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are concerned with descriptions of the tasks performed by personnel. However, there may be a need to provide qualitative descriptions of the technical system itself. The last criterion (10) was introduced for this purpose.

Another way of classifying the various TA methods is in terms of the application areas in which they might be seen as most useful. Figure 4.15 provides such a classification in terms of seven human factors applications, namely:

1. Design of operating procedures
2. Training needs analysis
3. Team organization
4. Human–machine allocation of tasks
5. Control panel design
6. Workload analysis
7. Input to human error analysis

It is worth pointing out that Figures 4.14 and 4.15 present only a broad qualitative classification along a number of criteria. It is conceivable that some methods may fulfill a criterion to a greater extent than others.

4.4. HUMAN ERROR ANALYSIS TECHNIQUES

The application of human error analysis (HEA) techniques is to predict possible errors that may occur in a task. The next stage of error analysis is to identify error recovery possibilities implicit within the task, and to specify possible

APPLICATIONS	HTA	OAET	DA CHARTS	OSDS	SFGS	CADET	IMAS
1 Design of operating procedures	Y	N	Y	N	N	P	P
2 Training needs analysis	Y	N	Y	N	N	Y	Y
3 Team organization	Y	N	N	Y	N	P	N
4 Human–machine task allocations	Y	P	P	Y	Y	Y	P
5 Control panel design	Y	N	Y	P	Y	Y	Y
6 Workload analysis	P	N	N	Y	N	Y	N
7 Input to human error analysis	Y	Y	Y	N	N	Y	Y

P = Criterion is only partially fulfilled

FIGURE 4.15. **How to Use Various TA Methods in Human Factors Application**

remedial strategies to eliminate the causes of errors or to enhance their likelihood of recovery before the consequences occur. The consequences of possible unrecovered errors are also often considered error analysis. The requirements for error analysis techniques are therefore as follows:

1. Provide assistance to the analyst in exhaustively identifying possible errors.
2. Identify error recovery opportunities.
3. Develop error reduction strategies (ERS).
4. Consider the consequences of possible errors for risk assessment or for cost–benefit analysis when considering alternative ERS.

There are a wide range of potential applications of HEA techniques (see Kirwan, 1992, for an overview). In a process plant, the various operating modes include normal operating conditions, maintenance, plant disturbances and emergencies. After carrying out a task analysis to define the worker's role in these areas, error analysis can be used to identify possible human failures with significant consequences and to specify appropriate hardware procedures, training, and other aspects of design to prevent their occurrence.

The other main application area for predictive error analysis is in chemical process quantitative risk assessment (CPQRA) as a means of identifying human errors with significant risk consequences. In most cases, the generation of error modes in CPQRA is a somewhat unsystematic process, since it only considers errors that involve the failure to perform some pre-specified function, usually in an emergency (e.g., responding to an alarm within a time interval). The fact that errors of commission can arise as a result of diagnostic failures, or that poor interface design or procedures can also induce errors is rarely considered as part of CPQRA. However, this may be due to the fact that HEA techniques are not widely known in the chemical industry. The application of error analysis in CPQRA will be discussed further in Chapter 5.

Error analysis techniques can be used in accident analysis to identify the events and contributory factors that led to an accident, to represent this information in a clear and simple manner and to suggest suitable error reduction strategies. This is achieved in practice by identification of the causal event sequence that led to the accident and the analysis of this sequence to identify the root causes of the system malfunction. A discussion of accident analysis techniques is included in Chapter 6.

4.4.1. Predictive Human Error Analysis (PHEA)

Predictive human error analysis can be performed manually or by means of a computer software package. Three types of analysis are possible within PHEA.

- **Preconditioned plan analysis:** This addresses errors in the planning of the task or ensuring that the correct preconditions apply.
- **Embedded plan analysis:** This considers errors arising from the plan specified in the HTA (e.g., ignoring the condition in the plan which specifies how the steps should be executed).
- **Task element analysis:** This aspect of the procedure systematically identifies a range of errors (e.g., failing to close a valve, closing the wrong valve) that could arise at each step of the task.

For the purposes of this description the focus will be on the task element analysis. The analysis procedure proceeds through a number of stages:

Task Element Selection
If the whole task being analyzed has already been identified as being highly critical, then it may be necessary to subject every step to a PHEA. However, in most cases only those steps which have a high risk potential if errors occur will be examined in detail. Procedures for identifying critical tasks are described in Chapter 5.

Detailed Analysis
The whole range of error types that could occur at each task step are described in Figure 4.16. The terms *action errors* and *checking errors* are self-explanatory. Retrieval errors refer to the retrieval of information either from an external source (e.g., a chart recorder or a procedure) or from memory. Transmission/ communication errors refer to communications among individuals either directly or via written communications. Selection/choice errors refer to making incorrect choices among alternative operations, for example, manual instead of automatic.

For each subset of task steps that have been defined, the analyst first asks if any steps in the group involve any of the activities implied by the error categories, for example, action, checking, communication etc. If an activity does not occur within the task steps being considered, then this is not considered further at this stage. This enables groups of task steps to be eliminated at an early stage of the analysis, to reduce the number of questions that need to be asked later.

At this stage of the technique, it is necessary for the analyst to make a general assessment of any error-inducing conditions due to poor PIFs in the situation under consideration, to determine if these are likely to give rise to any of the errors that will be considered at the next stage of the analysis. Typical error-inducing conditions such as poor procedures, time stress, inadequate interface design, have already been considered in Chapter 3.

The analyst then decides, for each step if any of the error modes from the complete error classification given in Figure 4.16 are possible. For example:

For task step 12.1: Open valve V17
Is it possible that the action could be omitted?
Is it possible that it may not be opened fully?

Action Errors	
A1	Action too long/short
A2	Action mistimed
A3	Action in wrong direction
A4	Action too little/too much
A5	Misalign
A6	Right action on wrong object
A7	Wrong action on right objec
A8	Action omitte
A9	Action incomplete
A10	Wrong action on wrong object
Checking Errors	
C1	Checking omitted
C2	Check incomplete
C3	Right check on wrong object
C4	Wrong check on right object
C5	Check mistimed
C6	Wrong check on wrong object
Retrieval Errors	
R1	Information not obtained
R2	Wrong information obtained
R3	Information retrieval incomplete
Transmission Errors	
T1	Information not transmitted
T2	Wrong information transmitted
T3	Information transmission incomplete
Selection Errors	
S1	Selection omitted
S2	Wrong selection made
Plan Errors	
P1	Plan preconditions ignored
P2	Incorrect plan executed

FIGURE 4.16. **Error Classification used in Predictive Error Analysis**

The answers to these questions are clearly dependent on the quality of the PIFs in the situation under consideration, for example, labeling or procedures. The consequences of the error, the factors that will support recovery of the error before the consequences occur, and the error prevention strategies will all be considered during the analysis.

Documentation

Figure 4.17 shows a useful format for documenting the results of error analysis. This is based on the HTA in Figure 4.2. For every critical error (e.g., action omitted) the implications or consequences for the system and the possibilities of error recovery are described in the same format. This facilitates the development of design or other solutions to prevent the error.

Applications of the Technique

The exhaustive nature of the technique means that it is well suited to the analysis of critical systems where it is essential that all credible error modes are identified. For this reason it is useful as a means of generating error modes for inclusion in CPQRA analyses.

For the purpose of procedures design, the technique can be used to identify errors with significant consequences at particular task steps. Warnings can be included at these steps to alert the worker to the consequences of errors. If the predicted errors have severe consequences and high likelihood of occurrence, then equipment redesign might be indicated. Error analysis also provides an input to training, in that it indicates the aspects of the job which require particular attention during training. The advantages and disadvantages of the PHEA can be summed up as follows:

Advantages

1. The technique is rigorous and exhaustive and hence is likely to ensure that most errors are identified.
2. A validation study of the technique showed that it was capable of predicting a high proportion (98%) of errors with serious consequences that actually occurred in an equipment calibration task over a 5-year period (Murgatroyd and Tait, 1987).

TASK STEP	TASK TYPE	ERROR TYPE	DESCRIPTION	CONSEQUENCES	RECOVERY	ERROR REDUCTION STRATEGY
1.1 Move set point to measured value	Action	Action Omitted	Set point left at original value	System may operate at wrong set point. Process hazard may occur (Moderate)	Noticeable change of value of variable may occur at step 1.2	Introduce check in checklist
	Action	Right action on wrong object	Set point changed on wrong controller	Same as above	Same as above	Clearly label controllers to distinguish among set point controls
	Action	Wrong action on right object	Controller set to wrong value	Same as above	Same as above	Introduce check in checklist

FIGURE 4.17. **Documentation of the Results of Human Error Analysis**

3. It provides a standardized procedure to ensure consistency among analysts. This was tested by carrying out two independent evaluations of the same task. Of the 60 errors identified in the above validation study, 70% were common to both analysts. Of the remainder, 11 differences were due to differences in knowledge of the equipment by the two analysts and 5 were due to different interpretations of the procedures.
4. The method provides an explicit link with the results of task analysis.
5. Some aspects of cognitive errors, that is, planning errors, can be addressed.

Disadvantages

1. The method requires a substantial investment of time and effort if there are a large number of task steps to be analyzed.
2. The success of the method requires a detailed knowledge of the task being evaluated. Time has to be invested to acquire this knowledge.
3. The user of the technique needs to be trained to correctly interpret the questions.
4. A separate evaluation of PIFs needs to be performed in order to predict which error types are likely.

4.4.2. Work Analysis

This is a technique developed by Petersen and Rasmussen. The full documentation of the technique is extensive and only an outline can be provided here. Full details are available in Petersen (1985). The major steps in performing work analysis are as follows:

Analyze the Task Element Sequence:

(a) Define task elements that cannot be omitted or changed without affecting the probability that the goal will be achieved.
(b) Define alternative routes (i.e., alternative plans/task elements) that could also achieve the goal.
(c) Subject each of these routes separately to the following analyses.

Analyze the Task Steps:

(a) Define the criteria for the overall success of the task or subtask under consideration.
(b) Define error recovery points, that is points in the sequence where previously committed errors have a high probability of recovery. This could be because there is considerable observable feedback, or because it would be physically difficult to proceed beyond that point given the occurrence of the earlier error(s).
(c) Define erroneous actions or action sequences for which detection is unlikely, reducing the likelihood of immediate error recovery.

(d) For these actions, identify error mechanisms (see flow charts in Appendix 2B) and resulting errors that could lead to an unacceptable (i.e., irrecoverable) effect on the task.
(e) Evaluate conditions for error detection and recovery at the points identified in (b). Identify errors that will render recovery mechanisms unsuccessful.
(f) Apply quantitative human reliability assessment techniques to evaluate the total task reliability, given the error modes and recovery paths identified in (d) and (e).
(g) If the error recovery probabilities at the point identified in (b) are assessed to be sufficiently high, ignore errors in the actions preceding these points.
(h) If not, repeat step (c) for these sequences [see (f) above].

Analyze Potential Coupled Failures

(a) Note the errors that could have an effect on systems other than those being worked upon (e.g., because they are in close physical proximity or are functionally coupled).

Analyze Effects of Task Disturbances

(a) Evaluate sources of disturbances. These could include unavailability of tools, instruments or personnel, equipment faults, or changes in work scheduling due to anticipated delays. The analysis should attempt to formally categorize the different problems that could occur.
(b) Assess the effects of unavailability of tools, equipment, personnel etc., for each of the task steps not covered by recovery and for the error recovery path assessed.
(c) Assess the likely improvisations that could occur if the disturbances considered under (b) occurred.
(d) For the improvised task sequence identified under (c), repeat the analyses described in the first three sections.

Advantages

- The technique provides a very exhaustive analysis of errors in both normal and disturbed conditions.
- Error recovery is explicitly analyzed.
- The effects of task disturbances are explicitly covered.

Disadvantages

- Because of the depth of analysis involved the technique is very resource intensive.

4.5. ERGONOMICS CHECKLISTS

4.5.1. Application of the Technique

Another method of predicting and reducing human error in the CPI is through the use of ergonomics checklists. These can be used by an engineer to ascertain whether various factors which influence performance of a task meet particular ergonomic criteria and codes of good practice. Items within the checklist can include the design and layout of the control panel, the labeling and location of equipment, the usability of the operating procedures, aspects of training and team communications as well as other PIFs which have been examined in Chapter 3. By applying the checklist several times on different aspects of a CPI task, the engineer can identify work conditions that can induce human error and subsequently specify error reduction strategies. Checklists can be used either retrospectively to audit an existing system or proactively to design a new system.

Although checklists are a useful way of transferring information about human–machine interaction to designers and engineers, they are not a standalone tool and they cannot provide a substitute for a systematic design process. The main concern with checklists is that they do not offer any guidance about the relative importance of various items that do not comply with the recommendations, and the likely consequences of a failure due to a noncompliance. To overcome such problems, checklists should be used in combination with other methods of task analysis or error analysis that can identify the complexities of a task, the relationships among various job components, and the required skills to perform the task.

4.5.2. Examples of Checklists

There are several checklists in existence that focus on different aspects of human–machine interaction. Some are intended to assess the overall design of the plant while others focus on more specific issues such as the design of the control panel, the dialogue between operator and VDU interfaces, and the usability of procedures and other job-aids. Depending on the scope of application, the items within a checklist can vary from overall subjective opinions, for example, "have operators been given adequate training in fault-diagnostic skills?" to very specific objective checks, for example, "is the information presented on the screen clear and is contrast in the range of 1 to 5–10?" On many occasions it is necessary to expand or modify an existing checklist to ensure that other standards or codes of practice are being met.

There are many checklists that can be used to identify error-inducing conditions and ensure conformance with particular ergonomic standards, and the following examples illustrate the range of areas covered.

Short Guide to Reducing Human Error in Process Operation (United Kingdom Atomic Energy Authority, 1987)

This guide is arranged as a checklist of questions on the following five areas of system design that impact upon plant safety: worker–process interface, procedures, workplace and working environment, training, and task design and job organization. The guide could be used in developing new plant designs or making changes to existing plant, auditing existing arrangements or investigating causes of incidents. The list of questions is intended to assess either the overall plant design or the reliability of performing a particular task. Table 4.1 provides an extract from this guide for the evaluation of operating procedures.

The guide is described as a "short guide" because it draws attention to general problems only. A more detailed guide (*The Long Guide*) which provides full explanations for each checklist item is also available (United Kingdom Atomic Energy Authority, 1991).

CRT Display Checklist (Blackman et al., 1983)

This checklist presents criteria for comparing different ways of presenting information on CRT displays.

VDU Checklist (Cakir et al., 1980)

This checklist presents detailed information for assessing VDU terminals and their workplaces. The items concern technical information about VDU characteristics but they do not directly consider the nature of the task performed using the VDU system.

Principles of Interface Design for Computer Controlled Processes (Bellamy and Geyer, 1988)

This is a list of ergonomic considerations that should be taken into account in the interface design of computer controlled processes. The principles refer essentially to monitoring and control tasks, and they have been derived from a literature review supplemented by the analysis of a number of incidents.

Advantages

- Checklists are quick and easy to apply. The answers to the questions in the checklist provide insights into remedial strategies.

Disadvantages

- Checklists do not provide any assistance to assess the relative importance of different items or to indicate the degree to which items may fail to meet the criteria. Thus, there is a need to undertake some prioritization of checklist failures, in order to avoid misinterpretation of the information.

TABLE 4.1

A Checklist on Procedures Extracted from the "Short Guide to Reducing Human Error" (UK Atomic Energy Authority, 1987)

Concise procedures

There should be no ambiguity about when procedures are to be used.

- Are the procedures available when required?
- Are the conditions in which the procedures must be used clear and unambiguous?
- Is there a simple unambiguous indexing method for choosing the required procedure?

Mandatory procedures

When procedures are mandatory, there should be no incentive to use other methods.

- Are procedures and manually operated safety interlocks sufficiently simple to use?
- Are there no easier, but more dangerous alternatives?
- Is there a convenient area of the workplace for using the procedural documentation?
- Are the documentary procedures routinely checked, compared with operator action and revised as appropriate?

Supporting procedures

Procedures should where possible support the worker's skills and discretion rather than replace them.

- Are the procedures and worker's skills complementary?
- Where the workers are skilled and experienced, and an absolutely standard sequence is not necessary, the procedures should be in the form of reminder checklists with guidance on priorities, rather than detailed instructions.

Correct operational procedures

Procedures should be easy to understand and follow.

- Can the instructions be easily understood and followed, particularly by a person who is unfamiliar with them?
- Is there a mechanism for keeping place in a sequence of instructions, so that it can be returned to after an interruption or distraction?
- Where two or more procedures share a common sequence of operations, or working environment, do they contain checks that the worker is continuing to use the correct procedure?
- Does a different person subsequently make an independent check that mandatory procedures have been carried out?
- Can emergency procedures be implemented whether or not the worker knows what is wrong?

- Checklists generally take no account of the context in which the tasks are carried out. Some form of task analysis or error analysis may also be required to gain an insight into the overall task context.
- Checklist are one-dimensional, and do not provide any guidance with regard to the reasons for the questions.

It is also important that the analyst should take some time to become familiar with the task prior to undertaking the checklist survey, otherwise a considerable amount of time will be devoted to discovering the background of the task rather than assessing the checklist items.

4.6. SUMMARY

The intention of this chapter has been to provide an overview of analytical methods for predicting and reducing human error in CPI tasks. The data collection methods and ergonomics checklists are useful in generating operational data about the characteristics of the task, the skills and experience required, and the interaction between the worker and the task. Task analysis methods organize these data into a coherent description or representation of the objectives and work methods required to carry out the task. This task description is subsequently utilized in human error analysis methods to examine the possible errors that can occur during a task.

The focus of this chapter has been on proactive application of these analytical methods such as safety audits, development of procedures, training needs analysis, and equipment design. However, many of these methods can also be used in a retrospective mode, and this issue deserves further attention in its own right. Chapter 6 describes analytical methods for accident investigations and data collection.