4

Analytical Methods for Predicting and Reducing Human Error

4.1. INTRODUCTION

The previous chapters described various approaches to understanding how human errors arise and provided a comprehensive overview of the wide range of factors that can influence the likelihood of human error. The methods described in this chapter draw upon these insights to provide a comprehensive set of tools that can be used by engineers to evaluate and reduce human error in their plants. These methods can be applied proactively, as part of design and audit procedures to identify and eliminate error-inducing characteristics of a system before an incident occurs. They can also be used "after the event" to understand the underlying causes of an incident and to prescribe suitable measures to prevent a recurrence (see Chapter 6). The use of methods within an overall error-management framework is described in Chapter 8.

The various analytical methods for predicting and reducing human error can be assigned to four groups or sections. In order to make a start on any form of analysis or prediction of human error, it is obviously necessary to gather information. The first section therefore describes a number of techniques that can be applied to acquire data about what the worker does, or what happened in an accident.

The second section describes various task analysis (TA) techniques. Task analysis is a fundamental methodology that is widely used by human factors specialists for a variety of purposes including procedures development, training specification, and equipment design. Task analysis methods organize the information generated by the data acquisition process into a variety of forms and representations, depending on the purpose of the analysis. For example, if the analyst is primarily interested in the design of the human–machine interface, the TA technique will focus on the input and output of information to the worker, the design of the information displays and on the thinking processes involved in operating the plant. In many cases there is a considerable overlap between data acquisition and TA methods.

The third category of methods addressed in this chapter are error analysis and reduction methodologies. Error analysis techniques can either be applied in a proactive or retrospective mode. In the proactive mode they are used to predict possible errors when tasks are being analyzed during chemical process quantitative risk assessment and design evaluations. When applied retrospectively, they are used to identify the underlying causes of errors giving rise to accidents. Very often the distinction between task analysis and error analysis is blurred, since the process of error analysis always has to proceed from a comprehensive description of a task, usually derived from a task analysis.

The last category of techniques are various forms of checklists of factors that can influence human reliability. These are used mainly in a proactive auditing mode. They have the advantage that they are quick and easy to apply. However, considerable training may be necessary to interpret the results and to generate appropriate remedial strategies in the event that problems are identified.

4.2. DATA ACQUISITION TECHNIQUES

The following techniques can be used to collect data about human performance in CPI tasks and provide input to task analysis methods described in Section 4.3. These data can include process information critical for the task, control strategies used by the workers, diagnostic plans etc. A distinction can be made among data collection methods that provide qualitative data (such as interviews, observations, and sources of documentation) and methods that can be used to measure aspects of performance (such as activity analysis, simulations, and information withholding). The latter methods can provide more precise data which can be quantified.

4.2.1. Discussions and Interviews with "Experts"

Analyzing complex tasks is usually best done in collaboration with a task expert. Anybody knowledgeable about a particular job might be described as an "expert." This includes process workers, supervisors, engineers, trainers, safety specialists, and managers. Discussions and structured interviews are likely to emerge at any stage during a task analysis activity. They can either be used during the analysis to collect basic information about the task or at the end of the analysis to check the accuracy of information that has been collected. The interviewer needs to be trained in order to make the task expert feel relaxed and not threatened or embarrassed by the situation. This is not always easy to achieve because people may get the impression that their expertise is being evaluated or compared with that of other experts. For this reason, the objective of the interview and the relevance of each question should be explained in advance to the interviewee. It is useful, therefore to structure the interview beforehand in terms of the aspects of human performance that are of interest to the study. This will also make the whole exercise more economical in terms of the period of time that task experts are taken away from their jobs.

A variant of individual interviews is verbal protocol analysis. In this technique, the person is asked to "think aloud" while carrying out a particular task. These self-commentaries are made while the task is being undertaken in order to avoid the inevitable distortion or forgetting that could occur if the reporting is left until afterwards. The main aim is to gather information on the psychological processes that underlie performance, which are not directly observable. It is essential that the process of providing a verbal commentary should not affect the way in which the task is carried out. To prevent people from elaborating on, or rationalizing their thought processes in any way, it is important to encourage a continuous, flowing commentary.

Useful protocols can only be produced for information that is coded in a verbal form in memory. Tasks that rely on visual imagery for their execution, or have become "automated" due to over-practice will be very difficult to verbalize. Hence the technique may provide little useful information and may even produce misleading reports for these tasks. To encourage task verbalization some coaching should be given to the task experts and the goals of the study should be explained so that they can make greater efforts to report on aspects of the task which are of particular importance.

Some form of audio recording will be essential to collect all the verbal information about the task. To help the analysis of the protocols, the analyst can link the protocol to the state of the chemical process at that time by noting the time and the values of particular indicators. Another technique is to make video recordings of the operations at the same time as the verbal protocols are collected. These can subsequently be played back with the individual who provided the original verbal protocol, in order to gain further insights into the reasons why certain strategies where used. After the tape recordings have been transcribed into a written form, the analyst can structure the available information to examine its content and draw the required inferences.

One way of analyzing the data is to use a columnar format, with columns such as Displays Used, Control Used, Action, Decision, Goal Pursued, etc. which are filled in directly from the protocol information. A useful discussion of the application of the technique to process control tasks is given by Bainbridge (1974), and Ainsworth and Whitfield (1984). Apart from collecting data about the task, discussions and interviews with the workers can get their direct commitment to a project and can make them feel that they "own" any proposed new work system.

4.2.2. Observation

Discussions and interviews with the task experts can be supplemented with observations of their actual performance, for example, taking notes on certain aspects of the task or taking video or audio recordings. Observational techniques can reveal information that may be difficult to acquire in any other way. Detailed physical task performance data can be recorded, and major environmental influences (e.g., noise, light, interruptions) can all be faithfully represented. Observations can also provide an insight into the way that the team members communicate, allocate job responsibilities, and make use of operating procedures and other resources.

Observations are appropriate for recording physical task sequences, or verbal interactions among several people. They are not suitable for collecting precision performance data, or studying cognitive tasks which involve covert mental processing.

It is a good practice to try and predict what level of information is expected to be extracted from the data before conducting sessions relying on observation. For instance, problems posed by movement and interaction among individuals, and the inability of a video system to capture extremely detailed events, must all be considered in advance. If certain aspects of the task are videotaped, the recording process itself should be as unobtrusive as possible. The minimum requirement is that it does not get in the way. Also, some people may react negatively to being observed and recorded. For this reason, the workers should be briefed about the objectives of the observational study in advance.

4.2.3. Critical Incident Technique

This technique sets out to collect data about near-incidents or critical events that have been experienced by the operating team but that are unlikely to be documented. The basic premise of the technique is that events that could have led to serious consequences would tend to be remembered by the workers. Through individual or group interviews, significant events are recalled which are then analyzed in order to generate useful information about the difficulties involved in the performance of a task, the adequacy of the operating procedures, any problems with the equipment or control panel design and so on. The technique can be used in three areas:

- To identify changes to be made in the system to ameliorate operational problems
- To provide data for task analysis methods concerning the difficulties involved in the performance of a task
- To provide data for error analysis methods by pinpointing error-likely situations

The critical incident technique was first described by Flanagan (1954) and was used during World War II to analyze "near-miss incidents." The war time studies of "pilot errors" by Fitts and Jones (1947) are the classic studies using this technique. The technique can be applied in different ways. The most common application is to ask individuals to describe situations involving errors made by themselves or their colleagues. Another, more systematic approach is to get them to fill in reports on critical incidents on a weekly basis. One recent development of the technique has been used in the aviation world, to solicit reports from aircraft crews in an anonymous or confidential way, on incidents in aircraft operations. Such data collection systems will be discussed more thoroughly in Chapter 6.

A degree of rapport must be built between the analyst and the worker in order for them to feel that their commentary will be treated confidentially. This is important in situations where an incident has not been reported in the past and the workers do not wish to open themselves or their colleagues to potential sanctions. Under such conditions, it may be appropriate for the analyst to provide the overall results of the study, rather than the actual content in terms of events etc.

The results should be treated with caution because the technique is subject to loss from memory, of detail, fabrication, and recall of anecdotal events.

4.2.4. Documentation

Documents such as job descriptions, operating manuals, emergency procedures, accident, and "near-accident" records, can be useful sources of information about the task to be studied. Pipework and instrumentation diagrams can also be used to gain an insight into the complexity of the process, the type of control loops installed, and the process parameters to be manually controlled by the workers.

Reference to such documents may be useful at early stages in the task analysis to inform the analyst about the overall nature and breadth of tasks carried out. Later, as the detail of the task is becoming established, such documents serve to provide crucial information. The use of experts in helping with the interpretation of documents is usually necessary, unless the analyst is directly involved with the system on a regular basis.

4.2.5. Activity Analysis

Data about the plans and routines used by workers in controlling a process can be obtained by means of an "activity analysis," a type of input–output analysis. A chart can be made showing how certain process indicators change over time in response to changes of the control settings. From this chart it is possible to determine the type of process information that workers use to carry out their tasks, the size of adjustment of the various control settings, their sequence of adjustment and so forth. The activity analysis usually results in a qualitative description of the workers' control strategies.

There are various types of charts that can be used to record an activity analysis. For tasks requiring continuous and precise adjustments of process variables, a chart displaying the graphs of these variables and the appropriate control settings will fulfill the objectives of the activity analysis. Figure 4.1 shows an activity chart of a subtask for a machine operator in a papermaking plant. This describes how to adjust the weight of a given area of paper to the desired value for each successive customer order and ensure that it remains within the specified limits until the order is completed.

The value of the "basis weight" can be obtained either by removing and weighing a sample, a procedure that can only be carried out during a reel change, or (less precisely) by means of a beta-ray gauge situated at the "dry end" of the machine. In the latter case, the value of the basis weight is controlled by means of a "stuff valve" which controls the flow of pulp into the "wet end" of the machine. Its value also changes with the overall speed of the machine. For a full description of the task see Beishon (1967), and Crossman, Cooke, and Beishon (1974).

For tasks that rely on decision-making rather than on fine manipulations, the activity chart can assume a columnar format, with columns recording process information attended and subsequent changes of discrete control settings.

4.2.6. Simulators and Mock-ups

Under this heading a variety of techniques are available which involve the development and use of some form of simulation of systems ranging from simple mock-ups of a piece of equipment to sophisticated computer-driven plant simulators. The simulation would be typically used to establish appropriate working methods, ergonomics of control layout and design, identification of potential sources of error, or to derive training recommendations. The technique can be used when the real equipment or system is not yet available for study or when the tasks to be examined are critical and operator error could give rise to hazardous conditions. Tabletop simulations, where individuals talk through their responses to emergencies, are used to research the responses of a team in terms of decision making and problem solving.

A range of other data collection techniques are used in conjunction with process simulation such as interviews, the verbal protocols described earlier, walk-throughs and questionnaires. An appropriate analysis of the task is necessary in order to determine the nature of the simulation to be used. An

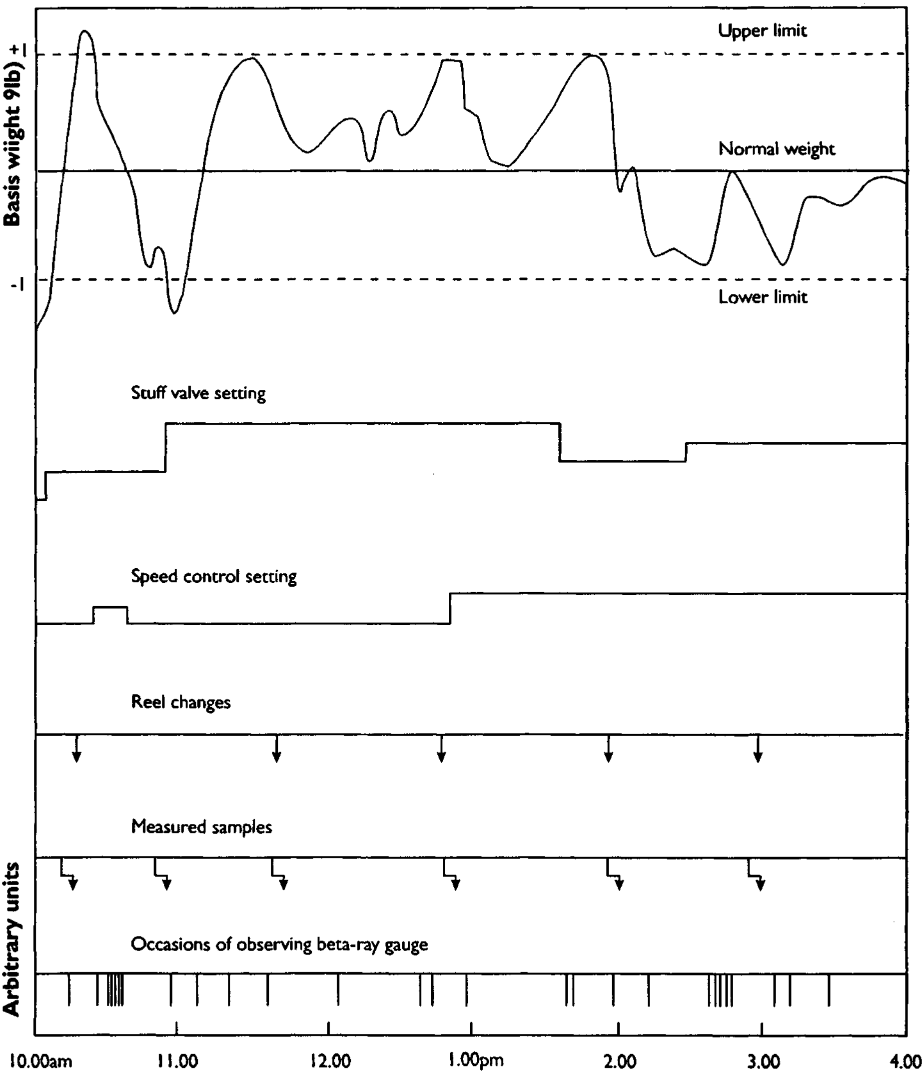

FIGURE 4.1. **Activity Analysis for the Control of "Substance" in Paper Making (Crossman et al., 1974).**

important issue to consider is which aspects of the tasks should be simulated and how faithful the representation will be. Against this has to be weighed the cost of the simulation. This will rise dramatically as more and more fidelity dimensions are built in. Stammers (1981) has offered a useful description of the different dimensions along which the fidelity of a simulator can vary.

Disadvantages may arise because the behavior observed may not be fully realistic. A static simulation, for instance, may not reveal the true nature of operators' dynamic interaction with the system. There is also the possible disadvantage of behavior in a simulator not fully replicating that found in the real situation. This can happen because of the absence of real stressors found in the actual task, for example, risk to life, criticality of the process, and presence of other workers and supervisors.

4.2.7. Withholding Information

The withheld information technique is used to explore the manner in which operators select and use information in process abnormalities. A particular abnormal process event is represented in a control panel "mock-up" or a "low-fidelity" simulator, and information is withheld from the worker until it is requested. This technique has been developed by Marshall et al. (1981) and has been used to elicit the diagnostic plans used by experienced workers during various process transients in a crude distillation unit. There are three main applications of this technique:

- To elicit the knowledge of experienced workers that cannot be verbalized easily
- To design control panels in a way that the search for process information is optimized
- To evaluate training programs and examine how new workers use control panel information to perform a task

To prepare for a withheld information session, the analyst must go through the following stages:

1. Write down the sources of information that the worker might use in the real situation including information provided verbally by his colleagues.
2. Prepare a list of events that need to be studied.
3. Prepare an event-symptom matrix showing the status of each information source for each event.
4. Ask the worker to use this information to diagnose the plant failure.

In this fashion, the way in which the workers reach decisions and deal with problems can be recorded. The problem with this technique is that the representation of the event is artificial and this may distort the data collection. The main objection is that the information offered to the worker is usually limited to easily identified information sources. It is quite feasible that workers can encode several sources of information in a display in a quite novel way which they cannot describe and which the analyst cannot anticipate.

4.3. TASK ANALYSIS

Task analysis is a fundamental methodology in the assessment and reduction of human error. A very wide variety of different task analysis methods exist, and it would be impracticable to describe all these techniques in this chapter. Instead, the intention is to describe representative methodologies applicable to different types of task. Techniques that have actually been applied in the CPI will be emphasized. An extended review of task analysis techniques is available in Kirwan and Ainsworth (1993).

4.3.1. Purpose of Task Analysis

The term *Task Analysis* (TA) can be applied very broadly to encompass a wide variety of human factors techniques. Nearly all task analysis techniques provide, as a minimum, a description of the observable aspects of operator behavior at various levels of detail, together with some indications of the structure of the task. These will be referred to as **action oriented approaches.** Other techniques focus on the mental processes that underlie observable behavior, for example, decision making and problem solving. These will be referred to as **cognitive approaches.**

In addition to their descriptive functions, TA techniques provide a wide variety of information about the task that can be useful for error prediction and prevention. To this extent, there is a considerable overlap between Task Analysis and Human Error Analysis (HEA) techniques described later in this chapter. HEA methods generally take the result of TA as their starting point and examine what aspects of the task can contribute to human error. In the context of human error reduction in the CPI, a combination of TA and HEA methods will be the most suitable form of analysis.

4.3.2. Applications of Task Analysis

Task analysis methods can be used to eliminate the preconditions that give rise to errors before they occur. They can be applied at the design stage when a new system is being developed, or when an existing system is being modified to ensure that the new configuration will not induce errors. They can also be used as part of an audit of an existing plant, in order to identify problem areas.

It is often assumed that TA cannot be applied during design, because until the plant has been fabricated the tasks to be performed by workers cannot be defined in sufficient detail. In fact, many TA techniques can be used to specify the nature of the tasks to achieve the required process plant functions, even before the exact configuration of the system has been finalized. This point will be elaborated later in the context of hierarchical task analysis.

An important aspect of a design process to minimize human error is the correct allocation of functions between human activities and automatic systems such as computer control, trips etc. From a consideration of the strengths of humans (e.g., their adaptability to cope with unpredictable situations) compared with automated systems, decisions can be made with regard to how much control should be allocated to the human in, for example, plant emergencies. A detailed discussion of allocation of function issue is provided in Price (1985) and Kantowitz and Sorkin (1987). The TA also provides information that is essential for a number of other aspects of human–machine system design. The comprehensive task description derived from the TA is a major input to the content of training and operating instructions or procedures. The results of the TA are also essential for the design of information presentation and control at the human–machine interface.

When used in the audit mode, TA can be used to develop the most efficient operating procedure for achieving the goals of a task. In many process plants it is common to find that there are wide discrepancies among the ways in which different workers or shifts carry out the same task. This is often due to inadequate or outdated operating instructions, and the absence of a culture that encourages the sharing of information about working practices. A systematic task analysis method provides the means for gathering and documenting information from different shifts and workers in order to develop the most efficient operating method from the point of view of safety, quality, and cost effectiveness.

Task analysis can also be used in a retrospective mode during the detailed investigation of major incidents. The starting point of such an investigation must be the systematic description of the way in which the task was actually carried out when the incident occurred. This may, of course, differ from the prescribed way of performing the operation, and TA provides a means of explicitly identifying such differences. Such comparisons are valuable in identifying the immediate causes of an accident.

4.3.3. Action Oriented Techniques

4.3.3.1. Hierarchical Task Analysis (HTA)

Hierarchical task analysis is a systematic method of describing how work is organized in order to meet the overall objective of the job. It involves identifying in a top down fashion the overall goal of the task, then the various subtasks and the conditions under which they should be carried out to achieve that goal. In this way, complex planning tasks can be represented as a hierarchy of **operations**—different things that people must do within a system—and **plans**—the conditions which are necessary to undertake these operations. HTA was developed by Annett et al. (1971) and further elaborated by Duncan (1974) and Shepherd (1985) as a general method of representing various industrial tasks involving a significant planning component. Although the technique was developed in the context of process control training, it has also been used in a number of other applications such as display design, development of procedures and job aids, work organization, and human error analysis. A case study of applying the method to procedures design is given in Chapter 7.

Hierarchical Task Analysis commences by stating the overall objective that the person has to achieve. This is then redescribed into a set of suboperations and the plan specifying when they are carried out. The plan is an essential component of HTA since it describes the information sources that the worker must attend to, in order to signal the need for various activities. Each suboperation can be redescribed further if the analyst requires, again in terms of other operations and plans.

Figure 4.2 shows an example HTA for the task of isolating a level transmitter for maintenance. Redescribing operations into more detailed plans and suboperations should only be undertaken where necessary, otherwise a great deal of time and effort is wasted. Since the description is hierarchical the analyst can either leave the description in general terms or take it to greater levels of detail, as required by the analysis.

The question of whether it is necessary to break down a particular operation to a finer level of detail depends on whether the analyst believes that a significant error mode is likely to be revealed by a more fine grained analysis. For example, the operation "charge the reactor" may be an adequate level of description if the analyst believes that the likelihood of error is low, and/or the consequences of error are not severe. However, if this operation was critical, it could be further redescribed as shown below:

1. Charge reactor
   Plan: Do 1, if pressure >20 psig, wait 5 minutes then do 2–6 in order.
   1.1 Ensure pressure in reactor is less than 20 psig
   1.2 Open charging port
   1.3 Charge with reactant X
   1.4 Charge with reactant Y
   1.5 Ensure seal is properly seated
   1.6 Close and lock charging port

If the consequences of not waiting until the pressure had dropped were serious and/or omitting to check the pressure was likely, then it would be necessary to break down the operation "charge reactor" to its component steps. This approach to deciding on the level of decomposition is called the $P \times C$ rule (where P is the probability of failing to carry out an operation and C the cost of the consequences). The size of the product $P \times$ C determines whether or not to describe the operation in more detail (Shepherd, 1985).

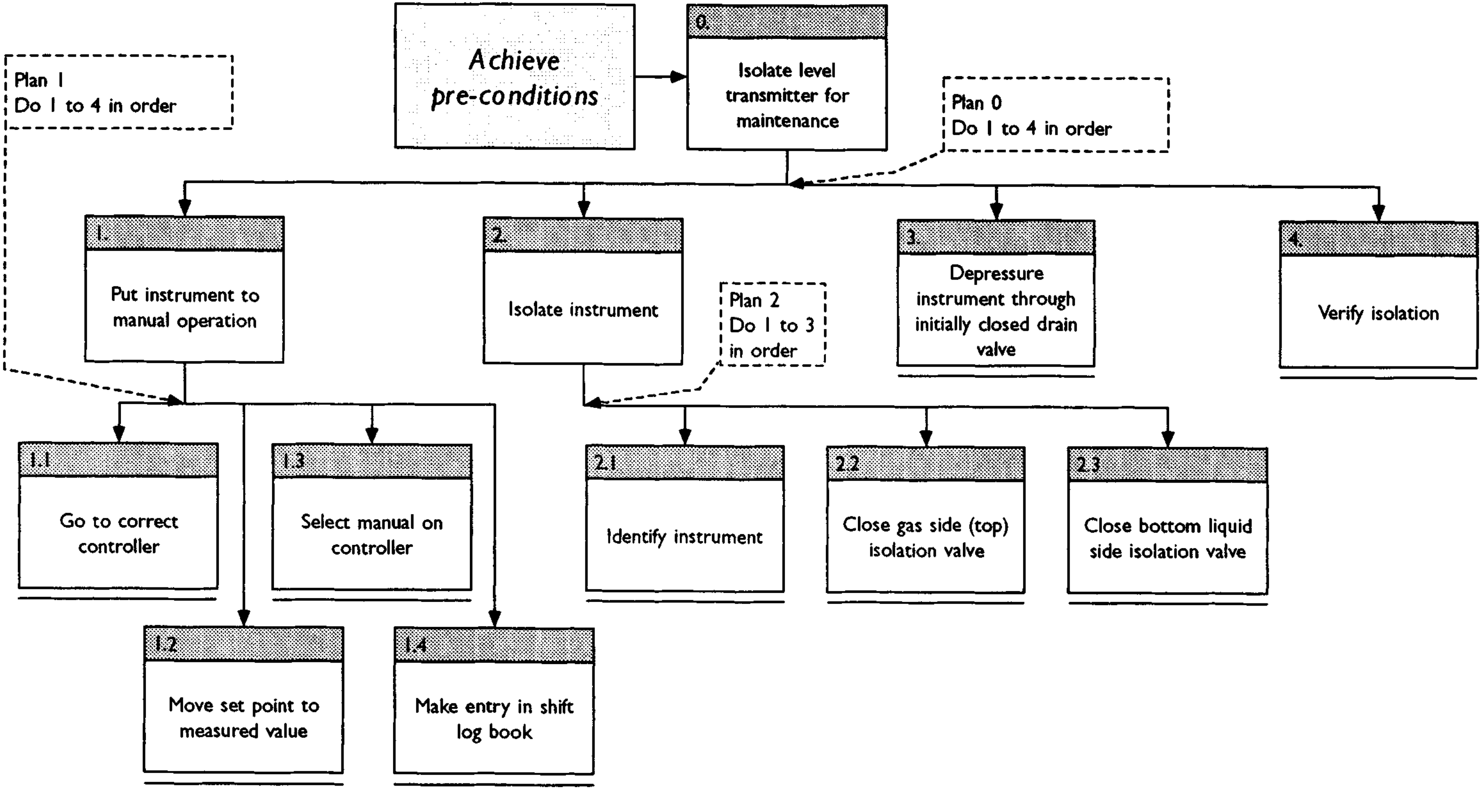

FIGURE 4.2. **HTA Diagram of Isolating a Level Transmitter for Maintenance**

This approach suffers from two major disadvantages.

- Both *P* and *C* are difficult to determine, as will be seen in Chapter 5 which reviews techniques for quantifying the likelihood of errors.
- Until the analyst has broken down the operation further, it is difficult to envision how a suboperation at the next lower level of breakdown might fail, and what the consequences of this failure might be.

In practice, a consideration of the general quality of the PIFs (performance-influencing factors) (e.g., training, supervision, procedures) in the situation being evaluated will give a good indication of the overall likelihood of error in the specific operation being evaluated. Similarly, the consequences of errors can be evaluated in terms of the overall vulnerability to human error of the subsystem under consideration. By considering these factors together, it is usually obvious where the analysis should be terminated. Differing levels of detail may be necessary for different purposes, for example, risk analysis, training specification or procedures design.

There are two main ways for representing a HTA description: the diagrammatic and tabular format. Diagrams are more easily assimilated but tables often are more thorough because detailed notes can be added. It is possible to start with a diagrammatic format and finally record the analysis in step by step format. This allows other aspects of the task to be considered such as information about the human–machine interface, communications with other team members, time characteristics, side-effects caused by failure to follow the correct plan, and the knowledge required to carry out a plan. An example of this format is provided in Figure 4.3 for the task step of optimizing a high pressure in a distillation column. Including this information in the task analysis will be very useful for gaining an insight into the workload imposed by various task components, the various points where performance may degrade, and finally into the methods that are likely to optimize human performance.

Analyzing complex tasks that entail considerable skill is usually done in collaboration with people who are knowledgeable about the job such as the workers, the supervisors, or the engineers. Information can be collected from a variety of sources including verbal protocols, activity analysis, operating procedures, emergency procedures, and records of critical incidents. It is rarely a good idea to rely on observing performance as a prime source of task information, especially in tasks involving substantial decision making, since the individual's intentions and information seeking strategies are seldom apparent. Because of the necessity to rely on cooperation of operating personnel, who have other demands on their time, it is useful to agree at the outset with the client how much time is likely to be required to ensure that such cooperation will be forthcoming.

TASK STEPS	INPUTS (CUES)	OUTPUTS (ACTIONS)	FEEDBACK	COMMUNICATIONS	TIME CHARACTERISTICS	TASK DEPENDENCIES	SECONDARY DUTIES, DISTRACTIONS	COMMENTS
4 Optimize pressure value (PR5) in column within 1–1.5 atm.	Pressure recorder indicates PR5 > 1.5 atm (No alarm indications)	If PR5 > 1.8 atm increase cooling rate in condenser (4.2) and decrease heating rate in reboiler (4.3) If PR5 < 1.8 atm do 4.2 only (CRO monitors recorders and OSO adjusts valves on site)	Pressure recorder Temperature recorder Condensate level in reflex drum	Radio communications between control room operator (CRO) and outside operator (OSO)	Optimization should start **not later than** 2 min from the initiation of the abnormal event	Fluctuations of temperature will degrade quality of products	CRO busy with other tasks in the control room	CRO can fail to detect PR5 increase OSO can omit to adjust rates of cooling to the required levels Hazards: Danger of explosion due to accumulation of vapors inside column OSO should wear protective clothing

FIGURE 4.3. **Tabular HTA Showing How to Optimize a High Pressure in a Distillation Column**

The advantages and disadvantages of the technique can be summarized as follows:

Advantages of Hierarchical Task Analysis

- HTA is an economical method of gathering and organizing information since the hierarchical description needs only to be developed up to the point where it is needed for the purposes of the analysis.
- The hierarchical structure of HTA enables the analyst to focus on crucial aspects of the task that can have an impact on plant safety.
- When used as an input to design, HTA allows functional objectives to be specified at the higher levels of the analysis prior to final decisions being made about the hardware. This is important when allocating functions between personnel and automatic systems.
- HTA is best developed as a collaboration between the task analyst and people involved in operations. Thus, the analyst develops the description of the task in accordance with the perceptions of line personnel who are responsible for effective operation of the system.
- HTA can be used as a starting point for using various error analysis methods to examine the error potential in the performance of the required operations.
- For application in chemical process quantitative risk analysis (CPQRA), the hierarchical format of HTA enables the analyst to choose the level of event breakdown for which data are likely to be available. This is useful for human reliability quantification (see the discussion in Chapter 5).

Disadvantages

- The analyst needs to develop a measure of skill in order to analyze the task effectively since the technique is not a simple procedure that can be applied immediately. However, the necessary skills can be acquired reasonably quickly through practice.
- In order to analyze complex decision making tasks, HTA must be used in combination with various cognitive models of performance. Also HTA presents some limitations in describing tasks with a significant diagnostic component.
- Because HTA has to be carried out in collaboration with workers, supervisors, and engineers, it entails commitment of time and effort from busy people.

4.3.3.2. *Operator Action Event Trees (OAET)*

Operator action event trees are treelike diagrams that represent the sequence of various decisions and actions that the operating team is expected to perform when confronted with a particular process event. Any omissions of such decisions and actions can also be modeled together with their consequences for plant safety. OAETs are described in Hall et al. (1982) and Kirwan and Ainsworth (1993), and have many similarities with the event trees used for the analysis of hardware reliability.

Figure 4.4 gives an example of an OAET for events that might follow release of gas from a furnace. In this example a gas leak is the initiating event and an explosion is the final hazard. Each task in the sequence is represented by a node in the tree structure. The possible outcomes of the task are depicted as "success" or "failure" paths leading out of the node. This method of task representation does not consider how alternative actions (errors of commission) could give rise to other critical situations. To overcome such problems, separate OAETs must be constructed to model each particular error of commission.

By visual inspection of an OAET it is possible to identify the elements of a process control task which are critical in responding to an initiating event. An important issue in the construction of OAETs is the level of task breakdown. If the overall task is redescribed to very small subtasks it might be difficult to gain insights from the OAET because it can become relatively unwieldy. Hierarchical Task Analysis provides a useful framework for the

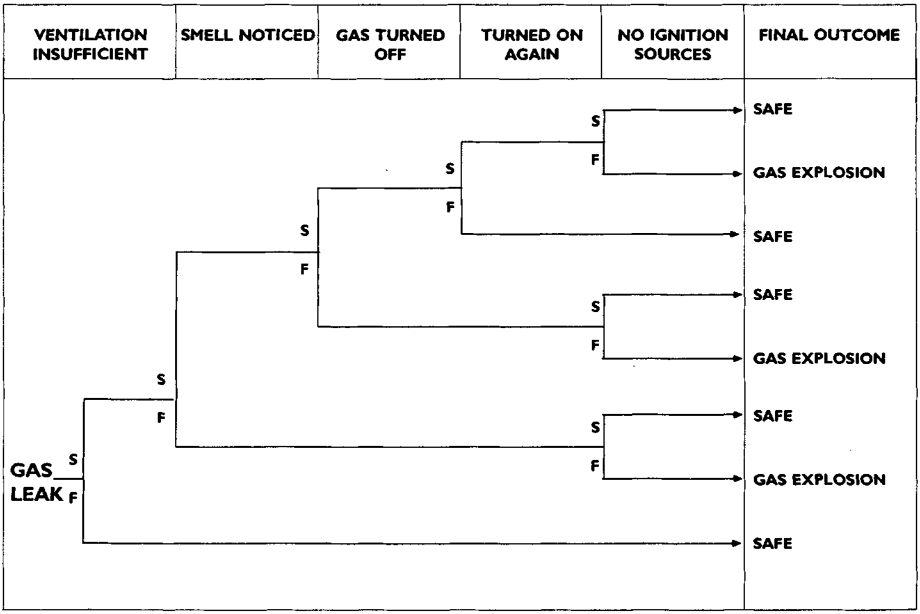

FIGURE 4.4. **Event Tree for a Gas Leak from a Furnace (S=Success; F=Failure).**

identification of required tasks, and also help the analyst clarify the appropriate level of task decomposition.

Care should also be taken in the use of recovery factors, because these can exert a significant effect. In general, recovery paths are appropriate where there is a specific mechanism to aid error recovery, that is an alarm, a supervising check, or a routine walk round inspection.

While OAETs are best used for the qualitative insights that are gained, they can also be used as a basis for the quantitative assessment of human reliability. By assigning error probabilities to each node of the event tree and then multiplying these probabilities, the probability of each event state can be evaluated (see Chapter 5).

The advantages and disadvantages of OAETs are as follows:

Advantages

- The OAET is a logical method of structuring information concerning operator actions resulting from a particular initiating event.
- OAETs help to identify those tasks which are important in responding to particular initiating events.
- OAETs readily interface with system analysis techniques that are commonly used by engineers in CPQRA applications.

Disadvantages

- The approach is not a satisfactory method of identifying mistaken intentions or diagnostic errors.
- OAETs are best suited to represent errors of omission. The important errors of commission (i.e., alternative actions that may be performed) are difficult to include satisfactorily.
- No assistance is provided to guarantee that the data used in the modeling process is complete and accurate. Therefore, the comprehensiveness of the final OAET will be a function of experience of the analyst. (This criticism applies to all HRA techniques.)
- The OAET approach does not address error reduction or make any attempt to discover the root causes of the human errors represented.

4.3.3.3. Decision/Action Flow Diagrams

These are flow charts that show the sequence of action steps and questions to be considered in complex tasks that involve decision-making. Decision/action flow diagrams are similar to the flow charts used in computer program development. Both charts are based on binary choice decisions and intervening operations. In general, the binary decision logic in decision/action charts expedites communications through the use of simple conventions and provides for easy translation of decision/action charts into logic flow charts for computerized sections of the system.

Decision/action charts can be learned easily and workers usually find them useful in formulating for the analyst their mental plans which may involve decision-making, time-sharing, or complex conditions and contingencies. Figure 4.5 shows a decision/action chart for a furnace start-up operation. Decision/Action charts have only a single level of task description, and when complex tasks are analyzed the diagrams become unwieldy and difficult to follow. Also, it is possible to lose sight of the main objectives of the task. To this extent, HTA is more appropriate because the task can be represented in varying degrees of detail and the analyst can get a useful overview of the main objectives to be achieved during the performance of the task.

A general problem in task analysis is how to describe tasks that involve diagnosis of system failures. Duncan and Gray (1975) have described diagnostic tasks in terms of decision trees that guide personnel through a number of checks to various system failures. Decision trees are very much like decision/action charts. Figure 4.6 shows a decision/action chart for diagnosing faults in a crude distillation unit.

Although little training is required to learn the technique, decision/action charts should be verified by different operators to ensure that a representative view of the decision task is obtained. The advantages and disadvantages of the technique are summarized as follows:

Advantages

- Decision/action charts can be used to represent tasks that involve decision-making, time-sharing, or complex conditions and contingencies.
- Workers find it easy to express their work methods in terms of flow diagrams. This representation can then provide input to other task analysis methods.
- They can be used to identify critical checks that the workers have to carry out to complete a process control task.
- For fault-diagnostic tasks, they can help the analyst to identify whether new staff members make effective use of plant information.

Disadvantages

- Decision/action charts are linear descriptions of the task and provide no information on the hierarchy of goals and objectives that the worker is trying to achieve.
- For complex tasks, the diagrams can become unwieldy.
- They offer no guidance concerning whether or not a particular operation or decision should be redescribed in more detail.

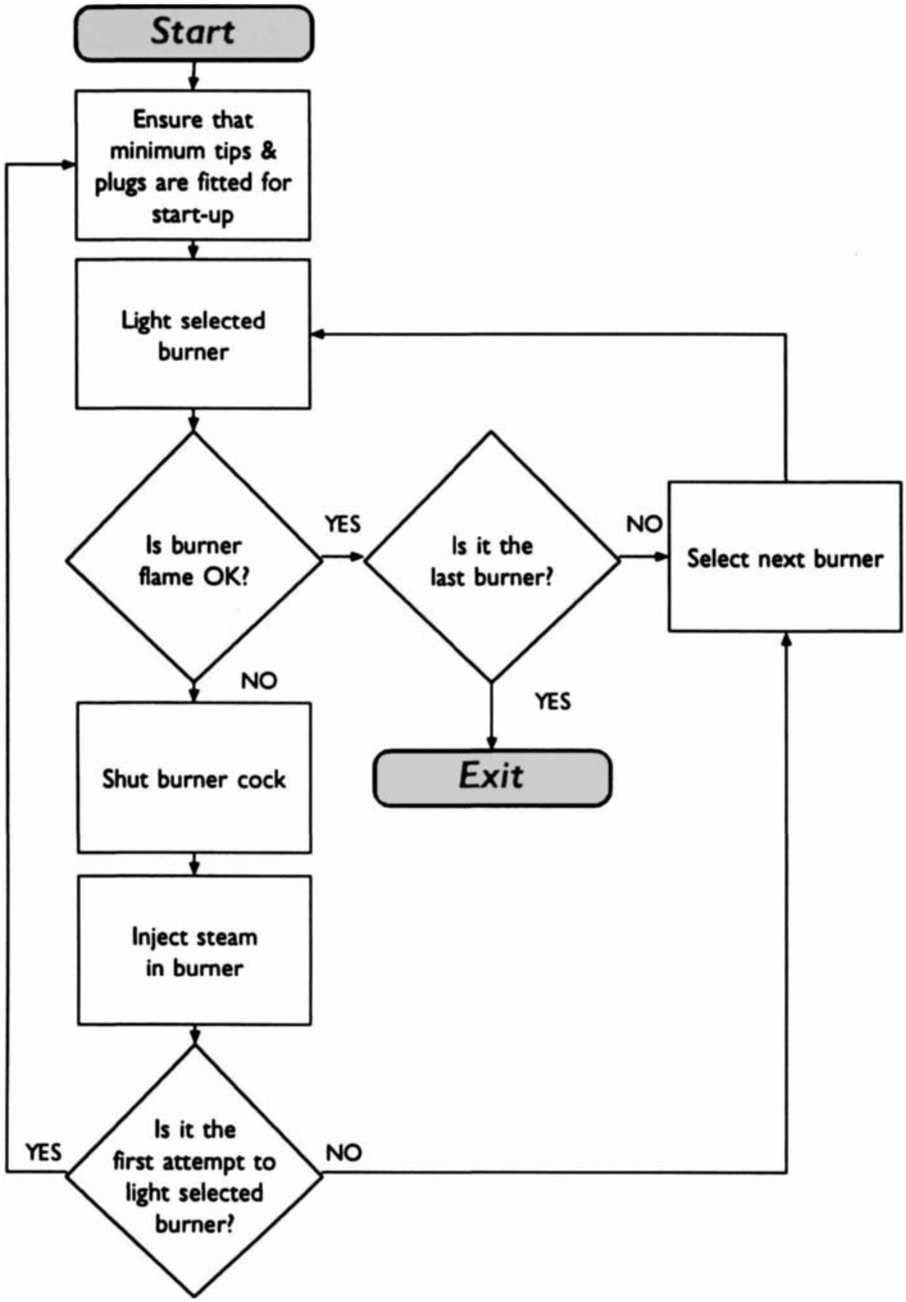

FIGURE 4.5. **Decision/Action Flow Diagram of a Furnace Start-Up Operation.**

4.3.3.4. Operational Sequence Diagrams (OSDs)

Operational sequence diagrams are flow-charting techniques that represent any sequence of control movements and information collection activities that are executed in order to perform a task. Various activities in the diagram are represented with a symbolic notation, supported where necessary by a text description. For the majority of simple applications, OSDs assume a linear flow drawn from top to bottom with a limited degree of branching and looping. The symbols used are usually tailored to fit the type of task being studied and its level of analysis.

The three significant OSD attributes are its sequential flow, its classification of activity type, and its ability to describe interactions between people and machines. In these respects, OSDs are similar to the Decision/Action charts, but more complex. The OSD can be seen as a static simulation of the system operations. This is also the reason why OSDs can become tedious to develop in the analysis of complex systems.

Operational sequence diagrams provide a versatile method representing the timing relationships among operations, functional requirements of human–machine interfaces, and spatial relationships among items of equipment on which operations are performed. Depending on the characteristics of the task being studied, the analyst can use one of the three OSD derivatives, namely temporal OSDs, partitioned OSDs, spatial OSDs, or a combination of these. Tasks with a high cognitive component produce particular problems of classification and identification of discrete operations. Such cognitive tasks will generally not allow the production of OSDs. Also complex tasks can cause problems, as is the case with most graphical methods of representation, because operational sequences very soon become incomprehensible, particularly if they are not highly linear.

The type of OSDs to be used depends on the data to be represented. The three main forms of OSDs will be considered in more detail below.

Temporal OSDs

These diagrams focus on the temporal or time relationships of operations and they can be used to solve resource allocation problems, to determine whether there is any potential for time stress, and to consider alternative work methods in the execution of a procedure. An example drawn from traditional industrial engineering methods is shown in Figure 4.7. The chart is used to analyze the interaction between people and equipment. As indicated in the summary portion of this chart, there is a high proportion of idle time which would probably indicate the use of alternative procedures in the execution of this task. The chart enables the analyst to see the relationships among the activities of the different components in planning such alternatives.

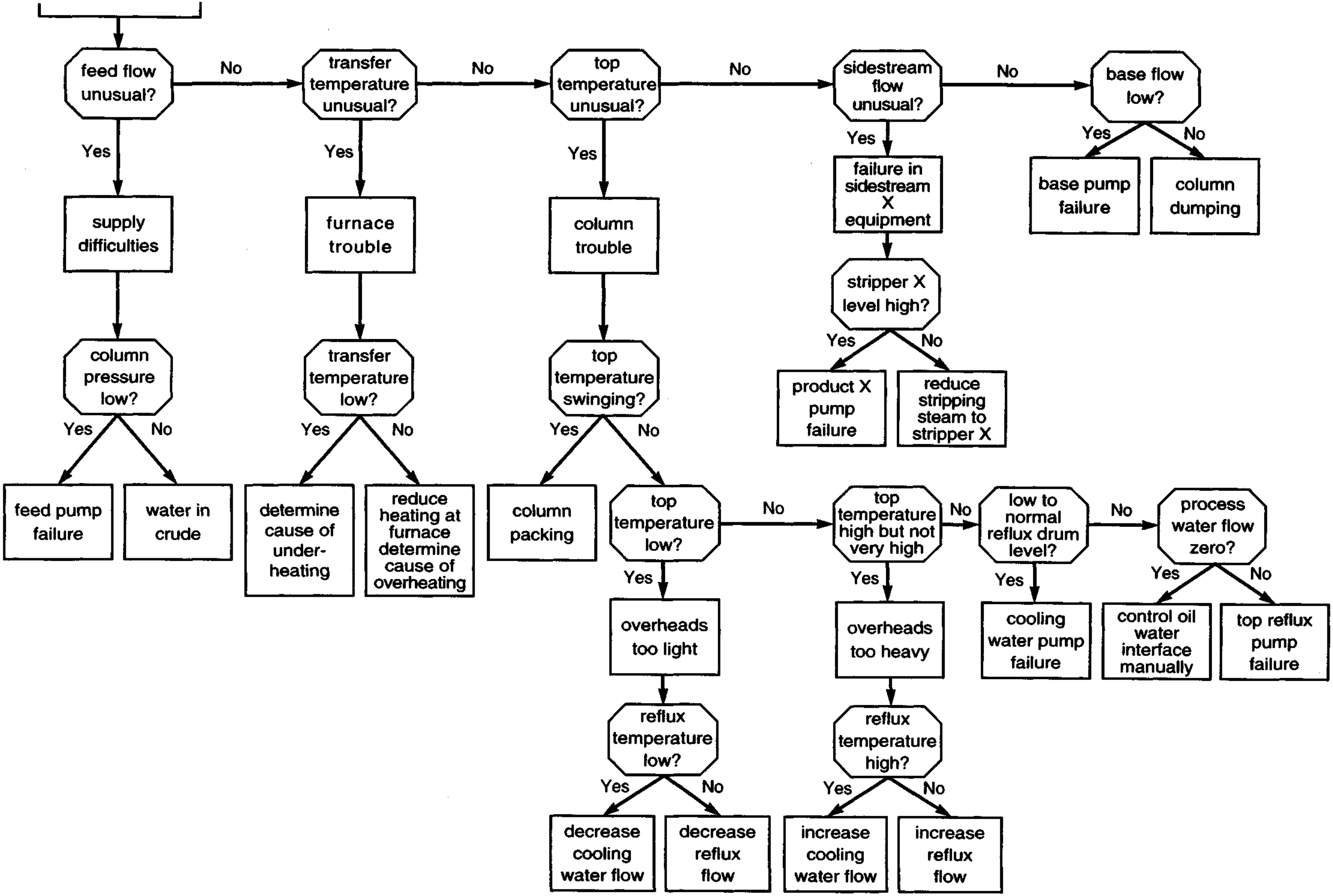

FIGURE 4.6. **Decision/Action Diagram for Fault Diagnosis in a Crude Distillation Plant (Duncan and Gray, 1975).**

OPERATION: Slitting Coated Fabric	OP. NO. S46
PART NAME: Coated Fabric	PART NO. F261
MACHINE NAME: Slitting Machine (Special)	MACH.NO. S431
OPERATOR NAME: J. S. Wilson S. K. Smith (Helper)	DATE:
OLD METHOD: ☒ IMPROVED METHOD: ☐	CHART BY: J. S. K.

<table>
<tr><th>Operator</th><th>Time*</th><th>Helper</th><th>Time*</th><th>Help</th><th>Time*</th></tr>
<tr><td rowspan="2">Run Machine</td><td rowspan="2">2.2 ▨</td><td>Prepare wrappers and labels</td><td>.9 ▨</td><td rowspan="2">Slit stock</td><td rowspan="2">2.2 ▨</td></tr>
<tr><td>Wait for machine</td><td>1.3 ■</td></tr>
<tr><td>Wait for helper</td><td>.7 ■</td><td rowspan="2">Wrap rolls</td><td rowspan="2">.9 ▨</td><td rowspan="6">Idle</td><td rowspan="6">3.0 ■</td></tr>
<tr><td rowspan="2">Label rolls</td><td rowspan="2">.6 ▨</td></tr>
<tr><td rowspan="2">Wait for operator</td><td rowspan="2">.7 ■</td></tr>
<tr><td>Open winder</td><td>.3 ▨</td></tr>
<tr><td>Wait for helper</td><td>.8 ■</td><td>Remove rolls</td><td>.8 ▨</td></tr>
<tr><td>Start machine</td><td>.6 ▨</td><td>Place on skid</td><td>.6 ▨</td></tr>
</table>

*Time in minutes

Summary			
	Operator	**Helper**	**Machine**
Idle Time	1.5 min	2.0 min	3.0 min
Working time	3.7	3.2	2.2
Total cycle time	5.2	5.2	5.2
Utilzation in per-cent	Operator utilization = $\frac{3.7}{5.2} = 71\%$	Helper utilization = $\frac{3.2}{5.2} = 62\%$	Machine utilization = $\frac{2.2}{5.2} = 42\%$

FIGURE 4.7. **Temporal Operational Sequence Diagram in a Slitting Coated Fabric Operation (from Barnes, 1980).**

Partitioned OSDs

In this case, the operations within a sequence are further defined according to various criteria such as whether they involve reception or transition of information, storage of information, manual control responses, inspections, and decisions. However, some other dimensions of an operation may require particular emphasis such as whether information is transmitted electronically, by external communication etc. A type of vertical axis can still be used to represent sequential order and if required this can incorporate the same timing information as temporal OSDs.

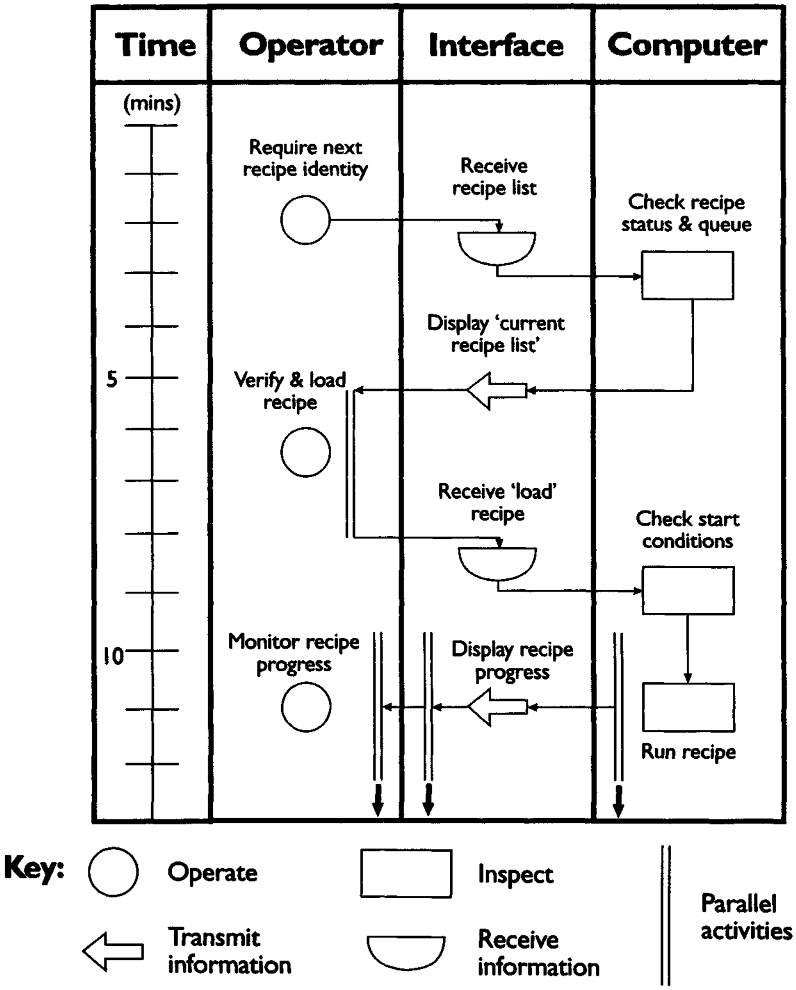

FIGURE 4.8. **Partitioned Operational Sequence Diagram for Loading a Recipe to a Computer Controlled Reactor (adapted from Kirwan and Ainsworth, 1993).**

Figure 4.8 shows a specific example of this type of diagram which includes some symbols. The diagram shows the tasks that the operator and the computer must perform in a computer controlled reactor. The central column is used to show any functional requirements of the human–computer interface.

Spatial OSDs

In spatial OSDs the flow of events and symbols is overlaid on a map of all items of equipment with which the operator interacts during the task. The map itself does not have to be very accurate, provided that the general geographical relationships among items of equipment are shown. The spatial OSD thus provides a graphical description of the perceptual–motor load a particular task imposes on the performance of the worker. For multiperson tasks, the operational sequences for several workers can be coded in different colors and superimposed onto the same equipment map. This can generate useful information for the distribution of tasks to different members of the operating team.

In summary, OSDs have the following advantages and disadvantages:

Advantages

- Operational sequence diagrams are very useful to show temporal, spatial, and even conceptual relationships among operations that are difficult to show by textual or tabular representations.
- To some extent, more than one type of relationships can be shown but this can give rise to excessive complexity.
- They can be used for solving resource allocation problems, looking at aspects of time-stress, and designing the human computer interface.

Disadvantages

- Operational sequence diagrams can become cluttered and confusing when used for complex or highly conditional tasks. It is particularly important that the analyst is working to the level of detail that is most appropriate.
- Spatial OSDs can also become very difficult to read if individual pieces of equipment are used many times.
- Operational sequence diagrams cannot represent highly cognitive tasks because it is difficult to assign cognitive components to discrete symbols.
- Although OSDs can be used to optimize general operator performance, they are limited to the extent that they can identify human errors.

4.3.3.5. *Signal-Flow Graph Analysis*

This technique is derived from a method developed by electrical engineers to facilitate the analysis of electrical networks. It has been applied to process operator studies by Beishon (1967). The method describes the process to be controlled in terms of "manually controlled" variables, "displayed" variables and "hidden" variables which can be deduced from those displayed or from calculations. By tracing the signal-flow graph (SFG) from the "controlled" to the "displayed" variables, it is possible to identify the control loops available to the worker and the types of deductions required to understand and control the system. SFG analysis is a method that represents "how the system works" rather than "how the worker should perform the task."

Signal-flow graphs are particularly useful in two respects. First, they make the process designer examine in considerable detail the dynamic structure and functioning of the process. Second, the nature of the interface between person and machine can be seen more clearly. The variables that are displayed in a system are, of course, available for study, but workers frequently respond to derivative functions of variables or "hidden" variables that must be deduced. Given that the process variables to be displayed will influence the worker's control strategy and that the number of deductions to be made will affect the mental workload involved, a process designer can select the type and amount of process information which will enhance performance of the task.

A study of paper making carried out by Beishon (1969) illustrates the part an SFG can play in the design of control panel information and specification of control strategies. The top part of Figure 4.9 shows a continuous paper making machine controlled by a worker. The paper is formed from a liquid containing fibers, the stock, which is spread out onto an endless belt of wire mesh. The water drains or is sucked through the mesh, leaving a sheet of paper that can be lifted on to endless belts of felt for pressing and drying. Part of the worker's job is to produce paper of different weights, or "substance values." In order to understand the complex factors that determine the important time relations in the process, a fairly complete SFG was drawn (see bottom part of Figure 4.9). The SFG was used to select appropriate process variables to be displayed to the worker to assist in improving his performance.

Signal-flow graphs are useful in another sense; they provide an objective representation of "how the system works" which can be used to evaluate the worker's subjective mental representation of the system. The influence modeling and assessment (IMAS) technique, which is described in subsequent sections, can also be used to elicit the worker's representation of the system. Both techniques, IMAS and SFG, can therefore be used for training personnel.

Advantages

- The SFG is a useful technique to represent the process variables that affect system performance.
- They can be used for designing the human–machine interface.
- They provide useful data for evaluating the worker's understanding of how the system functions.

Disadvantages

- Signal-flow graphs cannot explicitly identify the error potential for particular action steps.

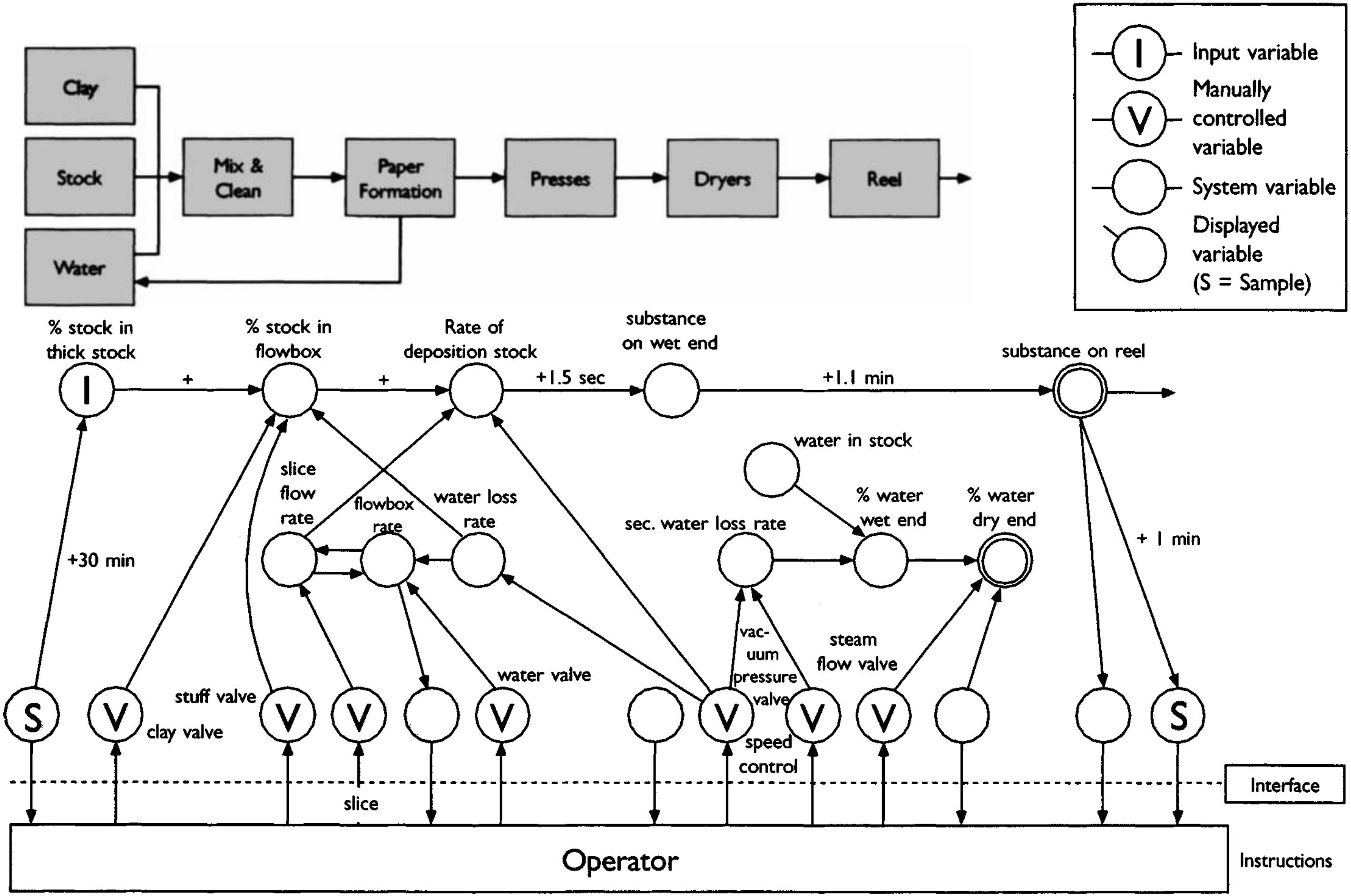

FIGURE 4.9. **Block Diagram and Signal-Flow Graph for "Substance" Control System in Paper-Making (from Beishon, 1969).**

- Signal-flow graphs do not provide a complete description of the process in a control task. The process may go through a sequence of stages, in which different variables are being altered, so that different control loops are important. The control task in such a sequence of stages can best be described by a sequence of SFGs, each of which shows the subset of process variables that are important at a particular stage.
- For a complete description of the task it is also necessary to specify the targets and tolerances to which the process should be controlled.

4.3.4. Cognitive Task Analysis Techniques

The task analysis techniques described in the previous section are mainly oriented toward observable actions, although hierarchical task analysis (HTA) allows it to address functional requirements as well as the specific actions that are required to satisfy these requirements.

Cognitive task analysis techniques attempt to address the underlying mental processes that give rise to errors rather than the purely surface forms of the errors. This is particularly important where the analysis is concerned with those aspects of process plant operation that require higher level mental functions such as diagnosis and problem solving. As plants become more automated, the job of the process plant worker is increasingly concerned with these functions and it is therefore necessary to develop analytical methods that can address these aspects of plant control. For example, the worker is often required to deal with abnormal plant states that have not been anticipated by the designer. In the worst case, the worker may be required to diagnose the nature of a problem under considerable time stress and develop a strategy to handle the situation. It is clearly desirable in these situations to provide appropriate decision support systems and training to improve the likelihood of successful intervention. It is also necessary to be able to predict the types of decision errors that are likely to occur, in order to assess the consequences of these failures for the safety of the plant. In all of these areas, task analysis techniques that address the covert thinking processes, as opposed to observable actions, are necessary.

The problems associated with the analysis of cognitive processes are much greater than with action oriented task analysis methods. The causes of "cognitive errors" are less well understood than action errors, and there is obviously very little observable activity involved in decision making or problem solving. These difficulties have meant that very few formal methods of cognitive task analysis are available, although several researchers have developed specialized methods when studying process control skills (see, e.g., Bainbridge, 1974).

Despite these difficulties, the issue of cognitive errors is sufficiently important that we will describe some of the approaches that have been applied to process industry systems. These techniques can be used in both proactive and retrospective modes, to predict possible cognitive errors (i.e., "mistakes" as opposed to "slips" using the terminology of Chapter 2) during predictive risk assessments, or as part of an incident investigation.

4.3.4.1. Critical Action and Decision Evaluation Technique (CADET)

This method is based on the Rasmussen stepladder model described in Chapter 2. It was first described in Embrey (1986). The basic units of CADET are the critical actions or decisions (CADs) that need to be made by the operator usually in response to some developing abnormal state of the plant. A CAD is defined in terms of its consequences. If a CAD fails, it will have a significant effect on safety, production or availability.

The following approach is then used to analyze each CAD. The first stage consists of identifying the CADs in the context of significant changes of state in the system being analyzed. The approach differs from the OAET (Section 4.3.3.2) in that it does not confine itself to the required **actions** in response to critical system states, but is also concerned with the decision making that precedes these actions. Having identified the CADs that are likely to be associated with the situation being analyzed, each CAD is then considered from the point of view of its constituent decision/action elements. These are derived from the Rasmussen stepladder model discussed in Chapter 2 and reproduced in linear form in Figure 4.10. The potential failures that can occur at each of these elements are then identified.

To illustrate how CADET can be applied to decision analysis Figure 4.11 describes a hypothetical example an experienced worker who has to diagnose a plant failure (e.g., top reflux pump failure in a distillation column). A column is created for each decision/action element of the Rasmussen decision ladder to allow an extensive description of how the worker processes diagnostic information and eliminates an initial set of possible equipment failures to arrive at the actual problem. CADET presents the analyst with a structured list of questions about potential diagnostic errors. The protocol in Figure 4.11 shows a good diagnostic strategy in which the worker is looking initially for spurious indications before drawing any conclusions about the state of process equipment. CADET can be used both to evaluate and to support human performance in terms of training exercises.

Lucas and Embrey (1987) further extended the CADET concept as a practical analysis tool by developing a structured questionnaire for use by an analyst when interacting with plant personnel. For each CAD the analyst is prompted to consider a possible failure at each of the stages in the Rasmussen model described in Figure 4.10.

The CADET technique can be applied both proactively and retrospectively. In its proactive mode, it can be used to identify potential cognitive errors, which can then be factored into CPQRA analyzes to help generate failure scenarios arising from mistakes as well as slips. As discussed in Chapter

DECISION/ACTION ELEMENT	OBJECTIVE	TYPICAL ERROR PATTERNS
Initial Alert	Alerting/Signal Detection of initial stages of problem	Distraction/Absent-Mindedness/Low Alertness
Observation	Observation/Data Collection from instruments	Unjustified Assumptions/Familiar Associations
Identification	Identify System State	Information Overload Time Delay
Interpretation	Interpret what has happened and its implications	Failure to Consider Alternative Causes/ Fixation on the Wrong Cause
Evaluation	Evaluation and Selection of Alternative Goals	Failure to Consider Side Effects/ Focusing on Main Event
Planning	Plan success path	Wrong Task May be Selected due to Shortcuts in Reasoning and Stereotyped Response to Familiar State
Procedure Selection/ Formulation	Choosing or formulating a procedure to achieve required objective	Procedural Steps Omitted/Reversed (Particularly if "Isolated")
Execution	Executing chosen procedure	Reversals of Direction or Sign (Up/Down Left/Right) when carrying out action. Habit Intrusion
Feedback	Observe change of state of system to indicate correct outcome of actions	Feedback ignored or misinterpreted

FIGURE 4.10. **Decision/Action Elements of the Rasmussen Model (Embrey, 1986).**

2, errors arising from misdiagnosis can be particularly serious, in that they are unlikely to be recovered. They also have the potential to give rise to unplanned operator interventions based on a misunderstanding of the situation. These error modes need to be explicitly identified by CPQRA analysts. Another proactive use of CADET is in the development of error reduction strategies based on the possible error root causes identified by the questionnaire. The technique can also be applied retrospectively to identify any cognitive errors implicated in accidents.

Pew et al. (1981), developed a series of "Murphy diagrams" (named after the well-known Murphy's Law: *If something can go wrong, it will*). Each decision element in the Rasmussen model has an associated Murphy diagram, which specifies possible direct "proximal") causes of the internal malfunction. Each of these causes are then considered in terms of indirect "distal") causes which could influence or give rise to the primary cause. A Murphy diagram for the

TIME	SIGNAL DETECTION	DATA COLLECTION	IDENTIFICATION	INTERPRETATION	GOAL SELECTION	CADET ANALYSIS
t_1	Column temperature alarm		Not a complete indication at this stage. It may be a spurious alarm	Cross-examine related indicators		**Data collection:** Can operator acquire irrelevant or insufficient data? Can operator fail to cross-check for spurious indications? **Identification/Interpretation:** Can operator fail to consider all possible system states and causes of problem? Can operator fail to perform a correct evaluation? Can operator fixate on the wrong cause? **Goal Selection:** Can operator fail to consider possible side-effects? Can operator fail to consider alternative goals? Can operator fixate on the wrong goal?
t_2		TR14 = High (new) TR15 = Very High (check)	Inadequate cooling of column or thermal conditions of input are disturbed	Distinguish between the two. Examine flow rate and temperature of input		
t_3		FI1 = Normal (new) FR15 = Normal (check) TRC8 = Normal (new)	Conditions are as specified. It must be inadequate cooling of column	Possible causes: • Cooling water pump failure • Top reflux pump failure		
t_4		LIC3 = High (new) Drum sight glass = High (check)	Conditions are as specified. It must be inadequate cooling of column	Level in drumis high, thus condensation is OK. It must be failure of the top reflux pump		
t_5		FIC8 = No Flow (new)	Conditions are as specified. It must be inadequate cooling of column	Top reflux pump failure (confirmed)	**Alternative goals:** • Reduce heating in reboiler • Reduce flow rate of input • Increase cooling in condenser	

TR14, TR15 = Column Temperature; LIC3 = Level in Reflux Drum; FIC8 = Reflux Flow; FI1, FR15 = Crude Flow at Entry Point; TRC8 = Crude Temperature at Entry Point.

FIGURE 4.11. **CADET analysis of a fault-diagnostic task in an oil refinery.**

decision element "Plan Success Path" is given in Figure 4.12. The Murphy diagram can be of considerable value to the analyst because it suggests specific causes of errors which will be amenable to design solutions. Only a relatively small number of decision elements will be associated with each CAD in most cases, which means that the process of analysis is reasonably manageable.

4.3.4.2. The Influence Modeling and Assessment Systems (IMAS)

Reference has already been made to the difficulty of accessing the mental processes involved in diagnosis and decision making. Success in these activities is likely to be dependent on the worker having a correct understanding of the dynamics of what is likely to happen as an abnormal situation develops. This is sometimes referred to as the worker's "mental model" of the situation (see Chapter 2 for a further discussion of this topic). Diagnosis in the event of a plant emergency does not depend only on the absolute values of variables (e.g., flow rates) but also relies upon the changes in these indicators over time. Knowledge of the mental model possessed by the operator can be extremely useful in predicting possible diagnostic failures.

The IMAS technique was originally developed as an on-line decision support system to assist personnel in making diagnoses during plant emergencies (see Embrey and Humphreys, 1985; Embrey, 1985). The technique is used to elicit the mental models of process abnormalities from personnel. These are in the form of graphical representations of the perceptions of the operating team regarding:

- The various alternative causes that could have given rise to the disturbance
- The various consequences that could arise from the situation
- Indications such as VDU displays, meters, and chart recorders available in the control room or on the plant that are associated with the various causes and consequences

A specific example of the representation of the mental model derived by this approach is given in Figure 4.13. This was developed for a process plant in which powders are transferred by a rotary valve to a slurry mix vessel. Because of the flammable nature of the powders, they are covered with a blanket of nitrogen. Any ingress of air into the system can give rise to a potential fire hazard, and hence an oxygen analyzer is connected to the alarm system. Because the system can only be entered wearing breathing apparatus, it is monitored via closed circuit television (CCTV) cameras. The situation under consideration occurs when there is a failure to transfer powder and the model represents the various causes of this situation and some of the possible consequences. Any node in the network can be either a cause or a consequence, depending on where it occurs in the causal chain. It can be seen that the various indicators (given in square boxes) are associated with some of the events that could occur in the situation.

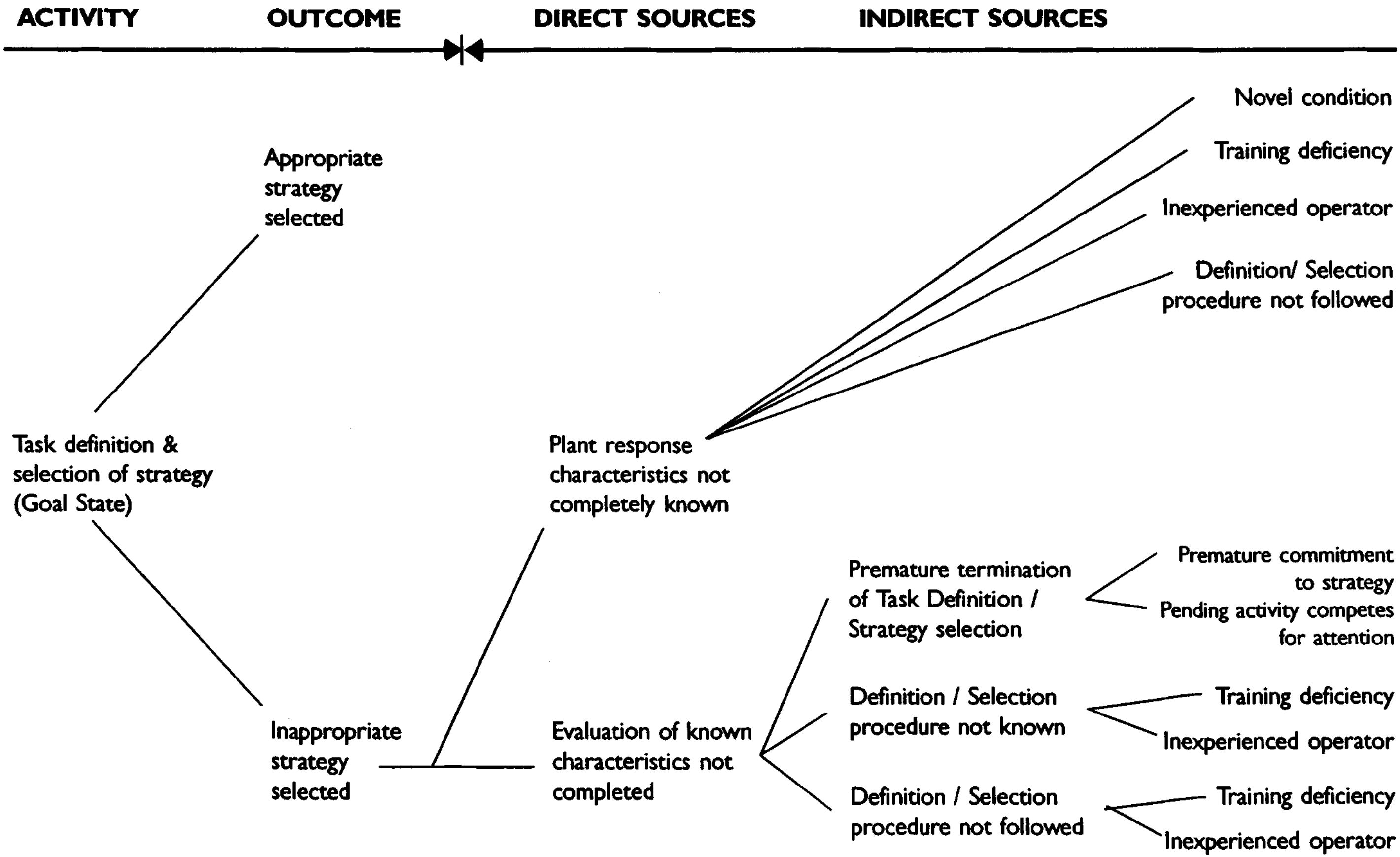

FIGURE 4.12. **Murphy Diagram for "Planning" Element of Rasmussen Model (Pew et al., 1981; see Figure 4.10).**

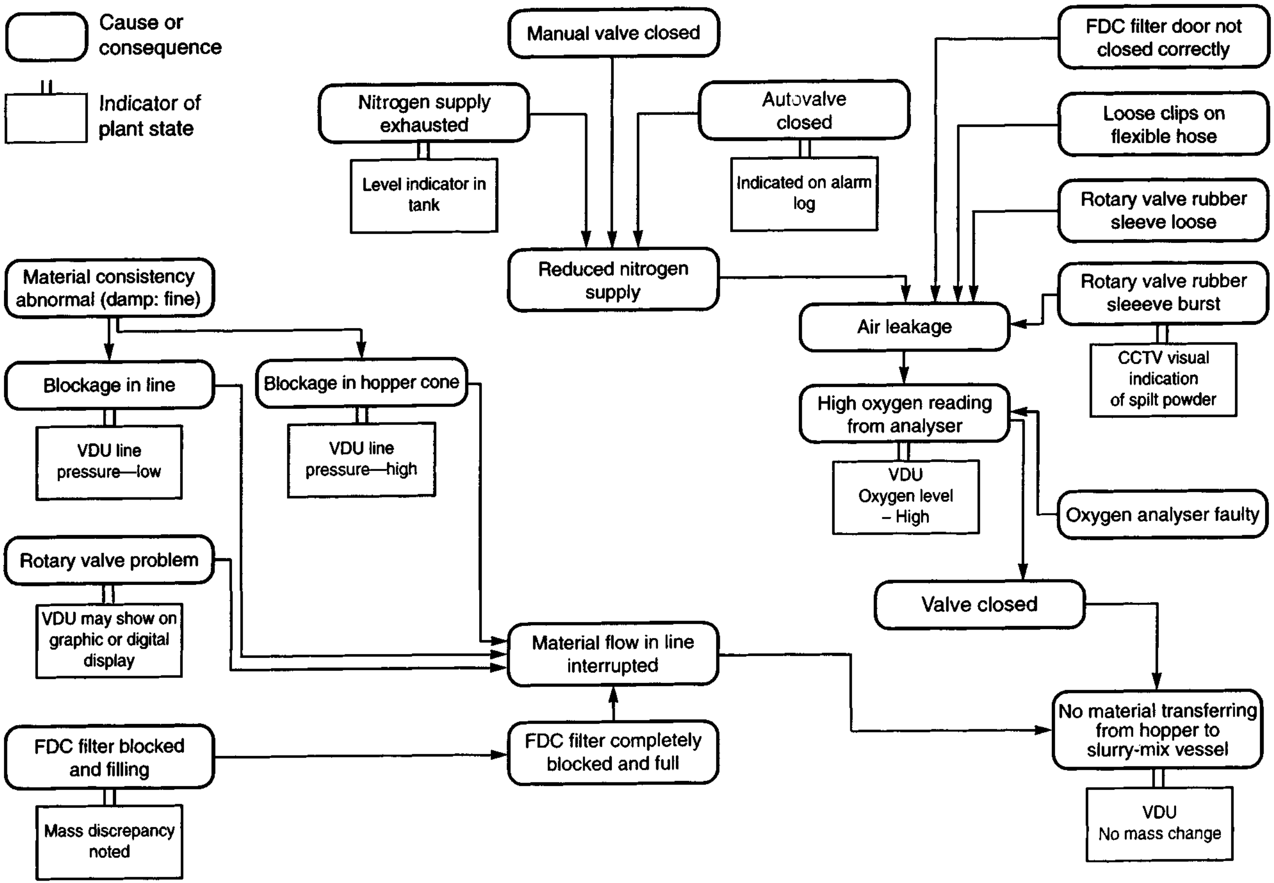

FIGURE 4.13. **Example of a Mental Model Elicited by IMAS (Embrey, 1985).**

The model may be developed using the expertise of an individual or several workers in a team. The process of eliciting the model can be performed by hand or with the aid of a computer program called LINKCC (Embrey and Humphreys 1985). In developing the mental model, the analyst begins at a specific point in a process disturbance (e.g., an increase of pressure in a line), and asks the worker what the event **stems from, leads to,** or is **indicated by.** Repeated applications of these questions produce a network representation of the "group model" of the operating team or the individual process worker. As can be seen from Figure 4.13, an event can stem from more than one alternative cause, and lead to more than one outcome. The task of the worker is to identify which of the alternative causes gave rise to the pattern of observed indicators.

It is important to note that the mental model representation elicited by this technique is not a process engineering model, but instead represents the process workers' understanding of the various causes and consequences of the disturbance. This may or may not be in accordance with the actual chemistry or dynamics of the physical process.

Application of IMAS

The mental model representation elicited by LINKCC can be used for a variety of purposes:

- *Evaluation of the Accuracy of the Mental Model of an Operator during Training*

One of the major problems in training personnel to acquire diagnostic skills is the difficulty of knowing whether or not their understanding of process disturbances is sufficiently comprehensive in terms of alternative causes and possible consequences. Elicitation of the mental model at various stages of training enables the trainer to evaluate the development and accuracy of the workers' understanding of a range of process disturbances. A set of representations of the mental models developed using experienced operational teams can be used as standards to define the knowledge requirements to handle critical plant disturbances. Comparison of the trainees' mental models with these representations will indicate where further training is required.

- *Information Requirements for Diagnosis*

Since the mental model elicited by IMAS explicitly identifies the information needed to identify the causes of disturbances (and to distinguish among alternative causes), it can be used to specify the critical variables that need to be readily available to the process controller at the interface. This information can be used as an input to the design and upgrading of interfaces, particularly when new technology is being installed.

- *Modeling of Cognitive Errors for CPQRA*

The traditional approach to CPQRA only considers human failures to perform required functions (usually errors of omission). However, many critical errors arise from misdiagnoses (mistakes) leading to erroneous, inappropriate actions which can have serious consequences for the plant. IMAS can be used to predict possible diagnostic errors by examining the model elicited from the worker and identifying the Performance Influence Factors (e.g., inadequate display of critical process information) that could give rise to misdiagnoses (e.g., where different plant abnormalities could exhibit similar symptoms).

- *Simulation of the Thinking Processes of the Operator during Plant Emergencies*

IMAS has a facility called EXPLORE allows the analyst to specify which indicators (e.g., temperatures, pressures, valve settings) are present, and which are absent in a particular scenario. EXPLORE then traverses the various links in the mental model representation network and generates a report that simulates the worker's thinking processes. This form of simulation provides useful information to the analyst with regard to the worker's capability to achieve correct diagnoses. Embrey (1985) gives an example of these simulations for the mental model in Figure 4.13.

The IMAS technique described above is useful, in that it addresses aspects of operational skills, that is, diagnostic and problem solving abilities, that are not covered by other techniques. To that extent it can be regarded as a method of cognitive task analysis. It is not essential to use a computer program to obtain useful results. The mental models produced by IMAS can be elicited by pencil and paper methods. Nevertheless interpretation and application of the results require some expertise.

4.3.5. Evaluation of Task Analysis Methods

The TA methods described so far can be evaluated in terms of their focus on different aspects of the human–machine interaction. To facilitate the process of selection of appropriate TA methods for particular applications. Figure 4.14 describes ten criteria for evaluation. These criteria are in terms of the usability of the methods for the following applications :

1. Analyzing actions
2. Analyzing cognitive behavior
3. Identification of critical decisions
4. Description of critical control panel information
5. Description of time related aspects of tasks
6. Identification of side-effects of errors
7. Identification of human–computer interactions
8. Description of team communications
9. Classification of task types
10. Description of the technical system

METHOD EVALUATION	HTA	OAET	DA CHARTS	OSD	SFGS	CADET	IMAS
1 Does the method focus on the observable aspects of operator behavior?	Y	Y	Y	Y	Y	N	N
2 Does the method focus on the mental processes that underlay behavior?	N	N	N	N	N	Y	Y
3 Can the method identify points where critical decisions have to be made?	Y	Y	Y	N	N	Y	Y
4 Can the method identify important information on the control panel?	Y	N	Y	P	Y	Y	Y
5 Does the method describe the temporal characteristics of the task?	P	N	P	Y	N	N	N
6 Can the method identify interactions between task-steps, and possible side effects?	Y	N	Y	N	N	Y	Y
7 Does the method describe the interactions between people and control systems?	Y	P	N	Y	Y	P	P
8 Does the method describe the communication requirements among team members?	Y	N	N	Y	N	N	N
9 Does the method classify tasks into different categories?	N	N	N	P	N	Y	N
10 Does the method provide a qualitative description of the technical system?	N	N	N	N	Y	N	N

P = Criterion is only partially fulfilled

FIGURE 4.14. **Criteria for Evaluating the Suitability ofVarious T.A. Methods**

In general, HTA, IMAS, and CADET fulfill most of the above criteria, hence they can be used together as a framework for carrying out both action and cognitive task analysis. When particular aspects of the human–machine interaction must be examined in greater detail; for example, the temporal characteristics of the task or the team communications, certain methods can be selected to provide this information—OSDs in this case. Most TA methods 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**

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