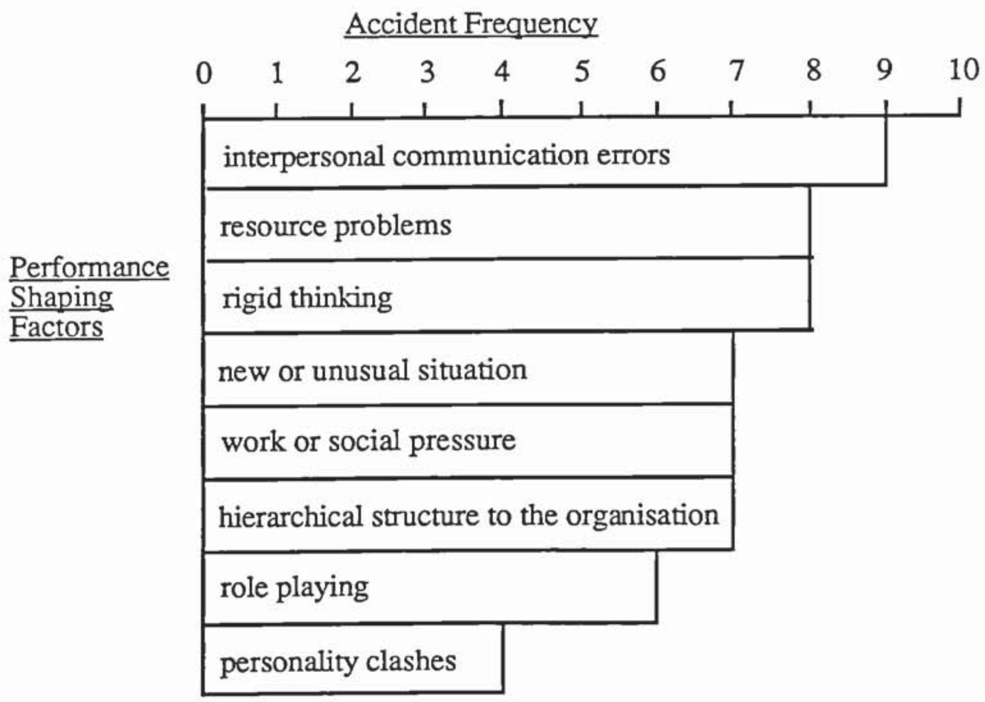


TABLE 2.2.7 PSFs Identified during Maintenance Problems

1. Equipment Maintainability
1.1 Equipment Access 1.2 Workspace Dimensions
1.3 Equipment Location 1.4 Visual limits

2. Environmental Factors
2.1 High Temperatures 2.2 Steam Leaks 2.3 High Noise
2.4 Caustics 2.5 Slippery surface 2.6 Illumination
2.7 Climatic exposure 2.8 Radiation exposure

3. Movement
3.1 Vertical access 3.2 Horizontal access 3.3 Lifts
3.4 Cranes 3.5 Lack of Work Platforms

4. Anthropometry & Human Strength
4.1 Lack of Access 4.2 Protective Clothing 4.3 Handling 275kg

5. Labelling & Coding
5.1 Background Contrast 5.2 Legibility 5.3 Unofficial Labelling
5.4 Lost Labels 5.5 Accessibility 5.6 Insufficient Labelling
5.7 Colour coding of Pipes 5.8 Identification of Identical Units

6. Stores, Supplies & Tools
6.1 Work aids for radioactive environment 6.2 Availability of Spares
6.3 Computer Inventories 6.4 Tool Room Location 6.5 Tool Theft
6.6 Tool Contamination / Decontamination

7. Information & Procedures
7.1 Faulty Procedures 7.2 Inadequate Vendor Manuals

8. Safety and Equipment Protection
8.1 Steam 8.2 Work on Improvised Platforms 8.3 Heat
8.4 Slippery Surface (oil & water leaks, ice) 8.5 High Voltage
8.6 Chemical Burns 8.7 Head Knocks 8.8 Tripping hazards
8.9 Escape Routes 8.10 Safety Clothing 8.11 Safety Equipment

9. Communication
9.1 Channel Capacity / Number 9.2 Work Area Coverage
9.3 Impeded by Protective Clothing 9.4 High Noise environment
9.5 Walkie-Talkies 9.6 Sound Powered 'Phones 9.7 Reliability

10. Preventive Maintenance and Diagnosis
10.1 Man-power limitations 10.2 Specialist Support
10.3 Co-ordination between operators & maintenance personnel
10.4 Built-in Diagnostics 10.5 Equipment designed for easy inspection

11. Job Practice
11.1 Organisational Climate 11.2 Extensive Overtime or Extra Days
11.3 Shift Transition Effects 11.4 Management / Union Relationship
11.5 Team Work 11.6 Authority 11.7 Dedication 11.8 Turn-over

12. Selection & Training
12.1 Simulation of Environment 12.2 Selection informal 12.3 Promotion
12.4 Certification Programmes 12.5 On-the-Job 12.6 Vendor Supplied

As a more comprehensive coverage of PSFs Bellamy (1986) provided a listing under eight main headings;

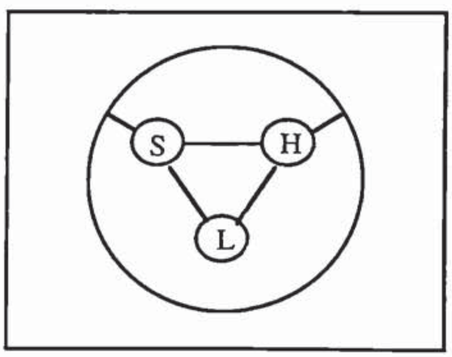
Performance Shaping Factors
1. man - machine interface (displays and controls)
2. task demands
3. task characteristics
4. instructions and procedures
5. stresses
6. sociotechnical factors
7. environment
8. individual factors

The one questionable sub-group of PSFs is that designated "stresses". Most PSFs can act as stressors if incorrectly designed therefore this specific classification is potentially misleading.

Edwards (1979) notes that error rates are "influenced by a large number of variables including those associated with motivation and stress" and states that any list would be almost infinite. To overcome this he suggested a conceptual model for grouping the variables (PSFs). This has been named the SHEL model (figure 2.2.7). The four components of this are;

1. 'Software' ie the rules, procedures and regulations governing the system
2. physical 'Hardware'
3. the Environment within which the other three variables interact
4. 'Liveware' the human element

FIGURE 2.2.7 The SHEL Model



This model stresses the importance of the interactions between personnel and other system components, re-affirming the traditional concept of ergonomics and error reduction;

'fitting the man to the job'

and

'fitting the job to the man'

These four different elements of the SHEL model must be accounted for within the PSF classification structure.

Within the professional safety community, realisation that the system can influence human action has led to the production of technical safety audits, for example Krivan (1986). Once again this is used to assess **existing** plants in situ , not for assisting the design of new plant. Such audits are used to ensure that the obvious safety procedures are being observed.

It is interesting to see that the reliability community acknowledge the need for design evaluation to "eliminate design features likely to lead to poor reliability in service, preferably at a stage of development when changes are least costly (eg design drawing stage)" Irwin (1983). Unfortunately amongst engineers this concept does not appear to extend beyond the equipment. Ergonomists have, however, always been concerned with design: Simpson and Mason (1983) review some general methods used within the mining industry. As previously stated, 1985 saw the publication of the 'Short Guide to reducing human error in process operations'. This summarised the aspects that were deemed important when designing or reviewing systems and comprised five main sections;

1 operator / process interface
2 procedures
3 work place and working environment
4 training
5 task design and job organisation

The long term plan is to produce a second, long guide to supply advice plus case study examples. The preliminary guide is only a cursory consideration of possible PSFs, highlighting a sub-group of perhaps some of the more important aspects. A more extensive list of PSFs was required for this research project.

The scope of the general ergonomics literature is summarised in Appendix One.

Finally of major influence was the technique devised by Whalley and Watson (1983) the Activity Matching Ability System - AMAS. This technique was designed to identify suitable jobs for steel workers returning to work after an accident or significant illness resulting in some form of disability whether temporary or permanent. One hundred factors were identified that would require matching in order to identify a suitable job where the capabilities of a returnee could cope with the job demands. Obviously if normal job demands could exceed limited capability, then conversely high job demands in these identified areas could exceed the capacity of the 'normal' work population. Hence those aspects considered within AMAS could be considered to be performance shaping factors requiring considered design.

To conclude: A PSF classification structure and detailed listing would be dependent upon the synthesis of the available literature, which would in turn be used as a basis for case study confirmation.

2.3 HUMAN HAZARD AND OPERABILITY STUDIES

2.3.1 Hazard and Operability Studies

HazOp studies were mentioned within section 2.2.1 with respect to their influence on classifying human error types. This is a technique used in the chemical process industries to identify "hazards and problems which prevent efficient operation" (Kletz 1981). It is a method of structured brain storming to be used by a group of engineers and managers in order to assist them with identifying all the possible ways in which hazards or operating problems may occur during a particular process.

To ensure that nothing is missed each pipeline and vessel represented on a P&ID (process and instrumentation diagram) is considered in turn in conjunction with each possible type of hazard and property of the system. These hazards are covered by applying a set of guide words:

NONE	- or NO eg flow
MORE OF	- any relevant physical property, eg flow, temperature etc
LESS OF	- any relevant physical property, eg flow, temperature etc
PART OF	- deviation in composition eg ratio, missing components etc
MORE THAN	- extra components eg within the process stream
OTHER	- incorrect components or alternative operations eg start up, shut down, uprating, low running etc

Properties of the system are for example; flow, pressure, temperature, level, concentration, composition.

For each line on the P & ID associated with the current vessel under consideration, each guide word is considered for each relevant property (for example Flow) and the following questions are asked:

Could there be No Flow (more flow, less flow etc) ?
If so HOW ?
What are the CONSEQUENCES ?
How will the operator know ? INDICATIONS
Are the consequences HAZARDOUS, or do they prevent operation ?
Can No Flow be PREVENTED ? (by changing design or method of operation)
Does the size of the hazard justify the EXPENSE of rectification ?

It has been suggested that for batch plants the guide words should be applied to the operating instructions (whether operator instructions or computer instructions) as well as the equipment. For example, 'Charge 1 tonne of A to the reactor':

'A' NOT charged
MORE 'A' charged
LESS 'A' charged
AS WELL AS 'A' charged
PART OF 'A' charged
OTHER THAN 'A' charged
REVERSE charge 'A'

2.3.2 Human HazOp

Whether via the instructions HAZOP or the P&ID HAZOP, for each guideword human causes should be considered as a reason for the resulting deviation.
For example:

NO FLOW,	operator failed to open valve
MORE A charged,	operator tipped more A than required into the vessel

The team should discuss the feasibility of each failure mode plus any possible and practical preventative measures. In this manner the effect of human failure within the system is systematically considered alongside equipment / process failure. It is however important to note that if following a P &ID, a NO FLOW situation may be caused by a Not Done operator failure (valve not opened) or an Other Than error (the wrong valve was opened) or a Part Of (only part of the required operating sequence was performed) or a Later Than (a delay occurred in opening the valve). Each of these operator errors have in their turn their own causes or reasons for occuring which must be considered.

Rarely, if ever, does the HAZOP team consider the underlying reason for human error since it is seen as a reason for failure in itself. This lack of understanding means that the 'preventative measures' tend to *remove* the human from a 'problem stage' in the process or suggest the provision of good operating instructions or the provision of checks / interlocks / warning signals / extra indication - all can be extremely relevant in certain situations but completely miss the point in others!

To run a successful HAZOP of any type requires a mixed team of design engineers, engineering managers, process managers and safety personnel who can set aside a period of several days, or weeks if a large plant or extensive investigation. To ensure that this technique is used to its full potential, at least one member of the team needs to be knowledgeable of human factors. This will ensure that the influence of human error is considered and that it is recognised when it is appropriate to consider this factor further in terms of preventive or limiting measures.

Once important human errors are identified during a HazOp they can be used as an input to the envisaged design aid in order to identifying the related PSFs.

In other words, not only does the Hazop technique have something to offer a PSF identification methodology in terms of generic error types, but reciprocally the resultant PSF identification technique would assist an Hazop.

2.4 TASK ANALYSIS - Identifying Expected Performance

The discussion has so far considered; 'what is human error', 'what causes human error', and 'what can be done about human error'. Human HazOps suggested how a problem could be identified as stemming from human performance but still to be considered is what is expected from the plant personnel in the first place. Only if an explicit understanding is achieved concerning **expected performance** can real progress be made towards identifying what could go wrong and how this should be avoided.

Most human reliability practitioners (Swain, Embrey, Rasmussen, Holnagel, Leplat, Bainbridge, Umbers) start with the premise that some form of task analysis must be completed prior to an error / human reliability assessment. By considering models of human performance a better understanding can be achieved of the task analysis requirements, in terms of the appropriate level and type of detail.

2.4.1 Models of Human Performance

Much research has taken place over the years (for example Sheridan, Newell and Simon, Welford, Broadbent, Singleton, Fitts and Posner, Dudley, Seymour) devoted to modelling human performance and more recently, operator performance - at the RISO Laboratories, Denmark, there is a strong reputation for this work deriving from such as Rasmussen and Hollnagel. Operator performance has also been considered by Timonen and Wahlstrom from Finland; Leplat, Boel and Daniellou from France; Kragt and Daniells the Netherlands; and in England Singleton, Bainbridge,Towell and Umbers. In the United States of America, Rouse (1980) published a current state of the art with respect to "Systems engineering models of human-machine interactions".

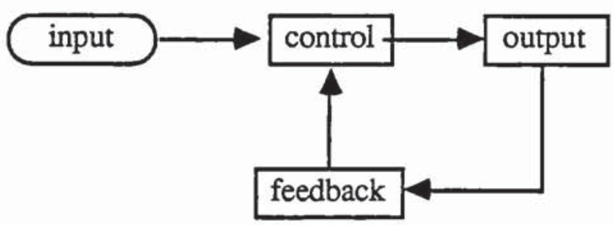
Human Performance models attempt to explain known or observed performance either purely mathematically; estimation theory, control theory, queueing theory, fuzzy set theory (Lewis, 1987) or psychologically. The latter classically include:

1.Signal DetectionTheory	- a signal has to be perceived against background 'noise' within the human system
2.Single Chanel Hypothesis	- only one item can be successfully performed at one time, humans are serial rather than parallel processors
3.Choice Reaction Models	- these include the influence of compatability and familiarity when choosing between reactions
4.Hicks Law	- reaction time increases with an increase in the degree of choice
5.IPC	- the Information Processing Chain is based upon the existance of a number of mental stages between stimulii perception and a relevant response

Directly related to the theory of human error, Singleton (1973) discussed Psychoanalytic theory and the 'no risk ----> high risk' continuum. This is based on the belief that in terms of reliability, people are to some extent risk takers. In contrast the Limited Capacity theory (Welford) states that accidents are the result of people working beyond their capability, due to such reasons as ignorance, system speed, excessive demand on their concentration or comprehension span, random internal activity and unexpected events. In order to ensure human reliability, some understanding of human capacity is necessary so that jobs are kept within human limits. The Cybernetic approach states that if there are no errors there is no action ie systems cannot operate and progress without errors and error correction. Yet another performance model is that of the Decision Theorists. This states that human error is determined by input and output problems. In terms of input there is always more than one interpretation of the stimulii, this has been specifically considered in terms of inspection tasks. Rejection versus acceptance of an item has two associated errors; Accepting what should have been a reject or Rejecting an acceptable item. Decisions are based not just on the visual input but also the accompanying criteria, for example customer standards. In terms of output, the theory is that responses only approximate the precise response required forming a distribution around this. Therefore, if there are performance boundaries that must not be transgressed, mechanical barriers are required. Note that MORT, Johnson (1980) includes the consideration of barriers in order to prevent "unwanted energy flow".

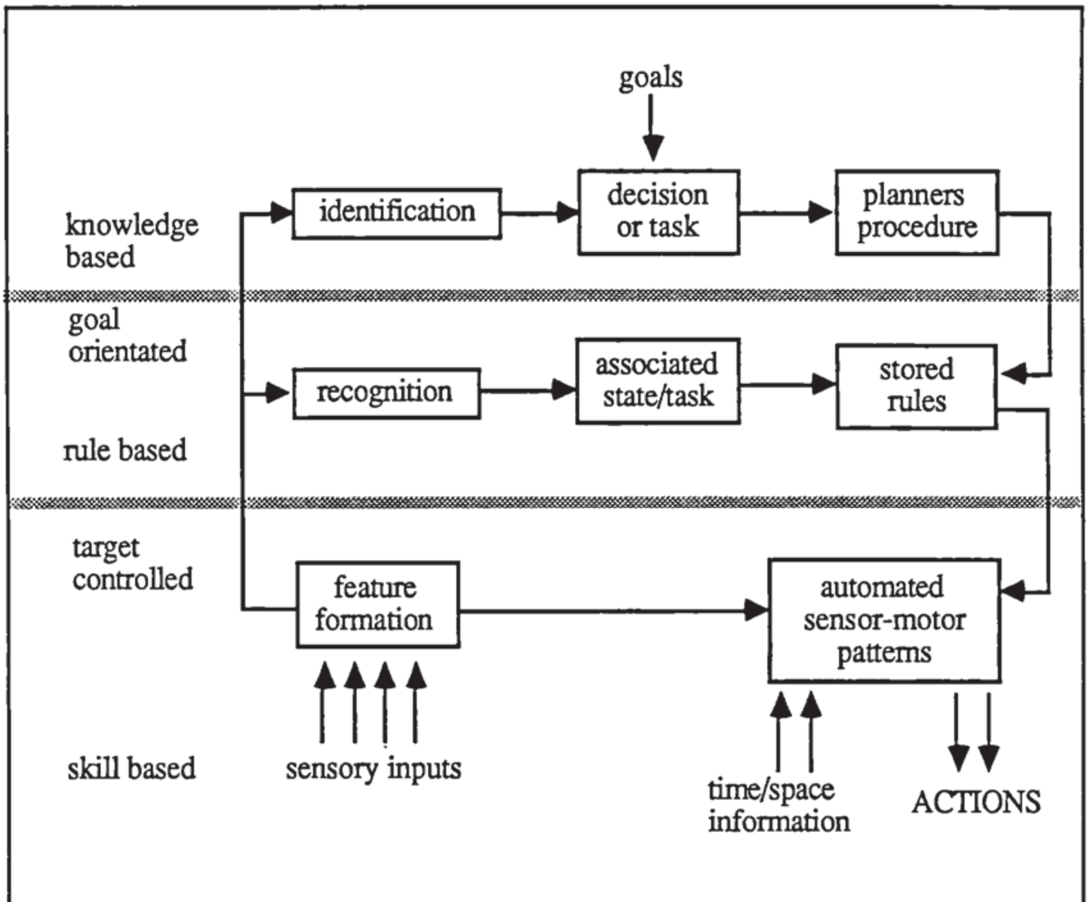
For this application it was considered important to have a psychological basis of task discrimination but with no need for a mathematical model. The intent was not to predict how operators would behave but to identify factors that could affect this performance. It was also important to be able to represent the possible stages of performance in a simple format so that those with no psychological background could quickly grasp the main important aspects. Nearly all the psychological models include some concept of the information processing chain, below is a classical simplified representation of the stages passed through from first receiving a stimulus to performing a response:

Alternatively, a 'control' model includes a feedback loop:



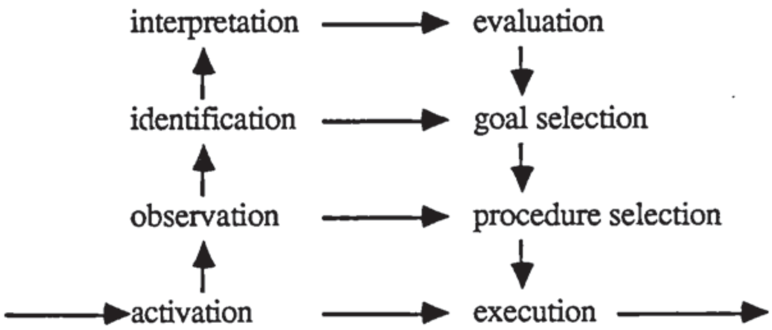
Rasmussen (1976) used the information processing chain as the basis of his extended model of human performance, producing a schema of the sequence of mental activities between response initiation and the resulting actions (figure 2.4.1).

FIGURE 2.4.1 Rasmussens model of human performance



Rasmussen's scematic illustration of different categories of human data processing.

Embrey (1983) presents a simplification of Rasmussen's Model:



Rasmussen extended this concept of the knowledge, rule and skill based information processing systems in 1981, indicating that the three generic types of task can have different error mechanisms.

Hollnagel's performance models are not surprisingly similar to Rasmussen's, representing the principles of knowledge, rule and skill based behaviour. Timonen and Wahlstrom (1978) also made reference to the Rasmussen model.

Bainbridge (1979) found an information processing approach to be the best means of modelling a controller's activities during the control of slowly changing systems with several interacting variables. Her conclusion was based upon a study of operators who controlled the distribution of electricity to a group of steel melting furnaces.

During a period of twenty years the prevalent view favoured an information processing model of performance, with Rasmussen's model dominating the theoretical literature for over a decade, 1976 to date. With this track record Rasmussen's model appeared to be the best starting point for task classification, especially since it provided an appropriate level of detail.

In order to identify actual tasks for this type of classification, a goal-oriented assessment method was required with some notion of sub-task ordering and a time dimension. Hierarchical Task Analysis provided this method of assessment.

2.4.2 Hierarchical Task Analysis

Hierarchical Task Analysis is a well established technique developed in the late 1960s and early 1970s (Annett and Duncan, 1967) and updated by Shepherd (1979) that presents a gradual increase in the level of detail associated with an identified human activity. The main application of HTA has been for defining personnel training requirements and more recently operating procedures. For many of the same reasons it is useful as a starting point for a designer decision aid. Other forms of task analysis concentrate predominantly on action forms, the observed **result** of task requirements, for example Gilbreth introduced time and motion studies which concentrated on **observable** activities breaking them down into elements (therbligs) and then coding. In the 1950s Crossman introduced perceptual and central processing elements but was still considering tasks in terms of resulting actions rather than describing task requirements. It is this emphasis on task objectives rather than actions which makes HTA so beneficial, especially when considering plants which have not yet been constructed and there is no opportunity for observing performance.

HTA redescribes the primary level of Job Requirement through Duties, to tasks, sub-tasks and sub-task elements. Each branch can be redescribed to an appropriate level, though it can be difficult to deduce what is an appropriate level at which to halt. The traditional rule appertaining to the level of detail relies on an assessment of the probability of performance failure P and the hypothesised cost of failure C, generally refered to as the P x C rule.

If C --> 0	cease description
If C --> high	cost of failure unacceptable so carry on with breakdown
If C --> 0 **but** P --> high	carry on breakdown

For this application HTA is being considered as a method to determine error causes, therefore the decision regarding further redescription is dependent upon identifying at least one **important** error type associated with the task under scrutiny. This concept is demonstrated in figure 2.4.2 and the associated table 2.4.1.

FIGURE 2.4.2 <u>Top level of an example HTA</u>

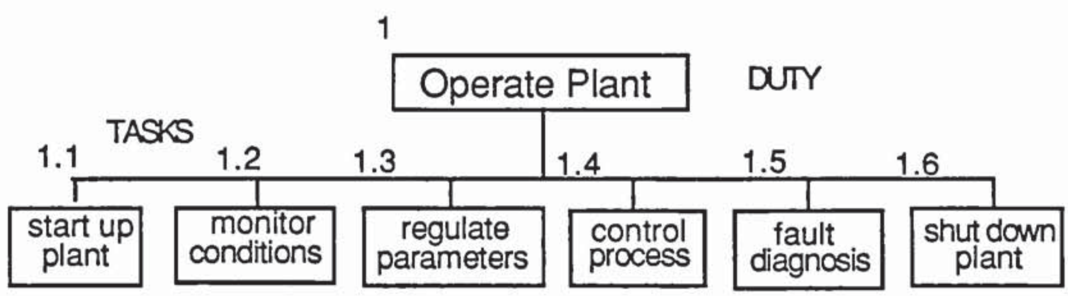


TABLE 2.4.1 Example HTA error table

start up plant	monitor conditions	regulate parameters	control process	fault diagnosis	shut down plant
O < ≠ ⬆ ⬅ ➡	O < ≠	O < >	O < > + m ≠ ⬆ ⬅ ➡	O < ≠ ➡	O < > ≠ ⬆ ⬅ ➡

The symbols appearing in table 2.4.1 have been developed by the author to code the error types defined for use within this research:

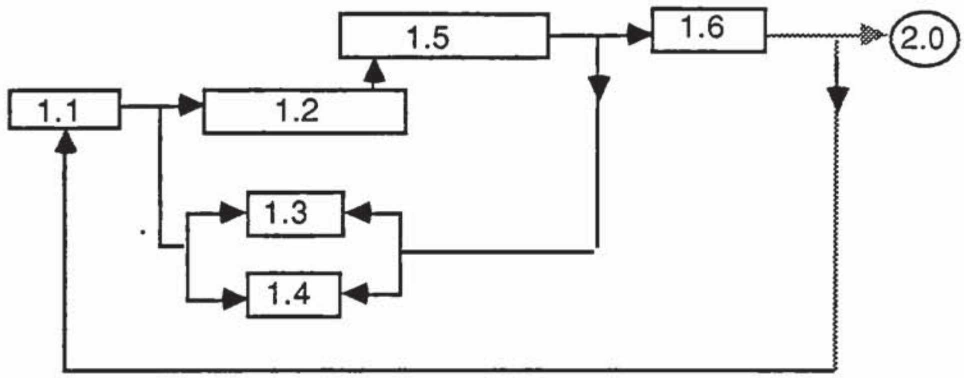
O	=	Not Done	≠	=	Other Than
<	=	Less Than	-	=	Part Of
>	=	More Than	⬆	=	Misordered
+	=	As Well As	⬅	=	Sooner Than
m	=	Repeated	➡	=	Later Than

The level of re-description in figure 2.4.2 is obviously insufficient, many errors are possible during each task (table 2.4.1), therefore the hierarchical task analysis should continue.

2.4.2.1 Task Plans

In this limited example it is possible to see that Operating the Plant is a self contained activity, unless fault diagnosis and control is impossible in which case the task becomes that of plant shut down.

Plan :



It had always been recognised that the task and sub-task order was an important part of an heirarchical task analysis but for this application the technique would benefit from an enhanced method. Time logic developed both by Allen and Villain, was examined in order to consider improvements of the task plan.

2.5 RELIABILITY AND THE CHEMICAL PROCESS INDUSTRY - From The 1980s Into The 1990s

Those responsible for human reliability, including ergonomists and psychologists have in general continued to consider the human involvement in systems in isolation from the plant and have continued to struggle to produce quantitative probabilities for inclusion within fault trees. Interestingly, the engineering profession, although requiring numerical assessments - generally for comparative purposes, acknowledge that more benefits are gained from the logic and thought processes required for fault tree construction and other similar techniques, than from the numbers themselves. Human reliability specialists would be wise to bear this in mind.

Specifically within the chemical industry a high regard is given to HAZOP and HAZAN studies which assist the identification of what could go wrong and what could be done to avoid this. Hence the need to establish thorough human error consideration as part of these techniques. Note that one suggestion has been the construction of a second set of keywords to achieve this aim. Though it would appear (section 2.3) that this would be an unneccessary complication.

One very important step towards developing a communication bridge between engineers and human factor specialists has been the initiative of the National Centre of Systems Reliability, England, who support the 'Human Factors in Reliability' Group and its sub-groups. This is a forum where representatives from universities, industry and consultancies; engineers, managers and human factors specialists (human reliability engineers, ergonomists, psychologists) meet together and follow a programme of work within sub-groups to tackle some of the major issues. 1985 saw the publication of the 'Guide to reducing human error in process operation' - Short Version (SRD 1985). The intent was to draw attention to certain factors, rather than to give specific advice with a long guide under production inorder to give more guidance.

In a more advisory capacity, the Human Engineering division of the Wright Patterson Air Force Base, USA, has been producing an Engineering Data Compendium relating to human perception and performance. This is to provide information to designers, relating to the capabilities and limitations of the human operator.

So why should the engineer of the 1980s and '90s be concerned about human reliability and how far should this concern be taken? Some notion of financial balance must be a part of any decision concerning human reliability, in the same way as it is for equipment reliability. The attitude of the British Factory Inspectorate is that a balance must be reached between excessive safety and viability. The company is obliged to show that all practical steps have been taken to avoid an accident. Therefore one reason for considering 'system' effects on human reliability would be to satisfy the HM Factory Inspectorate.

A second reason would be to ensure the best insurance premium terms. Whitehouse (1982) from the Insurance Technical Bureau published a paper titled "Risk Assessment: a positive influence on the safety and public acceptability of process plant". This paper included reference to the identification of the effects of human behaviour and the protective measures which could be taken. Research has also been undertaken by Powell and Canter (1982) sponsored by the insurance technical bureau to produce a method to assess the **management factor** in industrial loss. This technique was envisaged as an extra assessment for process plant insurance cover. There is the realization within the insurance profession that the human factor has a large influence upon the safe and efficient running of a system.

From a company's point of view, if an incident was to occur resulting in significant damage and a claim, it has been suggested that only one tenth of the cost of the accident is covered by insurance.

Insured:	compensation, medical expenses
Uninsured:	first aid, wage losses, production losses etc.

A specific estimate by Heinrich was a ratio of 1 : 4, insured to uninsured. Capital cost may be recovered but production losses will not; for example, loss of raw materials, loss of product and the cost of alternative services and supplies.

A list of losses could look something like this:

1 labour costs	2 cleaning up	3 repairs	4 first aid	5 retraining
6 overheads	7 increased maintenance		8 incident investigation	

9 reporting and recommendations 10 interim safety assessments
11 litigation and costs 12compensation
13 fines
14 increased insurance premiums 15 loss of custom
16 loss of goodwill from: i. employees, ii. neighbours, iii. suppliers and iv. customers.

One of the broadest considerations of the financial implications of accidents was presented by Maund (1982);

> " The cost of accidents, which include both capital and revenue losses are borne not only by the industry concerned but also by its suppliers and customers, its insurance companies, its neighbours, its families and also by the state"

Even minor incidents can result in unnecessary costs, merely an off-specification batch or a reduced production run may cost the company money as well as time.

Any method of reducing incidents and unneccesary losses and improving rates of return should be important to the Chemical Processing company of the 1980s and 90s. Since human reliability has been seen to have such a major effect on efficiency, then it must be in a company's interests to design a plant and its surrounding systems to maximise human performance and minimise human error.

It is recognised that a balance should be maintained between the "cost of safety" (Maund, 1982) amd the cost of accidents. Note that the cost of safety can be divided into capital and operating costs. Human reliability can be viewed in the same way. Ensuring human reliability during design may increase capital cost due to the analysis process, rather than the cost of the design itself, but this is immeasurably more cost effective than relying on operational assistance or 'revamps' when proven necessary. To ensure the balance of costs, the designer and manager need to be able to identify where the budget should be spent to ensure maximum return at minimum cost. Certain factors can be overcome by human versatility, others are not.

From a personal point of view, managers in Russia have been shown that incidents involving poor personnel performance within their industries, that result in devastating effects on the public as well as employees, are dealt with on a personal level. Managers who were associated with the nuclear accident at Chernobyl personally paid the price, with top managers sentenced to ten years at a labour camp for mismanagement of their plant personnel. Note the comments of Reason (1987) that relate to the psychological factors relating to this incident. The operators were some of the best in the country, a prestigious team carrying out a prestigious test programme but at the expense of normal operations.

The 1990s see the need for a technique designed for the chemical process industries, that will systematically assist the identification of what could go wrong with the plant personnel's task, give an insight into why this could happen and list the factors, performance shaping factors, that would degrade or improve the situation. This research report addresses this need.

CHAPTER THREE
METHOD

3.1 INTRODUCTION

Initially the author was unfamiliar with the chemical industry and the concepts of chemical engineering. In order to rectify this lack of knowledge an initiation programme was undertaken.

A selection of undergraduate chemical engineering lecture courses (Table 3.1.1) were attended to improve the author's theoretical knowledge. Whilst, during the same period, practical knowledge was gained at the sponsoring company's West Midlands site (Table 3.1.2).

TABLE 3.1.1 Chemical Engineering Lecture Courses

COURSE YEAR	SUBJECTS	
1	Structural Design	Chemical Engineering Unit Operations
2	Chemical Engineering Unit Operations II	Corrosion
	Optimization	Process Economics
	Safety & Loss Prevention	
3	Computation	Heat Transfer
	Process Management	Project Management

Initially two training modules normally used with new maintenance apprentices were undertaken within the training centre; these covered different types of pumps, valves and instrumentation. In addition time was spent with the site training officer learning about the site and company structure. As a practical introduction to the site, visits were arranged to most of the plants and warehouses in order to gain an awareness of the different levels of technology and types of process, including the differing human roles in plant operations.

TABLE 3.1.2 Initial Training undertaken by the sponsoring company

Safety Film	
Production Operators Manual	
Slide Tape Sessions:	• Valves and Pumps • Flow & Temperature Instrumentation • Pressure and Level Instrumentation
Site Visits to 17 Plants (ranging from 4 days for a large complex plant to 1/2 day for a related group)	Total Days = 15.5
Drawing Office Secondment	• Flow Sheeting • Flowsheet Symbology • P & ID • CAD Systems
Safety Department Secondment	Accident Interviews • Management Oversight Risk Trees • Fault Tree Analysis • Hazard and Operability Studies • Safety Review Procedures • Incident and Accident Research
Medical Department :	Medical Reports of Injuries at Work

Following this introduction a more extensive period of time was spent with both the safety department and the drawing office (works engineering). This training period included the understanding of Pipework and Instrumentation Diagrams (P&ID) and their symbology, the design process and the stages passed through during plant modifications and new plant design: flow sheeting, mass and energy balances, P&ID, Hazop and the first safety review, the first detailed draft and costing, the second safety review, the final detailed draft and the final safety review. Also observed was the allocation of tasks within the design team and the follow through by the senior design engineer during plant construction and commissioning.

Hazard and Operability Studies were observed and participated in during the time within the safety department and the author was also shown the system for unsafe incident reports, accident reports and accident investigations plus the role of the medical department. Unrestricted discussions with plant management (managers and supervisors) indicated the types of training and assessment used on site and also the company's attitude towards the workforce, the plant and safety. One factor that emerged was that plant managers and supervisors were rotated from one plant to another on a regular basis.

After gaining a better understanding of the industry, including the design and operation of chemical process plant, it was confirmed that there was a need to consistently identify potential influences on personnel and to prioritise each factor's importance. This had to be on a general level and for specific plants and their tasks - particularly important for existing plants in order to achieve cost effective modifications on limited budgets.

The main distinction (Table 3.1.3) for the research methodology was between the need to establish all the possible factors that could affect human performance on chemical process plants and to provide a technique for suggesting under what circumstances each factor would be particularly influential.

As can be seen, the major distinction within the research methodology was between the need to establish all the possible factors that could affect human performance on chemical process plants and a technique for suggesting *under what circumstances* each factor would be influential.

TABLE 3.1.3 Major Aspects of the Research Methodology

TOTAL AIM: **To provide a method for identifying specific factors that could affect human performance in a specified chemical process plant**

REQUIREMENT:
1. identify all possible factors
2. provide a structured methodology for selecting appropriate PSFs

1. identify all possible factors:

NEED:
1. classification structure
2. detailed listing

HOW:
1. knowledge of industry,
2. knowledge of literature
3. CASE STUDIES
   (To check / enhance / extend structure and listing)
4. company records
5. time on plant
6. check by re-design

2. provide a methodology:

HOW:
1. knowledge of literature (HR, HE, ER)
2. explore safety department methods &
3. drawing office methods,
4. consideration of case study dynamics,
5. synthesis of all resulting information

3.2 THE METHODS USED TO ESTABLISH A PSF CLASSIFICATION STRUCTURE AND DETAILED LISTING

Five primary sources of information were identified. Firstly the theoretical PSF literature; for example the work by Swain & Guttmann contained within the THERP reports 1975 - 1983, Embrey from the early 1980's onwards, and the MSc report, Singh 1982 which was the catalyst for this research. The second source of information was the work previous completed by the author, namely the Activity

Matching Ability System - AMAS (Whalley & Watson 1985); this was a technique developed to identify objectively those jobs suitable for steel workers returning to work after long term sickness absenteeism, whether caused by accident or illness. Thirdly the established ergonomic literature was an important source of data, presenting aspects that could degrade or enhance performance. In order to ensure relevance to the chemical process industries, two additional sources of information were considered - information currently logged by the supporting chemical company plus that gained by implementing a Case Study approach.

The existing and developing literature was compared and searched for existing PSF classification schemes. If any were found, the intent was to select one structure for this research or to combine the best aspects from several, prior to adaptation for the chemical industry (PSF research had been predominantly undertaken both for and by the nuclear industry). Once a classification structure was established, it was expected that the AMAS work and ergonomic literature could be used to extend the structure to the stage of an initial PSF listing.

This literature based approach had to be checked and improved to ensure specificity for the industry. The method chosen to accomplish this, was to collect industrial information from existing company records and through selected case studies.

3.2.1 Company Records

The following types of company records were considered suitable for retrieving human performance information:

1.	Company Accident Reports	Historical records of all major plant incidents leading to employee injuries and factory inspectorate involvement.
2.	Medical Department Records	Record of medical treatment received on site by company personnel; reason for attendance, if an injury how it had occured, time of day, job title and plant

3.	Incident Reports	Any occurrences considered potentially unsafe or leading to minor injury or damage are recorded by those involved or witnessed and sent to the safety department

In addition the following plant retained records were expected to provide a source of human performance information:

4.	Plant log books	historical information of the day to day running of the plant (kept by the operators)
5.	Supervisor Records	weekly log of important occurrences and production records
6.	Computer Printout (where applicable)	the log produced by the computer on computer controlled plants. A record of key parameter updates, alarm information and operator control actions

3.2.2 Case study requirements

It was considered important to cover a range of technology, human demands and plant environment:

Technology :	low - manually operated medium - manually initiated high - computer controlled
Human Demands:	physical versus psychological
Environment:	chemical hazards (this was suspected to be a major influence on stress)

3.2.3 Case study techniques

Previous industrial research indicated a number of techniques that could prove successful during case studies (for example Umbers,1981 and Bainbridge 1968, 1974). The following were considered for use during this research:

1.	Verbal Protocol	the operator is asked to verbalise his thought processes during an activity period. This has proved successful with skilled performance tasks eg police drivers
2.	Observation	general consideration of the workplace and work activities. Both informal walk-around and formal techniques eg checklists, task analysis, link analysis
3.	Informal Discussion	used to explore a range of aspects and ideas. Allows uninhibited free association, suggestions and ideas from plant personnel
4.	Interview	structured attainment of information suspected to be pertinent to accidents / incidents - both specific and hypothesised
5.	Measurement	establishment of physical constraints (for example; heights, distances and areas)
6.	Self Participation	training on plant, learning the technology, process, system etc
7.	Task Analysis	specifically hierarchical task analysis - formalized technique for assessing what activities are actually undertaken and how they are allocated
8.	MORT	management oversight risk trees technique. Causal diagrams plus strucured assessment scheme for management system factors

3.2.4 The selected case studies

The choice of case study was based upon the initial criteria (section 3.2.1) and the opportunities available. Table 3.2.1 summarises the studies that were actually undertaken. In terms of the methodology, a common philosophy was established but varying in detail. For each case study the specific stages traversed are outlined in Figures 3.2.1 to 3.2.5. Note that the documentation used during the studies also varied, for example case studies D and E made no use of historical company records.

In addition to these plant specific case studies, accident records for the whole site were studied for a three year period 1980-1983. Where possible, that is where sufficient detail was given, any influencing factors were identified and recorded.

3.3 HOW TO IDENTIFY RELEVANT PSFS FOR SPECIFIC SITUATIONS

In order to develop the identification technique (relevant PSFs for specific situations) it was necessary to examine the **dynamics** of the data for their 'situational characteristics'. In other words the data had to be examined for links between some feature of the system (task type, error type, response type) and individual psfs.

The evidence had to be searched once for factors that affected performance and again to check for circumstances in which these factors were more likely to be present and more likely to have an effect.

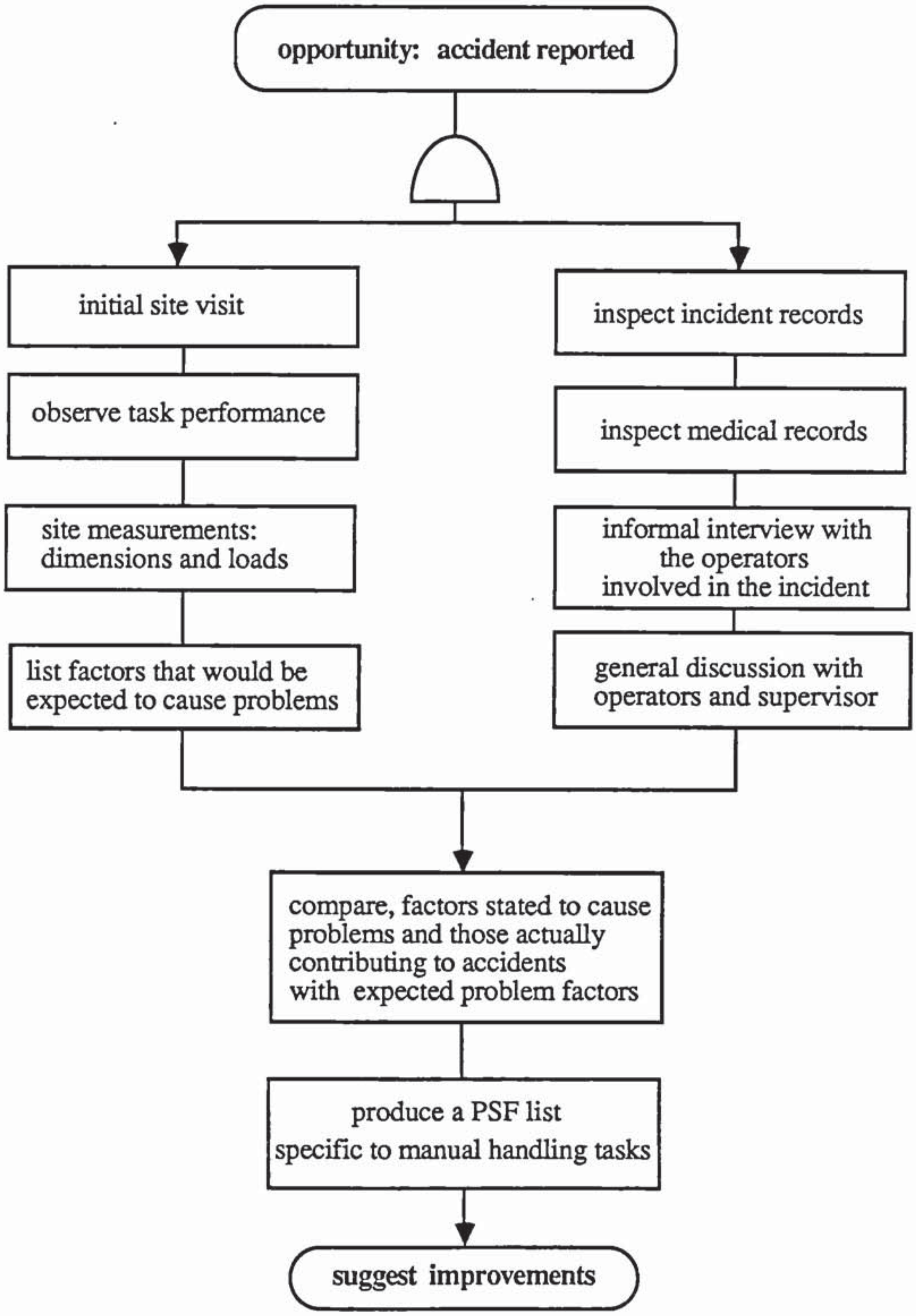
CASE STUDY	FEATURES	TECHNIQUES	PURPOSE
Case Study A	1. Low to Medium technology plant requiring manual operations plus some manually initiated tasks. The specific section considered was of LOW technology 2. High Physical demands - the sub-task considered was a manual handling task loading a powder mixer 3. Low chemical hazards- powder stable and inert	1. observation 2. measurement 3. discussion (operators, manager, supervisor) 4. interviews with operators 5. checks against incident, accident and medical reports	To consider a manual handling task which aspects may be leading to accidents - how could the situation be improved
Case Study B	1. Low to Medium technology, both manual and manually initiated operations. The whole plant and all the associated activities were considered. 2. High Physical demands 3. Low to Medium chemical hazards - known irritants	1. observation 2. measurement 3. discussion (operator, safety officer, design engineer) 4. incident / accident reports (before and after)	To help the transfer of a low technology plant from one site to another, improving the original but within equipment limitations
Case Study C	1. High technology plant, computer controlled. Some Low technology tasks 2. High Psychological demands, monitoring and fault diagnosis, DECISION MAKING. Some manual handling tasks 3. High chemical hazards, materials very toxic and corrosive.	1. observation 2. discussions (operators, supervisor, manager, design engineers, maintenance engineers) 3. self involvement ('training') 4. AMAS 5. information study (log books, supervisor logs, computer logs, incident records, medical records)	To study features influencing attitude and mental performance

TABLE 3.2.1a The selected Case Studies

CASE STUDY	FEATURES	TECHNIQUES	PURPOSE
Case Study D	1. Low technology plant, predominantly manual 2. High Physical demands plus High Psychological demands (but not specific decision making) 3. High chemical hazards,close personal proximity and likely contact	1.observation 2. formal discussions with supervisor 3. use of MORT technique	To consider the underlying causes of an incident. Policy and managerial influences on performance
Case Study E	1.Medium technology plant, predominantly manually initiated operations. 2. Medium Physical and Medium Psychological demands within sub-task considered 3. High chemical hazards and very close proximity (extremely toxic gas)	1. observation 2. measurement 3. discussion with safety officer	To improve the cylinder attachment area, including certain associated pipework. Remove the likelihood of a gasing incident

TABLE 3.2.1b The selected Case Studies

FIGURE 3.2.1 The Identifiable stages of Case Study A



3.2.2 Identifiable stages of Case Study B

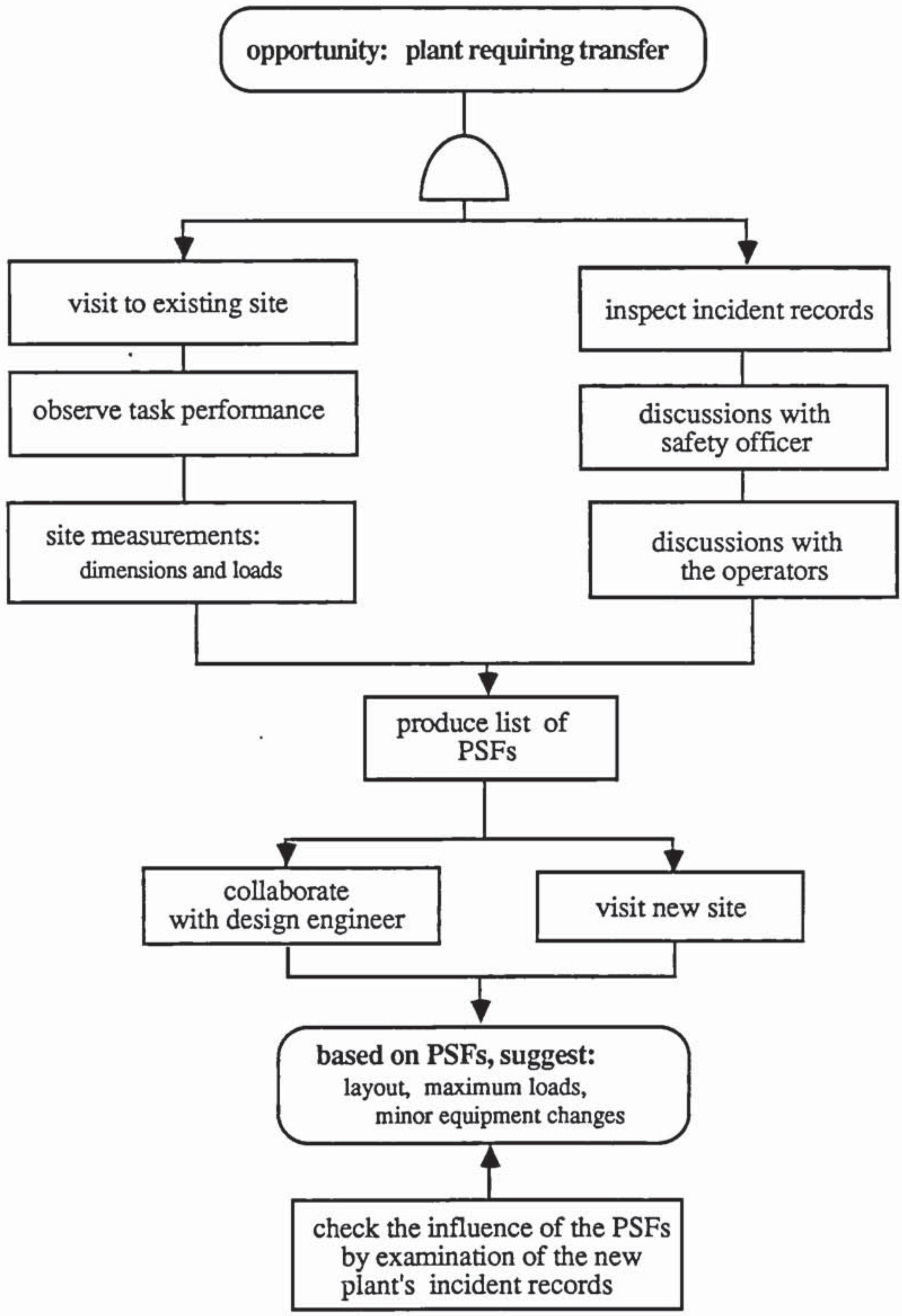


FIGURE 3.2.3 Identifiable stages of Case Study C

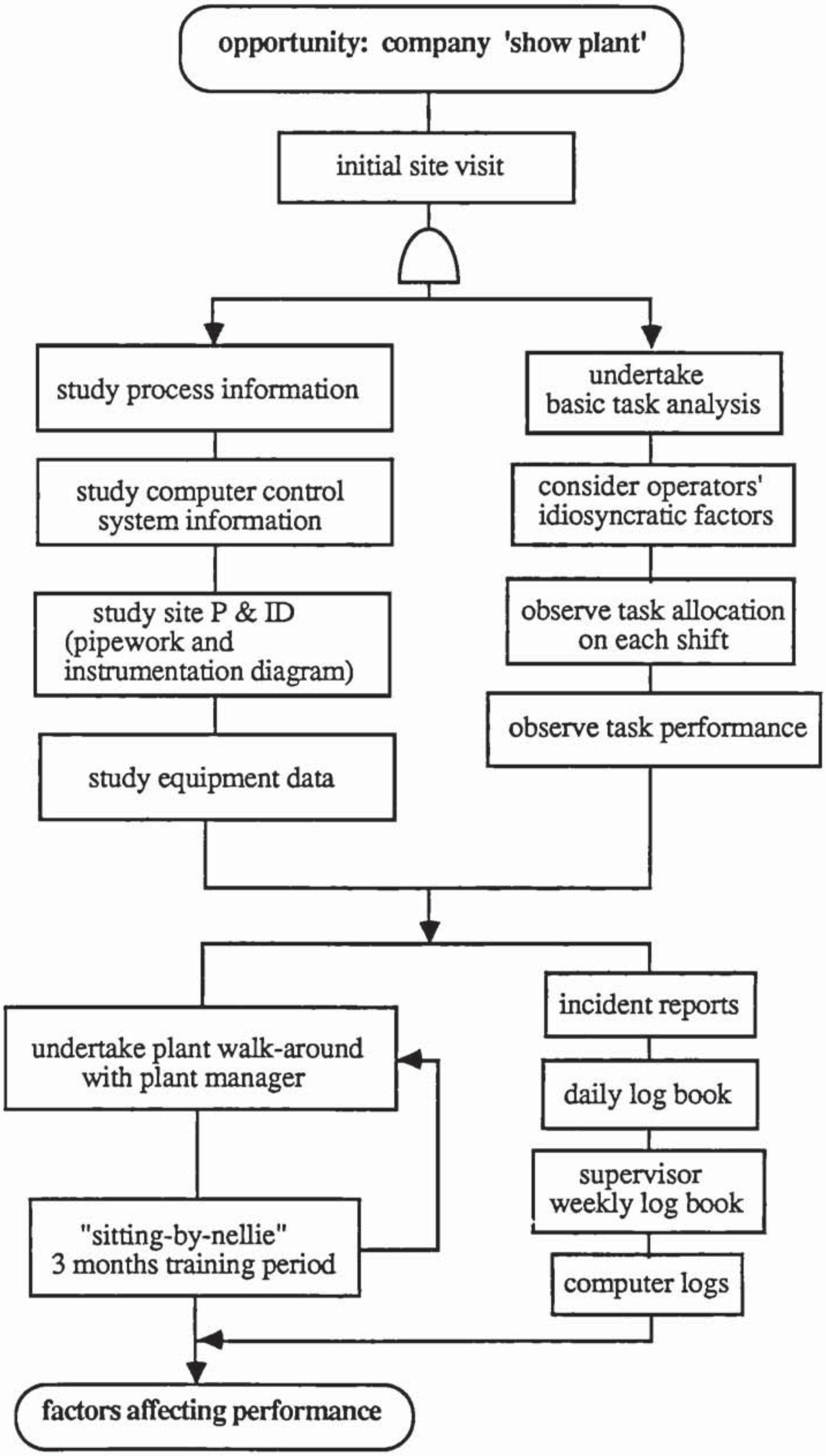


FIGURE 3.2.4 Identifiable Stages of Case Study D

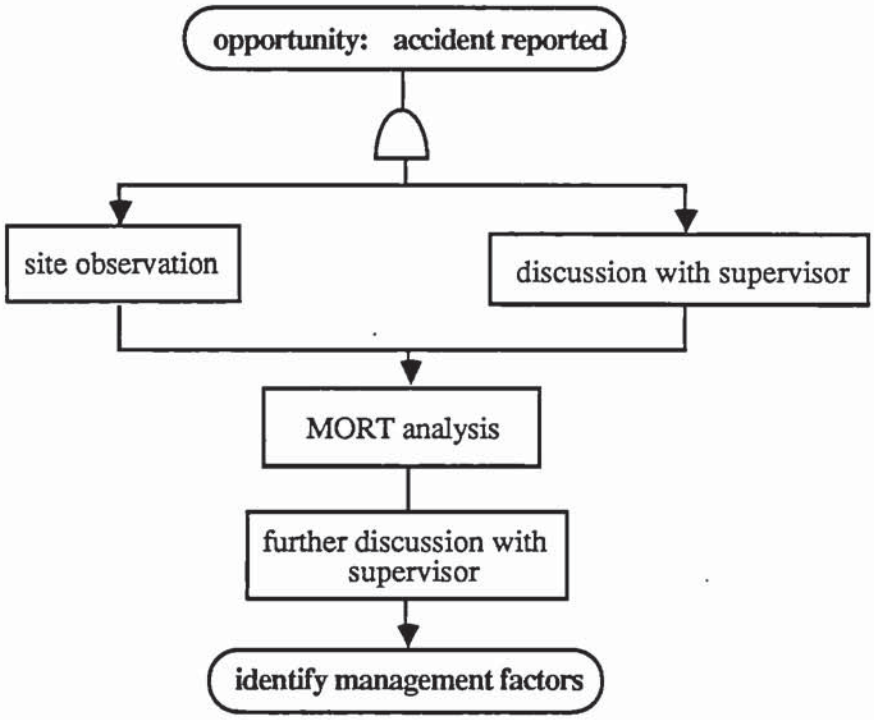
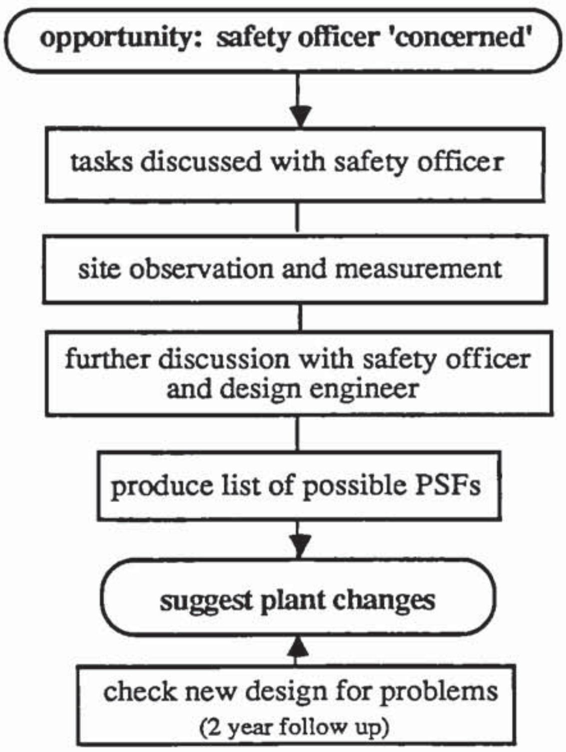


FIGURE 3.2.5 Identifiable stages of Case Study E



CHAPTER FOUR
INTERIM RESULTS

4.1 THE CASE STUDIES

Written reports were submitted to the sponsoring companies for three of the case studies (A, B and E). Note that case study E was in fact completed in late 1985 proceeding the development of the classification scheme and listing. These reports indicated the study method, the factors considered to have had an effect on safety and performance and the possible mechanisms for improving the performance shaping factors. Of particular interest were the factors considered to have had a **negative** influence. These have therefore been summarised and are given in Tables 4.1.1 - 4.1.3.

Case study D specifically considered the influence of managerial factors on performance using the technique 'Management Oversight Risk Trees' [Johnson 1980] to identify the particular factors that had influenced the incident. This technique is unique in its demand that the analyst determines whether the incident was in fact due to an 'assumed risk' (ie the potential had been identified but considered acceptable either in terms of cost vs benefit or the probability of occurrence), or an 'oversight and omission' (ie such an incident had not been thought of prior to the actual event). Either situation has implications for management and managerial effectiveness. Based on the evidence of the case study application plus subsequent use of the technique, it was acknowledged that although originally produced for the nuclear industry, the factors were pertinent to the chemical process industry. Since such a comprehensive coverage existed for management factors it was considered sufficient to produce a condensed set for inclusion within the PSF listing. The factors deemed to be of significant importance are presented in Table 4.1.4.

By far the most comprehensive and major case study was Case Study C. This involved the author training as an operator on the plant, spending a continuous period of three months at the plant which included one set of night shifts, discussions with plant personnel and observation of the difficulties facing a new recruit versus those facing the expert.

TABLE 4.1.1 The Main PSFs Identified During Case Study A

A. Key Events In Lost Time Accidents resulting from lifting
(site reports 1980-1983)

1. Lifting or carrying 50kg bags or drums

2. Handling (rather than lifting) 150kg, 175kg

3. Quantity of bags, e.g. 19 out of 20 bags before a problem

4. Abnormal loads, i.e. usually 25kg - only sometimes 50kg (muscles have not developed)

5. Temporary transfer to a different job (either same work, different plant or different work, same plant)

6. Carrying up steps

7. Height load lifted, e.g."22 inches" (36 kg maximum load for this height if a straight lift and hold, 72 kg if one lift only and put straight down), "45 inches" (maximum load of 20kg or 40kg)

8. Sudden exertion or prolonged exertion at extreme muscle tolerances. Key words; 'pulling', 'twisting', 'stretching', 'pushing' 100kg

9. Operator slipped

10. Two operators carrying and lifting together (6'-12')

11. 50kg, 84kg between two

12. Operator carried on working

TABLE 4.1.1(continued) The Main PSFs Identified During Case Study A

B. Specific Factors relating to the plant and task in Case Study A

1. 50 kg weights, these are too **heavy** for one operator.
(Although officially a one man job, a second operator usually **assists**)

2. Lifting and emptying the bottom two layers of bags from the pallet rather than the top three layers.
(The top bags can be slid off and carried but bottom bags needed lifting between 7" and 14" from the pallet to the level of the mixer opening & another 9" to place the bag at a carrying **height**, ie a lift of 16"-23")

3. Lack of **access space** on right side of pallet
(handicaps operator carrying on this side. Causes operator to **twist** to gain hold on load)

4. Lack of access space on right of pallet
(Extreme right rear corner of pallet is **inaccessible** without standing on the pallet)

5. Pallets are half boarded and could conceivably act as a **trip hazard**
(Possible fall over the edge from a 10 ft **open height** to the floor below, or trapping foot between boards)

6. **Co-ordination** is required when two people are carrying one bag, (particularly when lifting)

7. **Differences in strength** between two operators may cause imbalance and more risk for the strong operator.
(Similarly, **differences in height** can cause problems)

8. Although weights were the same on the **temporary job** the layout required a different work technique

9. Lack of **regular lifting training**
(this can allow poor lifting technique to become established)

10. The **mixer opening width** was insufficient for two people to place a bag in position for tipping
(there would always be concern about grazed or bruised knuckles)

TABLE 4.1.2 The Main PSFs Identified During Case Study B

Environmental

dust	work space	floor surface (slip hazard)
stairs	access space	emergency ladder
noise	limiting access	materials storage area

Equipment

work aids: lifting hoist	diameter of trolley wheels
height of vessel port holes	equipment labelling
dust container	protective clothing

Controls and Displays

scale compatibility	valve location
height of press handles	type of controller
electric panel control labelling	valve extensions
hoist controls identification	dial positioning
bar for opening/closing press plates (mechanised)	

Demands

carrying distances	lifting heights
weight of filled trays	pushing trolleys
weight of raw material	tray filling
pulling apart press tray coordination	

Displays

hoist warning light / hooter

Training

lifting

operating procedures

Materials

contact with personnel

TABLE 4.1.3 The Main PSFs Identified during case study E

Materials	
hazardous	close proximity
contact possible	
Environment	
workspace	workplace access
restricted escape access	obstructions
Controls and Displays	
gauge position relative to valves	horizontal reach
valve identification purpose and status	vertical reach
identification related to operating instructions	valve access
stereotype contravention	hand access
dial scale compatibility	valve choice
dial display visibility, conspicuity, colour coding	
Equipment	
safety equipment	safety equipment position
safety clothing eg air hoods	
pipework identification; contents, direction of flow	
Demands	
musculoskeletal loading	posture
rapid response in emergency	static holds
mental model (alternative routing through parallel pipework system)	

TABLE 4.1.4 Management 'Software' Factors

INFORMATION	
1	communication internal structure
2	communication external facilities
3	monitoring systems and assessment
4	data collection systems
5	documentation
MANAGEMENT POLICY	
6	risk assessment
7	safety programs
8	maintenance plans
9	operational policy
10	training
11	supervision
12	personnel selection
13	personnel motivation

4.1.1 **Case Study C - a microprocessor controlled high technology plant**

Initially, all the plant operators were visited on their different shifts in order to explain the purpose and requirements of the investigation and to ask for their reactions. Although doubt was expressed concerning the true nature of the work (the plant personnel had been informed that there would be a reduction in numbers in 1985) all agreed to the study taking place. Following these meetings, an introduction to the process and the plant was arranged. Relevant literature and flow diagrams were made available, and a tour of the plant took place.

The most important experience assisting this study was a two month training period as a Control Room operator. Surprisingly, the plant-specific training took the form of observation and hands-on experience overseen by the leading hand, with a couple of visits from the Plant Manager to assess the knowledge gained of the external plant. No systematic training took place, no training schedule emerged, and no training off the plant in terms of theory or simulation was given. In other words, the training received represented the traditional approach given to all new plant operatives. It must be pointed out however, that the original operator teams did receive theoretical classroom training and simulation exercises as the plant was commissioned and that the training was far more rigorous and structured.

Analysis of the system took several forms, amd made use of a range of assessment tools (Table 3.2.1., section 3.2.4)

Some sources of information proved more useful than others: The least profitable, due to long periods of passive interaction with the plant (ie monitoring tasks), was the verbal protocol technique. This only became apparent after gaining more experience of plant functioning and by attempting several verbal protocol recordings. The operator log book entries altered in content from plant handover to the time of this study. This was said to be due to a managerial complaint concerning the content (these records would act as a legal document in the event of an incident).

Although some information could be gained from the computer printout there were problems in linking together the output once removed from the printer. All the output had been saved from the plant's first commissioning phase to the present, but in no systematic order; the printouts had not been filed. Only certain types of information could be retrieved from the printouts, namely an hourly log of vital plant items plus set point or valve position alterations made by the operator. Any scanning activities were not noted, nor were any self-corrected errors, assuming they were identified before pressing the ENTER touch button.

It was observed that certain interface factors led to mistakes. The most predominant problem occurred on the VDU and caused repeated errors. This was due to an incompatibility between the commissioning engineer's mental model and that of the operator. Specifically, all but one output analog representation showed an increase, rise, or opening from left to right $0 \rightarrow 100\%$ on an horizontal indicator, the odd one out **decreased** from left to right. The reason for this was that the **fail-safe** position was always on the left but when operating it is difficult to remember this philosophy since in terms of control the stereotype is that the controls increase, open and raise to the right.

A second indirect cause of error was the audible alarm **silence button**. Situations had arisen where unqualified personnel had silenced the alarm whilst both operators were outside the control room. In this situation, if a new alarm occurs no audible alarm sounds to call the operators to attend and the plant can shut itself down. This has, in fact, happened.

During emergency fault diagnosis situations it was found that the Leading Hand had insufficient information available in the control room and that the meaning of some of the displayed information that was irregularly used was unclear, even with help from the fault diagnosis and instruction manual. A typical response pattern emerged: check displays, check VDU, ask the Number Two operator to undertake some status change on plant, check effect through VDU etc. There was a reluctance in some shift teams to give any responsibility to the Number Two operator.

The units used for Pressure indication on the microprocessor were millibars, whereas plant pressure indicators measured in bars or lb/in^2 and covered a range of different scale intervals. This could be a possible source of error if checking between two values or between the plant and VDU.

Another example of the influence of display design and communication was that; on the case study plant the product flowrate was measured in m^3/hr whereas at the receiver plant the units were lbs/hr. Although both teams were aware of this discrepancy some problems had occurred from time to time.

The most fundamental limiting factor for error data collection during this case study was that unexpected events rarely happened between 07.30 hrs and 16.30 hrs, the normal time period monitored during the assessment. Even the night shifts were relatively trouble free. This could have been due to an increase in the level of motivation of plant personnel (due to the interest shown in them during the study), resulting in their identification and correction of potential problems before they occurred. Alternatively this may have been part of a general trend in problem reduction as the plant equipment became more stable after nearly three years of operation. Some evidence for the effect of different Performance Shaping Factors during **normal** plant operation was established, but it was less easy to generalise from these data to establish their effect on an "incident" or a period of operator fault finding.

One set of four night shifts (19.00 - 07.00) was completed in order to gain some impression of the difference in working conditions between night and day.

The normal shift pattern is:	Four Night Shifts (18:00 - 06:00),	four days off
	Four Day Shifts (06:00 - 18:00),	four days off

During the study it became apparent that the two operators who worked together during each shift fulfilled separate functions. This had been engineered to a certain extent by a management decision to confer the title of Acting Leading Hand on one operator out of each pair. The basic differences were:

	Acting Leading Hand	Operator
1	control room based	plant based
2	sound knowledge of plant and microprocessor	sound knowledge of plant but limited knowledge of microprocessor
3	organises own work schedule within plant limits	organises own work schedule within plant limits and LH's discretion
4	decision making if plant problems occur	undertakes requested tasks and assists on plant
5	fault diagnosis	fault reporting from hourly plant checks
6	responsible for the safety of maintenance personnel, visitors and operator	no personnel responsibility
7	undertakes minor plant repairs	assists with repairs
8	mainly information processing tasks	mainly physical tasks

These role differences meant that any factors influencing their work would have differing importance for each operator. An overview of the differing task demands demonstrated by two high level heirarchical task analyses is given in figures 4.1.1. and 4.1.2. The split between control room and plant tasks is given in table 4.1.5. The most obvious personality difference between the two operators on each shift was that generally if any visitors arrived the Leading Hand had to assume the initiative, whilst the other operator withdrew. Even if the Leading Hand was not available, the Number Two operator would go out on plant or keep a low profile unless specifically asked for information. Apparently this was mainly due to this operator viewing the reception of visitors as the Leading Hand's job.

A prevalent opinion of the Leading Hands was that the second operator was really there as a "safety man", and that with very few modifications the job could be undertaken by just one operator, except for reasons of safety.

Another interesting facet of plant manning was the role of the Supervisor on a microcomputer controlled plant. Due to the various responsibilities and hours of work (08.00 to 16.30 hours for five days a week) it was difficult for the Supervisor to assume overall responsibility for a plant that requires a significant amount of practical experience to run successfully during problem periods, or to fault find. During such situations the Supervisor couldnot assume an advisory capacity. This particular Supervisor attempted to minimise this fundamental problem by logging any information gained from previous incidents, so building up a history of cause and effect. Day to day running of the plant had to be left to the Leading Hands, with only special requests or long term planning evolving from the Supervisor or Manager. The day to day operating requirements do not change in the way that they must in multi-product plants.

Note that the general company philosophy of manager and supervisor rotation from plant to plant could add to the difficulty of these individuals in assuming an authoritative or advisory role. In addition this plant manager had responsibility for three Supervisors and a total of nine plants, whilst the Supervisor had a second plant in his charge - though both plants were related since the case study plant produced the feedstock for the second.

FIGURE 4.1.1 Leading Hand. Task Analysis - Primary Level

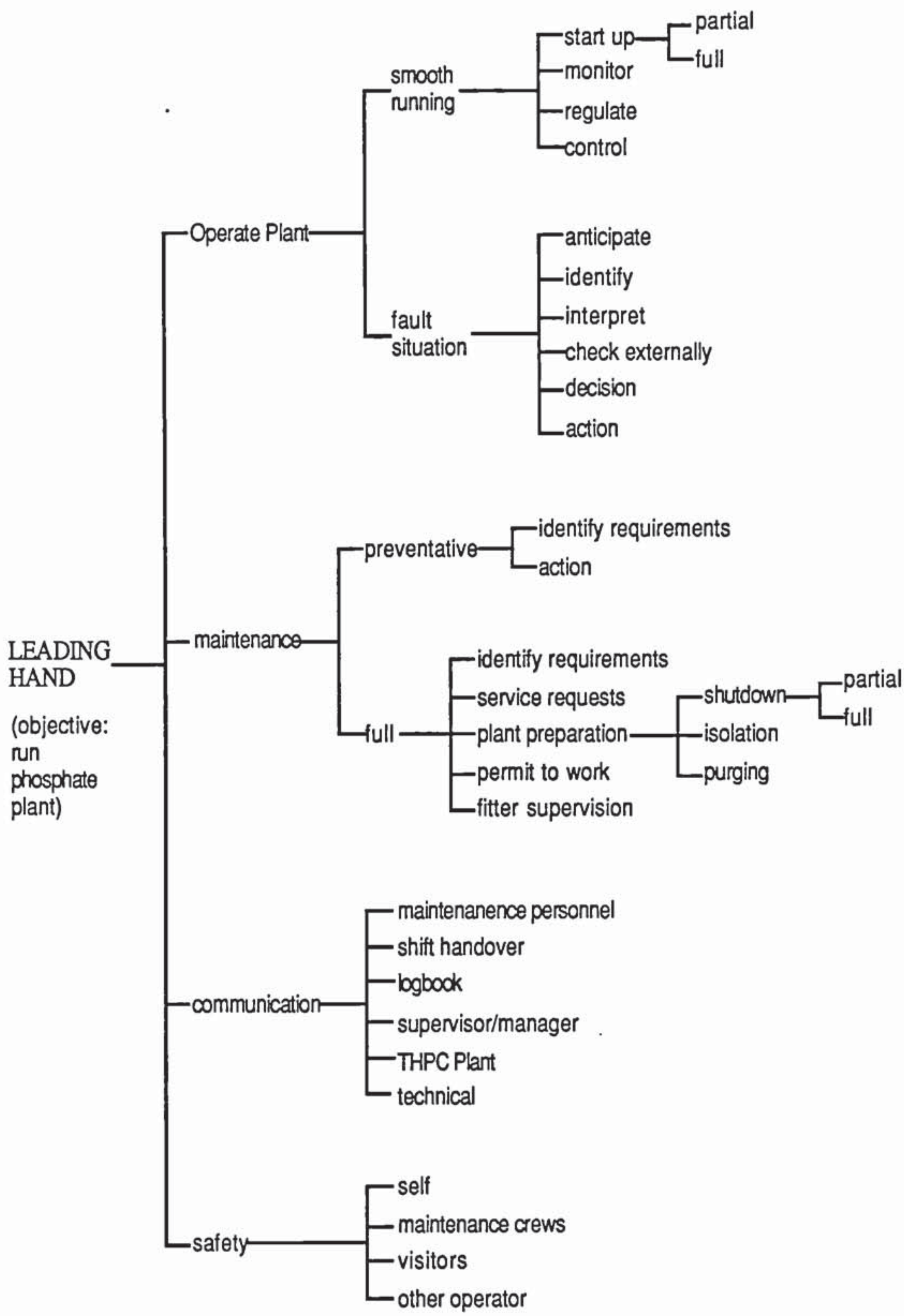
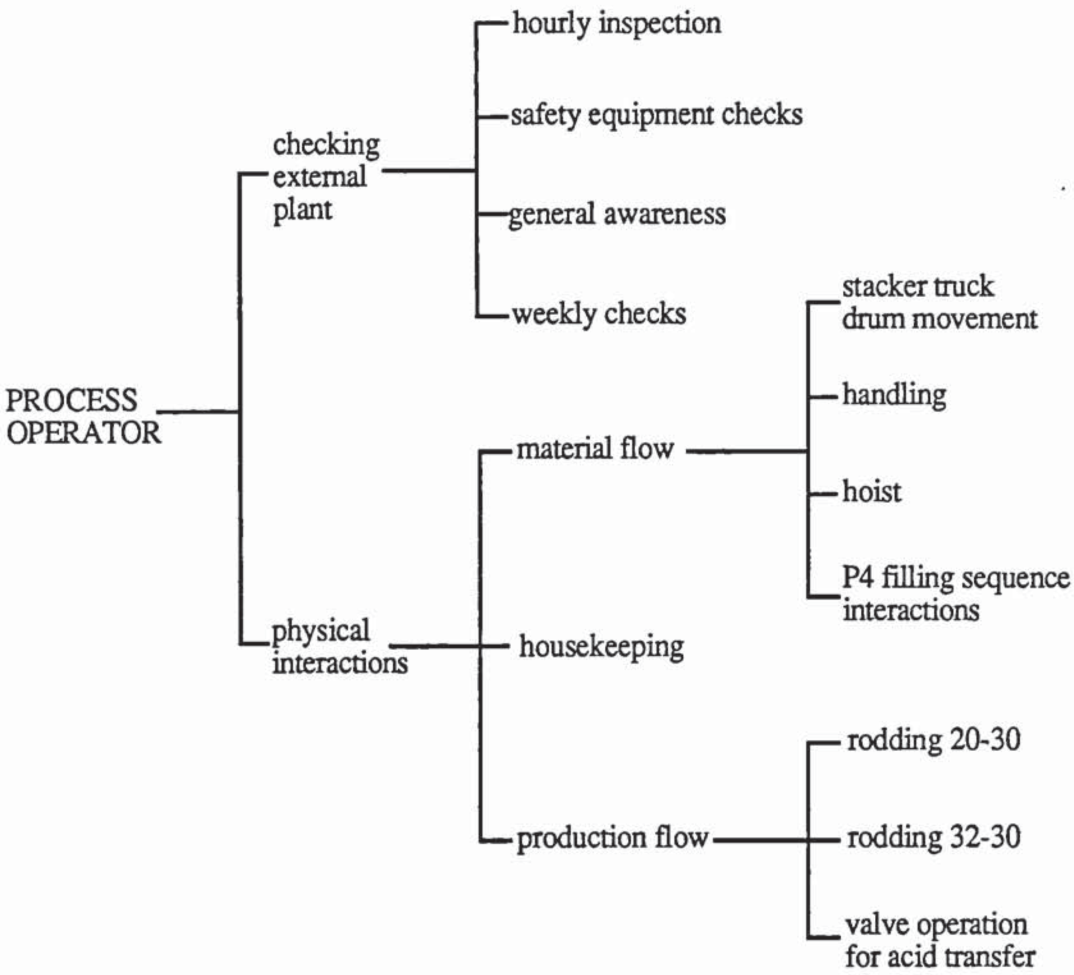


FIGURE 4.1.2 Number Two Operator Task Analysis



In order to assess the type of job demands an Activity Matching Ability System (Whalley and Watson) activity assessment booklet was completed by four of the eight operators (two acting leading hands and two number two operators). A copy of the AMAS information is given in appendix 2. This information indicated that there were some differences in the influential Performance Shaping Factors dependent upon the job role.

Cases of human failure taken from the supervisor logs for this plant during 1982 and 1983 are given in table 4.1.6. Looking at the fitter errors in more detail this six comprised:

1 too small an electrode sleeve fitted

2 non-return valve placed the wrong way round in the nitrogen line

3 bolts missing on pump discharge flange

4 discharge port on water jacket welded to reactor jacket

5 non-return valve from gas holder to compressor placed in line the wrong way round

6 the wrong type of thermocouple was supplied and fitted

The maintenance schedule problems were due in the main to incompleted work.

It became apparent from the supervisor log that operator performance was impossible to judge. It was easy to record fitting and maintenance errors, poor plant performance and equipment failures, but due to the nature of the plant and role of the supervisor virtually all operator 'human errors' were covert and impossible to observe directly.

TABLE 4.1.5 <u>Case Study C: Operator Tasks</u>

1.0	**CONTROL ROOM TASKS**
1.1	Start up (full/partial)
1.2	Shut down (full/partial)
1.3	Acid Drop and Acid to Demountable Tanks
1.4	Pump Back
1.5	Monitor/Alter feed rates (dependent on user plant THPC)
1.6	Monitor/Alter temperatures (effects gas quality)
1.7	Monitor plant pressures (fault warning)
1.8	Use of trends for extra monitoring facility (eg check gas used by THPC, check automatic pump back working normally, temperature constant, pressure constant)
1.9	Hourly Logs (scan VDU screens & note important aspects on standard plant log sheet)
1.10	Fault Diagnosis
1.11	Service Requests (dependent upon 2.1)
1.12	Permit to Work (dependent upon 2.2)
1.13	Responsibility for visitors/plant personnel safety
2.0	**CONTROL ROOM / PLANT TASKS**
2.1	Fault Diagnosis
2.2	Isolating, purging and ensuring plant safety for maintenance (similar tasks can be required during start up/shut down)
3.0	**PLANT TASKS**
3.1	Hourly Checks (visual inspection of plant)
3.2	Monitoring Water Flows (visual nb. seal pots)
3.3	Daily Checks (bleeding instrument air pipes)
3.4	Weekly Checks (eg switch over air compressors)
3.5	Loading Melter
3.6	Driving Stacker Truck
3.7	Burning off drums
3.8	Labelling Drums
3.9	Housekeeping
3.10	Small maintenance jobs if assistance unavailable
3.11	Minor safety repairs if assistance unavailable (eg weekends or night shift)

TABLE 4.1.6 Errors Identified From Supervisor's Log

ERROR TYPE	1982	1983	TOTAL
no spares	3	5	**8**
maintenance schedule	6	1	**7**
fitting error	3	3	**6**
communication	1	0	**1**
system fault	2	1	**3**
drawing board design error	4	0	**4**
computer configuration error	4	0	**4**
power cuts	1	0	**1**
lost towns water	1	0	**1**

Six months after the author's full time training period a self report system was established so that with co-operation from the plant personnel the operators could indicate problems that had arisen but were not of significant importance to complete an incident report. It was hoped that this informal and anonymous logging would give some insight into the factors that influenced operational performance. This logging occured from the beginning of December 1984 to the end of January 1985, a two month period.

This self report system took the form of anonymously completed cards (Appendix 3) which were placed into plain envelopes and collected on a regular basis. The cards included an initial PSF and keyword listing developed from case studies A, B, C and D, the literature and company records. Three important questions were included that covered aspects that had proved to be important:

1. Has this ever happened before?
2. Was it Absent Minded?
3. Was it self corrected?

Prior to the cards being left on the plant, the purpose was explained to each operator along with the method of completion. It was hoped that important PSFs would be identified and correspondingly ticked on the error collection card. A summary of the process problems encountered plus a collection of the indicated PSFs is presented in Table 4.1.7a, b and c.

Some cards were completed for events that could not be considered as operator initiated but they did describe the type of problems that can face an operator due to equipment or instrumentation failure. It was considered that this information was a useful addition to the developing profile of factors affecting human reliability. Note also that in two cases no PSFs were given. From discussion with the operators it was indicated that the PSF profile section was difficult to complete. For any subsequent application some changes would have to be made for the error collection cards.

Case study C provided some of the most useful insights into Performance Shaping Factors, particularly those of a more psychological and personal nature. The experience also indicated that such a methodology could provide a better understanding of mainly covert behaviour typical of a predominantly microprocessor controlled plant.

4.1.2 To Summarise

The case studies are in some ways complete in themselves, but must be considered as a group and as a step towards a better understanding of how factors within a system influence associated personnel and how in turn the people affect the system. Performance of people cannot be separated from system performance.

Seminara used the principle of Case Studies to look at the design of nuclear power plant control room displays, and at control design and its effect on performance. Indeed, he noted that operators had in several instances modified the control panels themselves as a response to near miss situations. In a more recent report (1980) Seminara states that;

> " each control room needs to be reviewed on a case by case basis for specific enhancement recommendations".

It is in recognition of this belief that this research has used case studies to assist the development of a Methodology to provide design guidance.

TABLE 4.1.7a <u>Summary Of Error Collection Card Scenarios</u>

Card No	PSF Numbers	Description	time	w-end/ week	control rm/plant	previous occurrence	absent minded	self corrected	equipment	control	display
1	6,8,25,38,47,80 83,84,86,89,99 111,117,121,125 137,146,149,152	Blockage in hot water supply from item 15 -> 12 (note item no. sequence)	10.00	w-end		√	×	√	items 15,12	13FIC1	13FIC1
2	none given (* 120,121,126)	Full acid tanks - wanted to send acid to effluent but unable to due to <u>new automatic cutout pump</u> 36 (nb tanks should <u>not</u> have been full)	23.10	week	plant	×	×	√	acid tank		control box plant
3	4,36,46,74,83 120,121,124 130,138,142	blocked line from 38 to demountable tank	14.00	week	plant	√	partly	×	item 38	32LIC1	32LIC1
4	38,77,83,87 111,127,138	reduced flow from displacement water header tank item 15 -> increased % output 13fIC1 -> PV falling -> feed reduced to converter 2 alternative corrective measures one causes automatic shutdown	09.30	w-end		√	×	√	items 15,12	13FIC1	13FIC1
5	3,36,39,74 77,80,83,87 120,143	leak on impulse line, told by previous shift went to inspect up removable ladder - manual valve actually on impulse line - ruptured pipe	11.00	week	plant	√	×	√	pipework		
6	36,39,40,74 83,87,96,139	frost burst diaphragm pressure relief valve - box opened and 5 gallons over operator	10.00	week	plant	√	×	√	75CPA		annunc panel low pressure item 50

Card No	PSF Numbers	Description	time	w-end/ week	control rm/plant	previous occurrence	absent minded	self corrected	equipment	control	display
7	68,82,86,102 105,113,148	static electricity discharge through right arm	18.20	week	control room	×	—	—	new chair		
8	74,83,86 95,96	lost feed to 13FIC1 discovered town water feed line ruptured no indication until water runs out the leak could have been spotted visually	06.30	week	control room	×	×	×	town water line	13FIC1	13FIC1
9	3,5,55,58,60 61,96,108,145 146	rod stuck in rodding point caused shutdown (trying to restart after shutdown caused by personnel mismanagement; no leading hands available for saturday shift	day	w-end	plant	×	×	×	item 20 item 30 rodding point	auto rodder	—
10	78,112,118	tanker took part of filling point with it on leaving	15.00	week	plant	?	√	×	filling point platform	—	—
11	74,86,95,125	cleaning out emergency baths - water froze causing slip hazard - gritted	07.00	week	plant	?	√	√	emergency baths	—	—
12	none given	reactor high pressure alarm - automatic shutdown. condenser back-pressure build up condenser temperature raised, flow reduced restarted at 06.57	06.53	week	control room	√	×	√	item 50		51mbar alarm 50 52FI1
13	none given	fire on central electrode gland	04.00	w-end	plant	√	√	√			

TABLE 4.1.7c Summary Of Error Collection Card Scenarios

Card No	PSF Numbers	Description	time	w-end/ week	control rm/plant	previous occurrence	absent minded	self corrected	equipment	control	display
14	74	Gas line to pilot plant frozen up and unable to transfer gas - pressure gauge frozen, no warning on local gauge pilot plant (fault diagnosis) nb should have been steam traced	11.00	week	both	×	×	√	gas line		pressure gauge local gauge
15	2,6,18,38 74,84,123 125	plant pressure associated with condenser flows. buildup shown on VDU steam lanced areas, plant shutdown gas through to combustion unit nitrogen purge to keep seals plant restarted but down again in morning	18.00-06.00	week	plant	√	×	√	item 50		
16	74,88,98 141,142	purging plant with nitrogen for repairs gas inlet blocked up, combustion unit blocked, all seals blown. removal of flame arrester in combustion unit to clean opened sampling point c/u and using hose bleed into bucket. flame arrester checked only twice a year	18.30	week	both	√ last cold spell 3 years previous	—	√	combus-tion unit	69V2 manual valve shut	
17	3,6,8,11,14 18,19,22,142	total failure town water supply to plant no displacement water no emergency cooling water (turned off elsewhere and plant not informed) Initial Fault Diagnosis	15.20	week	both	—	—	—			TWL A-1 (didn't work) PI (didn't work)
18	1,6,8,14,18,22 40,61,83,91 105,110, 117 125,130,138	feed water dropping off 13FIC1 blockages and rotting head tank	09.30	week	both	√	×	×	header tank item 14 item 12	13FIC1	13FIC1

4.2 GENERAL SITE INFORMATION

A review was undertaken of all the unsafe incident records for the site from 1977 to 1979 inclusive, a total of 133 reports. All but one of these had resulted in some form of minor injury.

These reports were generally completed by supervisors and contained four standard pieces of information; the Date (including the day of the week), the Time of day, whether Indoors or Outdoors and whether a Normal operation. This was followed by a short description of the incident and the injury. Obviously, some reports were more detailed than others - in some cases PSFs were mentioned and in others no mention was made at all.

e.g. Monday 10.40 am, normal operation, indoors,
carrying glass beaker, caught it against the desk edge and it broke.

It is possible to hypothesise about the cause of such a slip but this should not be used as evidence towards the identification of PSFs. From some of these incidents psychological aspects of a task could be inferred. This type of report, however, was still important in developing the concepts that led to the method of identifying PSFs and understanding the different types of error and their underlying causes.

Of the 133 reports, 87 included the direct identification of Performance Shaping Factors. Certain types of PSFs are far easier to recognize and report than others, psychological and personality factors had to be inferred.

A list of all the directly mentioned PSFs and the inferred PSFs (marked with an asterix) have been collated and are presented in Table 4.2.1. These are ordered by the dominant PSF group and are followed by their incident number record in brackets.

One other aspect that was checked was whether the incident rate was higher on certain days of the week than others. There is a traditional belief in industry that Mondays and Fridays are more error prone due to personality factors. The Monday morning return to work effect and on Friday afternoon people looking forward to the weekend. The chemical industry does however include a high proportion of shift workers which would spread out the Monday morning / Friday afternoon effect.

The only significant difference due to the day of the week was a lower level at the weekends, this could be due to non-reporting or to the reduction in workforce on site, or possibly due to less distraction and pressure. This evidence would suggest that the Monday / Friday belief is a fallacy possibly built up due to the tradition of blaming the individual who has an accident (carelessness, negligence). Similarly there was no obvious 'time of day' pattern.

TABLE 4.2.2 Distribution of incidents by Day of Week

DAY		Number of Incidents
Monday	:	24
Tuesday	:	33
Wednesday	:	19
Thursday	:	23
Friday	:	21
Saturday	:	3
Sunday	:	8

TABLE 4.2.1. Performance Shaping Factors indicated in site incident records
(number in brackets = incident record number)

Physical Demands

1 turning whilst lifting (6)
2 two workers carrying together (9)
3 moving 45 gallon drum (12)
4 two operators moving 200kg drum (26)
5 attempted to use fingers to lift manhole lid (29)
6 accuracy required when hitting wedge (69)
7 difficult to remove excess liquid from drum tops (72)
8 two workers tightening nuts on extractor together (81)
9 tightening clips on new hose to tanker spigot (93)
10 loco driver unable to see obstruction on track (100)
11 tried to straighten 45 gallon drum (111)
12 belting hopper side with tubing to improve product flow when filling bins (114)
13 carrying 50kg bag upstairs (123)

Psychological Demands

* 1 risk perception (4)
* 2 risk taking (11)
* 3 knowledge - battery overcharged (42)
* 4 memory (46)
* 5 risk perception - water from glove into syringe (49)
6 identification of correct bottle (51)
* 7 risk perception (71)
* 8 mental model - during fault diagnosis (72)
* 9 mental model - isolating valve position (80)
10 dependency on previous shifts (90)
* 11 risk perception re cleaning powder (92)
* 12 mental model + experience and knowledge - surprised activator spring loaded but the bar would not have been on otherwise (94)
13 problems of moving position on ladder not considered (95)
14 the individual considered that the fume ducting was not close enough to the rail track to be struck by the loco (100)
* 15 risk recognition of scaffold platform boards for two men's weight (113)

16 assembly of metal file (130)

* 17 responding to alarm, moving quickly? (133)

Controls

1 valve very stiff (14)

2 valve beneath tank near floor, access by crawling (80)

3 position isolation valve obstructing vehicle workspace, cut head (125)

Equipment Layout

1 water and steam pipes very close together (7)

2 pipework arranged along bottom of step immediately inside office door (30)

Equipment

1 slippery (8)

2 drum corroded (15)

3 incorrectly sized 'o' ring (20)

4 fume duct extension at bottom of hopper gave way (bolt came out) (40)

5 needs some form of drainage (48)

6 testing cubicle open fronted, perspex recommended (49)

7 damaged cover on motor chain drive and gearbox (57)

8 vent hole required in drum (61)

9 lip of drum makes excess product removal difficult (73)

10 unlagged steam main (75)

11 brick plinths beneath pipework eroded/damaged (bolt came out) (40)

12 loose equipment connections (90)

13 roof fans cause acid problem when raining, dissolved fumes (101)

Access

1 small step into office (30)

2 catwalk plate missing (32)

3 obstructed access (35)

4 walking backwards, tripped over long pipe left by fitter (38)

5 tripped over 1/2" steam drain line which had been raised with a fitting component (39)

6 standing on chair to reach item from storage area (84)

7 walking through building struck knee on protruding scaffold (98)

8 scrapped fuel ducting lying on ground near rail track, train hit it and it hit

operator (100)

9 gap between top step and cabin, foot slipped between (107)

10 trailing polythene strapping from pallet partly over gangway (110)

11 untidy floor space, caught lab coat on equipment when passing (121)

12 width of staircase stair rails (123)

Personality/Emotions

* 1 distracted - without thinking started cutting wheel (67)

* 2 returning for forgotten gloves at end of work - hurrying? annoyed? (77)

3 several reminders to wear goggles but not worn (78)

4 previously directed to wrong delivery point (93)

5 original hose very thin, asked for signed permission to use it - denied (93)

* 6 prepared to risk- take to get job done, steps not fully open, insufficient space (95)

* 7 operators fighting

8 responding to alarm

Operator Clothing

1 safety glasses (8)

2 self contained breathing sets (9)

3 not wearing gloves (11)

4 pvc gauntlets (12)

5 overalls difficult to remove (15)

6 helmet fell to ground and struck eye (27)

7 safety glasses worn (24)

8 full face breathing mask (28)

9 wearing goggles (33)

10 wearing safety spectacles (43)

11 possible acid transfer to eyes from gloves (45)

12 tunnel vision, safety glasses perforated metal side peices instead of transparent (46)

13 try three piece PVC suit instead of all-in-ones (48)

14 wearing helmet, eye glasses and rubber testing gloves (49)

15 fumes entered protective clothing
(wearing 2 pairs gloves + protecting arm sleeves) (52)

16 need industrial hair nets (59)

17 should wear goggles (61)

18 slow replacing goggles (67)
19 wearing goggles (74)
20 not wearing goggles (78)
21 fumes came through mask, diaphragm valve split (91)
22 gloves worn, flask slipped through hands (96)
23 gloves not worn, product on stilson handle (99)
24 facial characteristics - safety glasses S82CGC slid down nose (101)
25 oilmaster helmet less peaked than tuffmaster (101)
26 wearing eye protection (109)
27 safety glasses slipped down face (114)

Environment

1 poor lighting (8)
2 fumes (9)
3 toxic (11)
4 vision obscured by fumes (24)
5 windy conditions (33)
6 poor light (36)
7 dust blown into eye (42)
8 wisps of fume disguising trace fumes (53)
9 noisy (67)
10 dark (77)
11 poor lighting (93)
12 polythene sheet dropped from stanchion - acid trap (101)
13 dark (107)
14 wind blew powder into eyes (109)
15 light above steps broken (110)
16 vibration of vehicle movement (111)

Floor Surface

1 spraying water on fire, slipped (15)
2 slipped whilst discharging from hopper (27)
3 stepped on uneven ground (34)
4 slipped on building material left on floor by contractors (36)
5 rough road surface, stepped in pothole (64)
6 slippery due to compacted snow (76)
7 slippery ice surface yet had been gritted and salted (77)

8 old boards accross scaffolding showed signs of old spillages, broke in half widthways (113)
9 slippery floor surface (133)

Work Space

1 lodged frame on cabinet (2)
2 restricted storage space (4)
3 insufficient space (8)
4 untidy (10)
5 protruding tag on metal drum (10)
* 6 equipment access (11)
7 insufficient work space (23)
8 obstruction by drum (26)
9 insufficient work space (36)
10 scaffolding present for repair work (40)
11 fume extractor restricting vision (53)
12 working inside reactor - restricted space (62)
13 workbench slippery (79)
14 insufficient work space 80
15 no horizontal area to rest sample jar (91)
16 untidy area (93)
17 insufficient workspace for stepladder opened (95)
18 pallet of drums in vehicle (111)

Materials

1 scalding steam (7)
2 scalding hot tea (18)
3 steam line - pressure (23)
4 toxic fumes after fire (28)
5 leaking toxic vapour (41)
6 chemical reaction between materials emitting fumes (50)
7 corrosive fumes (52)
8 fumes coming off of damp product (71)
9 fumes (91)
10 cleaning powder in toilet (92)
11 shirt sleeves caught fire - product splashed then dried - spontaneous combustion (92)

12 burn to right hand from product on stillson handle (99)

Displays

1 no labelling of product drums (50)

Work Aids

1 used second key to knock valve key - unofficial aid (14)
2 had no lifters for manhole lid (29)
3 very cumbersome sample collection dip (very long handle) (71)

Procedures

1 inadequate stock of spares (20)
2 normal cleaning hose out of action (44)
3 should have been scheduled operation (48)
4 mixing, labelling and unlabelling drums on pallet (50)
5 left a bottle with stopper removed (51)
6 inspection of drums before/during reconditioning (53)
7 trained by watching experienced operators **
8 in future regular breathing apparatus checks (71)
9 operator pre-use test procedure (91)
10 post-use cleaning procedure (91)
11 steps not lashed or held by another (95)
12 drums not fastened on pallet (111)
13 fire alarm system not serviced since installed (129)
14 system of work (151)

Information

1 no instructions for equipment use (21)
2 no operating instructions (50)
3 no operating instructions (57)
4 no instructions for inspection method (71)
5 non-reporting of equipment problems (73)

CHAPTER FIVE

THE PERFORMANCE SHAPING FACTOR CLASSIFICATION STRUCTURE AND COMPREHENSIVE LISTING

5.1 THE CLASSIFICATION STRUCTURE

The most important initial decision for the classification structure was whether to follow the approach of Swain and Guttmann and Embrey: Explicitly, whether **stressors** should be used as a classification group or not. It was decided that a specific group of PSFs designated as stressors would be misleading and possibly counterproductive. Such a classification would suggest on the one hand that a factor not occuring in this branch could not influence the individuals perception and experience of stress, whilst on the other had if a PSF from the stress group did exist then this would automatically impart a negative effect on performance. Singh's first level of classification was accepted as the initial divide for this structure (Singh 1982). One small modification that occurred due to feedback from potential users (engineers and managers) was to rename the idiosyncratic section: Personnel. The term idiosyncratic was considered to be potentially misleading and 'emotive jargon' whose definition was not immediately explicit to the layman.

Singhs suggested structure did not descend below this point. It is impossible to explicitly demonstrate how the subsequent levels of subclassification were achieved but the general reasoning was to sub-group into sections of related PSFs (from an auditing point of view) and by the type of techniques needed to gain the information.

1. Type A Process Factors

A distinction could be made between the general characteristics of the **process chemistry** (established at the inception of the plant design by the chemical engineer and basically unchangeable after this point), and the **technology** (established by the P&ID and at least partially based on company policy, this can be altered but with difficulty and expense, ie by radical plant modification). The nature of the **materials** is virtually fixed by the product requirements but from the personnel point of view these can be variable (batch plants where different products are produced using the same process equipment).

2. Type B Personnel

It was recognised that some features of the personnel can be regulated whilst others cannot. Therefore those aspects which the management and the company could have some control over are considered in the most detail. The personality factors important for a particular type of job can be considered during personnel selection training and assessment but there are always factors of a more dynamic nature that can change over time and circumstances. Management need to be aware of these factors and consider them when designing their system support features. Note that in at least one aviation company in the United States the pilots are positively encouraged to report ill health or personal problems which they feel may affect their performance, placing them in desk jobs during the critical period of time.

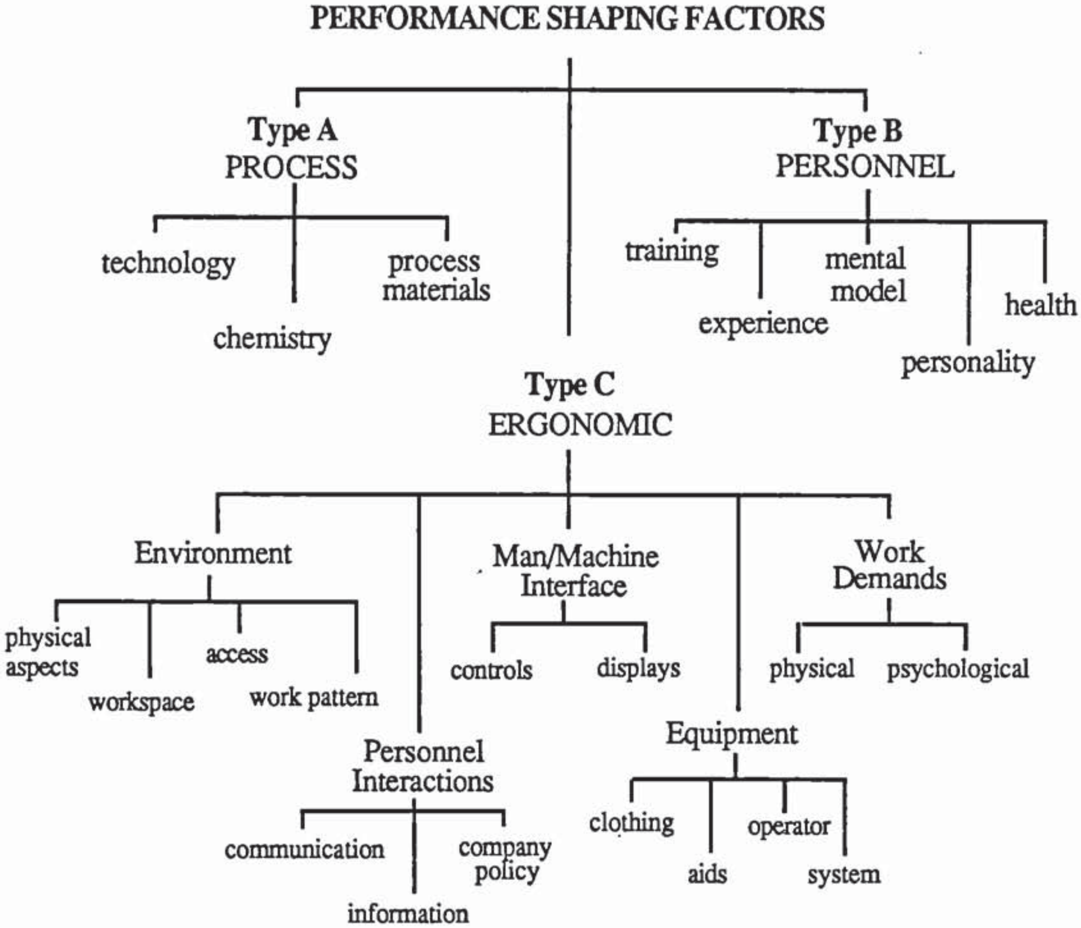
The distinctions in Section B are therefore between the training requirements, general experience, assessment of the individuals mental model, personality traits for use during personnel selection and aspects of health. It was considered that the **health** group which is subdivided into Recent Illness and Fitness could encorporate within the fitness section a profile of an individuals ability to compensate for the demands of a job. This would specifically cater for jobs that cannot be designed or modified to acceptable ergonomic standards.

3. Type C Ergonomic

The main section of the PSF classification, Section C, is that defined as Ergonomic PSFs. This includes five subdivisions all of which have lower sub groups before reaching individual PSFs. From an auditing point of view or design responsibility the first few groups are straightforward: the **Environment** and **Work Conditions,** the different forms of **Equipment,** the traditional **Interface Desigı** and **Personnel Interactions** (again proved to be of importance in the Challenger Space Shuttle and Chernobyl disasters). The fifth group: **Work Demands** (assessed by task analysis methods) has a more dynamic role. Obviously if the demands of a job fall beyond the abilities of most people then either these must be changed or the personnel selection function must be informed and specific personnel selected. Obviously the size and type of labour pool will have a great effect on this strategy. The basis of this group of PSFs was taken from the Activity Matching Ability System (Whalley and Watson)

The final classification structure is shown in figure 5.1.1. More recently it has been suggested (Lihou) that this structure should be extended to include a section entitled Corporate Facilities to tackle in order the situation of subsidiary companies and locationally separated parent bodies.

FIGURE 5.1.1 The PSF Classification Structure



5.2 THE COMPREHENSIVE PSF LISTING

Within each PSF classification group is a range of possible individual PSFs that are represented by a short keyword or descriptor. In certain cases there are alternative PSFs particularly within section A: Process Factors. These can have both a negative and a positive influence on performance ie they can **improve** some aspects of performance and **degrade** others for example **continuous involvement** can ensure that the individual/team is familiar with all aspects of the process and can easily identify unusual changes in plant performance but on the detrimental side the individual/team can be overworked and hence under stress if things do start to go wrong.

An important concept is that there is no simple divide between positive and negative PSFs. Note that the thrust of this classification structure has been to identify potential negative factors rather than positive. If the factors are designed to ergonomic standards then performance remains at its best level but if not performance deteriorates.

The intent was to produce a listing that could be expanded to include advice to the designer and / or to interface with computerised design guidelines (eg the Control Room Interface Design Aid, Whalley and Booth). In addition it had to be easily modified to produce an auditing tool in the form of a note booklet.

The detailed listing is given in Table 5.2.1. All the individual PSF keywords were identified as possible affectors of performance in certain situations either from the case studies or one of the other four sources of information identified in chapter three. It is very difficult to determine at exactly what level the PSFs become negative, in particular the demands group which above all others will be dependent upon the interactions between PSFs and between tasks. However to ignore potential performance shaping factors because they are difficult to assess avoids the issue and leaves the consideration of the system incomplete. It is important at this stage of development that the classification structure and detailed PSF listing is comprehensive and extensive so that nothing is missed. Future research and evidence from process plants may be used to tailor the scheme and to provide more explicit guidance to future designer and system assessors. If a PSF is present in a plant being designed or reviewed it does not mean that it needs removing but that it must be designed correctly.

TABLE 5.2.1 Individual PSF Listing with definitions

PSF DEFINITIONS

Type A PROCESS *(fixed system factors that can influence error causes)*

Technology

1. Frequency of personnel Involvement

1.1 Occasional involvement -	the task is only required on an infrequent, irregular basis.
1.2 Continual involvement -	the task is a regular demand at frequent intervals.
1.3 Continuous involvement -	the task is a constant, consistent requirement.

2. Extent of Automation

2.1 Micro-computer controlled -	operations control room based; actions are isolated from plant
2.2 Automated control -	indirect plant control.
2.3 Manual control -	direct physical interaction with the plant.

3. Fail Safe systems

3.1 Automatic -	system shuts down without operator intervention.
3.2 Operator Initiated -	operator has to request a shut-down but the sequence is automatic.
3.3 Operator Activity -	operator has to control all stages of a required shut-down.

Chemistry

4. Type of Process

4.1 Continuous -	no definable end-points to the chemical reactions.
4.2 Batch -	definate start and finish to each chemical reaction with a regular defined cycle.
4.3 Continuous / Batch -	a hybrid; certain reactions are continuous, others cyclical.

5. Predictability

5.1 Stable -	all chemical reactions are consistent with no potential for volatile behaviour.
5.2 Unstable -	chemical reactions are known to be prone to volatile behaviour.
5.3 Unknown -	the chemical process is new, therefore uncertainty surrounds the stability of the reactions.

6. Novelty

6.1 Standard -	the process is standard and well proven therefore personnel have relevant past experience to assist decision making.
6.2 New -	no historical information exists to assist decision making.

7. Accuracy demanded

7.1 High -	a high degree of care and precision is required.
7.2 Low -	a tolerance range exists.

8. Time Dependency

8.1 Dependent -	actions have to be completed within a set time limit (time pressure).
8.2 Independent -	no time limit exists for task completion.

9. Process Hazards

9.1 High -	a known high risk process / industry.
9.2 Standard -	certain risks are associated but of low public consequence.
9.3 Low -	minimal risks and consequences to individuals.

Materials

10. Personnel contact

10.1 Unlikely -	no direct contact expected with the process chemicals.
10.2 Possible -	normally no contact required but may occur in response to fault conditions.
10.3 Required -	'handling' materials is part of normal operations.

11. Proximity to process

11.1 Control room -	personnel separated from the process.
11.2 Plant based -	personnel constantly in plant locality.

12. Materials Hazards

12.1 Innocuous -	no known hazards associated with the process chemicals / materials.
12.2 Hazardous -	associated industrial illness or disease or high toxicity levels.

13. Variety of materials

13.1 high variety -	many different, and / or variable materials / chemicals associated with the process.
13.2 low variety -	limited, unchanging set of associated materials / chemicals.

Type B PERSONNEL *(variable personnel factors that can influence the type of error causes - can be altered by personnel selection and training)*

Training

14. General - company initiation training programme.
15. Safety - general safety training.
16. Specific - 'in-plant' training for the specific plant and process.
17. Structured - 'in-plant' training is pre-defined & repeatable.
18. Simulation - simulation / simulators are used in fault diagnosis training.
19. On-the-Job - the main method of training is by watching experienced personnel.
20. Apprenticeship - an extensive period of formal, supervised training
21. Amount - extent of training received; quantity and duration.
22. Assessment - methods of judging the success of training.
23. Retraining - updating &/or refreshing skills.

Experience (partly personnel selection)

24. Education - extent of formal education.
25. Technical Awareness - familiarity with high level technology.
26. Amount - quantity and duration of general experience.
27. Relevance - extent of related experience.
28. Specific - extent of specific plant experience.
29. Interrupted - length of time away from normal duties.

Mental Model

30. Completeness - extent to which the total situation has been covered.
31. Accuracy - extent to which personal understanding corresponds to the actual situation.

Personality (general personnel selection criteria)

32. Capability - level of 'on- the- job' performance.
33. Confidence - extent to which the individual feels secure with respect to own capabilities.

34. Motivation - extent to which the individual is committed to the company. (nb can be altered through incentives, work organization & company attitude.)

35. Risk Taking - dependent upon the extent to which the individual feels in control of own destiny, or is unconcerned about own safety.

36. Sociability - extent to which the individual can relate to other people.

37. Temperament - general personality characteristics:
introvert / extrovert; senser /thinker /intuitor / feeler

38. Mood - changeable personality characteristics, in response to the environment.

Health

39. General Fitness - select according to job demands, company medicals.

40. Recent Illness - resultant reduction in normal capabilities; **nb** performance can be impaired by the common cold.

Type C ERGONOMIC *(design factors that can be improved reducing error likelihood if designed to meet ergonomic standards. ' Hardware' changes can occur as modifications or whilst still at the detailed draughting stage; 'Software' can be altered by a change in management / company policy and is therefore relatively easy to change)..*

ENVIRONMENT

Physical

41. Location - the individuals normal place of work.
- 41.1 Control room - predominantly control room based.
- 41.2 Plant - predominantly out on plant.
- 41.3 Plant & Control room - work split between plant and control room.
- 41.4 Numerous locations - work responsibilities at more than one plant &/or control room.

42. Climatic Exposure - outdoor work, or less than full protection from the elements.

43. Lighting - illuminance, contrast, glare, reflection, spectrum;
nb different work requires different lighting.

44. Noise - wavelength, intensity, duration, peaks.

45. Vibration - frequency, amplitude, waveform, duration.
 45.1 constant - general lowering of performance, irritability, ill health
 45.2 unexpected - shock, distraction and random output errors

46. Temperature - work place temperature.
 46.1 Control - the individual can select and obtain a preferred temperature.
 46.2 No control - temperature is outside the individuals control.

47. Atmosphere - dust, fumes, gases, ventilation and humidity. Possible effect on lungs, work rate, visibility and psychological stress.

48. Skin Irritants - dust, oils, chemicals.

Work space
49. Horizontal - amount of unimpeded floor space available in which to work.

50. Vertical - vertical distance before headroom is impeded.

51. Surface Type - drainage, non-slip, integrity (damage).

52. Clutter - items requiring negotiation once at workplace.

53. Small Enclosed Area - eg vessel work, drains. Cramped working position, physical stress, Nb phobias.

54. Open Heights - obvious sensation of height. Nb phobias.

Access to Work place
55. Stairs - stairs are required to reach the work area or to perform the task.

56. Ladders - task is only achievable by use of a ladder, or a ladder is present as a safety exit.

57. Obstacles - items have to be negotiated in order to reach the workplace.

Work Pattern ('software')
58. Shift work - pattern of the working week. Nb changeover effects and circadian rhythms

59. Hours per week - basic number of hours at work per week.

60. Overtime - average number of extra hours worked per day.

61. Rest Periods - frequency and length of rest breaks.

62. Self Pacing - opportunity to self regulate the workload.

PERSONNEL INTERACTIONS ('software')

Communication

63. Direction - who is the information passing to.
    - 63.1 Upwards - communication passes upwards through company hierarchy.
    - 63.2 Downwards - communication passes downwards through company hierarchy.
    - 63.3 Across - communication occurs at the same personnel level possibly across divisions.

64. Type
    - 64.1 formal - recognised channels exist for work related communications.
    - 64.2 informal - no structured channels exist.

65. Method
    - 65.1 Direct - the message is received immediately with no intervention.
    - 65.2 Indirect - the message is delayed or is passed via an intermediary person or object.

66. Feedback - checks to ensure the message is received and understood as sent.

Information

<u>Recording methods</u> - methods for logging work related information.

67. Log sheets - used to record specific plant information at regular intervals.

68. Log Books - used to record work information as a current reference for other personnel eg on-coming shift.

69. Computer Printout - a reliable historical record of specific plant information & control changes.

<u>Instructions & diagnostic information</u>

70. Type -
    - 70.1 Verbal - instructions / information verbally communicated to personnel.
    - 70.2 Written - instructions that can be stored and re-checked by personnel.

71. Location - the position of instructions with respect to individuals workplace.

72. Accessability - ease with which instructions / diagnostics can be found & accessed; **nb** indexing

73. Format - layout of instructions/diagnostics and their interrelationships.

74. Legibility - ease with which instructions etc can be read; **nb** some dependency on environment.

75. Clarity - ease with which instructions can be understood (clarity of meaning).

Company Policy

76. Incentives - levels of pay and bonus schemes.

77. Management Strategy - managerial priorities and the method of informing the workforce.

78. Safety Policy - policy regarding reasons for effecting a shut-down.

79. Supervisión - level and type of personnel supervision.

80. Manning - level of social contact for each individual.

    80.1 team work - individual works directly as a member of a team.

    80.2 vicinity - others work in close proximity to the individual or in direct communication.

    80.3 isolation - no-one else works near by or within direct communication distance.

81. Selection Criteria - standard company methods for selecting the right person for the right job.

82. Training - existance of a structured training programme.

83. Promotion - standard methods used for determining an individuals promotion.

MACHINE INTERFACE

Controls

84. Direct Controls - personnel uses these controls directly on the plant or plant equipment.

    84.1 Switch -

        84.1.1 discrete (two way or three way)

        84.1.2 continuous

    84.2 Push-Button -

        84.2.1 discrete - item can be put into one state or another eg. pump ON / OFF

        84.2.2 continuous - a smooth range of possible states between two end points, the button is released at the required position eg. control of the horizontal motion of an overhead hoist (a constant velocity control)

84.3 Knob -
  84.3.1 discrete - stepped intervals

  84.3.2 continuous - a smooth range of possible states between two end points (usually used for increasing / decreasing)

84.4 Valve -
  84.4.1 discrete - valve is either OPEN or CLOSED eg ball valve

  84.4.2 continuous (variable) - rate of flow can be adjusted by part opening the valve eg gate valve

84.5 Lever -
  84.5.1 discrete

  84.5.2 continuous

84.6 Hand Wheel -
  84.6.1 one-handed - usually has an attached handle, 90' to the wheel, that can be gripped firmly with one hand.

  84.6.2 two-handed - strength requirement, not for fine adjustment

84.7 Chains - eg. used to control pulley system

84.8 Foot Button -
  84.8.1 discrete - ON / OFF type of response

  84.8.2 continuous - constant pressure used for control but at constant velocity

84.9 Foot Pedal - variable pressure allowing use as a velocity control eg accelerator pedal

85. <u>Indirect Controls</u> - control room based; control requirements signalled to plant via electrical or pneumatic signals.
  85.1 Control Panels -
    85.1.1 push button
    85.1.2 knob
    85.1.3 switch

  85.2 VDU -
    85.2.1 touch pads
    85.2.2 buttons
    85.2.3 keyboard

86. Location - position of each control, imparticularly in relation to each other.

87. Identification -	labelling nb. check the clarity of any coding used
88. Visibility -	line of sight, illumination.
89. Prompts -	reminder that the control should be operated.
90. Response Feedback -	information regarding the correct functioning of the control.
91. Response Time -	speed with which the control requested is met.
92. Access -	ease with which the control can be reached & operated.

Displays

Visual

93. Display Type

93.1 Digital -	precise units of measurement, quantitative information.
93.2 Analogue -	relative measurement, qualitative information.
93.3 Pictorial -	qualitative or static information; eg relationship between items or plant layout
93.4 Status -	absolute indicator of current situation with limited alternatives; eg lights

94. Scale Continuity -	check that scale graduations and units are standard through the plant

95. Display Location -

95.1 VDU Screen -	nb size, number, position wrt user(s), pages, organization, access, information density
95.2 Dedicated Panel	-size and location with respect to user(s)
95.3 Equipment -	place displays on equipment rather than removed

96. Control Association -	position of display (responsible for control feedback) in relation to associated control
97. Identification -	labelling nb clarity of any coding used & links with controls
98. Visibility -	line of sight, illumination
99. Legibility -	font & point size, spacing
100. Clarity -	conventions, density of information, coding types
101. Response Time -	speed with which display updates & indicates system changes

102. Access - ease with which the display can be reached eg for close scrutiny & check reading

103. Display / Control Interactions - immediate control feedback via an associated display indicating the control request as well as or separate to the system response

Auditory

104. Display Type

- 104.1 Verbalized - nb status / warning
- 104.2 Wave Pattern - nb status / warning
- 104.3 Pitch - nb status / warning

105. Identification - coding, eg. pitch, oscillations, volume

106. Legibility - volume of the auditory display vs background noise

107. Clarity - tonal characteristics vs background noise

108. Response Time - delay between system change and notification

EQUIPMENT

Clothing

109. Standard safety wear - eg. overalls, safety shoes, safety glasses, helmet, gloves

110. Special safety wear - over and above standard, eg. ear defenders, visor, airstream helmet, breathing apparatus, welding goggles, dust masks

111. Extra clothing - for specific jobs or environments, eg waterproofs, windcheaters, heat reflectant disposable overalls, winterwear

112. Availability

Aids

113. Need - job requirements are above normal operator ability

114. Type - eg. manual handling trolleys, fork-lift trucks, fault diagnosis aids

115. Availability

116. Serviceability - frequency of inspection

Operator Equipment

117. System Furniture - eg. control console, seating, storage, shelving

118. Domestic Equipment - eg. cooking/canteen facilities, easy chairs, lockers, showers, toilets

119. Utility Equipment - eg. gas sampling equipment, communication, minor repair kit

System Equipment

120. Standard - basic plant equipment (general characteristics)

121. Safety - additional plant safety systems plus operator safety equipment, eg. safety showers, escape sets

122. Backup - duplicated equipment eg. backup pump

123. Equipment Dimensions - general proportions of equipment and scale of process

124. Equipment Identification - method of labelling (coding) plant equipment

DEMANDS

Physical

<u>Musculoskeletal</u>

125. Posture - required work position, eg. sitting, standing, kneeling, crouching

126. Movement - amount of movement possible as well as that required to do the job

127. Control - extent of manual control operations (arm or leg muscles)

128. Power (lifting) - requires the use of the major muscle groups in both arms, shoulders and legs, plus a secondary requirement on abdominal and back muscles

129. Static (holding) -arm muscles only

130. Co-ordination - proprioceptive feedback needed to relate separate body movements

131. Dexterity - fine manipulative movements

Senses

132. Vision - colour, distance, close-up, 3-D, peripheral.

133. Hearing - frequency range, amplitude range.

134. Tactile - mainly as feedback for control selection and operation

135. Smell - a secondary warning device important on some plants

136. Kinesthetic - sense of motion

Psychological

137. Responsibility - extent of self regulation during work activities plus responsibility for others

138. Concentration - need to keep mind constantly on the job

139. Memory - need to remember changing information

140. Decisions - need and extent of responsibility for decisions

141. Alertness - need to percieve and respond quickly to plant situations

142. Flexibility - need to alter working pattern to fit changing situation

143. Risk Perception - need to recognize potentially serious situations

144. Work Organisation - required to regulate own work schedule

145. Monitoring - need to constantly check parameter status

146. Time Pressure - need to work quickly and accurately in a limited amount of time

CHAPTER SIX
LINKING HUMAN ERROR TO PERFORMANCE SHAPING FACTORS

6.1 INTRODUCTION

Case studies were a useful basis for considering the different system design features that could influence human error. However, to simply extend these conclusions to address new scenarios would be inadequate and even potentially misleading. What is required is a generic method based upon this experience but also based on the literature, including current theoretical models of performance and error. The resultant concept of a designer decision aid culminating from the combination of these different approaches will now be explained.

6.2 THE THEORETICAL MODEL

The basic philosophy of this model is that relevant Performance Shaping Factors (PSFs) are dependent upon; the type of task being performed (Task Type), the expected form of response (Response Type) and any deviations from the required performance that are conceived to be important for the specific circumstances (Error Types). Together these dictate the possible underlying error mechanisms and error causes which can in their turn, be influenced by aspects of the System. Once the set of potential error causes has been established, the possible PSFs can be identified.

6.2.1 Defining the Scenario

6.2.1.1 Task Type

A generic classification was required so that any specific task could be related to a standard structure. As a basis for this classification it was considered important to classify Tasks according to the type and extent of conscious decision making that would be required for successful completion. This was because the extent of mental involvement directly relates to certain types of error cause. The underlying theory of classification did however need to be relatively simple, so that designers and engineers with no psychological knowledge could still appreciate the distinctions between the different task types.

Rasmussen's (1979) method of considering the human information processing chain (note Section 2.4), in terms of the level of conscious mental activity, was selected as the most pertinent basis for this particular application due to its simplified representation of the different mental processes. This was sufficient to link sub-groups of the set of error causes to the particular mental activities associated with a specific task. Seven task types were identified for the generic classification, each with its own permutation of the information processing chain (Figure 6.2.1). The validity and comprehensiveness of these was checked by considering a range of real life tasks (Tables 6.2.1a,b). For this set of tasks it proved possible to allocate each to a single generic group: Although this cannot prove that the generic types are exhaustive it does suggest that this is the case. To test the reliability of the classification structure the author completed a test-retest classification of tasks and also checked inter-rater reliability. Five research students from the chemical engineering department were given the list of tasks plus an explanation of the seven generic task types. They were then asked to classify the list with respect to the seven types and to indicate any that they were unable to classify or were uncertain about.

Task Type 1: **Stimulus** / response

A direct instinctive reflex response to a well known situation with no requirement made of the higher level mental capacities; no conscious decision making is in evidence. Specific attention is not required for this type of task therefore the likelihood of absent minded errors is increased [Section 2.2, Reason (1977), Senders (1982)]. For example, 'stopping at a red light'.

Task Type 2: Stimuli **Integration** / response

The individual in this case needs to attend to a number of inputs that are all comprehensible and relate directly to an internal model. This results in a known response to a known group of variables with no decision making required and only a low level of active awareness (pattern recognition). Once again the opportunity for "absent minded errors" is high. For example, 'following diversion signs'.

Type Type 3: **Interpretation** / response

In this case a picture of the current situation is developed and the individual must relate this to an internal model and previous experience. It is impossible to generate a direct response and a

decision has to be based upon the available information plus recognition of the implications and the requirements. Active decision making is carried out at a high level of conscious awareness. Absent minded errors are extremely unlikely.
For example, 'route planning'.

Task Type 4: **Requirement** / Response

This is a predetermined response to an expected situation that has to be recognised and internally triggered. It is not directly related to an external stimulus though it is often time dependent. Absent minded errors can occur. For example, 'stopping for petrol (prior to warning light coming on)'.

Task Type 5: **Self Generation** / response

A self determined activity which may require planning and decision making to determine a method of obtaining the goal. Absent minded errors are unlikely since there is usually a high level of cognitive activity. For example, 'putting the radio on'.

Task Type 6: **Choice** / response

The individual has to select a particular plan when more than one could be correct or there are several alternative goals. This task is independent of environmental stimuli and interpretation. True absent minded error causes are impossible due to the high level of cognitive activity. For example, 'choosing where to stop for lunch'.

Task Type 7: **Correction Required** / response

This task type describes an error correction mechanism and as such stands separately from the previous six task types. There is a direct realization that something other than the planned response is being carried out or that the original response was inappropriate for the situation. This results from self monitoring. It is during this type of task that compounded errors may emerge: As the individual attempts to correct the situation the position may be made even worse - eg rule contravention may also take place. For example, 'discovering that you are driving the wrong way down a one way street, and reversing back up'.

FIGURE 6.2.1 <u>The Seven Generic Task Types Each With Associated Information Processing Chain</u>

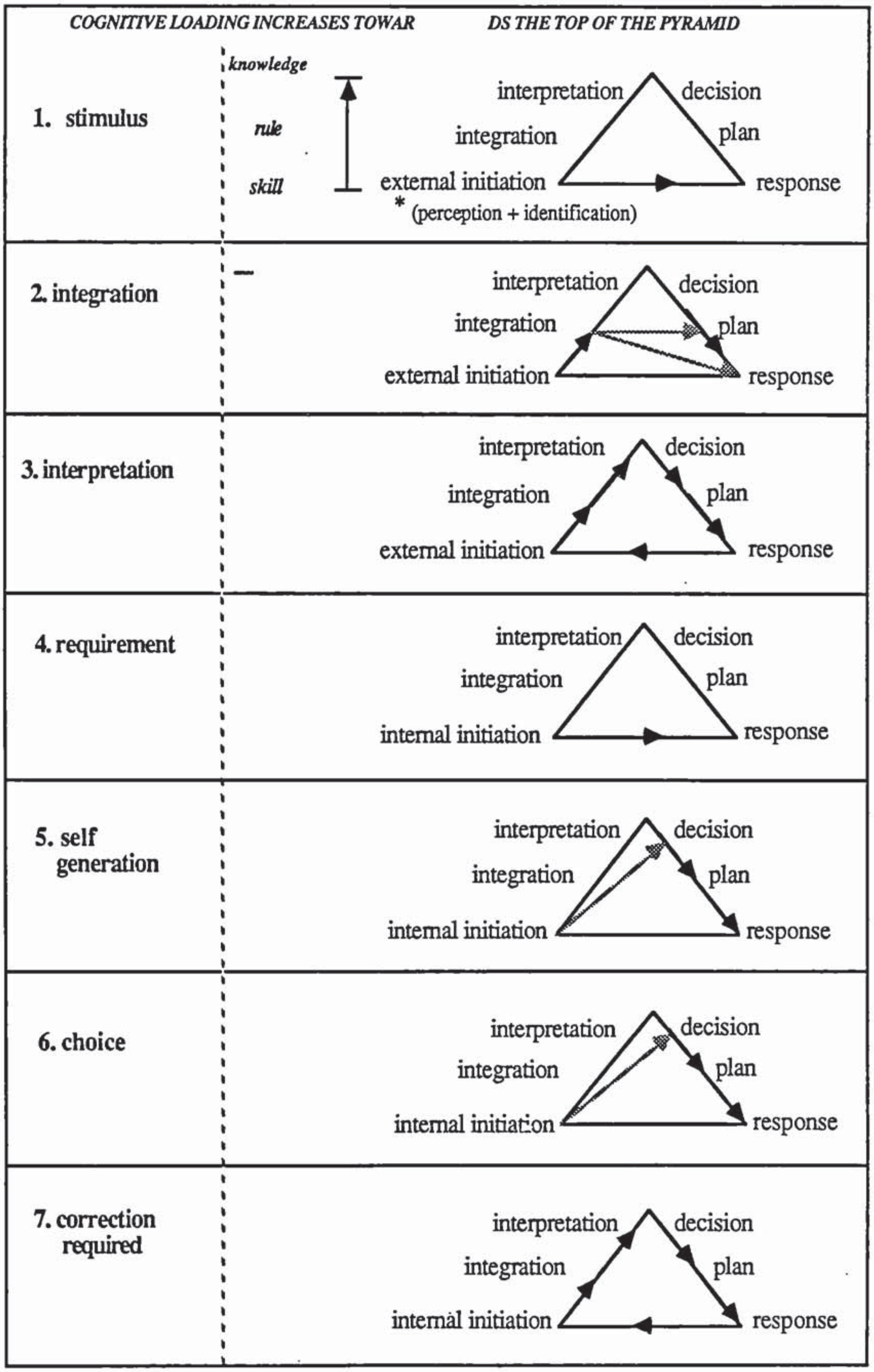


TABLE 6.2.1a Specific Task Examples for Each Generic Task Group

Task Type	Sequence	Discrete
1. stimulus	1. phosphorus level low in melter therefore top up from drums. 2. THPC requested, ensure correct tanks. 3. gas holder level rising so reduce production. 4. amps / volts ratio high so activate acid drop.	1. keg weight reached so cut off flow. 2. tray full so place on trolley. 3. pump stopped so switch to stand-by.
2. integration	1. vessel 32LI1 high alarm + demountable tank with sufficient residual volume ⇒ transfer acid. 2. temp falling in gasifier + absorption falling + flow reducing ⇒ gasification complete	1. low suction at dust extractor points + powder in atmosphere + dust bin full ⇒ empty dust bin 2. drying time expired + product colour change ⇒ remove from drying oven. 3. flake wet + temp high + product quality correct ⇒ slow down flaker.
3. interpretation	1. PRed rising + converter temp rising + low flow alarm 13FIC1 + no change in flow + P4 feed stopped + undisturbed but reduced reactor pressure, diagnose and correct. 2. boom from pipework whilst flaring off on start up, 61PI1 high reinitiate start up if safe to continue. 3. inhibited start up procedure check holding phase, check alarm flag 38 &39, check display alarms, rectify & continue start up.	

TABLE 6.2.1b Examples of Specific Tasks for each Generic Task Group

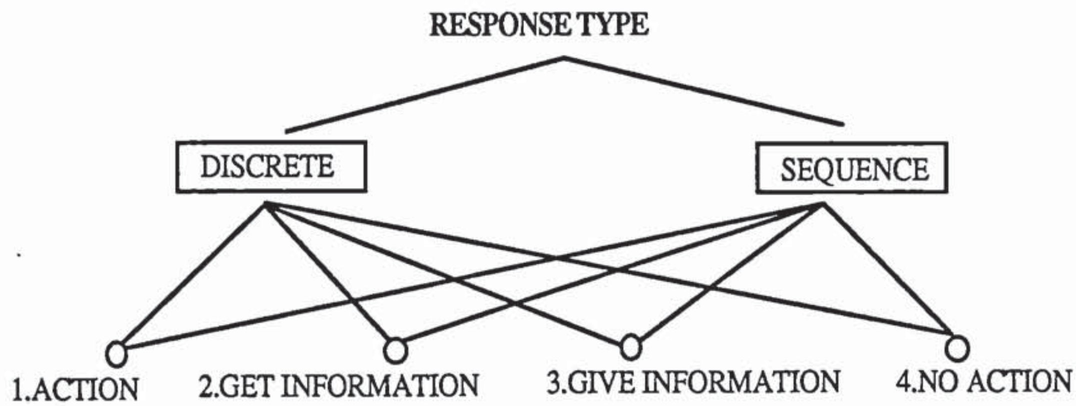
Task Type	Sequence	Discrete
4. requirement	1. it is time to make external plant checks. 2. the gas quality should be checked. 3. check stand-by pumps.	1. the empty drums require steam lancing. 2. check level in demountable acid tanks. 3. drain any liquid entrainment from instrument air lines.
5. self generated	1. what would happen to gas quality if Pred was raised & reactor temp reduced. 2. how does the remote control affect cascading set points? 3. put trends for converter reactor & hot condenser temp on same page to check normal running pattern.	
6. choice	1. start the batch either packing off in bags or kegs. 2. would a ball or a gate valve operate best given the product & operating conditions.	
7. correction required	1. temp rising in converter due to decrease in feed rate 13FIC1. Re-establish feedrate, reduce temp in 20 & re-attempt decrease. 2. melter overfilled with phos, inhibit phos pump-back cycle & delay further filling.	

6.2.1.2 Response Type

In the same way that task types required classification, response types also needed some degree of distinction. The primary division selected was; Discrete versus Sequence response types. A response sequence occurs when more than one response is required to fulfill a specific task goal, for example, 'changing gear in a car'. In this situation timing and ordering may be crucial. In contrast the discrete response is a single unit of performance that has no easily distinguished sub-sections and does not depend upon preceding or proceeding responses, for example, 'switching off radio'. This primary distinction between response types affects the type of errors that may occur and the potential error causes.

The secondary division is based upon whether the response is expected to be: an action (e.g. 'braking'), getting information (e.g. 'reading road signs'), giving information (e.g. giving directions'), or no action (e.g. 'waiting at a red light') (Figure 6.2.2). The first three types are active responses whereas the fourth is a passive interaction with the system ie waiting; sometimes it is as important to do nothing during process control (or any other scenario) as it is to actively respond. This classification structure is extremely generalised without intimate consideration of each category, (for example; it would have been possible to consider specific types of action but this would have resulted in unneccessary complexity) but this level of distinction proves satisfactory for assisting error type selection and for error cause inference.

FIGURE 6.2.2 Generic Response Types



Note that originally no distinction was made between response types; however, as a result of studying incident reports it appeared that control aspects should be kept separate from communication (for communication the direction of flow is important, hence the distinction between getting and giving information) and that these, plus the no action category, affected the type of error that could result.

Table 6.2.2 presents the seven response type categories each with an accompanying example. The diagrammatic method of representation devised during this research for use in task analysis plans is also included, note that a task number can be shown in the box.

TABLE 6.2.2 The Seven Identified Response Types

primary / secondary	DISCRETE	SEQUENCE
ACTION 1.3	"turn pump on"	"analyse gas sample"
NO ACTION 1.2	"pump is on, therefore do nothing"	
GIVE INFORMATION 1.4	"enter pump status" eg. into fault diagnosis facility	"give instructions for achieving the required quality"
GET INFORMATION 1.1	"check that pump is on"	"find out what the current gas quality should be"

6.2.1.3 Error Types (or Action Deviations)

As discussed in section 2.2 there are numerous methods of error classification, these are influenced both by the reasons for studying error and the underlying school of psychological theory (behaviourism, cognitivism, functionalism). For this design aid it was important that the error types had relevance and meaning for engineers.

One P&ID (Pipework and Instrumentation Diagram) assessment that many engineers would already be familiar with was the Hazard and Operability Study (HAZOP) technique used to identify possible system failures and their causes. The key words used within HAZOP to denote these different failure modes had similarities to the functionalists human error classification favoured by Singleton (1974) and identified within the classification of Rouse and Rouse. This approach, based upon deviations from the expected response, appeared to be an appropriate taxonomy for use in a designer's aid. In addition, by using synonymous terms, the potential was established for linking the technique into a HAZOP study as a complementary method for studying the effects of human error and PSFs upon any system under review.

As in a HAZOP it is the responsibility of the user to identify which deviations constitute relevant (or credible) errors in a given situation for a given task. Some help is however given by the design aid since the impossible error types are not presented as options at the error input stage. Their elimination would be based upon the expected response type previously entered by the user. Table 6.2.3 presents the designer aid key words for human errors adjacent to those used for failures in an HAZOP study.

TABLE 6.2.3 Human Error Types Related to HAZOP Keywords

ERROR TYPES			
HAZOP keyword	Designer Aid keyword	HAZOP keyword	Designer Aid keyword
1. No	1. Not Done	——	6. Repeated
2. Less	2. Less Than	6. Reverse	7. Sooner Than
3. More	3. More Than	6. Reverse	8. Later Than
4. As well As	4. As Well As	6. Reverse	9. Mis-ordered
5. Other than	5. Other Than	7. Part of	10. Part of

In order to facilitate a diagrammatic representation of error type, for example to enhance the presentation of an Heirarchical Task Analysis, each error type was given an unique symbol (Figure 6.2.3)

FIGURE 6.2.3 Symbolic Coding for Error Type

ERROR TYPES

1.	Not Done	0			
2.	Less Than	<		Timing errors	
3.	More Than	>	7.	Sooner Than	←
4.	As Well As	+	8.	Later Than	→
5.	Other Than	≠	9.	Mis-ordered	└▲
6.	Repeated	m	10.	Part Of	—

6.2.1.4 PSF Elimination

The user needed the option of making a preliminary elimination of irrelevant sections of the PSF classification structure and PSF keywords where alternative PSFs existed (nb the detailed PSF listing Section 5.2). By giving the user the option to partially establish a PSF profile, particularly important for existing plants, those PSFs which are obviously irrelevant (predominantly type A factors) could be immediately discounted before a linked - search was initiated for the sub-tasks.

For example;

1. Frequency of personnel Involvement

   1.1 Occasional involvement - the task is only required on an infrequent, irregular basis.

   1.2 Continual involvement - the task is a regular demand at frequent intervals.

   1.3 Continuous involvement - the task is a constant, consistant requirement

Only one of these PSFs can be true for an operating plant's task or process, therefore unnecessary mappings can be avoided if inappropriate PSFs are deleted.

This option should however only be used for existing plants or aspects that cannot possibly be changed, otherwise the chance of making useful comparisons is lost.

6.2.2 Establishing a finite set of Error Causes

By following a similar process to that used whilst establishing the PSF classification structure and individual PSF keywords (ie by combining knowledge gained during the case studies with that from studying process plant incident records and the available theoretical literature), a set of error causes was produced sub-grouped by a structure of underlying error mechanisms. The first level of this structure distinguished between error causes that are internally generated, those that are externally generated and those that are due to a combination of external and internal mechanisms (note the similarities with electronic equipment failure classification, Henley & Kumamoto Section 2.2). In order to assert and convey these distinctions a supporting terminology was devised:

1. Internal error mechanisms have been termed ENDOGENOUS;

2. External error mechanisms have been termed EXOGENOUS;

3. The combination of internal and external mechanisms has been termed HETEROGENEOUS.

Eight sub-mechanisms were also established forming a secondary level of grouping prior to the individual error causes. The Exogenous mechanism was subdivided into two whereas the Endogenous and Heterogeneous mechanisms were each given three sub-divisions. The total group of error causes numbered 35 and they are shown, grouped by error mechanisms, in Figure 6.2.4., a short definition of each error cause is provided in Table 6.2.4.

The intention was that the error causes formed a finite group, however it was conceivable that this would prove to be an inaccurate assumption at a later date. It is therefore suggested that any software written to support this methodology should have an independent data base in order to enable the easy addition, subtraction or reconfiguration of the error cause set. This suggestion was justified once the list was used with case histories. The error cause taxonomy was extended to include two more causes. These extra error causes have been included within Table 6.2.1, labelled, 23a. perception retarded and 30a. pre-occupation

FIGURE 6.2.4 Error Causes Grouped by Error Mechanisms

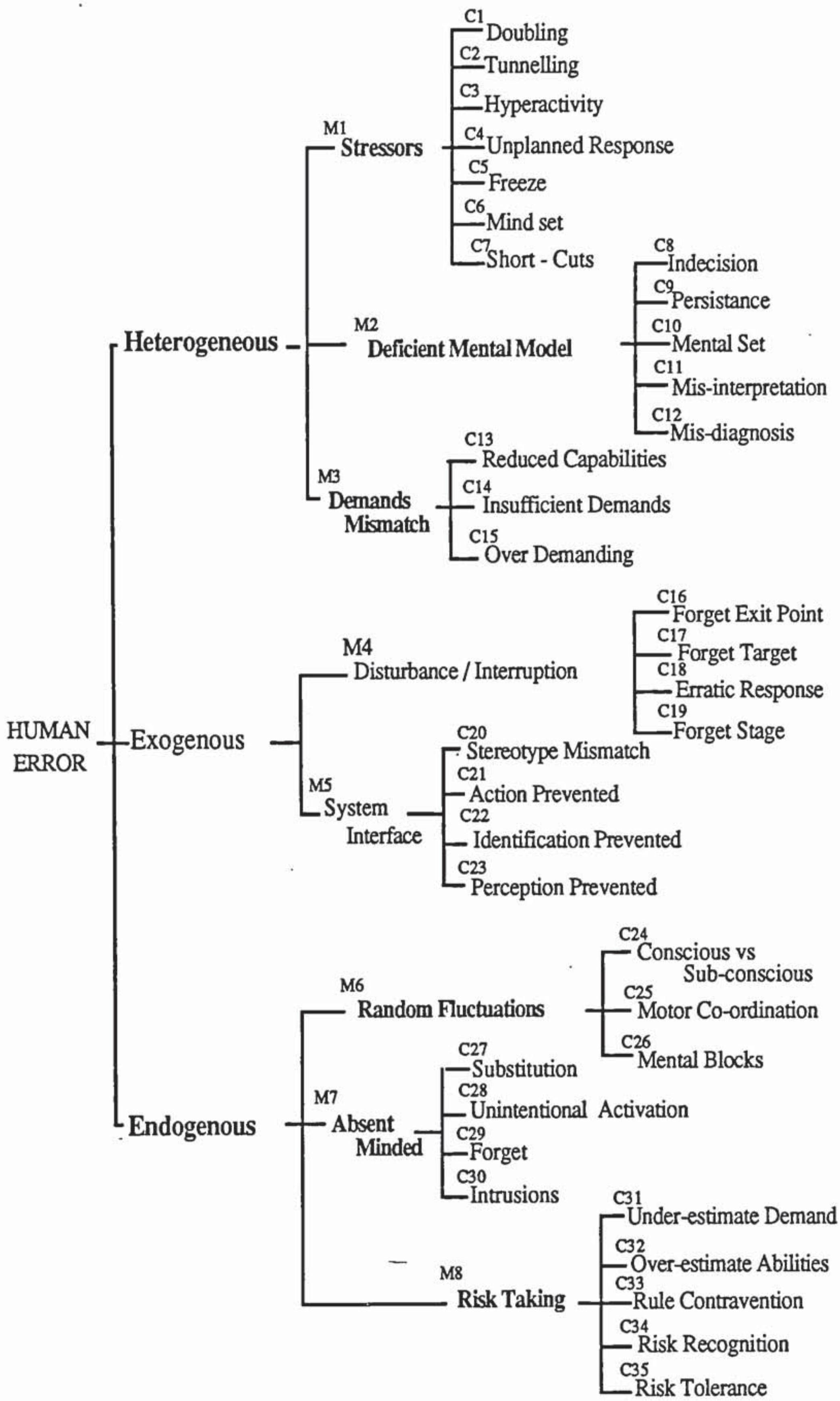


TABLE 6.2.4 Error Causes with Definition Summaries

HETEROGENEOUS
(human errors that are caused by the interaction of internal and external factors)

Stressors (self-correction unlikely)

1.	doubling:	Repetition of the same act, as though unaware of its completion. May actually be aware that the activity is a repetition but be unable to override and regain control.
2.	tunnelling:	All awareness and effort concentrated on one aspect to the detriment of the total activity. Other supportive information is ignored. It is not always the highest priority activity that gains the monopoly of attention.
3.	hyperactivity:	Rapid switching occurs from one activity to another without accomplishing closure for any task or task component.
4.	unplanned: response	Unexpected reflex response, generally in a very cavalier fashion with no active reasoning or subsequent explanation for the behaviour. A loss of high level cognitive control.
5.	freeze:	An inability to act physically or mentally. The mind goes blank and muscles refuse to respond.
6.	mind set:	A persistant repetition of logical reasoning that has either been proved incorrect or despite conflicting evidence.
7.	short-cuts:	An attempt to reach the solution more quickly than the normal procedure or plan will allow; due to the recognition that insufficient time is available to complete all the task steps.

Deficient Mental Model (self-correction improbable)

8.	indecision:	Insufficient knowledge or information to choose an immediate path of action; either caught between several options or unable to think of even one course of action.
9.	persistence:	The continuation along one course of action with any counter evidence fitted to the current model or ignored.
10.	mental set:	If a certain system response is expected, given certain preconditions, conflicting evidence will be molded to fit the expectations. In addition nonexistant indicators will be "seen" or be reported as present post event.

11. misinterpretation:
A number of indications and readings are misunderstood, their interdependance is incorrectly interpreted due to insufficient or faulty undertanding. The individual is unlikey to be aware that an error potential exists.

12. misdiagnosis: The situation is correctly interpreted but the manner in which to proceed in order to accomplish the required outcome is miscalculated due to insufficient or faulty understanding. The individual is unlikely to be aware that an error potential exists.

<u>Demands Mis-match</u> (error recovery very unlikely)

13. reduced capabilities: The individual is unable to work to normal capacity, neither mentally nor physically, due to internal or external restraints.

14. insufficiently demanding: Insufficient demand on the worker can lead to reduced arousal, particularly if the work is psychologically under demanding.

15. over demanding: If the normal system demands are outside or to the edge of percentile limits, physical or mental break-down is probable at some point in time whilst performing the task.

<u>EXOGENOUS</u>
(error causes due to factors external to the individual)

<u>Disturbance / Interruption</u> (error recovery is possible)

16. forget exit point: The individual keeps working during the interruption and passes the point at which the task should have been completed ie. works automatically with no checking by high level cognitive processes: OR the task is recommenced yet the disruption continues to occupy the mind causing the same effect.

17. forget target: During tasks that require a high cognitive awareness plus Short Term working memory, a disturbance can captivate the thought processes causing loss of the task plan.

18. erratic response:
An interruption causes disruption to on-going activities resulting in an erratic / irrelevant action or thought.

19.	forget stage:	The individual attempts to re-commence the interrupted thought process or action but is uncertain of the current position in the sequence.

System Interface (potential for error recovery)

20.	stereotype mismatch:	The required task/interface is unusual or abnormal contravening expectations. At some point in time or if under stress the individual will revert to the normal stereotype.
21.	action prevented:	The individual is prevented from accomplishing the necessary response.
22.	identification prevented:	The methods used for identification are ambiguous, misleading or non-existant resulting in uncertain or incorrect identification.
23.	perception prevented:	Stimulii are hidden, disguised, inaccessible, or unavailable therefore there is either no available task trigger or confirmatory information is missing.
23a.	perception retarded:	General displays are difficult to locate and read.

ENDOGENOUS

(error causes due to internal aspects of the individual)

Random Fluctuations (opportunity for self-correction)

24.	conscious vs sub-conscious:	Consciously aware of the current situation and relevant actions but the sub-conscious is in control leading to an incompatible response. A feeling of watching oneself perform incorrectly but with no facility to stop.
25.	motor co-ordination:	A sporadic/unpredictable/uncontrollable deviation occurs during the activity.
26.	mental blocks:	Recall of familiar information is prevented often coupled with the sensation of being on the edge of remembering.

Absent Minded (opportunity for self-correction)

27.	substitution:	One action sequence (or part sequence) is completed instead of another; both the intended sequence and the actual executed sequence shared common components providing one or more cross-over points. Often the jump will be to the more familiar sequence.

28. unintentional activation:
A standard, but for once incorrect, sequence or response is triggered by a familiar stimulii with no conscious decision making. The task is performed without thinking and may not be remembered later.

29. forget: An activity that is either usually automatic with no cognitive supervision or a task that is planned but cannot be immediately performed may be missed out. It may be remembered later or if prompted. (Task plans cannot be held indefinitely within Short Term Memory & cannot be accessed from Long Term Memory if cues are insufficient)

30. intrusions: (thinking ahead) If engaged in a task that requires little cognitive supervision the brain can be engaged in pre-planning activities, this may however interfere with current operations especially if the future plan becomes stronger and more dominant than that currently being performed.

30a. pre-occupation: Thinking about or continually checking one item may lead to the incorrect completion of the current task.

<u>Risk Taking</u> (error correction possibilities)

31. under-estimate demands: Characteristics of the task suggest that it is less difficult or dangerous than in reality. The individual bases decision on past experience or optimistic judgement.

32. over-estimate abilities: Over self confidence plus lack of conflicting evidence due to the novelty of the situation, can result in the individual persuing unrealistic goals and over stretching capabilities.

33. rule: Often coupled with an error recovery attempt. The contravention: individual knowingly breaks the rules but usually as a trade-off to attain an appropriate goal.

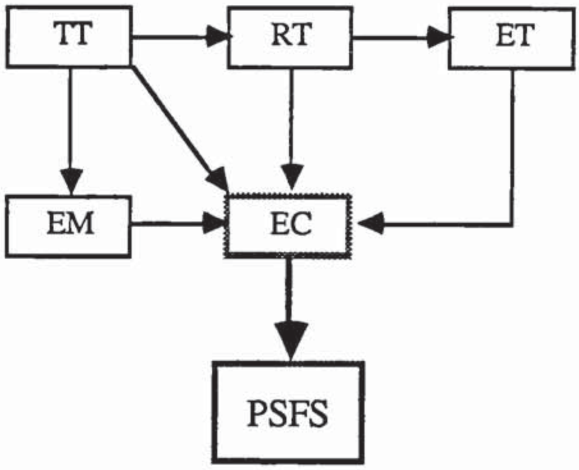
34. risk recognition: The consequences of improper actions are not fully considered.

35. risk tolerance: The attitude is that risks are a fact of life and that accidents will always happen to someone else. A lack of self determinism accompanied by active risk taking, nb. the path of least resistance.

6.3 LINKING MECHANISMS

6.3.1 Linking Inputs To Error Causes

The primary linkages proceed from task type, response type, and error type to possible error causes. In addition task types link indirectly to error cause through error mechanisms. Error causes in turn link to individual PSFs:



As previously stated (Section 6.2.2) error causes ultimately formed a finite set of 37. What was required was a method by which a relevant subset of these could be obtained based upon the three user inputs.

1. Each **Task Type** incorporates either part or all of the **Information Processing Chain** (Table 6.3.1) and each stage of the IPC has an associated subset of error causes (Table 6.3.2) hence the link from task type to possible error causes is accomplished. In addition each task type also maps onto a number of possible error mechanisms (also shown in Table 6.3.1) each of which have their subset of error causes (Table 6.3.3) hence a double mapping or two subsets of error causes are associated with Task Type. This ensures that specific characteristics of the task are not lost, especially with respect to risk taking, as would be the case if only the IPC was considered as an influence on error cause.

   Hence the mappings established so far are:

   1. **TT ----> IPC ---> EC**

   &

   2. **TT ----> EM ---> EC**

TABLE 6.3.1 Task Type Associated With IPC Stages and Error Mechanisms

	TT (task type)	IPC (information processing chain)	EM (error mechanism)
T1	stimulus	i1, i2, i6	m1, m3 - m7
T2	integration	i1 - i3, i6	m1, m3 - m7
T3	interpretation	i1 - i6	m1 - m6, m8
T4	requirement	i3, i5, i6	m1, m3 - m7, m8
T5	self generation	i4 - i6	m1 - m6, m8
T6	choice	i3 - i6	m1 - m6, m8
T7	correction	i1 - i6	m1 - m6, m8

TABLE 6.3.2 The IPC Stages Mapped on to their Subset of Error Causes

	PROCESSING STAGE	ERROR CAUSES
I1	Perception	C2, C5, C10, C13, C14, C15, C23,C23a, C30a
I2	Identification	C5, C8, C9, C10, C13, C15, C20, C22, C26, C30a
I3	Comprehension	C5 ,C6, C9,C10, C11, C13, C15, C20, C24, C26, C30a, C31, C34
I4	Decision	C3, C5 - C9, C12 - C15, C17, C26, C32, C33, C35
I5	Plan	C1, C3, C5, C7, C8, C12 - C15, C17, C19, C26, C30a, C32, C35
I6	Response	C1, C3, C4, C5, C7, C13 - C16, C18 - C21, C25, C27 - C30a

TABLE 6.3.3 Error Mechanisms With Associated Error Causes

ERROR MECHANISM		CAUSES	ERROR MECHANISM		CAUSES
M1	Stressors	C1 - C7	M5	System Interface	C20 - C23
M2	Deficient Mental Model	C8 - C12	M6	Random Fluctuations	C24 - C26
M3	Demands Mismatch	C13 - C15	M7	Absent Minded	C27 - C30
M4	Interruption	C16 - C19	M8	Risk Taking	C31 - C35

2. **Response Type** has both an indirect and direct mapping to error cause. The direct mapping from response type to error cause is given in Table 6.3.4. The indirect link is through the Response Type influence on possible error types (Tables 6.3.5 and 6.3.6). Sequence Responses encompass all ten error types whereas discrete responses limit error types to eight. As far as the sub-classifications are concerned:

Action:	Full list of ten error types
Get Information:	**Deletes** error types E2, E3, E4, E7
Give Information:	**Deletes** error types E2, E3, E6, E8
No Action:	Has only E_2, "as well as ", an error of commission, associated with it.

Each error type maps directly onto a number of error causes establishing the fourth Error Cause Subset (Table 6.3.7).

Therefore the final two mappings to error cause are:

3. **RT ---> ET ---> EC**

and

4. **RT -----> EC**

TABLE 6.3.4 <u>Response Types linked to Error Causes</u>

Action	No Action	Get Information	Give Information
1. doubling	1. doubling	1. doubling	1. doubling
2. tunneling	--------	2. tunneling	--------
3. hyperactivity	--------	3. hyperactivity	3. hyperactivity
4 unplanned	4. unplanned	--------	--------
response	. response	--------	--------
5. freeze	--------	5. freeze	5. freeze
6. mind set	6. mind set	6. mind set	--------
7. short cuts	--------	--------	7. short cuts
8. indecision	--------	8. indecision	--------
9. persistence	9. persistence	--------	--------
10. mental set	10. mental set	10. mental set	10. mental set
11. misinterpret	11. misinterpret	11. misinterpret	11. misinterpret
12. misdiagnosis	12. misdiagnosis	12. misdiagnosis	12. misdiagnosis
13. reduced	--------	13. reduced capability	13. reduced
capability	--------	--------	capability
14. insufficiently	14. insufficiently	14. insufficiently	--------
demanding	demanding	demanding	--------
15. overdemanding	--------	15. overdemanding	15. overdemanding
16. forget exit point	--------	--------	16. forget exit point
17. forget target	17. forget target	17. forget target	17. forget target
18. erratic response	18. erratic response	18. erratic response	18. erratic response
19. forget stage	--------	19. forget stage	19. forget stage
20. stereotype	20. stereotype	20. stereotype	--------
mismatch	mismatch	mismatch	--------
21. action prevented	--------	--------	21. action prevented

TABLE 6.3.4 (continued) Response Types linked to Error Causes

Action	**No Action**	**Get Information**	**Give Information**
22. identification	22. identification	22. identification	--------
prevented	prevented	prevented	--------
23. perception	23. perception	23. perception	--------
prevented	prevented	prevented	--------
23a. perception	--------	23a. perception	--------
retarded	--------	retarded	--------
24. concious vs	24. concious vs	24. concious vs	24. concious vs
subconcious	subconcious	subconcious	subconcious
25. motor	--------	25. motor	25. motor
coordination	--------	coordination	coordination
26. mental blocks	--------	26. mental blocks	26. mental blocks
27. substitution	--------	27. substitution	27. substitution
28. unintentional	28. unintentional	28. unintentional	28. unintentional
activation	activation	activation	activation
29. forget	--------	29. forget	29. forget
30. intrusions	--------	30. intrusions	30. intrusions
(thinking ahead)	--------	(thinking ahead)	(thinking ahead)
30a. preoccupation	--------	30a. preoccupation	30a. preoccupation
31. underestimate	31. underestimate	--------	--------
demands	demands	--------	--------
32. overestimate	32. overestimate	--------	--------
demands	demands	--------	--------
33. rule	33. rule contravention	--------	33. rule
contravention	--------	--------	contravention
34. risk recognition	34. risk recognition	--------	--------
35. risk tolerance	35. risk tolerance	35. risk tolerance	35. risk tolerance
37	20	29	23

TABLE 6.3.5

Primary Response Type linked to Error Types

ResponseType: Primary Division		Error Types
D1	Discrete	e1 - e8
D2	Sequence	e1 - e10

TABLE 6.3.6

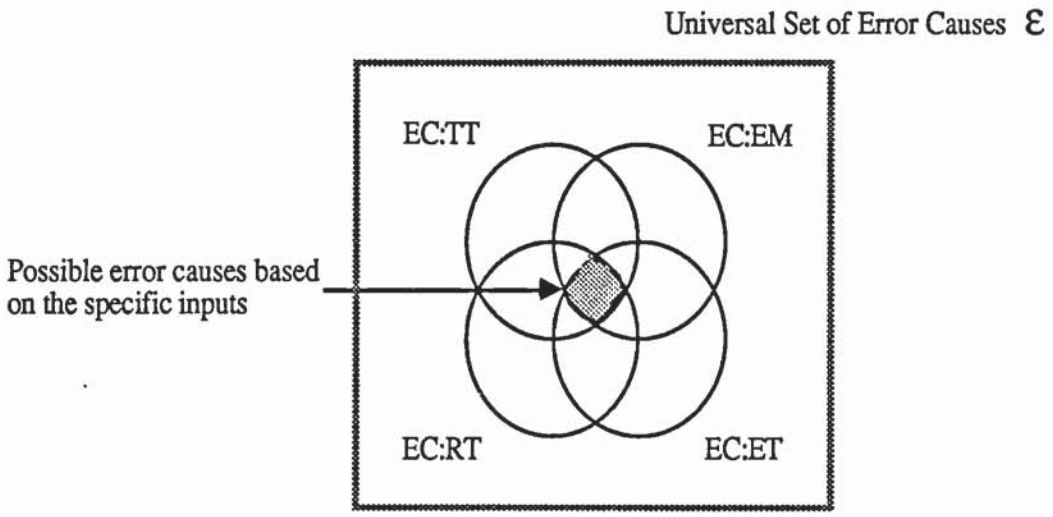
Secondary Response Type linked to Error Types

Response Type: Secondary Division		Error Types
R1	Get Information	e1, e5 e8, e9, e10
R2	Give Information	e1, e4, e5, e7 e8, e9,e10
R3	Action	e1 - e10
R4	No Action	e4

6.3.2 Combining the Error Cause Selection Routes

At this point within the analysis each sub-task has four associated subsets of the universal set of error causes. In order to ensure that the final set of error causes is specific to the situation, a potential error cause can only be accepted if it is present at least once within each of the sub-sets, otherwise it is rejected (Figure 6.3.1). For example if only the error type 'As Well As' was considered appropriate, any error cause that resulted in for example an 'Other Than' error but not an 'As Well As' error would be irrelevant (despite it having been present within the task type subset).

FIGURE 6.3.1 Identifying Potential Error Causes



If more than one error type was considered important an error cause could occur more than once within the EC / ET subset. Similarly, some error causes are associated with several IPC stages and if more than one of these was associated with a particular task type then an error cause would occur more than once within the EC / ET subset. An error cause can only appear once, if at all, within the other two subsets (error cause by response type and error cause by error mechanism). A frequency count should be kept for each error cause. The reason for this is that an error cause is considered to have more opportunity to occur if it is associated with more than one stage of the mental process or if it is linked with more than one of the identified error types. Once the set of possible error causes is finalised these access the PSF database. If the error cause has a frequency of four (ie the base count of one link from each subset) an associated PSF receives a weighting of one. If the error cause frequency is five, the PSF receives a weighting of two etc.

6.3.3 Linking Error Causes to PSFS

As a result of establishing the PSF classification structure and extending this to individual PSF keywords (chapter five) a PSF database was constructed. Error causes acted as the direct link into this PSF database. Certain PSFs were likely to affect some error causes more than others and some would influence many error causes. Therefore each error cause was given a set of mappings to many individual PSFs and each PSF had several mappings to different error causes. A multiple mapping system emerged (Figure 6.3.2). The specific associations between the error causes and the PSFs is given in Table 6.3.8.

Once an initial PSF listing has been generated it is suggested that the designer personally eliminates PSFs known to be irrelevant for a specific situation, or that have already reached the ergonomic standard, ie the path is reversed back up the linkages with PSF removal reducing the likelihood of the associated error causes. If this technique was to be extended to provide a human reliability analysis such a reversal could demonstrate the improvement in reliability possible by ensuring PSFs are non-negative.

FIGURE 6.3.2 The multiple mapping system

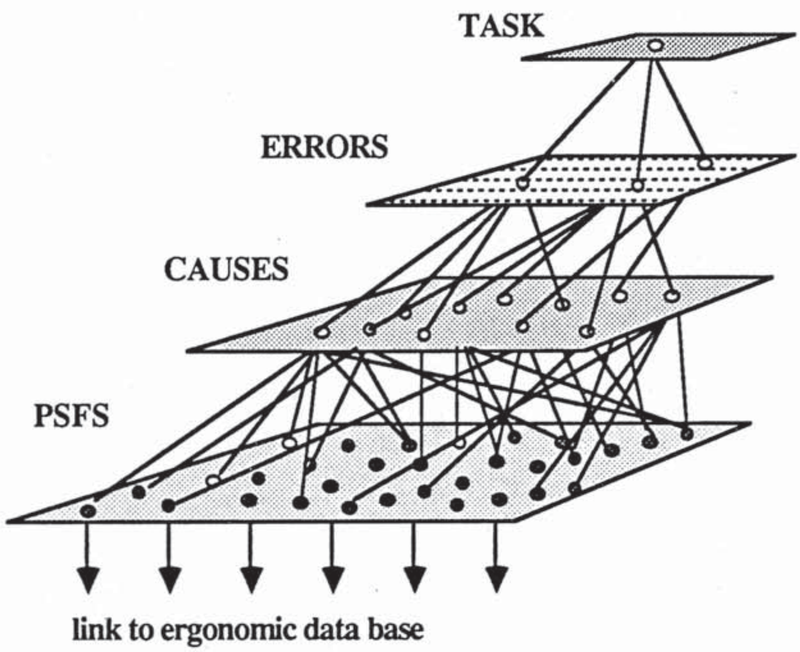


TABLE 6.3.7 Error Types linked to Error Causes

ERROR TYPE	ERROR CAUSE
ET1 NOT DONE	c2 c3 c5 c6 c7 c8 c10 c11 c12 c13 c14 c15 c17 c19 c21 c22 c23 c26 c29 c31 c33 c34 c35
ET2 LESS THAN	c3 c7 c10 c11 c12 c13 c15 c17 c20 c25 c30A c35
ET3 MORE THAN	c5 c9 c10 c11 c12 c16 c17 c18 c20 c25 c27 c30A c35
ET4 AS WELL AS	c3 c4 c10 c12 c14 c16 c17 c18 c25 c28 c30 c32 c33 c34 c35
ET5 OTHER THAN	c3 c4 c6 c7 c9 c10 c11 c12 c15 c17 c18 c20 c22 c24 c25 c27 c30 c30A c33 c34 c35
ET6 REPEATED	c1 c3 c6 c14 c18 c19 c25 c30A
ET7 SOONER THAN	c3 c4 c7 c10 c11 c12 c14 c18 c20 c25 c28 c33 c34 c35
ET8 LATER THAN	c3 c5 c8 c10 c11 c12 c13 c15 c17 c20 c22 c23A c26 c29 c30 c33 c34 c35
ET9 MIS-ORDERED	c3 c4 c13 c15 c18 c19 c24 c28 c30 c30A c33
ET10 PART-OF	c2 c3 c5 c7 c11 c13 c15 c17 c19 c26 c29 c30A c33 c34 c35

TABLE 6.3.8 Mappings between Error Causes and PSFs

Error Cause ->	Performance Shaping Factors							
M1								
1. Doubling 45								
	A3.3,	A5.3,	A6.2,	A7.1,	A8.1,	A9.1,	A10.2,	A11.2,
	A12.2,	A13.1;	B21,	B26,	B29,	B30,	B33,	B37
	B38;	C42,	C43,	C44,	C45.2,	C46.2,	C47,	C53,
	C54,	C56,	C62,	C63.1,	C63.2,	C63.3,	C72,	C77,
	C78,	C81,	C83,	C85,	C87,	C90,	C91,	C96,
	C97,	C101,	C105,	C108,	C146.			
2. Tunneling 54								
	A3.3,	A5.3,	A6.2,	A7.1,	A8.1,	A9.1,	A10.2,	A11.2,
	A12.2,	A13.1;	B21,	B26,	B29,	B30,	B33,	B37,
	B38;	C42,	C43,	C44,	C45.2,	C46.2,	C47,	C53,
	C54,	C56,	C62,	C63,	C72,	C77,	C78,	C81,
	C83,	C84,	C85,	C87,	C88,	C90,	C93,	C95,
	C96,	C97,	C98,	C101,	C104,	C105,	C108,	C110,
	C125,	C132,	C133,	C138,	C141,	C146.		
3. Hyperactivity 49								
	A3.3,	A5.3,	A6.2,	A7.1,	A8.1,	A9.1,	A10.2,	A11.2,
	A12.2	A13.1;	B21,	B26,	B29,	B30,	B33,	B37,
	B38,	C42,	C43,	C44,	C45.2,	C46.2,	C47,	C53,
	C54,	C56,	C62,	C63,	C72,	C77,	C78,	C81,
	C83,	C87,	C90,	C91,	C96,	C97,	C101,	C105,
	C108,	C115.2,	C116,	C122,	C124,	C126,	C141,	C142,
	C145.							
4. Unplanned Response 40								
	A3.3,	A5.3,	A6.2,	A7.1,	A8.1,	A9.1,	A10.2,	A11.2,
	A12.2,	A13.1;	B21,	B26,	B29,	B30,	B33,	B37,
	B38;	C42,	C43,	C45,	C46.2,	C47,	C53,	C54,
	C56,	C62,	C63,	C72,	C78,	C81,	C83,	C87,
	C91,	C96,	C97,	C101,	C105,	C108,	C141,	C146.
5. Freeze 47								
	A3.3,	A5.3,	A6.2,	A7.1,	A8.1,	A9.1,	A10.2,	A11.2,
	A12.2,	A13.1;	B21,	B26,	B29,	B30,	B33,	B37,
	B38;	C42,	C43,	C45,	C46.2,	C47,	C53,	C54,
	C56,	C62,	C63,	C72,	C78,	C81,	C83,	C87,
	C91,	C93.6	C96,	C97,	C101,	C104.2,	C104.3,	C105,
	C108,	C110,	C112.3	C121,	C137,	C139,	C146.	

Error Cause ->	Performance Shaping Factors							
6. Mind Set 43								
	A3.3,	A5.3,	A6.2,	A7.1,	A8.1,	A9.1,	A10.2,	A11.2,
	A12.2,	A13.1;	B21,	B26,	B29,	B30,	B33,	B37,
	B38;	C42,	C43,	C45,	C46.2,	C47,	C53,	C54,
	C56,	C62,	C63,	C72,	C78,	C81,	C83,	C87,
	C91,	C93,	C96,	C97,	C101,	C104,	C105,	C108,
	C139,	C140,	C146.					
7. Short-cuts 51								
	A3.3,	A5.3,	A6.2,	A7.1,	A8.1,	A9.1,	A10.2,	A11.2,
	A12.2,	A13.1;	B21,	B26,	B29,	B30,	B35,	B37,
	B38;	C42,	C43,	C44,	C46.2,	C47,	C53,	C54,
	C56,	C62,	C63,	C72,	C78,	C81,	C83,	C87,
	C91,	C96,	C97,	C101,	C105,	C108,	C110,	C111,
	C112.3,	C115.2,	C115.3,	C116.2,	C116.3,	C121,	C125,	C126,
	C142,	C143,	C146.					
M2								
8. Indecision 57								
	A1.1,	A2.1,	A2.2,	A3.2,	A3.3,	A6.2,	A11.1,	A13.1;
	B16,	B19,	B20,	B21,	B22,	B23,	B25,	B26,
	B27,	B28,	B29,	B30,	B31,	B33;	C41.1,	C63.2,
	C64,	C65.2,	C66,	C67,	C68,	C69,	C70,	C71,
	C73,	C74,	C75,	C81,	C82,	C84,	C85,	C87,
	C89,	C90,	C91,	C93,	C95,	C96,	C99,	C101,
	C103,	C104,	C105,	C108,	C124,	C137,	C139,	C140,
	C146.							
9. Persistence 59								
	A1.1,	A2.1.	A2.2,	A3.2,	A3.3,	A6.2,	A11.1,	A13.1;
	B16,	B19,	B20,	B21,	B22,	B23,	B25,	B26,
	B27,	B28,	B29,	B30,	B31;	C41.1,	C63.2,	C63.3,
	C64,	C65.2,	C66,	C67,	C68,	C69,	C70.1,	C70.2,
	C71,	C73,	C74,	C75,	C81,	C82,	C87,	C88,
	C89,	C90,	C93,	C95,	C96,	C98,	C101,	C102,
	C103,	C104,	C105,	C106,	C108,	C132,	C133,	C140,
	C141,	C143,	C145.					
10. Mental Set 46								
	A1.1,	A2.1,	A2.2,	A3.2,	A3.3,	A6.2,	A11.1,	A13.1;
	B16,	B19,	B20,	B21,	B22,	B23,	B25,	B26,
	B27,	B28,	B29,	B30,	B31;	C41.1,	C63.2,	C63.3,
	C64,	C65.2,	C66,	C67,	C68,	C69,	C70,	C73,
	C74,	C75,	C81,	C82,	C89,	C90,	C93,	C96,
	C101,	C104,	C108,	C138,	C139,	C145.		

Error Cause ->	**Performance Shaping Factors**							
11. Misinterpretation 52								
	A1.1,	A2.1,	A2.2,	A3.2,	A3.3,	A6.2,	A11.1,	A13.1;
	B16,	B19,	B20,	B21,	B22,	B23,	B25,	B26,
	B27,	B28,	B29,	B30,	B31;	C41.1,	C64,	C65.2,
	C66,	C67,	C68,	C69,	C70,	C73,	C74,	C75,
	C81,	C82,	C84,	C85,	C86,	C87,	C90,	C93,
	C94,	C95,	C96,	C97,	C99,	C100,	C103,	C104,
	C105,	C107,	C124,	C145.				
12. Misdiagnosis 41								
	A1.1,	A2.1,	A2.2,	A3.2,	A3.3,	A6.2,	A11.1,	A13.1;
	B16,	B19,	B20,	B21,	B22,	B23,	B25,	B26,
	B27,	B28,	B29,	B30,	B31;	C41.1,	C64,	C65.2,
	C66,	C67,	C68,	C69,	C70,	C73,	C74,	C75,
	C81,	C82,	C90,	C96,	C103,	C120,	C124,	C139,
	C143.							
M3								
13. Reduced Capabilities 56								
	A1.3,	A3.3,	A7.1;	B16,	B21,	B23,	B24,	B29,
	B32,	B33,	B37,	B39,	B40;	C42,	C43,	C44,
	C45.1,	C46.2,	C47,	C48,	C49,	C50,	C51,	C52,
	C53,	C55,	C56,	C57,	C58,	C59,	C60,	C61,
	C68,	C71,	C72,	C81,	C83,	C84,	C86,	C91,
	C92,	C95,	C96,	C98,	C99,	C101,	C102,	C108,
	C109,	C110,	C111,	C112.2,	C112.3,	C115.2,	C115.3,	C116.
14. Insufficiently Demanding 19								
	A1.1,	A2.1,	A3.3,	A7.1,	A8.2;	B24,	B32,	B37,
	B39;	C81,	C83,	C85,	C126,	C132,	C133,	C137,
	C138,	C141,	C145.					
15. Over Demanding 48								
	A1.3,	A2.2,	A2.3,	A3.3,	A7.1,	A13.1;	B24,	B32,
	B37,	B39;	C61,	C70.1,	C81,	C83,	C84,	C85.1,
	C85.2,	C86,	C87,	C93.1,	C97,	C104,	C105,	C113,
	C114,	C120,	C123,	C124,	C125,	C126,	C127,	C128,
	C129,	C130,	C131,	C132,	C133,	C135,	C137,	C138,
	C139,	C140,	C141,	C142,	C143,	C144,	C145,	C146.
M4								
16. Forget Exit Point 22								
	B37,	B38;	C41,	C44,	C45.2,	C63,	C64.2,	C80,
	C84,	C85,	C89,	C90,	C96,	C98,	C118,	C127,
	C133,	C138,	C139,	C141,	C143,	C145.		

Error Cause -> **Performance Shaping Factors**

17. Forget Target 22

B37,	B38;	C41,	C44,	C45.2,	C63,	C64.2	C80,
C84,	C85,	C86,	C90,	C96,	C101,	C104,	C108,
C118,	C127,	C133,	C138,	C139,	C145.		

18. Erratic Response 17

B37,	B38;	C41,	C44,	C45.2,	C63,	C64.2,	C80,
C84,	C85,	C86,	C90,	C118,	C127,	C133,	C138,
C145.							

19. Forget Stage 24

B37,	B38;	C41,	C44,	C45.2	C63,	C64.2,	C80,
C84,	C85,	C89,	C90,	C91,	C96,	C101,	C103,
C104,	C108,	C118,	C127,	C133,	C138,	C139,	C145.

M5

20. Stereotype Mismatch 30

A2.1,	A2.3;	B16,	B18,	B23,	B27;	C41.3,	C41.4,
C43,	C44,	C65.2,	C73,	C74,	C84,	C85,	C86,
C87,	C93,	C94,	C95,	C96,	C97,	C100,	C103,
C104,	C105,	C107,	C117,	C122,	C139.		

21. Action Prevented 33

A2.3;	B23,	B27;	C41.3,	C41.4,	C43,	C44,	C49,
C51,	C65.2,	C71,	C74,	C84,	C85.2	C88,	C92,
C95,	C96,	C101,	C103,	C109,	C110,	C111,	C112,
C113,	C114,	C115,	C116,	C119,	C120,	C121,	C122,
C123.							

22. Indentification Prevented 18

A1.1,	A2.3;	B23,	B27;	C41.3,	C41.4,	C43,	C44,
C65.2	C71,	C74,	C84,	C85,	C86,	C87,	C88,
C97,	C124.						

23. Perception Prevented 12

A2.3;	B23,	B27;	C41.3,	C41.4,	C43,	C44,	C65.2
C88,	C95,	C98,	C102.				

24. Perception Retarded 18

A2.3;	B23,	B27;	C41.3,	C41.4,	C43,	C44,	C65.2
C88,	C95,	C96,	C98,	C101,	C102,	C109,	C110,
C111,	C123.						

Error Cause ->	Performance Shaping Factors

M6

25. Conscious vs Sub-conscious 18

A1.3, A3.3; B21, B33, B34, B37, B38, B40; C45, C58, C59, C60, C61, C62, C65.2, C138. C145, C146,

26. Motor Co-ordination 29

A33; B21, B33, B34, B37, B38, B40; C45, C55, C56, C57, C58, C59, C60, C61, C62, C65, C84, C85, C86, C109, C110, C111, C117, C119, C127, C130, C131, C146.

27. Mental Blocks 31

A1.1, A3.3; B33, B34, B37, B38, B40; C45, C58, C59, C60, C61, C62, C65, C71, C87, C90, C95, C96, C97, C99, C102, C103, C105, C121, C122, C124, C138, C139, C140, C146.

M7

28. Substitution 25

A1.3, A4.1, A13.2; B21, B26, B34, B36, B37, B38, B40; C58, C59, C60, C61, C62, C65.2, C76, C80.3 C96, C138, C139, C140, C141, C144, C145.

29. Unintentional Activation 28

A1.3, A4.1, A13.2; B21, B26, B34, B36, B37, B38, B40; C58, C59, C60, C61, C62, C65.2, C76, C80.3, C93, C95, C96, C104, C138, C139, C140, C141, C144, C145.

30. Forget 27

A1.3, A4.1, A13.2; B21, B26, B34, B36, B37, B38, B40; C58, C59, C60, C61, C62, C65.2, C76, C80.3, C87, C92, C102, C138, C139, C140, C141, C144, C145.

31. Intrusions 24

A1.3, A4.1, A13.2; B21, B26, B34, B36, B37, B38, B40; C58, C59, C60, C61, C62, C65.2, C76, C80.3, C138, C139, C140, C141, C144, C145.

Error Cause ->		Performance Shaping Factors							
32.	Pre-occupation 34								
		A1.3,	A4.1,	A13.2;	B21,	B26,	B34,	B36,	B37,
		B38,	B40;	C44,	C46.2,	C47,	C48,	C50,	C51,
		C58,	C59,	C60,	C61,	C62,	C65.2,	C76,	C80.3,
		C110,	C111,	C113,	C118,	C138,	C139,	C140,	C141,
		C144,	C145.						
M8									
33.	Under-estimating Demands 31								
		A1.1,	A3.2,	A3.3,	A6.2,	A9.3,	A10.1,	A11.1,	A12.1;
		B18,	B22,	B23,	B25,	B31,	B33,	B34,	B35,
		B37,	B38;	C60,	C71,	C72,	C76,	C77,	C78,
		C79,	C81,	C82,	C83,	C84,	C93,	C146.	
34.	Over-estimating Abilities 32								
		A1.3,	A3.2,	A3.3	A6.1,	A6.2,	A9.3,	A10.1,	A11.1,
		A12.1;	B18,	B22,	B23,	B25,	B31,	B33,	B34,
		B35,	B37,	B38;	C60,	C71,	C72,	C76,	C77,
		C78,	C79,	C81,	C82,	C83,	C85,	C110,	C146.
35.	Rule Contravention 36								
		A3.2,	A3.3,	A6.1,	A9.3,	A10.1,	A11.1,	A12.1;	B14,
		B15,	B22,	B23,	B25,	B31,	B33,	B34,	B35,
		B37,	B38;	C60,	C71,	C72,	C76,	C77,	C78,
		C79,	C81,	C82,	C83,	C84,	C85,	C91,	C112.2,
		C112.3,	C115,	C121,	C146.				
36.	Risk Recognition 35								
		A2.1,	A3.2,	A3.3,	A6.2,	A9,3,	A10.1,	A11.1,	A12.1;
		B15,	B16,	B19,	B22,	B23,	B25,	B31,	B33,
		B34,	B35,	B37,	B38;	C60,	C71,	C72,	C76,
		C77,	C78,	C79,	C81,	C82,	C83,	C91,	C101,
		C104,	C105,	C146.					
37.	Risk Tolerance 37								
		A1.3,	A2.2,	A3.2,	A3.3,	A5.1,	A6.1,	A9.3,	A10.1,
		A11.1,	A12.1;	B14,	B15,	B19,	B22,	B23,	B25,
		B31,	B33,	B34,	B35,	B37,	B38;	C60,	C71,
		C72,	C76,	C77,	C78,	C79,	C81,	C82,	C83,
		C109,	C112.3,	C115,	C116,	C146.			

The result of using the designer decision aid is that a listing is produced of all the implicated individual PSF keywords with an attached frequency weighting (in terms of the number of links). An example is shown in Table 6.3.9. This frequency is the number of times a particular keyword has been implicated as having a direct influence on potential error causes. Each task can be assessed independently or a total can be produced for a group, or all, of the tasks related to a particular plant or process. It is expected that this fequency would act as an indicator of the level of importance of each PSF so that during design those aspects that are implicated most often assume higher priority when ensuring compatibility with ergonomic standards. During a system of human reliability analysis the frequency could be used as a PSF weighting factor.

TABLE 6.3.9 An Example of a Performance Shaping Factors Listing

PSF number	PSF sub-group	Specific PSF	frequency
37	Personality	Temperament	157
101	Displays	Response Time	143
96	Displays	Control Association	133
33	Personality	Confidence	131
139	Psychological Demands	Memory	126

It is anticipated that if an ergonomic standards database existed it should be accessed by the PSF keywords to give:

1. An accurate definition of the keyword
2. A reasoned account of its importance and implications for the system
3. Associated design criteria.

The possibility for such a structured database was explored for the specific situation of designing the interface for process plant control rooms. This resulted in CRIDA - the Control Room Interface Design Aid which exhibits the three specified requirements (Whalley and Booth 1986).

CHAPTER SEVEN
APPLICATION OF THE DESIGN DECISION AID

7.1 INTRODUCTION

When auditing an old plant the PSF listing can form a useful tool in its own right, acting as a check and a prompt. An exercise was undertaken with the sponsoring company whereby two different groups of approximately twenty personnel convened on separate occasions to assess performance shaping factors in this way. Each event was attended by design engineers, maintenance engineers and process personnel all of whom had some level of managerial responsibility.

These events were run as work-shops with a mix of personnel forming groups of four (in order to ensure both engineering and operating experience). A set of eight colour photographs of situations and areas around the site were given to each group and they were asked to discuss and assess the ergonomic aspects of each based on a list of ergonomic performance shaping factors (table 7.1.1). This proved very successful at stimulating thought and discussion especially since both good and poor aspects were included.

When considering PSFs in the context of a plant assessment; as the assessor moves around the plant and discusses different aspects with the different plant personnel, a model of the system can be established focusing on particular potential problem areas. Taking this one step further, if a Task Analysis is completed or a Hazard and Operability Study undertaken the possible failures, in terms of human errors, can be hypothesised and related to their likely causes. By relating this information to the PSF audit profile it is possible to suggest which areas would give most benefits if improved. Note, as stated in the listing (Section 5.2), there are difficulties with changing certain aspects of the system design once a plant is already built and running. More benefit can be achieved for the new plant whilst it is still at the drawing-board stage.

TABLE 7.1.1 Ergonomic PSF used in the WorkShops

ERGONOMIC CONSIDERATIONS

Man-Man-Machine Interface

Controls
direct controls
indirect controls
location
identification
feedback
prompts
response time
access
visibility

Displays
display type
location
identification
scale continuity
legibility
clarity
response time
access
visibility

Communication
formal
informal
direction
sender
receiver
method
direct
indirect
feedback

Information
access
form
format
clarity
legibility
recording mechanisms

Management
supervision
strategy
selection
incentives
instructions
team work
attitude

Environment

Work Pattern
shift work
hours per week
overtime
rest periods
self control

Physical
lighting
glare
atmosphere
fumes
gases
dust
noise
heat
cold
vibration
skin irritants

Location
control room
on plant
plant & control room
number of locations
climatic exposure

Access
sufficient room
sufficient height
stairs
ladder
terrain

Equipment

Clothing
standard
special
safety
availability

System Equipment
safety
fail safe
operator
dimension
standard
backup
interaction

Operator Equipment
system furniture
domestic
utility
identification

Aids
availability
requirement
serviceability
type

Demands

	Physical			Psychological	
posture	movement	control		responsibility	concentration
power	static	co-ordination		memory	decisions
dexterity	vision	tactile		time pressure	accuracy
hearing	smell	kinesthetic		alertness	flexibility
				risk perception	
				organisation	monitoring

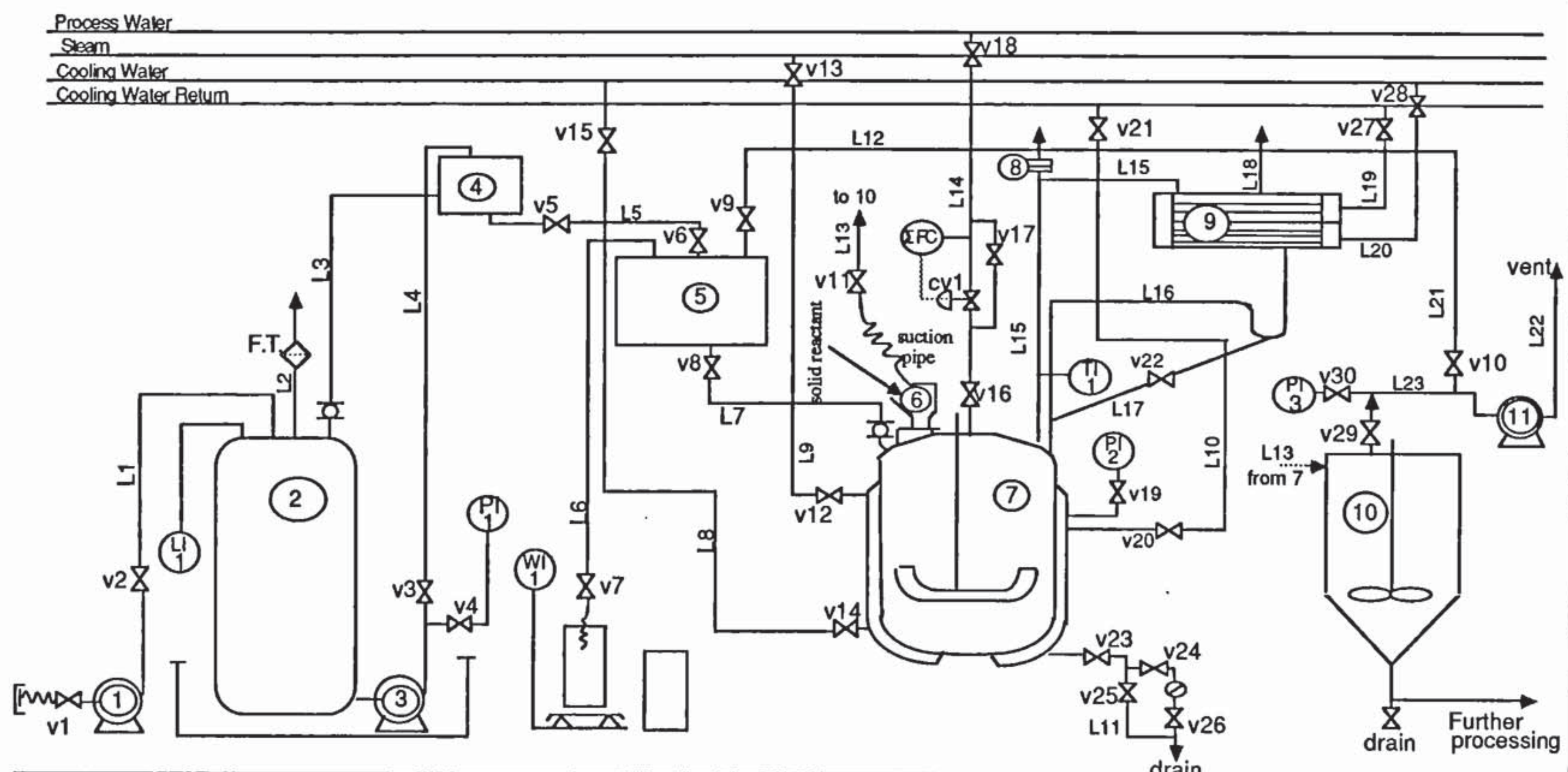
7.2 THE EXAMPLE APPLICATION

The following example demonstrates how the full technique can identify factors that affect human reliability.

7.2.1 The Plant

The plant that forms the basis for this example was a batch process plant in operation during the 1960s. Initially an hierarchical task analysis was produced based on its Pipework and Instrumentation Diagram (P&ID) (Figure 7.2.1), plus a short description of the chemistry and method of operation (summarised in Table 7.2.1). This is one of the two alternative starting points for considering human error and performance shaping factors. The top two levels of the production part of the task analysis are shown in Table 7.2.2, obviously a full task analysis would also cover plant preparation, shutdown, start-up, communication, fault diagnosis etc. Section 4 **'Complete Reaction'** was selected as the basis for this example. The TA redescription is presented in Table 7.2.3 and the accompanying task plan is reproduced in Figure 7.2.2.

FIGURE 7.2.1 Example application P & ID



ITEM No	1	2	3	4	5	6	7	8	9	10	11
Description	solvent discharge pump	solvent storage	solvent feed pump	solvent head tank	meter tank	solid reactant chute	Reactor	Bursting Disc	Condenser	Wash Vessel	Vacuum Pump
Quantity	1	1	1	1	1	1	1	1	1	1	1
Material	M.S.	M.S.	M.S.	M.S.	Pb lined M.S.	M.S.	glass lined M.S.	carbon	M.S.	cast iron	
Size/Rating	0.5 m^3/ min	30 m^3	0.1 m^3/ min	0.4 m^3	10 m^3		2.3 m^3	6 in. diam		70m^3	

Table 7.2.1 Description of the Chemistry and Method of Operation of the Plant Used in the Example Application

ANALYSIS OF POTENTIAL HUMAN ERROR (BATCH PROCESS PLANT)

1. **Reactions**

The reaction system involved is complex being heterogeneous and consisting of three phases, (a) an organic phase containing the majority of the organic feedstock and product, (b) an aqueous phase, and (c) a solid phase comprising a solid reactant. The solid reactant is soluble in water but essentially insoluble in the organic phase. Consequently a solvent is added, soluble in both the aqueous and the organic phase, to improve the contact efficiency across the organic/aqueous boundary for the solid and organic reactants. The solvent also serves to remove some of the heat of reaction from the system by being vaporised and subsequently condensed away from the reactor.

The Reactor Charge per batch is:

organic feedstock	785 kg
solid reactant	310 kg
solvent	325 kg
water	80 kg

2. **Method of Operation**

The organic feedstock is held on a separate producing plant in a $30m^3$ capacity storage tank and analysed daily. Material for this reaction is weighed into drums, two drums being sufficient for one reactor charge. The solvent is received in road tankers and stored in a $30m^3$ capacity mild steel tank, Item 2. Each solvent delivery is analysed prior to acceptance. The solid reactant is received in drums. Certificates of analysis are received with each consignment and no further testing is normally carried out on site.

The operating procedure for each batch is as follows: The solvent is pumped to a meter head tank, Item 4, from which the excess overflows back to storage. The organic feedstock is charged to a second meter head tank, Item 5, by applying vacuum to the tank and sucking the pre-weighed charge from the two drums. When these drums have been charged, the solvent is run in from the first meter tank in order to mix with the organic feedstock. The man-lid on the reactor, a 2.3^3 glass lined reactor with anchor type stirrer, Item 7, is opened and $0.08m^3$ of water added. To this, half of the solids are added via the manhole. The solvent/organic feedstock mix is next run into the reactor and the stirrer started. The remaining solids are then added to complete the charge and the man-lid closed and secured.

Steam is then put on to the reactor jacket and the temperature is raised. When vapour is evolved, as indicated on the temperature indicator in the vapour line adjacent to the reactor (T1.1), the steam is turned off, the jacket vented and cooling water applied. The usual time for steam heating is between 15 and 30 minutes. Once reacting, solvent is refluxed up the vapour line and condensed in a shell and tube condenser, Item 9. The condensate runs into the reactor via a separate reflux line.

The refluxing usually dies down after about one to one and a half hours and the cooling water to the reactor jacket is then isolated, although the jacket is left full of water. After a further half an hour, the jacket is drained and steam put on the reactor for about ten hours to take the reaction to the required degree of completion. At the end of the batch, a suction pipe is inserted through the manhole connection and material sucked into Item 10, from where it is pumped away for further processing.

TABLE 7.2.2 Top Two Levels of the Hierarchical Task Analysis

Produce Product

1. Supply Reactants
   - 1.1 supply correct quantity and quality of water
   - 1.2 supply correct quantity and quality of water
   - 1.3 supply mix of feedstock and solvent
   - 1.4 close man-lid
   - 1.5 activate stirrer

2. Start Reflux
   - 2.1 steam to reactor jacket
   - 2.2 check rise in vapour line temperature
   - 2.3 turn off steam

3. Cool Reactor
   - 3.1 vent jacket
   - 3.2 apply cooling water
   - 3.3 isolate jacket

4. Complete Reaction
   - 4.1 drain jacket item 7
   - 4.2 re-establish steam
   - 4.3 look for completion
   - 4.4 turn off steam
   - 4.5 vent jacket item 7

5. Empty Reactor
   - 5.1 insert suction pipe through man-hole
   - 5.2 suck material into item 10
   - 5.3 pump from item 10 for processing

TABLE 7.2.3 Hierarchical Task Analysis for the Sub-Task 'Complete Reaction'

Complete Reaction

1 Drain jacket item 7

1.1 time = 0.5 hrs from isolation

1.2 if V24 open then CLOSE

1.3 if V25 closed then OPEN

1.4 open V23

2 Re-establish steam

2.1 when no flow from item 7 to drain, close V25

2.2 ensure V26 open

2.3 open V24

2.4 ensure V14closed

2.5 ensureV20 closed

2.6 ensure V13 open

2.7 open V12

3 Look for completion

3.1 =10 hrs from steam on take a sample

3.2 check analysis results

3.3 if reaction incomplete Wait then Resample

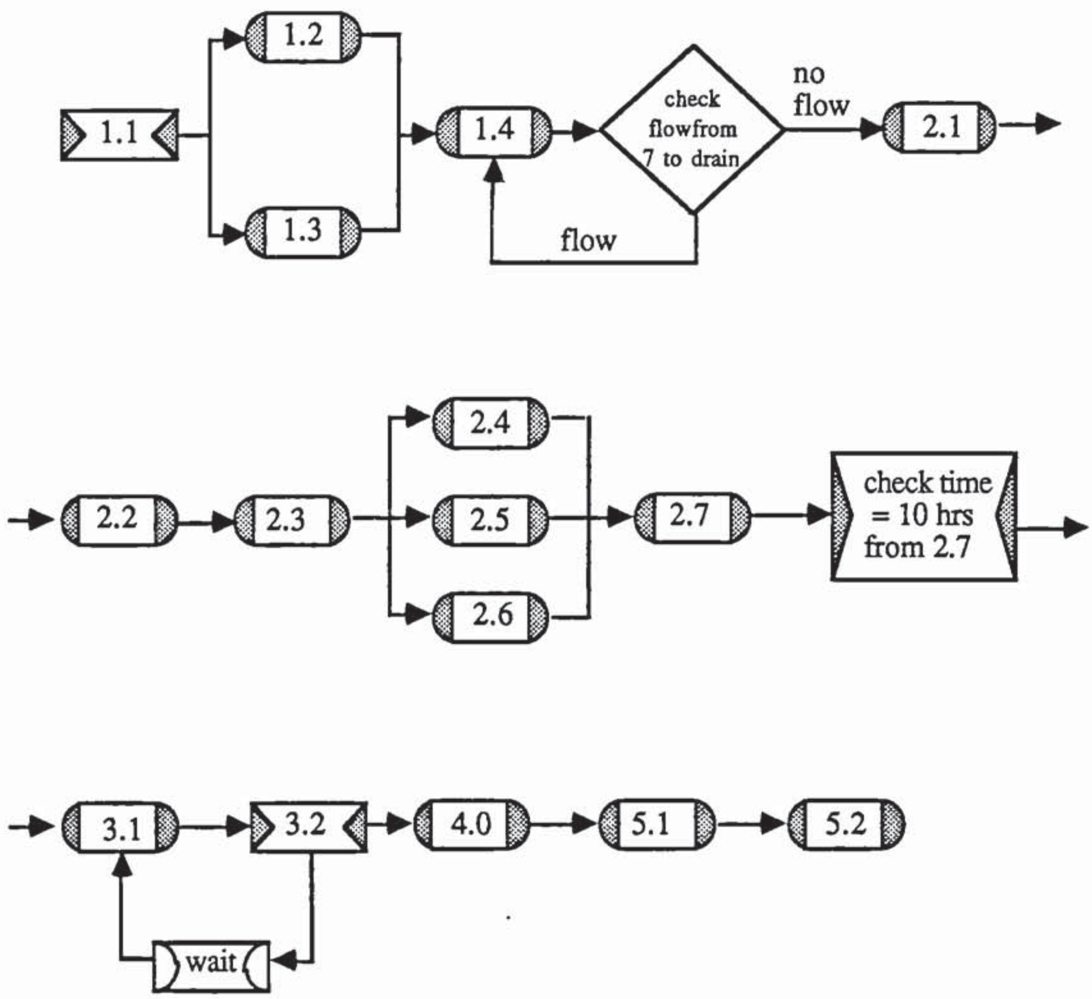
4 Turn off steam (close V12)

5 Vent jacket (item 7)

5.1 close V24

5.2 open V25

FIGURE 7.2.3 Task Plan for the Example Sub-Task 'complete reaction'



Once the task analysis was completed the **Generic Task Type** was identified for each task and sub-task. Following this, **Error Types** were identified that were considered important for each sub-task. This information is presented in Table 7.2.4. The **Response Type** is indicated within the task plan by the box surrounding the task description.

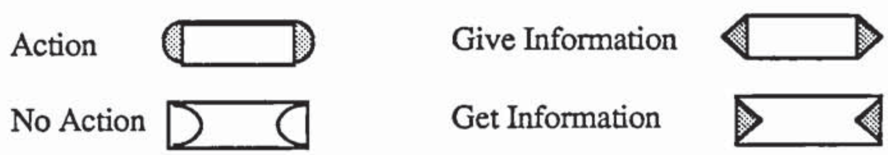


Table 7.2.4 Inputs to the Design Aid Program

1.1 KEEP CHECK ON TIME UNTIL T = APPROX HALF HOUR

Task Type: requirement

Response Type A: sequence **Response Type B:** get information

Error Types: not done / other than / later than

1.2 T = HALF HOUR IF V24 OPEN THEN CLOSE

Task Type: stimulus

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than / sooner than / later than / mis-ordered

1.3 IF V25 CLOSED THEN OPEN

Task Type: stimulus

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than / sooner than / later than / mis-ordered

1.4 OPEN V23

Task Type: stimulus

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than / sooner than / later than / mis-ordered

2.1 WHEN NO FLOW FROM ITEM 7 TO DRAIN, CLOSE V25

Task Type: stimulus

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than / sooner than

2.2 ENSURE V26 OPEN

Task Type: requirement

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than / mis-ordered

2.3 OPEN V24

Task Type: integration

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than / mis-ordered

2.4 ENSURE V14 CLOSED

Task Type: requirement

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than

2.5 ENSURE V20 CLOSED

Task Type: requirement

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than

2.6 ENSURE V13 OPEN

Task Type: requirement

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than / sooner than / mis-ordered

2..7 OPEN V12

Task Type: requirement

Response Type A: sequence **Response Type B:** action

Error Types: not done / other then

3.1 KEEP CHECK ON TIME UNTIL APPROX 10 HOURS AFTER STEAM ON

Task Type: requirement

Response Type A: sequence **Response Type B:** get information

Error Types: not done / other than / later than

3.2 AT APPROX 10 HOURS TAKE SAMPLE

Task Type: stimulus

Response Type A: sequence **Response Type B:** action

Error Types: not done/ less than/ other than/ sooner than/ later than/ part of

3.3 CHECK RESULTS OF ANALYSIS

Task Type: integration

Response Type A: sequence **Response Type B:** get information

Error Types: not done / other than / part of

3.4 IF ANALYSIS IS INCOMLETE WAIT THEN RESAMLE

Task Type: interpretation

Response Type A: sequence **Response Type B:** no action

Error Types: as well as

4.0 TURN OFF STEAM ie CLOSE V12

Task Type: interpretation

Response Type A: discrete **Response Type B:** action

Error Types: not done / other than / later than

5.1 CLOSE V24

Task Type: integration

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than / mis-ordered

5.2 OPEN V25

Task Type: integration

Response Type A: sequence **Response Type B:** action

Error Types: not done / other than / mis-ordered

7.2.2 Identifying the Factors that affect Performance

A useful appreciation of the possible causes of error can be gained simply by bearing in mind the main aspects of each sub-task and considering the possible errors in turn. Look at the link charts between task type and error cause (Table 6.3.2) and error type and error cause (Table 6.3.7). If a specific error cause is indicated on both charts then it is a potential for the specific scenario.

This visual analysis can become very time consuming; the more sub-tasks that are involved and the more potential errors, the greater the number of links to be considered and collated. Obviously, to progress to identifying individual PSFs in this manner means a long and laborious manual process. This analysis is however, ideal for computerisation and a pilot program (for the IBM pc) has been developed by Lihou Loss Prevention Services Ltd. Using this program, output is possible both for the individual sub-tasks and, more importantly, for identified sets of sub-tasks. If a designer is concentrating on one area of a plant, then all the tasks that take place in that area should be considered in order to identify all the factors that could affect performance. It is the summation of the profiles that is important. An alternative reason for considering the task in such detail could be as a preliminary to an human reliability assessment in which case the factors and error causes for each sub-task would be required.

7.2.3 The Error Cause Profile

By relating the error cause profile (Table 7.2.5 and Figure 7.2.3) back to the individual sub-tasks associated with 'complete reaction' it is possible to place the generic terms into context.

It is of as much interest to look at which error causes are shown to be unlikely or of negligible importance - In this case:

1 **Doubling** - the Error Type 'Repeated' was not identified as important therefore 'doubling' could not apply.

16 **Forget Exit Point** - none of the tasks could progress past the completion point, eg the valves were on / off handled ball valves.

24 **Perception Retarded** - this received 15 links compared with the maximum of 120. Since the majority of tasks were Requirement and as such not perceptually initiated, there would be little reliance on display / stimulus identification.

33 **Under Estimate Demands** - Only tasks including comprehension in their information processing chain can have the opportunity for underestimating demands. In addition error mechanism 8, 'Risk Taking' must be possible for the task type.

34 **Over Estimate Abilities** - Only tasks including Decision Making and / or Planning within their information processing chain can have the opportunity for over estimating abilities.

35 **Rule Contravention** - This occurs as the result of active decision-making therefore only tasks including this component in the information processing chain can be considered.

When looking at the error mechanism groups those related to the mental model are low, as would be expected since the majority of tasks are operating at the skill base level - well known responses to well known situations or requirements. The risk taking group is also very low but with some possibility of poor risk recognition or risk tolerance. In general, risk-taking is associated with some form of decision-making or active mental involvement. An example of **risk-tolerance** would be; a valve that should have been closed **is not checked** since it should have been closed at an earlier point in the batch process and has never yet been found to be open at this stage.

System interface causes are perhaps surprisingly low but this is only a comparitive inference:

'Response Prevented' can only be an error cause for the error type Not Done;

'Identification Prevented' for Not Done, Other Than, and Later Than;

'Perception Prevented' for Not Done

'Perception Retarded' for Later Than.

The slight difference between these causes (for example it would seem from the error cause to error type linkage that Identification Prevented should be higher that the other two), is due to the IPC links: The task type links for Requirement tasks, ie those that are self initiated, do not include the Perception and Identification stages of the IPC therefore there are **fewer task stages** that can have Identification Prevented as an error cause. This outweighs the high number of error types that produce an association. One comparatively important system interface cause is **Stereotype Mismatch**. This mismatch can occur at a number of stages within the IPC and can result in error types; Less Than, More Than, Other Than, Sooner Than, Later Than.

The most important error causes associated with a disturbance or interruption were: **Erratic Response**, this would result in a slip, an unintentional physical or mental action and would be possible for any task type; **Forget Stage**, this would be possible for any task type that forms part of a sequence. In this example all but one sub-task was designated as part of a sequence.

Within the grouping associated with Random Fluctuations; **conscious versus subconscious**, **motor co-ordination** and **mental blocks** were all indicated possible error causes.

Absent minded error causes can occur for any task not requiring full cognitive involvement. Since the majority of sub-tasks in this example were stimulus within a sequence, absent minded error causes are implicated far more often than deficient mental model causes. **Unintentional Activation** was the least important cause within this group. This can be explained in terms of error type - the two associated error types are As Well As and Sooner Than which were two of the least frequently implicated - in fact As Well As was only designated an error type on one occasion. By far the most links within this group were made to **Pre-occupation**. This is particularly due to the high number of Requirement tasks (eight of nineteen) where the activity is internally initiated. By implication, if the individual is pre-occupied the necessary internal prompt will not occur. Pre-occupation can also interfere with stimulus tasks, the stimulus being missed or ignored.

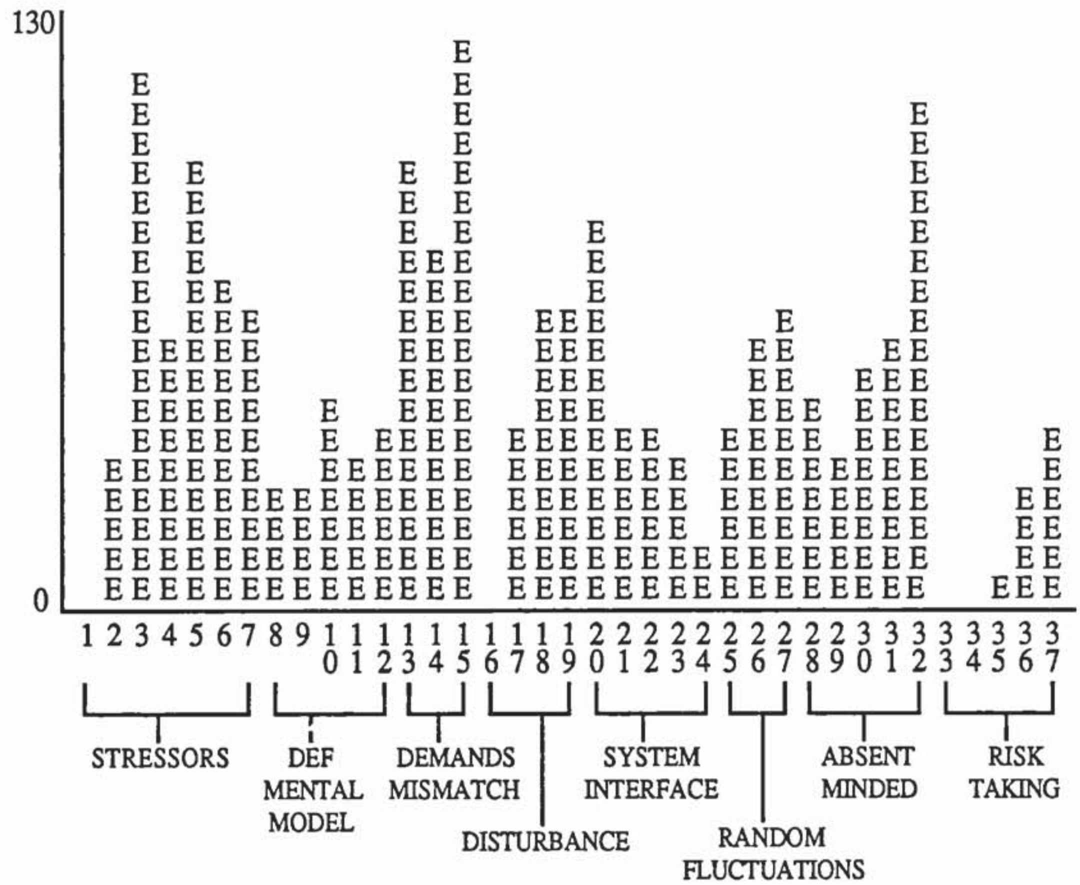
TABLE 7.2.5 Summated Error Cause Profile For The Example Task Analysis

No	ERROR CAUSE	FREQUENCY
2	Tunneling	37
3	Hyperactivity	120
4	Unplanned Response	59
5	Freeze	101
6	Mind Set	74
7	Short Cuts	69
8	Indecision	28
9	Persistence	26
10	Mental Set	50
11	Misinterpretation	37
12	Misdiagnosis	41
13	Reduced Capabilities	100
14	Insufficiently Demanding	82
15	Overdemanding	127
17	Forget Target	40
18	Erratic Response	68
19	Forget Stage	69
20	Stereotype Mismatch	87
21	Response Prevented	42
22	Identification Prevented	40
23	Perception Prevented	35
24	Perception Retarded	15
25	Concious vs Subconcious	41
26	Motor Coordination	62
27	Mental Block	67
28	Substitution	49
29	Unintentional Activation	34
30	Forget	56
31	Intrusions	62
32	Preoccupation	111

33	Underestimate Demands	3
34	Overestimate Abilities	4
35	Rule Contravention	8
36	Risk Recognition	29
37	Risk Tolerance	39

FIGURE 7.2.3 Error Cause Chart for the Example Task Analysis

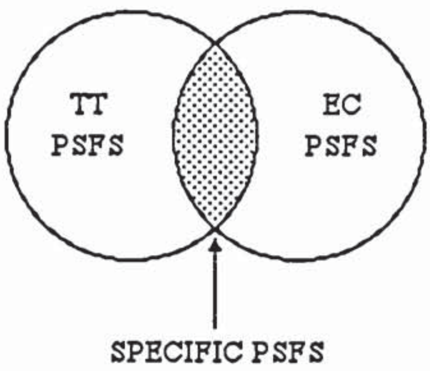
ERROR CAUSE CHART



7.2.4 The PSF Listing

This technique is generic in nature therefore the assessor must go through the PSF listing asking questions about the actual plant in relation to each indicated factor. If a factor is in fact already well designed and considered then it can be deleted, similarly any factor that is obviously irrelevant can be deleted. This leaves the assessor with a list of factors that need more attention. Design guidelines can be sought and passed to the designer along with a prioritisation list.

From the detailed PSF List (Table 5.1, p 122), it can be seen that there are 146 individual PSFs, the majority of which are sub-divided into more specific aspects. This produces a set of well over 200 PSFs that are linked to error causes and hence back to error types and task types. It is expected that future developments will ensure more specific relevance by producing weighted links direct from task type situations to PSFs to be intersected with the error cause mappings.



The Lihou Loss Prevention Services Ltd program provides the option of printing the top 10%, 25%, or 50% of the associated PSF Listing. For this example, the top half of the mapped PSF listing was selected for output , ie those PSFs with a frequency higher than the mean. This was a list of 86 specific PSFs (Table 7.2.6) therefore the total number of PSFs with recorded links must have been 172. As more and more sub-tasks are considered together the multiple mappings include more of the PSFs. Hence for large systems with many different task types it would be expected that all the PSFs would ultimately be associated. The designer or the team involved in reviewing design safety requires help with prioritising such a list.

TABLE 7.2.6 Specific Computer Generated PSF Listing for the Example Application

PSF	PSF sub-group	Specific PSF	Frequency
21	Training	Amount	1170
37	Personality	Temperament	1153
139	Psychological Demands	Memory	1091
96	Displays	Control Association	934
3.3	Technology	Safety Systems - Operator Activity	917
146	Psychological Demands	Time Pressure	909
145	Psychological Demands	Monitoring	904
101	Displays	Response Time	896
26	Experience	Amount	880
62	Work Pattern	Self Pacing	854
61	Work Pattern	Rest Periods	850
33	Personality	Confidence	832
141	Psychological Demands	Alertness	831
40	Health	Recent Illness	794
140	Psychological Demands	Decisions	777
108	Auditory Interface	Response Time	770
81	Policy	Manning - Selection	763
138	Psychological Demands	Concentration	756
65.2	Communication	Method - Indirect	748
60	Work Pattern	Overtime	739
84	Controls	Direct	702
58	Work Pattern	Shift Work	693
29	Experience	Interrupted	686
104	Auditory Interface	Type	668
90	Controls	Response Feedback	657
59	Work Pattern	Basic Hours	656
103	Displays	Display/Control Interaction	637
34	Personality	Motivation	634
91	Controls	Response Time	624
1.3	Technology	Personnel Involvement - Continuous	623
105	Auditory Interface	Identification	621
1.1	Technology	Personnel Involvement - Occasional	610

PSF	PSF sub-group	Specific PSF	Frequency
93	Displays	Type	589
23	Training	Retraining	584
38	Personality	Mood	584
44	Environment	Noise	579
144	Psychological Demands	Work Organisation	559
71	Information	Instructions - Location	552
85	Controls	Indirect	548
110	Clothing	Specific Safety Wear	541
30	Mental Model	Completeness	509
95	Displays	Location	504
83	Policy	Promotion	493
5.3	Chemistry	Predictability - Unknown	492
87	Controls	Identification	479
72	Information	Instructions - Accessibility	472
16	Training	Specific	467
9.1	Chemistry	Process Hazard - High	460
12.2	Materials	Hazard - Hazardous	460
6.2	Chemistry	Novelty - New	459
80.3	Policy	Manning - Isolation	455
13.1	Materials	Variety - High	454
86	Controls	Location	453
97	Displays	Identification	449
7.1	Chemistry	Accuracy Demanded - High	447
109	Clothing	Standard Safety Wear	435
8.1	Chemistry	Time - Dependent	423
47	Environment	Atmosphere	407
137	Psychological Demands	Responsibility	405
32	Personality	Capability	404
27	Experience	Relevance	401
111	Clothing	Environmental Clothing	399
126	Physical Demands	Movement	398
77	Policy	Management Strategy	396
76	Policy	Incentives	395
13.2	Materials	Variety - Low	388
82	Policy	Training	385

PSF	PSF sub-group	Specific PSF	Frequency
41.2	Environment	Location - Numerous	379
28	Experience	Specific	371
142	Psychological Demands	Flexibility	364
39	Health	General Fitness	346
11.1	Materials	Personnel Proximity - Control Room	339
102	Displays	Access	336
31	Mental Model	Accuracy	334
35	Personality	Risk Taking	331
53	Work Space	Small Enclosed Area	329
64.2	Communication	Type - Informal	329
78	Policy	Safety Policy	327
4.1	Chemistry	Process - Continuous	312
36	Personality	Sociability	312
51	Work Space	Surface	312
24	Experience	Education	309
143	Psychological Demands	Risk Perception	303
124	System Equipment	Identification	299
42	Environment	Climatic Exposure	296
70.1	Information	Instructions - Verbal	296

Within the list produced during this example there is a shift in order of magnitude of approximately 4 - the final designated PSF has only a quarter of the number of links of the first PSF, 296 links recorded versus 1170.

Looking at the listing, the first number on the left hand side of the printout is the PSF item number and if appropriate the specific sub-section. The first label indicates the associated PSF section and the second label gives the specific PSF keyword. The final column is the total of links from error causes to PSFs. If every error cause was associated with one particular PSF then the maximum number of times it could be implicated would be the same as the total number of error cause mappings ie the summation of all the error cause frequencies. In this example the maximum conceivable number of links from error causes to PSFs would be 1912. The actual highest number is 1170, therefore there is no PSF that is implicated by every single error cause.

Obviously there will be certain PSFs that will always come near the top in any assessment due to their high importance for any type of task. This could tempt the assessor into believing such an identification system to be redundant and to create a simple prioritisation for use in every situation. Such a gross solution would ignore radical differences caused by task type and error type. For example, the profile for a diagnostic task would prove very different from that requiring simple stimulus responses, as are predominant in this application. If we look at this profile the primary PSF is the Amount of Training, this is obviously important for Stimulus and Requirement tasks - these need to be well learnt so that they can be performed with little mental involvement. Retraining appears within the top quarter of the profile which links in well with Stereotype Mismatch causes. If the operators were initially trained on one plant and subsequently had to swop the original stereotypes would remain dominant particularly under time pressure or other forms of stress. Within the training section of **Type B** PSFs there are a further 8 PSFs which have not reached the top half of the listing, these would become more dominant during cognitive tasks (3. Interpretation, 5. Self Generation, 6. Choice and 7. Correction Required).

There is no extra benefit to be gained from presenting PSFs in rank order once the user has selected the percentage of PSFs to be considered (top 10%, 25% or 50% by this program). Future work will alter the output to provide the PSF priority list arranged by sub-group, ie firstly **Type A**, next **Type B** and finally **Type C.**

Within these types, PSFs will be ordered by sub-group. For this example;

Type A

	Technology
3.3	fail-safe system - operator activity
1.3	personnel involvement - continuous
1.1	personnel involvement - occasional
	Chemistry
5.3	predictability - unknown
9.1	process hazard - high
6.2	novelty - new
• 7.1	accuracy demanded - high
8.1	time dependent
4.1	process - continuous
	Materials
13.1	variety - high
13.2	variety - low
11.1	personnel proximity - control room

Note that for certain PSFs two alternative situations have been indicated. Another feature of the identification technique is that during a pre-analysis certain PSFs can be selected and eliminated if already fixed for the design: For example **company policy** may dictate that a new plant has to have only **occasional** personnel involvement; or if an existing plant, it may rely on **continuous** human activity. If there is still an opportunity for choice the higher the PSF has come in the analysis listing the more care must be taken if it is selected as the feature for incorporating in the plant.

Presented with this set of the most implicated PSFs for the process the designer can consider each in turn in relation to the plant.

7.2.4.1 A Review of a selection of the implicated PSFs

1. Failsafe Systems = operator activity

Perhaps Operator Activated would be a safer choice here than full involvement. Alternatively, ensure a set procedure is given, that the actions are simple and easy to remember and impossible to contravene, eg interlocks to prevent mis-ordering. Training should be thorough and abilities reviewed regularly, particularly on plant where for example, shutdowns are rare.

2. Personnel Involvement

Both occasional and continual involvement have been indicated as potential PSFs therefore if possible the better situation would be 1.2 continual involvement, ie regular involvement in the plant operation but not all the time. If involvement has to be continuous ensure that the task demands are within operator capability, this may require extra manning. Note that during problem situations the demands on the operator can rapidly rise creating difficulties if there is no way of delegating or prioritising tasks. Perhaps if normal operations require continuous involvement there should be automatic failsafe systems. Having only occasional operational involvement can lead to problems with the personnel's mental model of the process, (ie accurate understanding of the plant), fault diagnosis may be delayed or incorrect. Regular training and reviews would be required for personnel working in this manner. The more complex the plant and process the more tempting it is to give operators minimal hands-on workload, but note that the mental workload demands are dramatically increased during problem situations putting this type of operator and system at risk. The operator is suddenly having to carry out rapid and complex decisions after lengthy periods of pure monitoring. This problem can be alleviated by using quiet periods for simulation exercises and self testing. In this particular example, personnel involvement is continuous and therefore this PSF can be deleted.

3. Chemistry - predictability unknown

There is often nothing the designer can do about this but it must be realised that this can act as a stress factor and as such influences the mechanism **Stressors** group of error causes. In this case the chemistry was well understood therefore the PSF can be deleted.

4. Process Hazards - high

If these cannot be reduced by using alternative process chemicals and chemistry or different equipment then ensure that personnel are fully protected and aware of the hazards with information presented in an unemotional and informative fashion with full explanation of the potential hazards, the situations in which they may occur and how the situation may be rectified. Providing information lowers the stress level for most people since it is possible to feel more in control, fear of the unknown is always the worst. In this example the process hazards were moderate and hence this PSF can be deleted.

5. Novelty -new

In this example the batch process was well known hence this PSF can be deleted.

6. Time Dependent

This group of sub-tasks were dependent on the process timing. This time dependency can influence error causes from the group of Stressors. This is particularly true when the chemical reaction is rapid. In this situation the reaction was slow and once the reaction was complete the operator response did not have to be immediate. This factor can be deleted.

7. Process - continuous

This was a batch reactor plant therefore this PSF is redundant and can be deleted.

8. Materials - variety

Materials have been implicated as potential PSFs. A large variety of chemicals can act as a stress factor and also affect the mental model. This PSF can also affect the error cause **Over Demanding** due to the possibility of having to remember the properties of a large number of chemicals and the processes in which they should be used. Hence care would need to be taken with labelling the chemicals and providing clear daily instructions for the processes and the chemicals required - there should be no reliance on memory. Conversely a low number of chemicals can become so well known that there is a higher likelihood of Absent Minded error causes. This should not constitute a problem if the chemicals are stored separately and the order of additions is kept standard. For this group of sub-tasks the operator was not responsible for the chemicals,therefore this PSF can be deleted.

9. Personnel Proximity - control room

For these tasks the operator was involved on plant therefore this PSF can be deleted.

Each PSF indicated in the listing can be considered in this way so that irrelevant PSFs or those that have already been adequately considered are deleted. The remaining list of factors should be annotated with aspects to look for and check so that the system design can be as compatible with human personnel performance as possible. The ultimate aim would be to produce a compatible computerised interrogation system so that the relevant number could be entered as a request for design information and ergonomic, health and British standards.

CHAPTER EIGHT
DISCUSSION

It was a conscious decision that the purpose of this research was **not** to produce an human reliability technique giving error probabilities. From the literature review it appeared that too much emphasis was being placed on numbers (THERP, TESEO, SLIM-MAUD) at the expense of error prevention and understanding. The philosopher, Plato suggested that the steps towards an answer were at least as important as the answer itself. This philosophy is supported by the engineering fraternity with respect to fault tree analysis, as indicated in section 2.1 (Rogovin). The original research brief was to identify factors that could affect human reliability in the chemical process industries, however, this in its self would not have tackled the problem of understanding. Therefore the literature review was used to provide a platform from which to address the underlying concepts of error type, error cause plus surrounding models of human performance. It was then possible to build upon this understanding by undertaking the case studies.

By providing an historical review of the literature the intention was to place in context the developments surrounding human and equipment performance. Obviously the comprehensiveness of such a review was dependent upon finding and accessing the relevant information, it was inevitable that there would be gaps or that others would be able to cite additional information which could have been included. Never the less the success of such a coverage is not diminished if it has demonstrated to the reader the gradual development in understanding and methodology. The intention was also to fuse together the two concepts of human and equipment reliability and to consider the specific changes that have taken place within the chemical process industries. Although this review does not give detailed explanations of all the techniques and models, sufficient references have been provided for the interested reader to access additional information. What it has done is to provide a record of how the perspective relating towards reliability has changed during the twentieth century. The structure of the Time Chart (Table 2.1.1) assists the location of any additional information into this historical record of developing awareness.

It could be suggested that existing human reliability models should have been reviewed in order to provide more background to this research. However, many adequate reviews already existed; for example Bontoft (1983), Embrey (1979), Meister (1971). In addition it was not the intent to produce yet another HRA (Human Reliability Assessment) technique, therefore the need was significantly diminished. Instead, it was considered to be more beneficial to consider what human error was and the distinction between error types (the external manifestation of human performance problems) and their underlying reasons, 'error causes'. Perhaps it could be argued that this concept has been over emphasised, yet until clarity is obtained it is impossible to fully justify the reasons for establishing one method of PSF identification rather than another.

Many different error type classifications had been suggested over the years but those attempting to include some psychological dimension had tended to blurr into error causes, for example Reason (1977), Rasmussen (1979). The reason for distinguishing between outward manifestations of error and such aspects as, the stage during the psychological process at which things went wrong, was to ease the identification of potential problems and to ensure that the busy engineer with minimal or no psychological training could identify potentially important failures.

By definition an error type would have more than one possible cause. These causes had to cover all the psychological influences and all the stages during an 'activity' at which a mistake or break-down could occur. The literature review introduced a range of approaches towards this problem and the error cause debate.

A selection of performance and human behaviour models were reviewed so that human error could be related to correct performance. These models also demonstrated the complexity of the covert performance associated with task completion. It would have been a mistake to approach the identification of factors that cause human malfunction, without considering how people ever reach a position of success.

This research required a model of human performance and error. However, it was not pertinent to carry out an in-depth, critical analysis of the different performance models, merely to identify one that would assist the engineer with understanding performance and identifying factors which may affect this. It was the Information Processing Chain (IPC) that had stood the test of time and had been applied to processing tasks, for example Bainbridge (1968) and in particular

Rasmussen (1979).

Based on a firm understanding of human performance, its underlying processes, what could go wrong and some idea of why (note the extent to which PSFs had already been considered by others, section 2.3), it was possible to approach the case studies.

Case studies were considered important as a source of practical examples of system influence on performance. It is easy to hypothesis what should be a problem but theory is not necessarily substantiated by fact. Although much useful experience and knowledge was gained from the set of five case studies proving them to be a success, there were problems.

The choice of case studies was not systemmatic or neutral. They were very much dependent upon the opportunities that were presented. Fortunately the selection did succeed in covering a range of technology, human involvement, process hazards and process type (batch and continuous). These were the main factors that had been considered important by Singh (1982).

The other aspect that remains unsatisfactory was that although PSFs were identified as influential during an accident or error (from case studies and company records), it cannot be categorically stated that these factors are not the same when an activity is a success. To expand: The hypothesis is that if certain negative PSFs exist within a system then performance becomes more error prone due to their unfavourable influence. Conversely, if a system does not contain these negative influences then performance will be less error prone (note that it does not mean that performance will be error-free). Given the fact that an incident has occurred within a system containing negative PSFs all it is possible to state is; an error has occurred and these factors were present. It cannot be proved that these factors were actually negative PSFs thereby causing or exacerbating the error or that if they had not been present that the error would not have occurred. Even if a factor was sometimes present and sometimes not and to date an error had only occurred if the factor was present, it could only be **suggested** that the factor caused the error. It is possible to disprove the hypothesis, never to prove it ; that is , if an error occurs when the factor **is not** present then the relationship is refuted, otherwise the assumption remains but always with the opportunity to be proved wrong. Fortunately it is unnecessary to be quite so black and white. In this example it is obviously acceptable to state that the factor has a strong influence on human error. Yet in real situations, most potential PSFs are constantly present therefore distinguishing any relationship is even more problematic.

Interpreting the case studies may be problematic but should be considered in a positive manner. If a factor had not been recorded, it is unlikely to have been a major source of influence on the accident or error, whereas a factor recorded as present most probably was. The purpose of the case studies was to identify **possible** PSFs in order to, improve the classification structure devised from the literature and to extend the taxonomy with relevant individual factors. At this stage it was not the intent to examine the extent of influence or to ensure validity. Complete validation of their influence needs to take place through rigorous laboratory controlled testing. Of note is the fact that no incidents or errors have occurred with the system alterations carried out during case studies B and E. These changes were made in response to the identification of negative PSFs.

Additional problems were encountered when collecting case study data. Certain data collection techniques , for example Verbal Protocol (Umbers, 1981) proved inappropriate for tasks associated with long periods of monitoring. Also the type of information collected was peripheral to the requirements of this research. The most fruitful sources of information proved to be incident records, interviews, observation and measurement. The error cards devised for case study C provided extra information which would otherwise have been missed. These cards still require more thought in terms of their design, for example the operators had difficulty completing the PSF section, but they proved their value as an information source.

As well as indicating general PSFs, the case studies demonstrated aspects of the task that affected the types of error committed and aspects which were less susceptible to certain PSFs. It was this that led to the distinction between response types; Get Information, Give Information, Action and No Action, with all but the latter being either discrete or sequence. The case studies also confirmed that either a P & ID (pipework and instrumentation diagram) or an HTA (hierarchical task analysis) could be used to initiate a check for potential PSFs.

Despite some drawbacks the case studies proved a valuable source of information. Note that the Inst. of Chemical Engineers makes use of case histories as a data source and vehicle for demonstrating problems to others.

There were two main groups of research results; one was the direct identification, classification and taxonomy of PSFs, the second was the presentation of a methodology for identifying potentially important PSFs for specific scenarios. The latter not only created a technique for use by the system designer or consultant but the approach explicitly demonstrated the underlying philosophy. The techniques of Embrey (1985) tended to avoid this complexity, those of Swain and Guttmann (1982) particularised performance into tasks specific to the nuclear industry but with no generic basis, TESEO (Bello,1980) had no overt model and the idea of a monte carlo simulation tested all the possible outcomes rather than encorporating a performance model (Remember Plato!).

The PSF classification synthesised the knowledge gained from the literature and the case studies. Note the emphasis given to Process Factors, the primary PSF division being: A. Process Factors, B. Personnel Factors and C. Ergonomic Factors. Apart from re-terming idiosyncratic factors 'personnel' the division agrees with that of Singh (1982). There were two reasons for supporting this approach:

Firstly it was observed that such aspects as the extent of technology did affect human performance. Consider the factor; 'amount of human involvement', engineers tend to believe that the less involvement the less opportunity for error and so the more reliable. Conversely, psychologists have shown that this lack of involvement restricts the 'mental model' or understanding of the process, reduces awareness of system dynamics and leads to stress, plus its associated problems, when called on to act in an abnormal or emergency situation. This means that at the time when the process is at its most vulnerable, personnel are extremely likely to make mistakes.

The second reason for keeping these factors within their own grouping was that they tend to be the first aspects that are fixed when a new system is being designed and built. Once fixed they are the most difficult to change.

Thirdly they are a substantial group of factors that would require acceptance or elimination prior to sub-task checks for relevant PSFs. These process factors, together with others spread through the different classification groups, provide a general plant specification. Pre-identification of these avoids the output of redundant, inappropriate PSFs. This is particularly important for the future once the full potential of the technique is realized; that is, the back-tracking from the PSF level (after eliminating well designed or irrelevant factors or aspects that now identified, will be designed appropriately) up through the causal paths, in order to assess the improvement these changes may make by reducing the likelihood of error causes and hence errors. Such an aim would require more development work to assign weightings to the error causes and PSFs in relation to their different associations. In a similar way to Swain and Guttmann's (1983) probabilities of error with certainty boundaries, giving best - worst error likelihoods, each generic task scenario would require two error probability figures as boundaries. The best figure would be reached by ensuring all the negative influences were neutralized and by providing any suitable positive PSFs.

Prior to this research several researchers had appreciated the role of PSFs (Swain and Guttmann, Edwards, Embrey, Williams, Bellamy) but a classification system had not been forwarded nor a detailed and comprehensive listing of individual factors. The full PSF listing is presented in such a way that it can be altered or extended to account for new information or fitted to the requirements of a particular industry. These PSF keywords could be used as entries to a data base of ergonomic design advice with a full account of why the factor could be important.

The criticism could be made that this set is too detailed but the hierarchical structure means that the level of detail can be curtailed:

For example; TYPE C FACTORS (ergonomic)
- i.i Personnel Interaction
  - i.i.i Communication
    - i.i.i.i direction
      - i.i.i.i.i across departments

The factor 'communication across departments' could be considered as part of the factor i.i.i Communication , that is two levels of the hierarchy are removed.

Similarly; TYPE C FACTORS

i.i Machine Interface

i.i.i Controls

i.i.i.i Direct controls

i.i.i.i.i pushbutton

i.i.i.i.i.i continuous

This time it would be possible to stop at the level of Direct controls, Controls or perhaps at Machine Interface.

It was intended that the PSF classification and listing should be available for many different purposes, not just that associated with this research. By structuring the PSFs in this way, it was possible to include as much detail as possible since any that was redundant for a particular purpose could be easilly ignored. This was a more versatile approach than limiting the PSFs to a more manageable few. Even AMAS the activity matching ability system (Whalley and Watson) contained one hundred demand factors.

Rather than trying to link PSFs directly to types of error it appeared that it was more useful and logical to link them to error causes creating an indirect link to both the type of error and the type of task. This reason, coupled with the philosophy of promoting understanding, led to the development of an universal set of error causes. By maintaining error types and error causes as two distinct groups, it was possible to avoid the problems experienced with those classification structures documented in the literature review.

The result was a methodology for identifying PSFs based on set theory, (certain error causes are associated with certain types of task, certain types of response and certain error types) in addition to a chain of cause and effect (PSFs influence error causes and error causes influence error types). A basic error cause could only become a potential cause if it was common to all the three variables identified for a specific situation. In other words an error cause had to be contained within the intersection of the sets; error cause by task type, error cause by response type and error cause by error type.

This establishment of a relevant set of error causes ment that only those PSFs were implicated that could; affect the task **and** lead to the designated errors.

The final problem was how to provide weightings for each individual factor in order to prioritize the PSF subgroup. As portrayed in this thesis and demonstrated by the case study application in Section Seven, a frequency weighting was built up for each PSF. Every time a link was connected to a specific error cause its frequency total was increased by one. Similarly, each time a link was connected to a specific PSF its frequency total was increased by one. Due to the multiple mapping system this ment that frequencies of over a thousand were quickly reached after very few sub-tasks. A reducing factor could be included to bring these numbers back down to a more meaningful level. By looking ahead to the proposed Phase Two, it can be seen that this use of frequencies will be unsatisfactory. The mathematics of set-theory is that of probabilities. It is therefore proposed that a second generation technique would replace frequencies with 'probability weightings' at both the error cause and PSF level. Assuming an error does occur and it is due to only one error cause then the probabilities of the possible error causes must add up to one. This relies upon a simplified model of human error but it does bring the weightings back into a range more familiar to the engineer, it also provides a more rigorous check of which are the most likely causes and allows easy comparison between task profiles. What would be lost is the feel for one task or situation being more error prone than another.

To recapitulate, the current use of frequency weightings provides a useful prioritization of PSFs and error causes but to be more mathematically rigorous these need to be replaced by probability figures.

This thesis has extended our knowledge of those factors that influence human reliability in the chemical process industries. Beyond this it has provided a classification of PSFs, error causes, error types, task types and response types. It has identified the relationships between these and presented a methodology for identifying important factors for the system designer, not forgetting that the system encompasses 'hardware', 'software', 'liveware' and the environment (Edwards, 1976). Indeed Chapter Seven demonstrates the application of the research to a task example and presents the output from the first generation computerised technique (PHECA - Lihou Loss Prevention Services Ltd) based on the documented methodology. There is however no room for complacency, an extension and verification of this philosophy is still required. Remember the THERP technique (Swain and Guttmann) was the result of over twenty years work!

CHAPTER NINE
CONCLUSIONS

The original aim of this research was to identify aspects from the whole system surrounding a chemical process plant, that could influence human performance and hence human reliability. In addition, it was considered important to suggest how to identify which were the important factors for specific tasks and situations.

In terms of the main aim, a classification structure for performance shaping factors has been produced together with a detailed listing. This covers process factors, personnel factors (originally termed idiosyncratic, Singh 1982), and 'ergonomic' factors. The detailed list is comprehensive but extendable due to the structuring of the taxonomy.

The need to identify important PSFs for specific situations has been addressed by the advancement of a PSF identification methodology. Infact this has been taken one stage further since a prototype computer technique based on this model has been developed to run on the IBM pc by Lihou Loss Prevention Services Ltd.

To summarise the achievements: Based on the available literature, the completion of case studies and the analysis of company records, three aspects have been accomplished;

1 A PSF classification structure
2 A detailed PSF listing
3 A method / model for identifying relevant PSFs

In addition a possible method has been suggested for providing the link to **design advice** once a PSF has been established as important (Whalley and Booth, 1986). Currently this work has only addressed control room interface design but the concept could be extended to embrace the whole set of PSFs. A pilot computer program, CRIDA (the Control Room Interface Design Aid) has been produced once again running on the IBM pc.

Overall this research work should be viewed as the basis of a system- -atic technique for PSF identification, PSF advice and for determining the extent to which PSFs actually affect human error. The latter point is particularly important.

Looking ahead, this work has suggested that only the relevant PSFs should be identified for a specific situation. This would require some means of eliminating those factors that are known not to apply (remember this is a generic technique) or are well designed or have been rectified. Once this has been achived the re-ascent can take place through the linkages from the remaining PSFs, to error causes, to error types. To accompany this back-tracking, those lines that have now been cut remove the associated negative influence on performance. In effect this increases the likelihood of **error free** performance which ensures increased reliability.

Several aspects still remain to be considered;

1 validation of the PSF identification method

2 identification of the extent to which each PSF can affect performance

3 consideration of the combinatorial effects and the counter measures of positive PSFs

4 links to an advisory data base

5 proof that such a technique works,
ie that design is improved and human reliability increased

The latter would require a research programme where perhaps an existing plant was redesigned and a comparison made between the two in terms of error types, error rates and their consequences (that is accidents, incidents and production achievement).

Note that case study B used accident records and interviews to determine PSFs. Changes were then suggested based on this data plus an ergonomic review. The short term follow up showed that operators who had transfered with the plant considered it to be much improved and less dangerous. On follow up it was found that there were no accidents or incidents recorded with the re-designed sections.

Similarly case study E (completed after the main case study period) used a provisional PSF listing to prompt the identification of specific PSFs for that situation. Like case study B, re-design took place and to date no incidents have occured in the changed area.

These two small examples suggest that Requirement Five will infact prove positive and are sufficient encouragement to continue with this work. A suggested outline for future research is presented in table 9.1.1.

TABLE 9.1.1 Suggested programme of Future work

1 **Validation** of the identification technique

1.1 selection of a range of different tasks and situations in a number of companies and types of process

1.2 for each case, undertake an error and PSF assessment

1.3 compare results with actual recorded data, ie accident and incident reports and an assessment of the existing PSFs

1.4 check any correlation of results and statistical significance,
null hypothesis : 'the technique **does not** indicate the relevant PSFs for a given situation'

2 & 3 Extent of **PSF influence** / relative importance plus **combinatorial effects**

2.1 based on laboratory pilot plant or rig, systemmatically introduce and remove (neutralize) negative and positive PSFs

2.2 run a standard set of operating, maintenance and managerial tasks associated with the rig for each PSF alteration

4 Provide a **link to an advisory data base**

4.1 assess the existing software (including CRIDA)

4.2 develop software for this specific purpose

4.3 check the systems 'ease of use' and ensure helpful guidance

4.4 select and check the design data to be included in the data base

5 **Validate** the technique

5.1 **Practicability :** would the industry use the technique ?
how easy is it to use ? how expensive in terms of peoples time ?

5.2 **Relevance :** does the technique work ? The ultimate check would be to build two plants for the same purpose, one developed with the technique in use, the other without. Then monitor operations over an extensive period of time. Check for a positive significant difference between the two. Null Hypothesis 'using the technique produces no change in human reliability during plant operation'

6 Extend the technique to stage two: **Back tracking of the links**

(This would indicate the extent of improvement possible by correctly designing the PSFs and facilitate the development of the technique as a predictive / comparative tool for error probabilities)

APPENDICES

APPENDIX ONE

Summary of Factors covered by the Ergonomics Literature

ERGONOMIC CONSIDERATIONS

1.0 Environment

1.1 Noise vs audio signals ('WHO' criteria)

1.2 Lighting levels (ILS code)
Lighting glare)
Lighting reflection) n.b. suspended ceilings
Lighting luminance level (adjustability)
Lighting contrast (screen / room / plant night / day)
Dust

1.3 Humidity and temperature

1.4 Electrostatic and negative ion deficiency

2.0 Access

2.1 Position of seating and control desk (in particular rapid exit facility and work zone)

2.2 Access from controls and displays (n.b. instrument engineers)

2.3 Movement around control room

2.4 Position of additional 'furniture'

3.0 Interface Design

3.1 Displays and controls consistency plus operator perceptions for running the plant

3.2 Population stereotypes

3.3 Conspicuity / legibility / labelling

3.4 Feedback, prompts and response lags

4.0 Operator Equipment

4.1 'System furniture' dimensions of seating and console

4.2 Information filling / storage facilities

4.3 Protective clothing

5.0 Task Analysis and Task Allocation

5.1 Physical demands

5.2 Psychological demands

5.3 Logical task differentiation / overlap between operators. Formal identification

6.0	Communications		
6.1	Between operator in control room	)	
6.2	With operator on plant	)	n.b.
6.3	With supervisor / manager	)	mechanisms
6.4	With laboratory analysts	)	formal / informal
6.5	With microprocessor	)	direct / indirect

7.0	Information		
7.1	Presentation and access n.b. index	)	n.b.
7.2	Content	)	different purposes
7.3	Availability	)	different types
7.4	Language used	)	recording mechanisms
7.5	Instructions	)	

8.0 Social structure
8.1 Motivation - n.b. decor
8.2 Team work plus leadership?
8.3 Task determination (Section 5.0)
8.4 Rest periods - work rotation
8.5 Management attitudes - sense of purpose

9.0 Training
9.1 * Simulation facilities - initially and during plant operation or down time
9.2 General introductory
9.3 Specific aspects
9.4 Allowance for individual differences
9.5 Time allocated

10.0 Assessment (of Training)
10.1 Operator acquired mental model
10.2 Fault hypothesis and solutions
10.3 Simulation tests

APPENDIX TWO

Example of a completed AMAS Form

ACTIVITY MATCHING ABILITY SYSTEM

ACTIVITY ASSESSMENT

Job Assessment Form

This form is intended to be used to collect job demands information for comparison with a person's ability profile. AMAS is a scheme devised for use within the British Steel Corporation in order to identify suitable production jobs for employees requiring a job change on the grounds of disability.

The full details of AMAS are given in the Final Report to BSC and the Commission of European Communities, ECSC Agreement Number 7247/18/047 "The Rehabilitation and Resettlement of Occupationally Disabled Workers in the British Steel Corporation with Specific Reference to Scunthorpe Works"

(Tick the most appropriate box)

ACTIVITY MATCHING ABILITY SYSTEM

(JOB ASSESSMENT)

SECTION A: SOCIAL

1. ~~Job Title~~

2. Area of Plant: Phosphine Plant

3. ~~Seniority~~

2W 6.00am – 6.00pm

4. Shift Work: days [ ] 2 shift or occ. 3 [ ] 3 shift system [ ] 2 off

6.00pm – 6.00am

5. ~~Hourly Rate~~

2 off

SECTION B: WORK ENVIRONMENT

Physical Environment

6. EXTREME HEAT:

n/a [✓] occasionally: not part of normal job [ ] frequent job requirement [ ]

7. EXTREME COLD:

n/a [ ] in winter only [✓] all year [ ]

8. VIBRATION - HAND/ARM:

n/a [✓] occasionally: not part of normal job [ ] frequent job requirement [ ]

9. VIBRATION - WHOLE BODY:

n/a [✓] occasionally: not part of normal job [ ] frequent job requirement [ ]

10. NOISE - NEED FOR EAR DEFENDERS:

not required ☑ | when moving around ☐ | required during work ☐

11. PRESENCE OF DUST:

only settled dust ☑ | possibly ☐ | visible in atmosphere ☐

12. PRESENCE OF IRRITANT GAS, e.g. SO_2:

n/a ☐ | possibly ☐ | known to be present in area ☑

13. PRESENCE OF CARBON MONOXIDE:

n/a ☑ | possibly ☐ | known to be present in area ☐

14. PRESENCE OF ISOCYANATES, EPOXY RESINS OR GRASS POLLENS:

n/a ☐ | possibly ☐ | often present due to work type/area ☑

15. PRESENCE OF SKIN IRRITANTS:

n/a ☐ | protective clothing sufficient ☑ | skin contact with possible irritants ☐

<u>Potential Risk Factors</u>

16. POTENTIAL RISK IN AREA FROM ENVIRONMENT & OTHERS:

n/a ☐ | low risk or minor consequence ☐ | high risk or major consequence ☑

17. JOB INVOLVES RISKS ASSOCIATED WITH HANDLING OBJECTS OR OPERATING MACHINERY:

n/a ☐ possible consequences for individual ☐ possible consequences for others ☑

18. WORK AT HEIGHTS:

n/a ☐ protection e.g. by railings ☑ occasionally or frequently no protection ☐

SECTION C: EQUIPMENT

Work Station

Location:

19. OTHER WORK PLACES (REQUIRING A MOVE):

none ☐ 1 ☑ 2+ ☐

20. PATHWAYS TO REACH WORK PLACE AFTER CLOCKING ON AND RARE USE DURING SHIFT:

level ☑ level + stairs ☐ level + ladder ☐

21. TRANSPORT TO WORK PLACE AFTER CLOCKING ON:

available ☐ possible but not available ☑ impossible ☐

22. UNEVEN GROUND:

n/a ☑ access ☐ during shift ☐

Contents:

23. PEOPLE WORKING IN IMMEDIATE AREA:

close proximity ☑ | in vicinity ☐ | isolated ☐

24. SIZE OF IMMEDIATE AREA:

open area ☐ | room ☑ | small pulpit ☐

25. WORKSEAT:

adjustable ☑ | non-adjustable ☐ | none ☐

26. CHAIRBACK:

adjustable ☐ | non-adjustable ☑ | none ☐

Controls:

Hand Controls:

27. PUSH BUTTON:

n/a ☐ | one hand ☑ | both hands ☐

28. FLICK SWITCH OR TOGGLE SWITCH:

n/a ☑ one hand ☐ both hands ☐

29. LEVER:

n/a ☐ one hand ☑ both hands ☐

30. KNOB OR ROTARY SELECTOR SWITCH:

n/a ☐ one hand ☑ both hands ☐

31. HANDWHEEL (includes small Crankwheel)

n/a ☐ one hand ☑ both hands ☐

32. LARGE CRANKWHEEL OR CONTROL:

n/a ☐ one hand ☐ both hands ☑

33. KEYBOARD:

n/a ☐ one hand ☑ both hands ☐

Foot Controls:

34. SINGLE FOOT CONTROL:

n/a ☐ one foot ☐ both feet ☑

Display type:

35. MANUAL MEASUREMENT, e.g. use of ruler:

n/a [ ] required [✓] major requirement [ ]

36. ANALOGUE OR DIGITAL DISPLAYS INCLUDING NUMERICAL VDU:

n/a [ ] required [ ] major requirement [✓]

37. CAMERA MONITOR:

n/a [✓] required [ ] major requirement [ ]

38. LIGHTS AS INDICATORS:

n/a [ ] required [ ] major requirement [✓]

39. AUDITORY INFORMATION, e.g. sirens:

n/a [ ] required [ ] major requirement [✓]

SECTION D: WORK DEMANDS

Physical

Posture:

40. SITTING 'UPRIGHT', CONTROLS WITHIN EASY REACH:

n/a ☐ required ☐ major requirement ☑

41. SITTING BENT OVER, e.g. crane driver:

n/a ☑ required ☐ major requirement ☐

42. STANDING NATURALLY:

n/a ☐ required ☐ major requirement ☑

43. KNEELING REQUIRED:

n/a ☐ required ☐ major requirement ☑

44. NEED TO WORK AT DIFFERENT LEVELS, e.g. by crouching, stooping:

n/a ☑ mid-range waist height ☐ floor level ☐

45. NEED TO TWIST BODY (CAN THE JOB BE DONE WITHOUT?):

n/a ☐ required ☐ major requirement ☑

46. NEED TO TURN HEAD INTO EXTREME POSITIONS:

n/a [ ] required [ ] major requirement [✓]

47. NEED TO CHANGE FROM ONE POSTURE TO ANOTHER:

n/a [ ] required [✓] gross posture changes a major requirement [ ]
(i.e. floor → seat → standing)

48. NEED TO MAINTAIN BALANCE/EQUILIBRIUM, e.g. work in unstable positions:

n/a [ ] required [ ] major requirement [✓]

eg standing top of reader

Limbs:

Feet/legs: (Code separately from standing or moving requirements)

49. RIGHT FOOT/LEG REQUIRED (nb. extent of requirement):

n/a [ ] required [ ] major requirement [✓]

50. LEFT FOOT/LEG REQUIRED (nb. extent of requirement):

n/a [ ] required [ ] major requirement [✓]

51. ONE FOOT/LEG REQUIRED EITHER LEFT OR RIGHT:

n/a [✓] required [ ] major requirement [ ]

52. SIMULTANEOUS USE OF FEET/LEGS ON SAME OR DIFFERENT CONTROLS:

n/a ☐ required ☐ major requirement ☑

53. NEED FOR FOOT/LEG CO-ORDINATION AND FOOT/FOOT CO-ORDINATION:

n/a ☐ required ☐ major requirement ☑

Hands/arms;

54. RIGHT HAND/ARM REQUIRED (nb. extent of requirement):

n/a ☐ required ☐ major requirement ☑

gear stacker truck lifting

55. LEFT HAND/ARM REQUIRED (nb. extent of requirement):

n/a ☐ required ☐ major requirement ☑

gears stacker truck handbrake

56. ONE HAND/ARM REQUIRED EITHER LEFT OR RIGHT:

n/a ☐ required ☐ major requirement ☑

control room

57. SIMULTANEOUS USE OF HANDS/ARMS ON SAME OR DIFFERENT CONTROL:

n/a ☐ required ☐ major requirement ☑

valves stacker truck

58. NEED FOR FINGER/HAND DEXTERITY:

n/a ☐ required ☐ major requirement ☑

59. NEED FOR HAND/ARM CO-ORDINATION & HAND/HAND CO-ORDINATION:

n/a ☐ required ☐ major requirement ☑

Muscles:

Movement:

60. CRAWLING/SLIDING REQUIRED:

n/a ☑ required ☐ major requirement ☐

61. WALKING REQUIRED:

n/a ☐ short distance ☐ major requirement ☑

e.g. walking conveyors

62. CLIMBING STAIRS/LADDERS GENERALLY REQUIRED DURING SHIFT:

n/a ☐ stairs ☑ ladders ☑

Muscle Groups required for Dynamic Strength:

63. LIFTING:

n/a ☐ required ☑ major requirement ☐

64. LEGS PLUS PELVIS MUSCLE POWER (excluding walking/running)

n/a ☐ required ☑ major requirement ☐

feet on rocking pot.

65. ARMS PLUS UPPER BODY FOR STRENGTH, e.g. turning crankwheel, lifting objects:

n/a ☐ requirement ☐ major requirement ☑

Muscle groups 'activity' NOT for strength:

66. FOOT/LEG SYSTEM USED, e.g. car foot controls:

n/a ☐ one foot ☐ both feet ☑

stacker truck

67. UPPER ARM/SHOULDER WORK, e.g. deseaming

n/a ☐ one arm ☐ both arms ☑

burning drums off
moving drums
removing lids

68. OUTER RANGE, forces at extreme reach of upper limbs:

n/a ☐ one arm ☑ both arms ☐

certain valves not often used.

69. FINGER/HAND/FOREARM USED, e.g. painting:

n/a ☐ one arm ☑ both arms ☐

Senses:

Vision:

70. NEED TO RECOGNIZE PATTERNS, e.g. inspection tasks:

n/a ☑ requirement ☐ major requirement ☐

71. NEED TO RECOGNIZE COLOUR DIFFERENCES:

n/a [ ] requirement [✓] major requirement [ ]

72. NEED TO RECOGNIZE SHAPE &/OR SIZE DIFFERENCES OF OBJECTS:

n/a [✓] requirement [ ] major requirement [ ]

73. NEED TO RECOGNIZE THE STATIONARY POSITION OF AN OBJECT, i.e. distance judgement:

n/a [ ] requirement [ ] major requirement [✓]

requirement: (inaccuracies undesirable but have no effect on other people)

major requirement: (inaccuracies can effect others)

drums onto Roller

74. NEED FOR PERIPHERAL VISION:

n/a [ ] requirement [✓] major requirement [ ]

75. NEED TO JUDGE THE SPEED OF MOVING OBJECTS WHEN CARRYING OUT TASKS:

n/a [✓] requirement [ ] major requirement [ ]

76. NEED FOR NEAR VISION (short distance):

unnecessary [ ] large items e.g. controls [ ] small items e.g. print [✓]

77. NEED FOR FAR VISION (long distance) :

n/a [ ]   requirement [ ]   major requirement [✓]

Hearing:

78. NEED TO RECOGNIZE SOUND PATTERNS, e.g. speech:

n/a [✓]   requirement [ ]   major requirement [ ]

79. NEED TO RECOGNIZE SOUND DIFFERENCES & VARIATIONS:

n/a [ ]   requirement [✓]   major requirement [ ]

Fault diagnosis/recog

80. NEED FOR DIRECTIONAL HEARING, e.g. to locate faults:

n/a [ ]   requirement [✓]   major requirement [ ]

Tactile:

81. NEED FOR PRECISION IN TACTILE RECOGNITION/DISCRIMINATION, e.g. for control location:

n/a [✓]   helpful [ ]   vital information [ ]

Intellect:

Responsibility:

82. TYPE OF INSTRUCTIONS GIVEN:

precise instructions [ ] guidelines [✓] none [ ]

83. RESPONSIBILITY FOR CHECKING OWN OR OTHERS' WORK OUTPUT:

never checks work [ ] checks but re-checked [ ] total responsibility [✓]

84. RESPONSIBILITY FOR TIME LOSSES:

n/a [ ] minor [ ] major [✓]

85. EXTENT OF RESPONSIBILITY FOR WORK SCHEDULING:

n/a [✓] minor [ ] major [ ]

Communication:

86. EXTENT OF NECESSARY CONTACT WITH OTHER WORKERS, nb. isolation vs team work:

n/a [ ] requirement [ ] major requirement [✓]

87. NEED FOR SPEECH TO CARRY OUT WORK:

n/a [✓] requirement [ ] major requirement [ ]

88. NEED TO MAKE AND/OR UNDERSTAND HAND SIGNALS TO CARRY OUT WORK:

n/a [✓] requirement [✓] major requirement [ ]

n/b 2 ops. contact between control rm & plant through. closed video

89. NEED TO WRITE TO CARRY OUT WORK:

n/a [ ] requirement [ ] major requu..rement [✓]

90. NEED TO READ TO CARRY OUT WORK:

n/a [ ] requirement [ ] major requirement [✓]

Job Specific:

91. LENGTH OF REQUIRED TRAINING FOR SOMEONE NEW TO THE JOB:

up to 1 week [ ] a few weeks [ ] several months [✓]

92. NEED FOR SPECIAL INSTRUCTIONS, i.e. requiring a change in normal work procedure:

n/a [ ] infrequent [ ] frequent [✓]

Capacity:

93. NEED TO REMEMBER CHANGING INFORMATION FOR THE JOB:

n/a [ ] requirement [ ] major requirement [✓]

94. OCCURRENCE OF PEAKS IN WORK LOAD DURING THE SHIFT:

self paced ☐ steady continuous ☐ high demand peaks ☑

fault sits.

95. DIFFICULTY OF DECISION MAKING:

straight relationship between info. & action ☐ recognition of several diff. info. inputs for action ☐ decision strategies ☑

96. TIME PRESSURED DECISION MAKING:

n/a ☐ requirement ☐ major requirement ☑

97. NEED FOR ACCURACY OF OUTPUT:

n/a ☐ requirement ☑ major requirement ☐

98. NEED FOR VIGILANCE - ALERTNESS:

n/a ☐ requirement ☐ major requirement ☑

99. NEED FOR TOTAL CONCENTRATION:

n/a ☑ requirement ☑ major requirement ☐

(if plant running OK

100. NEED FOR DIVIDED ATTENTION:

n/a ☐ requirement ☐ major requirement ☑

problem situations

-------oOo-------

APPENDIX THREE

Error Collection Card

Plant: ____________________

Time:

Weekend/Week

Control Room/Plant

Description:

Associated Equipment:
Associated Display:
Associated Control:

Has this ever happened before? Yes/No

Absent Minded? Yes/No

Self Corrected? Yes/No

Influencing Factors: P.T.O.

PERFORMANCE SHAPING FACTORS

<table>
<tr><th rowspan="2">PROCESS</th><th colspan="5">ERGONOMIC</th><th rowspan="2">IDIOSYNCRATIC</th></tr>
<tr><th colspan="2">Man/Man/Machine Interface</th><th>Environment</th><th>Equipment</th><th>Demands</th></tr>
<tr>
<td>Personnel
Involvement
1 continuous
2 continual
3 occasional
Technology
4 manual
5 semi-automatic
6 microprocessor
Chemistry
7 batch reaction
8 continuous
9 sensitivity
10 accuracy req.
11 time
12 novelty
13 predictability
Materials
14 hazards
15 contact
16 proximity
17 variety</td>
<td>Controls
18 direct controls
19 indirect c'trls
20 location
21 identification
22 feedback
23 prompts
24 response time
25 access
26 visibility
Displays
27 display type
28 location
29 identification
30 scale continuity
31 legibility
32 clarity
33 response time
34 access
35 visibility
Indicators
36 warning
37 status
38 display/control interactions
Communications
39 formal
40 informal
41 direction
42 sender
43 receiver
44 method
45 direct
46 indirect
47 feedback</td>
<td>Information
48 access
49 form
50 format
51 clarity
52 legibility
53 recording mechanisms
Management
54 supervision
55 strategy
56 selection
57 incentives
58 instructions
59 team work
60 attitude</td>
<td>Work Pattern
61 shift work
62 hours per week
63 overtime
64 rest periods
65 self control
Physical
66 lighting
67 glare
68 atmosphere
69 fumes
70 gases
71 dust
72 noise
73 heat
74 cold
75 vibration
76 skin irritants
Access
77 sufficient room
78 sufficient height
79 stairs
80 ladder
81 terrain
Location
82 control room
83 on plant
84 plant & c.r.
85 number of locations
86 climatic exposure</td>
<td>Clothing
87 standard
88 special
89 safety
90 availability
Aids
91 availability
92 servicability
93 requirement
94 type
System Equipment
95 safety
96 standard
97 fail safe
98 backup
99 operator interaction
100 dimension
101 identification
Operator Equipment
102 system furniture
103 domestic
104 utility</td>
<td>Physical
105 posture
106 movement
107 control
108 power
109 static
110 co-ordination
111 dexterity
112 vision
113 tactile
114 hearing
115 smell
116 kinesthetic
Psychological
117 responsibility
118 concentration
119 memory
120 decisions
121 time pressure
122 accuracy
123 alertness
124 flexibility
125 risk perception
126 organisation
127 monitoring</td>
<td>Training
128 general
129 safety
130 specific
131 retraining
132 simulations
133 structured
134 apprenticeship
135 qualifications
136 amount
137 on the job
Experience
138 amount
139 relevance
140 interrupted
141 specific
Mental Model
142 completeness
143 accuracy
Personality
144 temperament
145 motivation
146 risk taking
147 sociability
148 mood
149 confidence
150 capability
Health
151 recent illness
152 fitness</td>
</tr>
</table>

APPENDIX FOUR

Publications

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