

# TASK ANALYSIS TECHNIQUES

David Embrey PhD  
Managing Director  
Human Reliability Associates Ltd

## 1. Introduction

Task analysis is a fundamental methodology in the assessment and reduction of human error. A wide variety of different task analysis methods exist, and it would be impracticable to describe all these techniques here. Instead, the intention is to describe representative methodologies applicable to different types of task.

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 which underlie observable behavior, e.g. decision making and problem solving. These will be referred to as **cognitive approaches**.

TA methods can be used to eliminate the preconditions that give rise to errors before they occur. They can be used as an aid in the design stage of a new system, or the modification of an existing system. They can also be used as part of an audit of an existing system.

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.

## 2. Action Oriented Techniques

### 2.1 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 sub-tasks 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.

Hierarchical Task Analysis commences by stating the overall objective that the person has to achieve. This is then redescribed into a set of sub-operations 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 sub-operation can be redescribed further if the analyst requires, again in terms of other operations and plans. Figure 1.1 shows an example HTA for the task of isolating a level transmitter for maintenance.

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.

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. Unfortunately, until the analyst has broken down the operation further, it is difficult to envision how a sub-operation 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 (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, e.g. 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.

### ***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 which 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.

### ***Disadvantages of Hierarchical Task Analysis***

- 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.
- Because HTA has to be carried out in collaboration with workers, supervisors and engineers, it entails commitment of time and effort from busy people

SEE LECTURE NOTES AND HANDOUTS FOR EXAMPLES

## 2.2 Operator Action Event Trees (OAET)

OAETs are tree-like diagrams which 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.

Figure 1.3 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 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 sub-tasks it might be difficult to gain insights from the OAET because it can become relatively unwieldy.

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 i.e. an alarm, a supervising check, a routine walk round inspection and so on. 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.

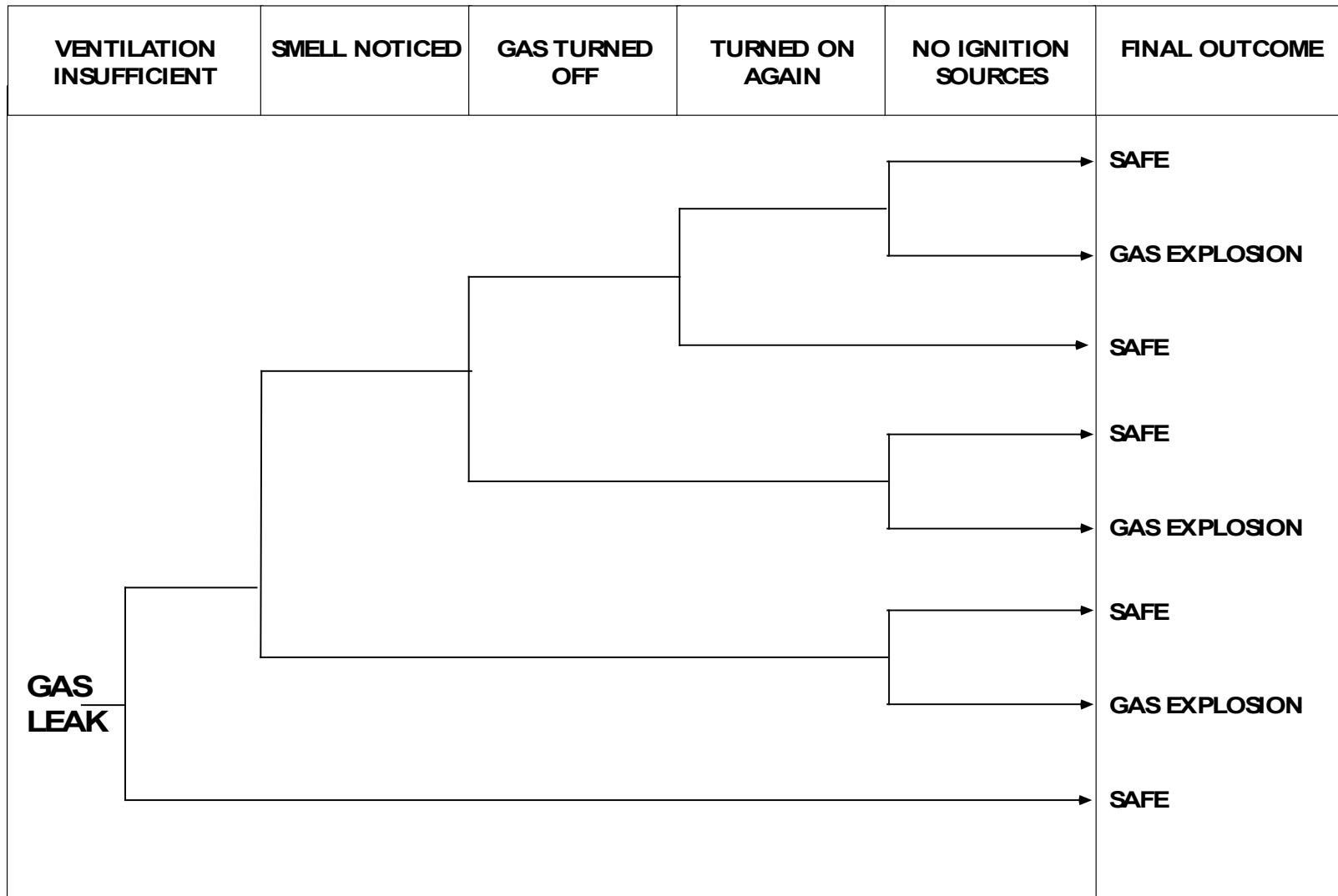
### *Advantages of OAETs*

- 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.

### *Disadvantages of OAETs*

- 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 (ie. alternative actions which 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.



d:\rpt\scops\_ch4.idw p3

Figure 1.3: Event tree for a gas leak from a furnace

## 2.3 Decision/action flow diagrams

These are flow charts which show the sequence of action steps and questions to be considered in complex tasks which 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 1.4 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.

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.

### *Advantages of flow diagrams*

- Decision/Action charts can be used to represent tasks which 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 of flow diagrams*

- 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.

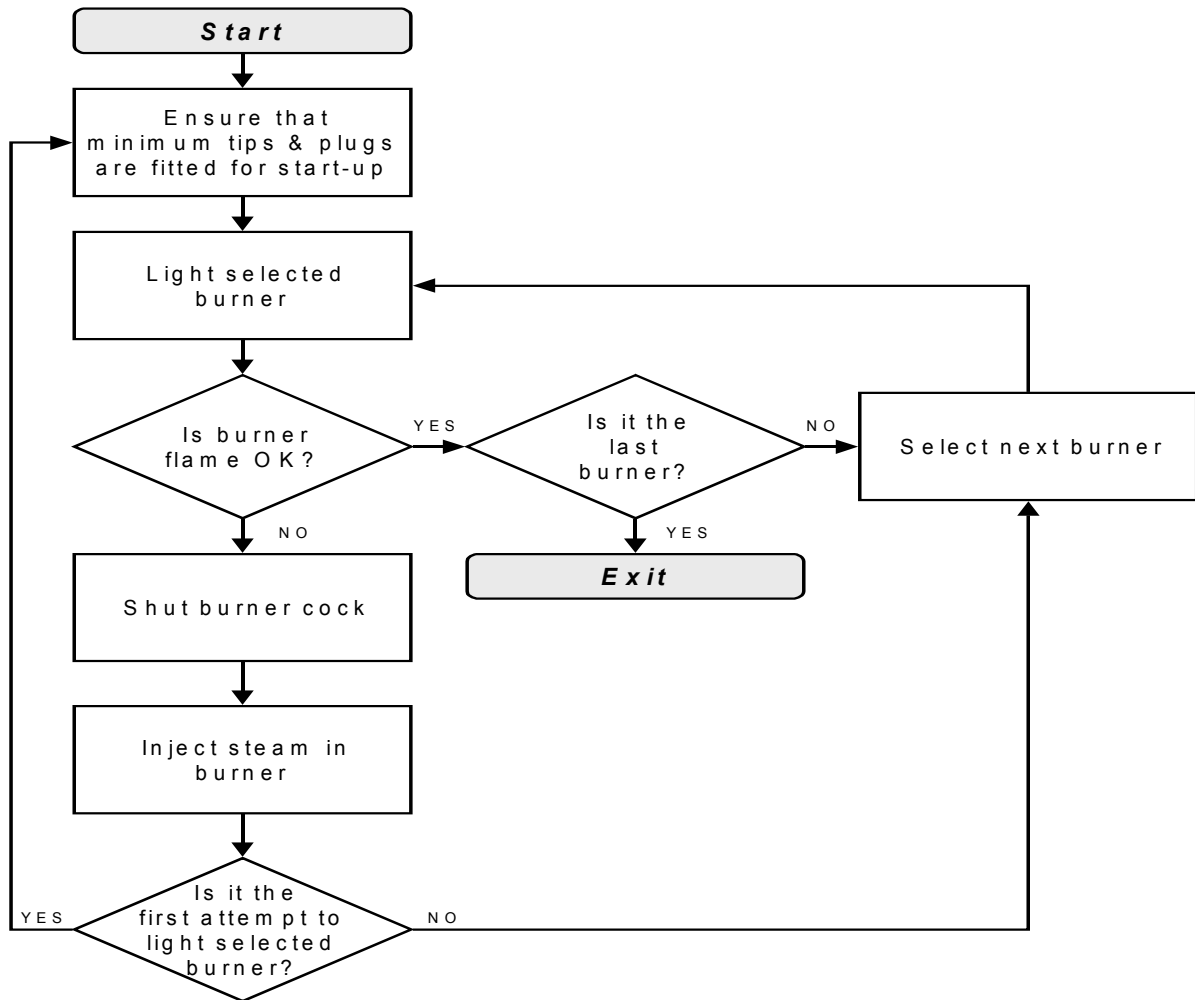


Figure 1.4: Decision / Action Flow Diagram of a Furnace Start-Up Operation

### 3. Cognitive Task Analysis Techniques

The task analysis techniques described in the previous section are mainly oriented towards 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 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 which 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 which 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.

Despite these difficulties, the issue of cognitive errors is sufficiently important that we will describe some of the approaches that have been applied to systems. These techniques can be used in both proactive and retrospective modes, to predict possible cognitive errors during predictive risk assessments, or as part of an incident investigation.

### 3.1 Critical Action and Decision Evaluation Technique (CADET)

This method is based on the Rasmussen step ladder model. 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 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 which 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 Step Ladder model and reproduced in linear form in Figure 1.5. 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 1.6 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 1.5 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.

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 used to help generate failure scenarios arising from mistakes as well as slips. 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. The technique can also be applied retrospectively to identify any cognitive errors implicated in accidents.



<b>Decision/ Action Element</b>	<b>Objective</b>	<b>Typical Error Patterns</b>
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 1.5: Decision/ Action Elements of the Rasmussen Model (Embrey, 1986)**

Time	Signal Detection	Data Collection	Identification	Interpretation	Goal Selection	CADET Analysis
t <sub>1</sub>	Column temperature alarm		Not a complete indication at this stage. It may be a spurious alarm	Cross-examine related indicators		<p><b>Data collection:</b></p> <ul style="list-style-type: none"> <li>Can operator acquire irrelevant or insufficient data?</li> <li>Can operator fail to cross-check for spurious indications?</li> </ul> <p><b>Identification / Interpretation:</b></p> <ul style="list-style-type: none"> <li>Can operator fail to consider all possible system states and causes of problem?</li> <li>Can operator fail to perform a correct evaluation?</li> <li>Can operator fixate on the wrong cause?</li> </ul> <p><b>Goal Selection:</b></p> <ul style="list-style-type: none"> <li>Can operator fail to consider possible side-effects?</li> <li>Can operator fail to consider alternative goals?</li> <li>Can operator fixate on the wrong goal?</li> </ul>
t <sub>2</sub>		TR14 = High (new) TR15 = Very High (check)	Inadequate cooling of column or thermal conditions of input are distributed	Distinguish between the two. Examine flow rate and temperature of input		
t <sub>3</sub>		FI1 = Normal (new) FR15 = Normal (check) TRC8 = Normal (new)	Conditions are as specified. It must be inadequate cooling of column	Possible causes: <ul style="list-style-type: none"> <li>Cooling water pump failure</li> <li>Top reflux pump failure</li> </ul>		
t <sub>4</sub>		LIC3 = High (new) Drum sight glass = High (check)	" "	Level in drum is high, thus condensation is OK. It must be failure of the top reflux pump		
t <sub>5</sub>		FIC8 = No Flow (new)	" "	Top reflux pump failure (confirmed)	<p><b>Alternative goals:</b></p> <ul style="list-style-type: none"> <li>Reduce heating in reboiler</li> <li>Reduce flow rate of input</li> <li>Increase cooling in condenser</li> </ul>	

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 1.6: CADET analysis of a fault-diagnostic task in an oil refinery

## 3.2 The Influence Modelling and Assessment Systems (IMAS)

Reference has already been made to the difficulty of accessing the mental processes involved in diagnosis and decision-making. We can, however, be certain that 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. Knowledge of the mental model possessed by the operator can be extremely useful in predicting possible diagnostic failures.

The IMAS technique is used to elicit Subjective Cause-Consequence Models (SCCM) of process abnormalities from personnel, a SCCM is a graphical representation of the perceptions of the operating team regarding:

- The various alternative causes that could have given rise to the disturbance
- The various consequences which 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 Subjective Cause-Consequence Model derived by this approach is given in Figure 1.7. 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.

The SCCM may be developed using the expertise of an individual or several workers in a team. In developing the SCCM, 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 of the 'mental model' of the operating team or the individual process worker. As can be seen from Figure 1.7, 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.

### *Application of IMAS*

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 SCCM at various stages of training enables the trainer to evaluate the development and accuracy of the workers' mental models of a range of process disturbances. A set of SCCMs 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 SCCMs will indicate where further training is required.

Since the SCCM explicitly identifies the information needed to identify the causes of disturbances (and to distinguish between 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.

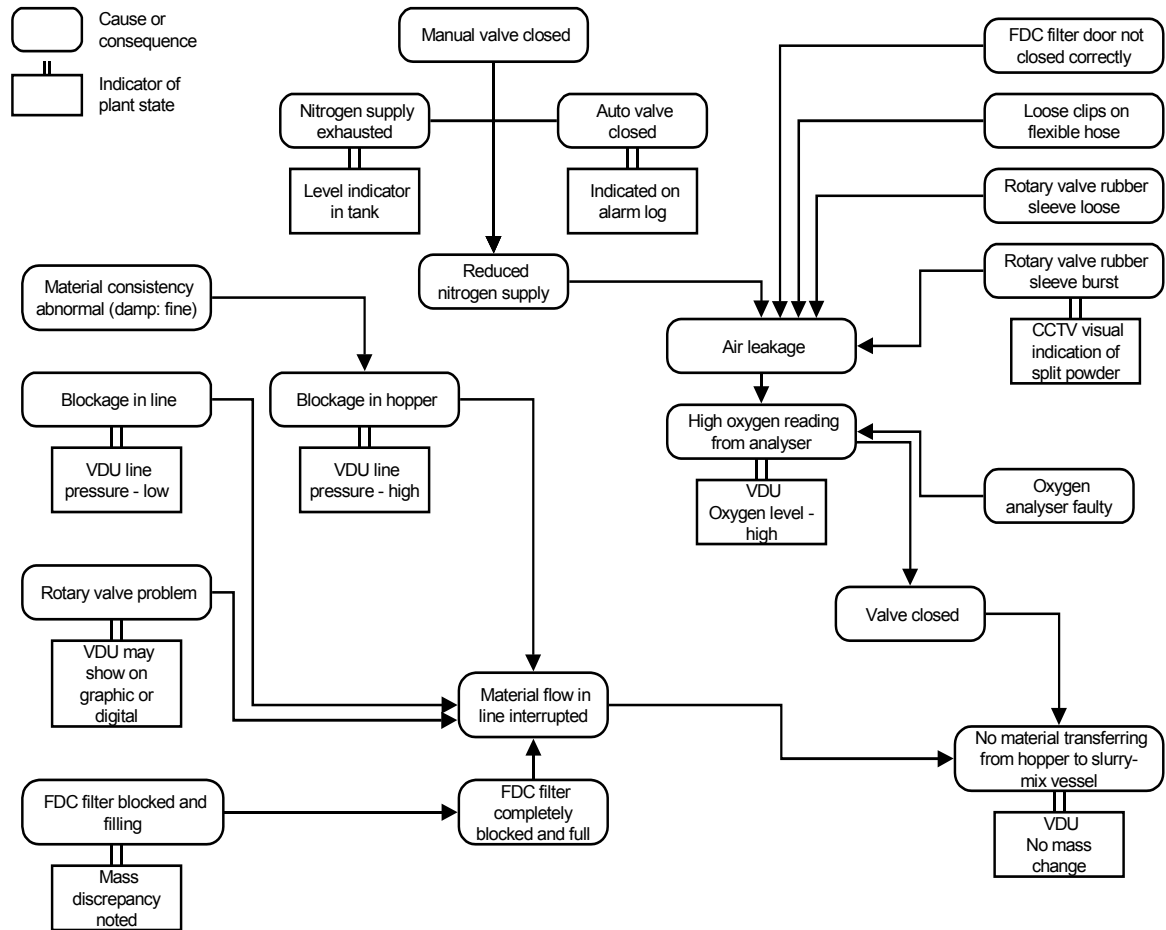


Figure 1.7: Example of a Mental Model Elicited by IMAS (Embrey, 1985)

## 4. 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 research interests, Figure 1.8 describes ten criteria for method evaluation.

In general, HTA and CADET fulfill most of the ten criteria, hence they can be used jointly as a framework for carrying out both action and cognitive task analysis. 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 1.9 provides such a classification in terms of seven human factors applications.

It is worth pointing out that Figures 1.8 and 1.9 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.

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

**P = Criterion is only partially fulfilled**

**Figure 1.8: Criteria for Evaluating the Suitability of Various T.A. Methods**

Applications	HTA	OAET	DA Charts	CADET	IMAS
1 Design of operating procedures	Y	N	Y	P	P
2 Training needs analysis	Y	N	Y	Y	Y
3 Team organization	Y	N	N	P	N
4 Human-machine allocation of	Y	P	P	Y	P
5 Control panel design	Y	N	Y	Y	Y
6 Workload analysis	P	N	N	Y	N
7 Input to human error analysis	Y	Y	Y	Y	Y

P= Criterion is only partly fulfilled

**Figure 1.9: How to Use Various TA Methods in Human Factors Applications**