IMPROVING HUMAN RELIABILITY BY DESIGN

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System design can influence human reliability by affecting the likelihood of human error. The individual aspects of a system that can improve or detract from human performance are known as Performance Shaping Factors. This paper presents a technique for identifying associated PSFs for a specific task type with an example of the technique applied to one section of a task analysis.

INTRODUCTION

In recent years, following a number of major incidents and enquiries, attention has been focused on equipment reliability and its influence on Safety, particularly in the nuclear industry. The methods evolved to ensure this Safety have varied from Hazard & Operability Analysis to Item Failure Data Collection for use in Predictive Models. Fault Trees have been used to identify the level in a system at which failure of one item may lead to a further failure and more recently, these Fault Trees have been combined with Item Failure Data to produce a Failure Probability Diagram.

Chemical plants are, however, systems - and more importantly, they are Man-Machine Systems fulfilling R B Miller's(1953) most basic definition.

> Man-Machine Systems are "machines and men plus the processes by which they interact within an environment".

By only considering the reliability of process hardware, half the system remains unassessed. It is as important to consider human reliability as it is to consider equipment reliability particularly in the area of man-machine interaction.

HUMAN RELIABILITY involves the concept of human error, and the factors that influence human performance. EQUIPMENT RELIABILITY is dependent upon probability of failure under given conditions during a particular period of time. These two concepts have certain similarities and need to be integrated.

HUMAN RELIABILITY

Most companies will state that from 8% to 50% of their accidents are due to "human failure" (Kletz 1976) but the underlying cause may be more difficult to ascertain.

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For example, lack of training may be indicated, or lack of motivation, or lack of physical or mental capability often due to excessive demands within the system. These factors may all contribute to a human failure.

Assessment techniques tend to concentrate on assessing a system in terms of potential operator errors. It is important to remember that human error can occur at a number of stages throughout a system's development. Meister gives four such stages:

i. drawing board design
ii. production engineering
iii. testing/commissioning
iv. operation.

Equally, during the final stage of operation, errors can be produced by different personnel associated with the system. The fault can be initiated by the process operator, the maintenance crew, or management. All three should be viewed as components of the overall system design (the MORT analysis developed by Johnson (1980) considers the potential for management misjudgement).

When using any reliability assessment method, whether for equipment, human or both, the assessor must have a purpose for the assessment. Is the aim:

- to assess a current system's safety?
- to assess a new system's design?
- to evaluate a certain facet of the system?
- to assess the training needs of personnel?
- to assess potential areas of production loss?
- to produce a maintenance schedule?

For example, the system and manufacturing materials may be totally inert and have no accident potential, but any plant down time may be extremely expensive in terms of lost production. In this case, equipment and human failure assessments produce vital predictions of potential trouble areas.

In order to assess the potential effect of human performance on system reliability and productivity, the influence of Performance Shaping Factors, task demands and the opportunity for error must all be examined. Once such objective information starts to be available, the design of systems can be improved. Already a significant amount of ergonomic and psychological data exists, but system designers tend to consider the recommendations as subsidiary to the main engineering problems. This is partially due to a lack of recorded evidence of the effects of these factors in an application context rather than a laboratory, plus a tendency to assume that their inclusion would increase plant cost and designer time.

Performance Shaping Factors, as their name suggests, are any aspects (factors) of the system that influence (shape) the response (performance) of system personnel. These can either be positive or negitive attributes of the system; promoting desirable and reliable personnel performance or degrading and retarding performance. The problem facing the system engineer is to maximise the one and minimize the other, within the practical limitations of a project brief and budget.

In the past, PSFs have been used as weighting factors within human reliability analysis using subjectively conceived indices to contribute to the analysis; for example Swain & Guttmann (1980). More recently Embrey (1985) has taken the initiative of ranking self generated PSFs via paired comparisons; although a 'help' facility has been included to suggest possible PSFs these still remain self diagnosed as already existing within a known system. In both cases the emphasis is to assess 'that which is already available' rather than guiding original design.

The overwhelming problem of applying PSFs within HRA is that of combinatorial effects, how do the various individual PSFs interact? It is unlikely that they are simply numerically additive and it is difficult to deduce whether positive attributes will directly negate the negative. However, just as equipment engineers accept the effect of environment upon their components designers must accept the effect of environment upon human performance. Even if it is impossible to specifiy to what extent an aspect of the design is important it is possible to indicate which aspects require careful thought, modification and avoidance. In other words the Design Engineeer must understand the task, consider what aspects may affect its successful completion and then design to ergonomic standards to minimise any detrimental influence and maximise a positive contribution. In order to accomplish this goal a systematic basis for considering PSFs is required.

During the period 1983-1984 a number of case studies were undertaken in the Chemical Process industry (Whalley, 1984) in order to examine the type of performance shaping factors influencing operator performance. This work resulted in a classification structure for PSFs and an extended table of individual PSFs (Whalley and Maund, 1985). What remained was the need for a mechanism to link these design modifiers to error cause and back through to error and task type so that a designer could readily identify the most potentially influenctial aspects of system design in terms of specific error scenarios. From 1985 to date work has been on going to establish a provisional linking mechanism.

AIDING PROCESS PLANT DESIGN

The philosophy behind this technique is that the identification of relevant PSFs is dependent upon the Task Type and the Error type. This is possible by integrating five main linkage steps as the basis of a software program (Figure 2).

Task Types

The main hypothesis is that all specific tasks can be categorised into seven generic task groups which influence the information processing chain(Figure 3) leading to a response:

1 stimulus/response ('that has happened so I respond like this...')
2 stimuli integration/response ('that and that and that have happened so I do this..')
3 interpretation/response ('that has occured so what shall I do?..')
4 requirement/response ('it is time for me to do this...')
5 self generation/response ('I want to achieve this but how do I do it?' or 'why don't I do this?...')
6 choice/response ('which shall I do next..?' 'I want to do this not that...')
7 correction required/response ('I am doing this but I should be doing that..')

Response Types

Similarly all responses can be classified into the following finite set of response types: The primary classification distinguishes between discrete and sequence response types and the secondary classification determines whether the resulting response should be;

1 Action
2 Giving information
3 Getting information
4 No action

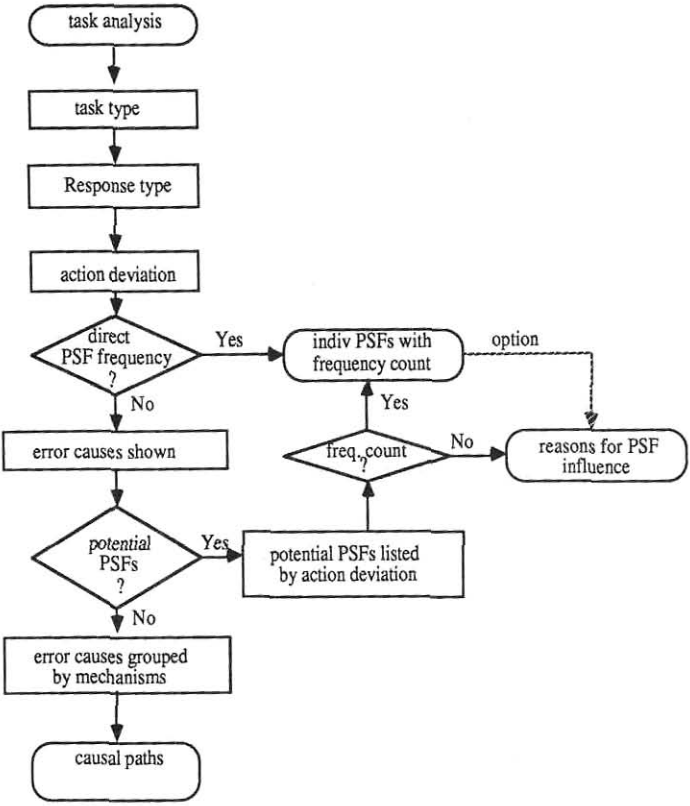

Figure 2 Stages of the Design Decision Aid

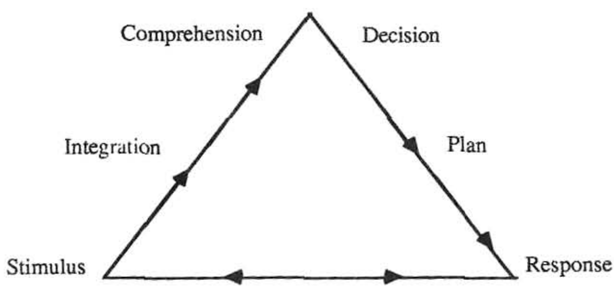

Figure 3 Information Processing Chain (Rasmussen)

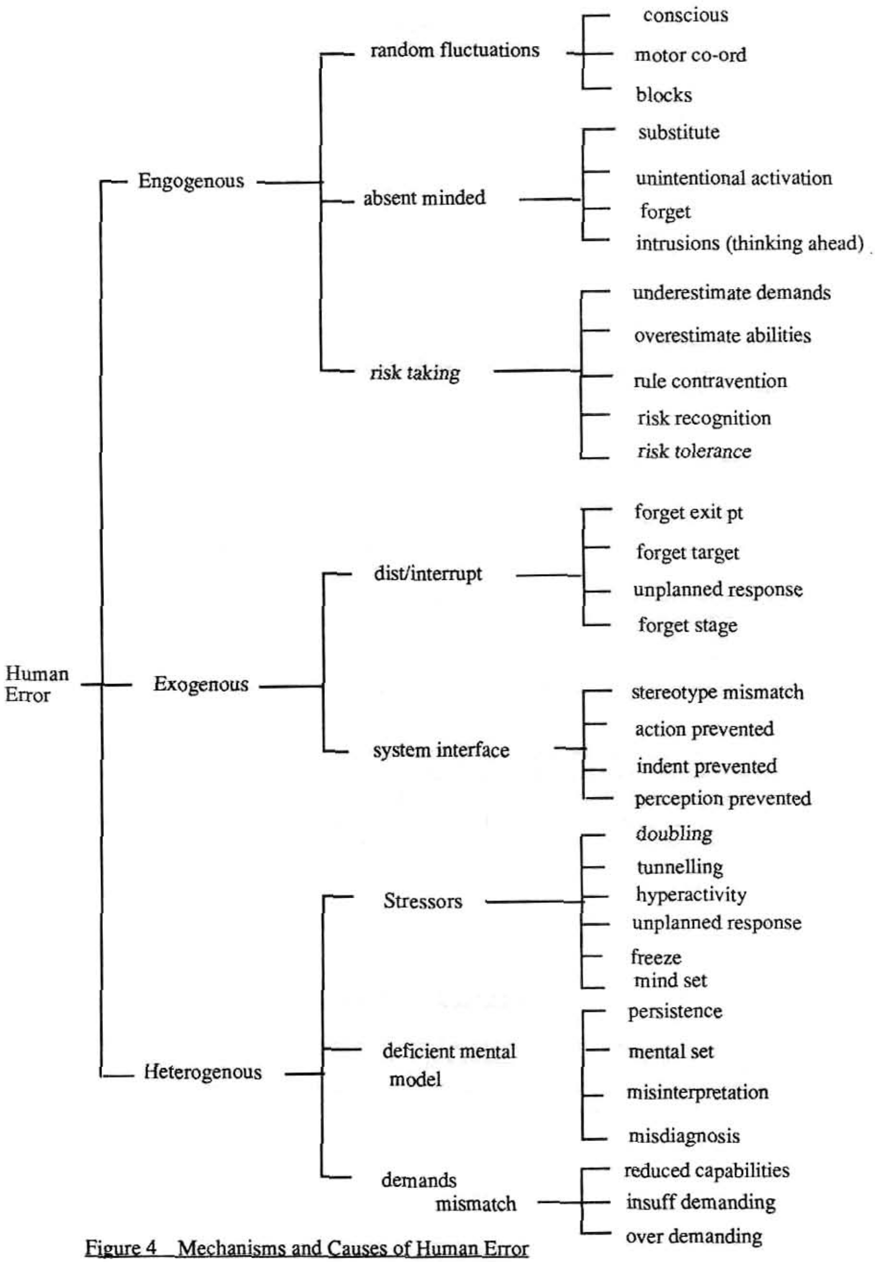

Figure 4 Mechanisms and Causes of Human Error

Action Deviation

Each of the above response types is associated with a sub-set of the following action deviatio (error types). These deviations have been identified in terms of classical error type terminolog (Singleton, 1978):

1 omission (not done/part done)
2 commission
3 repetition
4 substitution (opposite/instead of)
5 delays
6 misordering for sequential actions only

Error Causes

The error causes defined for this technique stem from eight underlying mechanisms, (Figure 4), but their potential is dependant upon which stages of the information processing chain are involved, the type of task and the activity deviation under consideration.

Potential PSFs

PSFs are interrelated with the stage in the information processing chain and the cause of error; by working in this direction through the program the PSFs associated with the error causes and task types can be identified, some of which will obviously be irrelevant given a specific task and situation. In other words the program is not intending to eliminate designer skill but point out areas requiring careful attention. If the same process is carried out for each subtask identified as important from a task analysis, each will have its own list of potential error causes with each of these linked to associated PSFs. With a count mechanism established the frequency with which individual PSFs are implicated can be produced. It is this profile of the PSFs that can be used by the system designer to redirect resources to the area most likely to contribute to the causes of human error.

It is conceivable that the designer has no interest in error causes, therefore it is possible to jump straight to the individual PSF listing with attached frequency count. Alternatively error causes can be linked to PSFs in turn so that the PSFs are grouped by error cause. If the designer judges that certain error causes are irrelevant for the particular task or situation they can be eliminated so that the PSF association is not invoked.

USING THE DESIGN AID

Based on a task analysis in this case of a batch process (Lihou '85) the possible error causes at each stage in the process can be identified and linked to potential performance shaping factors. This example will concentrate on the tertiary redefinition of sub-task 1.4 'Charge Water to the Reactor' (Figure 5) in order to demonstrate the use of the designer aid.

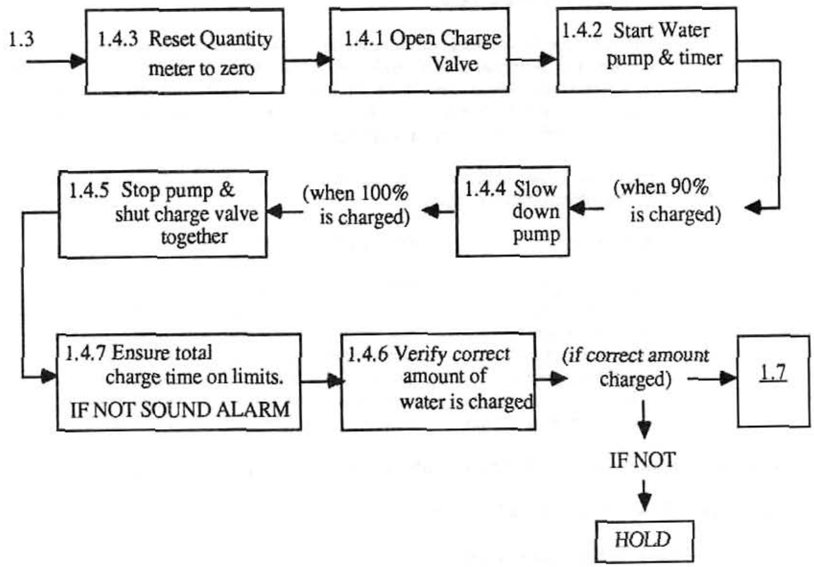

Figure 5 Tertiary Task Analysis

The first requirement is to identify the Task Type for each sub-task; as already stated this directly influences which stages in the Information Processing Chain are involved.

SUB-TASK		TASK TYPE		INFORMATION PROCESSING CHAIN
1.4.3	=	Requirement	=	Comprehension + PLAN + Response
1.4.1	=	Requirement	=	Comprehension + PLAN + Response
1.4.2	=	Requirement	=	Comprehension + PLAN + Response
1.4.4	=	Stimulus	=	Perception + Identification + Response
1.4.5	=	Stimulus	=	Perception + Identification + Response
1.4.7	=	Interpretation	=	Perception + Identification + Comprehension + Decision + Plan + Response
1.4.6	=	Interpretation	=	Perception + Identification + Comprehension + Decision + Plan + Response

The inclusion of the PLAN stage within the information processing chain is dependent upon the complexity of the required response; ie, whether a sequence of actions is called for OR a discrete action , plus the extent of operator familiarity. It may be that an understanding of the situation immediately triggers the necessary response rather than requiring a planning stage. In this particular example of a batch process with a standard task sequence the PLAN stage appears redundant - it does however depend on the experience of the operator.

Two additional decisions required by the designer define the type of response expected (this is partly dependant upon the level of redefinition descended to with the initial task analysis). In this example the ordering of sub-tasks for 1.4 'Charge water to Reactor' is important , they need to be performed as a sequence rather than as discrete independant tasks. However, due to the redefinition to lower order sub-tasks these have to be considered as requiring a discrete response or sequence of actions in their own right: 1.4.2 and 1.4.5 obviously have more than one associated action therefore they are defined as 'Sequence'. The remaining subtasks in the example appear to require discrete actions.

As attention focusses upon each sub-task in more detail it can be seen that 1.4.1 to 1.4.5 require an ACTION as a response whereas 1.4.6 and 1.4.7 are slightly different. Both of these sub-tasks are a decision stage which result in an action if the requirement is not fulfilled otherwise remaining as a monitoring stage with no action. Two assessments are therefore required one each for the conditions normal and abnormal.

In the same way that Task Type influences the information processing chain the expected Task Reponse influences the possible error types.

SUB-TASK		RESPONSE		POSSIBLE ERROR TYPES
1.4.3	=	discrete/action	=	omission + commission + repetition + substitution
1.4.1	=	discrete/action	=	omission + commission + repetition + substitution
1.4.2	=	sequence/action	=	om + com + rep + sub + timing + mis-ordering
1.4.4	=	discrete/action	=	om + com + rep + sub
1.4.5	=	sequence/action	=	om + com + rep + sub + timing + mis-ordering
1.4.7	=	do nothing or action	=	commission OR om + com + rep + sub
1.4.6	=	do nothing or action	=	commission OR om + com + rep + sub

If using the computerised technique each sub-task will be assessed in turn, for example -

Sub-task 1.4.3 'Reset Quantity meter to zero'

Please select task type:

1 Stimulus
2 Integration
3 Interpretation
4 Requirement
5 Self Generation
6 Choice
7 Correction

INPUT -> 4

Task selected = REQUIREMENT

Appropriate Information Processing Chain:

COMPREHENSION + PLAN + RESPONSE

Is the PLAN step relevant to your specific task? YES/NO

INPUT -> N

Is the expected Response Type Discret or Sequence?

INPUT -> D

Please select Expected Response Type:

1 Action
2 Get information
3 Give information
4 Do nothing

INPUT ->1

You Have Defined Response Type as:

DISCRETE ACTION

The possible Error Types for this Response are:

OMISSION + COMMISSION + REPETITION + SUBSTITUTION

Please select error types relevant for your specific task:

INPUT -> O , S

Do you wish to view potential error causes?

INPUT -> Y

Given

Task Type	= requirement
Information Processing Chain	= Comprehension + Response
Expected Response Type	= Discrete Action
Selected Error Types	= Omission + Substitution

The possible error mechanisms are:

1 Stressors
2 deficient mental model
3 demands mis-match
4 disturbance/interruption
5 system interface
6 random fluctuations
7 absent minded

Do you wish to view error causes grouped by mechanisms?

INPUT -> Y

The possible causes of error are:

HETEROGENOUS (system and operator causes)

1 Stressors
 5 freeze
 6 mind set

2 Deficient Mental Model
 9 mental set
 10 mis-interpretation

3 Demands Mis-match
 12 reduced capabilities
 14 over demanding

EXOGENOUS (system causes)
- 4 Disturbance/interruption
  - 18 forgest task/task stage
- 5 System Interface
  - 19 stereotype mismatch
  - 20 action prevented

ENDOGENOUS (operator causes)
- 6 Random Fluctuations
  - 23 conscious or sub-conscious
  - 24 motot co-ordination
  - 25 mental blocks
- 7 Absent Minded
  - 26 substitution
  - 28 forget task
  - 29 intrusions (thinking ahead)

TOTAL 15 from 34

Do you wish to Narrow Your Selection of Error Types?

INPUT -> Y

NB[if N had been selected, the opportunity to reselect error types is given]

Please select from:

1 Omission
2 Substitution

INPUT -> 1

You have redefined error type as: Omission

Do You wish to consider specific stages of the Information Processing Chain?

INPUT -> Y

NB [if N no alternative choice is given]

Please select from:

1 Comprehension
2 Response

INPUT ->2

Given

Task type	= requirement
Information Processing Chain	= response
Expected Response Type	= discrete action
Selected Error Type	= omission

The possible error mechanisms are:

1 Stressors
2 Demands mismatch
3 Disturbance/interruption
4 System interface
5 Random fluctuations
6 Absent minded

The possible causes of error are:

HETEROGENEOUS

1 Stressors
   5 freeze

2 Demands mis-match
   12 reduced capabilities
   14 over demanding

EXOGENOUS

3 Disturbance/Interruption
   18 forget task/ task stage

4 System Interface
   19 Stereotype mismatch
   20 action prevented

ENDOGENOUS

5 Random Fluctuations
   24 motor co-ordination

6 Absent Minded
   28 forget task

TOTAL 8 from 34

Do you wish to narrow your selection of Error Types?

INPUT -> N

Do you wish to reselect error types?

INPUT-> N

Do you wish to select from Information Processing Chain?

INPUT -> N

Do you wish to return to full Information Processing Chain?

INPUT -> N

Are there any error mechanisms you wish to eliminate?

INPUT -> Y

Please select mechanisms for elimination

1 Stressors
2 Demands mis-match
3 Disturbance/Interruption
4 System Interface
5 Random Fluctuations
6 Absent minded

(In this example the sub-task is part of the preparation phase therefore it may be considered that the operator will not be under stress to complete the action therefore the designer may choose to eliminate this mechanism)

INPUT -> 1

ASSOCIATED PSFs: Requirement: Response: Discrete Action: Omission

1 Demands Mis-match

Reduced Capabilities recent illness, impaired fitness, confidence, mood, motivation , normal capabilities, selection criteria, supervision, team work, manning levels, safety clothing, special clothing, availability of safety clothing.
Over Demanding frequency requirement, accuracy demanded, time dependancy, process hazards, personal 'contact' with materials, materials hazard, climatic exposure, access space horizontally, access space vertically, method of access, lighting, atmosphere, temperature, vibration, skin irritation, shift work, hours worked, overtime, control visibility, control access, manning level, equipment dimensions, physical demands, type of interaction, frequency of interaction.

2 Disturbance/Interruption

Distracted from task/task stage chemical instability, possible materials, contact, materials hazards, climatic exposure, sudden noise, alarm intrusion, team work, receiving direct formal communication, receiving indirect formal communication, receiving direct informal communication, receiving indirect informal communication.

3 System Interface

Stereotype mis-match control type, control status identification, control layout, control visibility, control response feedback, associated display type, associated display scale increase, location of display to control, associated display identification, associated display visibility, assoc display legibility, assoc display clarity, display response time, display/control interaction, specific training, retraining.

Action Prevented direct control size, direct control force, control layout, control identification, control access, control use prompt, horizontal access area, vertical access area, obstacles, surface type, unavailable safety clothing, unavailable aids, unavailable safety equipment, unservicable equipment/aids, equipment dimensions, equipment identity.

4 Random Fluctuations

Motor co-ordination frequency of involvement, accuracy demanded, time dependences, vibration, shift work, overtime, rest periods, control type, control size, force required, control layout, display/ control interactions, supervision, isolation, special clothing, safety clothing, type of interaction, freq interaction, control muscles, static muscles, co-ordination, dexterity, time pressure, alertness, specific training, amount of training, amount of specific experience, op accuracy.

5 Absent Minded

Forget task frequency of involvement, number of locations, rest periods, work organisation, control use prompted, control visibility, assoc display visibility, isolation, concentration req, amount of experience, personal conceptions, mood,

The PSF Frequency Output is of the following type:

PSF	Frequency	%
2 frequency of personnel involvement	3	42
21 horizontal access	2	30
41 control layout	3	42
44 control access	2	30
134 confidence	1	14

CONCLUSIONS

As is apparent from the example, the complexity of the information linkages means that the technique is greatly assisted by computerisation, therefore, the data sets plus accompanying logic are being reproduced in LISP (list programming) for use on an IBM pc.

Currently the design aid fixates upon eliminating or identifying negative performance shaping factors however, it is intended to extend the aid to suggest appropriate positive PSFs for design inclusion. Although the technique is still in the development stage its potential to guide design resources is already in evidence and as soon as logic testing has been completed the design aid will be taken back into the industrial environment for evaluation through practical application.

REFERENCES

1. Embrey DE (1985), A computer based technique for human reliability assessment, *Ergonomics International 85, Eds ID Brown, R Goldsmith, K Coombes, MA Sinclair* (Taylor & Francis: London & Philadelphia).

2 Johnson WG (1980) MORT Safety Assurance Systems Occupational Safety & Health and the National Safety Council. (New York: Marcel Dekker)

3 Kletz TA (1976) Accident data - the need for a new look at the sort of data that are collected and analysed Journal of Occupational Accidents 1 (95-105)

4 Lihou DA & Jackson PP (1985), Using task analysis to specify PLC software for batch processes, IChemE symposium series No 94.

5 Miller RB (1953) A Method for man-machine task analysis US Air Force, Wright Air Development Center, Dayton Ohio, Report 53-137.

6 Rasmussen *J (1980)* What can be learned from error reports? *Changes in Working Life*, Eds KD Duncan, MM Grunberg, D Wallis (Wiley: New York).

7 Singleton WT (1974), Man-Machine Systems, (Penguin Education).

8 Swain AD & Guttman HE (1980) Handbook of Human Reliability Analysis with emphasis on Nuclear Power Plant Applications Washington DC: US Nuclear Regulatory Committee, Report No.NUREG/CR-1278

9. Whalley SP (1984) Factors affecting Human Reliability in the Chemical Process Industry: First Year Report Internal report Chemical Engineering Dept. University of Aston

10 Whalley SP & Maund JK(1985)The identification and classification of performance shaping factors in the chemical industry Contempory Ergonomics 1985 edited by DJ Oborne.(Taylor & Francis: London & Philadelphia).