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Hierarchical Task Analysis

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Abstract

This chapter begins by placing Hierarchical Task Analysis in its historical context. The method is presented as a general analytic strategy for providing solutions to initially specified performance problems. The unit of analysis is an *operation* specified by a *goal* and activated by an *input,* attained by an *action,* and terminated by *feedback.* The method is based on the systematic decomposition of goals and subgoals and operations and suboperations to any desired level of detail until the source of performance failure, physical or cognitive, is identified and a solution can be hypothesised. A seven-step procedure is described and illustrated. A variety of uses and adaptations of the method are outlined, including cognitive task design; hazard and operability assessment; training needs in contexts such as power generation, air traffic control, and military command and control tasks. Finally, Hierarchical Task Analysis is realistically evaluated as requiring both time and skill to yield useful results.

INTRODUCTION

Hierarchical Task Analysis (HTA) was first developed in the 1960s (Annett & Duncan, 1967; Annett, Duncan, Stammers, & Gray, 1971; Cunningham & Duncan, 1967) in order to overcome the limitations of classical time-and-motion methods in analysing complex nonrepetitive cognitively loaded tasks. Originally developed for training process control tasks in the steel and petrochemical industries, HTA is now widely used in a variety of contexts, including interface design and error analysis in both individual and team tasks in power generation and command and control systems, as well as many others (Ainsworth & Marshall, 1998; Kirwan & Ainsworth, 1992; Shepherd, 2001).

The process of HTA is to decompose tasks into subtasks to any desired level of detail. Each subtask, or *operation,* is specified by a *goal,* the *input conditions* under which the goal is activated, the *actions* required to attain the goal, and the *feedback* indicating goal attainment. The relationship between a set of subtasks and the superordinate task is termed a *plan,* and several plan types can be distinguished, including *procedures, selective rules,* and *time-sharing* tasks. The overall aim of the analysis is to identify actual or possible sources of performance failure and to propose suitable remedies, which may include modifying the task design and/or providing appropriate training. HTA is probably best seen as a systematic search strategy that is adaptable for use in a variety of different contexts and purposes within the human factors enterprise (Shepherd, 1998).

Origins of HTA

During the 1950s, new technology was introducing major changes in the design of industrial and military tasks. In particular, "automation," while reducing physical effort, was increasing the mental effort required to monitor and control complex machinery. The classical methods of analysing tasks, such as Gilbreth's motion study (Gilbreth, 1911), which had been in use for half a century, were proving inadequate to describe tasks of increasing complexity and ever more important mental content. R. B. Miller (1953, 1962) developed a method for man–machine task analysis that decomposed the main task functions into subtasks. For each subtask specified the display, the relevant control and action to be taken, feedback indicating response adequacy and objective criteria of accuracy and characteristic malfunctions. In short Miller's method focused on performance outcomes and the data-processing characteristics of operator tasks.

During this period, information-processing theories of human performance were extended from the basic concept of limited capacity in the execution of simple perceptual-motor tasks (Fitts, 1954; Hick, 1952) to more general accounts of the acquisition of skill (Annett & Kay, 1956, 1957), selective attention and memory (Broadbent, 1958), and the principle of feedback control (Annett, 1969). Miller, Galanter, and Pribram (1960) articulated a wide-ranging theory of goal-directed behaviour that was based on the concept of a nested hierarchy of feedback loops, referred to as TOTE (Test, Operate, Test, Exit) units, and it is this general conception that underlies the *operation* as the chosen unit of analysis in HTA.

A further influence on the early development of HTA was the concept of *systems analysis,* especially as articulated by Chapanis (1951). The effective output of a complex human–machine system may be characterised in terms of deviations from its designed output, or its error variance. The total error variance σ_T^2 is the sum of the variances of the various system components $\sigma_a^2 + \sigma_b^2 + \sigma_c^2 \cdots$ (provided they are uncorrelated). Because the root mean square error contributed to the total by each component increases quadratically with its size, any steps taken to reduce the major sources of error will contribute disproportionately to the reduction of total error. Putting this principle together with the concept of a nested goal hierarchy, then, we see that the obvious strategy for any human factors analysis is the successive decomposition of goals and subgoals in order to identify significant sources of error variance associated with each. We can then use this information as a basis for proposing modifications that will yield maximum benefit in optimising performance outcomes. With this brief introduction to the historical background, we now take a closer look at the underlying principles before turning to practical advice on the conduct of HTA. For a more extensive account of the early background to the development of HTA, see Annett (2000).

DEFINITIONS AND PRINCIPLES

Analysis Versus Description

In this section the principles on which HTA is based are stated succinctly. These principles were all present or implicit in the original statement of HTA (Annett et al., 1971) but are elaborated here for clarification. Being clear about the underlying principles and the definition of technical terms will make it easier to understand when and how to use HTA. Analysis is not just a matter of listing the actions or the physical or cognitive processes involved in carrying out a task, although it is likely to refer to either or both. Analysis, as opposed to description, is a procedure aimed at identifying performance problems, that is, sources of error, and proposing solutions. This distinction between *task description* and *task analysis* was made by R. B. Miller (1962) and emphasises the purpose of the analysis as providing solutions to initially specified problems. The problem might be to design a suitable interface or perhaps to decide what kind of training to provide, and in each case the course of the analysis might be different depending on what kinds of information are most relevant to the question being asked.

Tasks and Goals

A task is defined in the *Shorter Oxford Dictionary* as "any piece of work that has to be done" and, as such, every task has a goal. The figurative definition of a goal is "the object of effort or ambition." HTA differs radically from earlier methods of analysis by beginning, not with a list of activities, but by identifying the goals of the task. In routine repetitive tasks, actions vary little, while ever the environment and purpose remain constant. In complex tasks, the same goals may be pursued by different routes and different means, depending on circumstances peculiar to each occasion. Hence, simply to list actions without understanding what they are for can be misleading. Complex systems are designed with goals in mind, and understanding how a system attains or fails to attain its designated goal is the primary purpose of the analysis. A goal is best stated as a specific state of affairs, formally a *goal state*. The goal state can be an event or some physically observable value of one or more variables that act as criteria of goal attainment. At any one time a goal may be *active* or *latent*. Active goals are those being currently pursued; latent goals are those that may be pursued under conditions that might arise. The importance of this distinction will become apparent when we consider the concept of a *plan*.

Decomposition and Redescription

Goals are often complex; that is, they are defined by more than one event or by values of more than one variable. When these can be individually identified, the analysis should specify these component goal states by the process of *decomposition*. HTA envisages two kinds of decomposition. The first comprises identifying those goal states specified by multiple criteria, for example to arrive at a destination (an event) having expended minimum effort and with no injury. The second kind of decomposition comprises the identification of subgoals in any routes that may be taken to attain the overall goal state. Goals may be successively unpacked to reveal a nested hierarchy of goals and subgoals. This process of decomposition, also referred to as *redescription,* has the benefit, according to the general principle proposed by Chapanis (1951), of comprising an economical way of locating sources of general system error (actual or potential) in failure to attain specific subgoals.

Operations: Input, Action, and Feedback

An *operation* is the fundamental unit of analysis. An operation is specified by a goal, the circumstances in which the goal is activated (the *I*nput), the activities (*A*ction) that contribute to goal attainment, and the conditions indicating goal attainment (*F*eedback); hence operations are sometimes referred to as *IAF units*. Operations are synonymous with TOTE units (Miller et al., 1960) and are feedback-controlled servomechanisms. Just as goals may be decomposed into constituent subgoals, so operations may be decomposed into constituent suboperations arranged in a *nested hierarchy*. Suboperations are included within higher order (or superordinate) operations, with the attainment of each subgoal making a unique contribution to the attainment of superordinate goals. The suboperations making up a superordinate operation should be mutually exclusive and collectively comprise an exhaustive statement of the subgoals and superordinate goals.

An *action* can be understood as an injunction (or instruction) to do something under specified circumstances, as illustrated by the classic example of a TOTE for hammering a nail into a piece of wood—"Is the nail flush?/No → Hammer! → Is the nail flush?/Yes → Exit!" (Miller et al., 1960). Input and feedback both represent *states* or *tests* in the formulation by Miller et al. These states register either error, therefore requiring action, or the cancellation of error, signalling the cessation of that action. An action can be understood formally as a *transformation rule* (Annett, 1969, pp. 165–169), which is a specification of how a servo responds to an error signal and its cancellation. For example, in a manual tracking task, the transformation rule can be specified by an equation, known as a *transfer function,* which quantifies the control output required to correct for an error signal of given direction and magnitude (McRuer & Krendel, 1959). However, this is a special case, and normally, for example in self-assembly kits, computer software handbooks, and cookbooks, instructions are specified in terms of commonly understood verbs. Some verbs (such as *chamfer, defragment,* and *marinate*) form part of a technical vocabulary that may need redescription in simpler terms (how *does* one chamfer wood, defragment a computer disk, or marinate meat?). These redescriptions comprise a set of suboperations. As already indicated, suboperations collectively redescribe their superordinate operation, but typically we need to know not only the constituent suboperations but also the order, if any, in which they should be carried out (e.g., "to chamfer, first secure the piece to be chamfered, then obtain a suitable file," and so on).

Plans

The specification of the rule, or rules, governing the order in which suboperations should be carried out is called a *plan*. Plans can be of various types; the most common is simply a *fixed sequence* or *routine procedure,* such as "do this, then this, and then this," and so on. Another common type of plan specifies a *selective rule* or *decision*—"if x is the case, do this; if y is the case, do that." These two types of plan are significant because they imply knowledge on the part of the operator. It may be simple procedural knowledge, or the plan may require extensive declarative knowledge of the environment, the limits and capabilities of the machine, safety rules, and much else besides. In this respect HTA anticipated the requirement for what is now known as cognitive task analysis (Schraagen, Chipman, & Shalin, 2000).

A third distinct type of plan requires two or more operations to be pursued in parallel; that is, the superordinate goal cannot be attained unless two or more subordinate goals are attained at the same time. This is known as a *time-sharing* or *dual task* plan, and this type also has significant cognitive implications in terms of the division of attention or, in the case of team operations, the distribution of information between team members acting together.

When a goal becomes active, its subordinate goals become active according to the nature of the plan. For example, in a fixed sequence the goal of each suboperation becomes active as the previous subgoal is attained. When the plan involves a selective rule, only those goals become active that are specified by the application of the rule; the rest remain latent, and in a time-sharing plan two or more goals are simultaneously active.

Stop Rules

The decomposition of goal hierarchies and the redescription of operations and suboperations might continue indefinitely without the use of a stop rule, which specifies the level of detail beyond which no further redescription is of use. The ultimate stop rule is just that: "stop when you have all the information you need to meet the purposes of the analysis." However, because a general purpose of HTA is to identify sources of actual or potential performance failure, a general stop rule is "stop when the product of the probability of failure and the cost of failure is judged acceptable." This is known as the $p \times c$ criterion (Annett & Duncan, 1967), and its prime benefit is that it keeps the analytical work down to a minimum and it focuses the attention of the analyst on those aspects of the task that are critical to overall system success. In practice, lack of empirical data may mean that p and c can only be estimated, but it is the *product* of the two that is crucial to the decision to stop or continue decomposition. The obvious reason for stopping is that the source of error has been identified and the analyst can propose a plausible remedy in terms of either system design, operating procedures, or operator training, that is, by redesigning the cognitive task. A point that is often overlooked is that performance is a function not only of the system but of the operator. Thus a great deal more detail may be required if the aim of the analysis is to create a training program for complete novices than if the aim is to examine the possible effects of a redesigned equipment or operating procedure on the performance of experienced operators.

HTA may be used for design purposes and need only be carried down to the level of equipment specificity. Team training often follows training in individual operator skills, and the analysis of team tasks may be usefully taken down to the level at which operations involve communication and collaboration between individuals. For example, in the case of interface design, the analysis might proceed only to the degree of detail prior to the physical specification of devices (Ormerod, Richardson, & Shepherd, 1998). In the HTA for teams-HTA(T)-the analysis was specifically aimed at identifying operations that were especially dependent on the exercise of team skills such as communication and collaboration (Annett, Cunningham, & Mathias-Jones, 2000); another variation on the hierarchical decomposition approach, Task Analysis for Knowledge Description (TAKD), was initially aimed at identifying *generic* skills common to a wide range of Information Technology tasks (Diaper, 1989, 2001). In these cases, both the depth of analysis and the most relevant types of data are heavily influenced by the purpose and hoped-for product of the analysis.

HOW TO CARRY OUT AN HTA

HTA is a flexible tool that can be adapted to a variety of situations and needs. Data may be derived from any number of different sources; the analysis can be continued to any desired level of detail and there is no rigid prescription of how the results may be used. Shepherd (1998) refers to HTA as "a framework for analysis" but it is arguable whether the intrinsic adaptability of HTA is necessarily advantageous. A strictly specified procedure may be preferred to an esoteric craft; for one thing, the former is easier to learn (Patrick, Gregov, & Halliday, 2000), and, as Diaper (2001) points out, the process of automating or proceduralising a method

TABLE 2.1
Summary of the Principal Steps in Carrying Out HTA

Step Number	*Notes and Examples*
1. Decide the purpose(s) of the analysis.	1. Workload, manning, error assessment. 2. Design new system or interface. 3. Determine training content or method.
2. Get agreement between stakeholders on the definition of task goals and criterion measures.	1. Stakeholders may include designers, managers, supervisors, instructors, or operators. 2. Concentrate on system values and outputs. 3. Agree on performance indicators and criteria.
3. Identify sources of task information and select means of data acquisition.	1. Consult as many sources as are available; direct observation, walk-through, protocols, expert interviews, operating procedures and manuals, performance records, accident data, or simulations.
4. Acquire data and draft decomposition table or diagram.	1. Account for each operation in terms of input, action, feedback and goal attainment criteria and identify plans. 2. Suboperations should be (a) mutually exclusive & (b) exhaustive. 3. Ask not only what *should* happen but what *might* happen. Estimate probability and cost of failures.
5. Recheck validity of decomposition with stakeholders.	1. Stakeholders invited to confirm analysis, especially identified goals, and performance criteria. 2. Revert to step 4 until misinterpretations and omissions have been rectified.
6. Identify significant operations in light of purpose of analysis.	1. Identify operations failing $p \times c$ criterion. 2. Identify operations having special characteristics, e.g., complex plans, high workload, dependent on teamwork, or specialist knowledge.
7. Generate and, if possible, test hypotheses concerning factors affecting learning and performance.	1. Consider sources of failure attributable to skills, rules, and knowledge. 2. Refer to current theory or best practice to provide plausible solutions. 3. Confirm validity of proposed solutions whenever possible.

guarantees reliability and often leads to a deeper understanding of the underlying process. However, it might equally be argued that there are few procedures capable of dealing with all eventualities, and the unthinking application of a rigidly proceduralised tool may sometimes lead to a gross misinterpretation of the task. HTA can nevertheless be carried out in a number of different ways that may involve greater or lesser attention to individual steps in the fundamental procedure, which is outlined in the paragraphs that follow. In general, the benefits of HTA, and its reliability and validity, are proportional to the effort that goes into following this procedure. The analyst is nevertheless entitled to trade off effort for value-added by shortening or adapting the procedure to suit specific needs. Some ways of doing this are mentioned in the following steps, which are summarised in Table 2.1.

Step 1: Decide the Purpose(s) of the Analysis

The purpose of the analysis has important implications for the way in which it is carried out, including the preferred data collection procedures, the depth of the analysis, and the kinds of solutions (results) that can be offered. Typical purposes are designing a new system, troubleshooting and modification of an existing system, and operator training, all of which involve the design or redesign of the cognitive tasks required of the operators. When used for system design, the primary source of information is the design team, but few designs are totally novel and, as suggested by Lim and Long (1994), an analysis of a comparable extant system may prove useful in identifying difficulties to be avoided in the new design. In this case relevant data may be collected from records of performance, errors, and accidents; the views of expert users, supervisors, and managers; and by direct observations. Depending on the observed, reported, or even anticipated symptoms of failure, the analyst's attention may well focus on particular aspects of the task, such as displays, communications, complex decision rules, or heuristics to be employed for successful performance. Particular attention may be paid to operations where these play a critical role, and reference to published ergonomic design standards may be valuable.

The intended product of the analysis is also important in determining the appropriate stop rule. For a fully documented training program for novices to be produced, the level of detail may have to be able to generate very specific, plain language, "how to do it" instructions. If the purpose is to identify the type of training required, the analysis should identify operations and plans of particular types that are thought to respond to particular training methods. For example, where inputs are perceptually or conceptually complex, special recognition training exercises may be required, or where procedures are especially critical, operating rules and heuristics and system knowledge are to be learned (Annett, 1991). In summary, the analysis should anticipate the kinds of results that would provide answers to the original questions, such as design recommendations, training syllabi, and the like.

Step 2: Get Agreement Between Stakeholders on the Definition of Task Goals

Task performance, by definition, is goal-directed behaviour and it is therefore crucial to the analysis to establish what the performance goals are and how one would know whether or not these goals have been attained. A common problem is to interpret this question as about observed operator behaviour, such as using a particular method, rather than performance outcomes, such as frequency of errors and out-of-tolerance products. Bear in mind that the effort of analysis is ultimately justified by evidence of the outcomes of performance; this issue is taken up again in the later section on validity.

Different stakeholders (designers, trainers, supervisors, or operators) can sometimes have subtly different goals. It is better to identify problems of this kind early in the analysis by thorough discussion with all relevant stakeholders. If goals appear to be incompatible, the analyst can sometimes act as a catalyst in resolving these issues but should not impose a solution without thorough discussion. As the decomposition proceeds, more detailed goals and more specific criterion measures are identified, and it can emerge that different operators with ostensibly the same overall purpose have slightly different plans (ways of doing things), which may imply different subgoals. Objective performance measures provide the opportunity to compare methods in terms of superordinate criteria.

The key questions, which may be asked in many different forms, are, first, What objective evidence will show that this goal has been attained? and, second, What are the consequences of failure to attain this goal? Answers to the first question can form the basis of objective performance measures that may subsequently be used in evaluating any design modifications or training procedures proposed on the basis of the analysis. Answers to the second question may be used to evaluate the $p \times c$ criterion and hence the degree of detail of the analysis. Answers to both questions form the essential basis for agreement about the system goals. If goals cannot be stated in these objective terms, then the sponsors and stakeholders are unclear about the purposes of the system, and the validity of the entire analysis is called in question.

Step 3: Identify Sources of Task Information and Select Means of Data Acquisition

If the purpose is to look for ways to improve operator performance on an existing system, then records of actual operator performance, including both the methods used by operators and the measures of success or failure will be important. Errors may be rare, but critical incident data can provide useful insights into the origins of performance failure. If the purpose is to make recommendations on a new design, then data relating to comparable (e.g., precursor) tasks may be helpful, but the designer's intentions are critical. In the absence of actual performance data, the analyst should challenge the designer with "what if" questions to estimate the consequences of performance failure. Sometimes data concerning performance on preexisting systems or comparable tasks may provide useful information.

Preferred sources of data will clearly vary considerably between analyses. Interviews with experts are often the best way to begin, particularly if they focus on system goals, failures, and shortcomings. Direct observation may provide confirmatory information but, especially in nonroutine tasks, may yield relatively little information concerning uncommon events that may be critical. Formal performance records such as logs and flight recorders may be available, especially in safety-critical systems, but these are often designed primarily with engineering objectives in mind and the human contribution to system performance can sometimes be difficult to determine from the mass of recorded data. Focused interview with recognised experts aimed at identifying performance problems is often the only practicable method of obtaining estimates of the frequency and criticality of key behaviours. In some cases, in which the informants are unclear about what would happen in certain circumstances and what would be the most effective operator strategy, it may be helpful to run experimental trials or simulations. In at least one (personally observed) case in which even skilled operators were not clear about the cues used in reaching an important decision, an experiment was run in which the effects of blocking certain sources of information were observed. In this instance it was determined that the operator was, unconsciously, using the sound of the machinery rather than the sight of the product to reach a key decision.

Step 4: Acquire Data and Draft a Decomposition Table or Diagram

In general, the more independent sources of data consulted, the greater the guarantee of validity of the analysis. It is all too easy to think of operations simply as actions. The critical feature of HTA is always be to be able to relate *what* operators do (or are recommended to do) and *why* they do it and what the consequences are if it is not done correctly. Only when this is thoroughly understood is it possible to create a meaningful table or diagram. A useful logical check on the validity of a proposed decomposition table is that all suboperations must be (a) mutually exclusive and (b) exhaustive, that is, completely define the superordinate operation.

Notation. The use of standard notation generally helps in the construction of tables and diagrams as well as the interpretation of results, and it aids communication between analysts and stakeholders. The recommended notation system provides a unique number for each identified operation that may be used in both diagrams and tables. The notation should also specify plans and indicate stops. Stops represent the most detailed level of the analysis, typically the level that is most relevant to the results of the search, and recommendations for further action.

Both tabular and diagrammatic formats have their advantages, and typically both are used. The diagrammatic format often helps to make clear the functional structure of the task, whereas

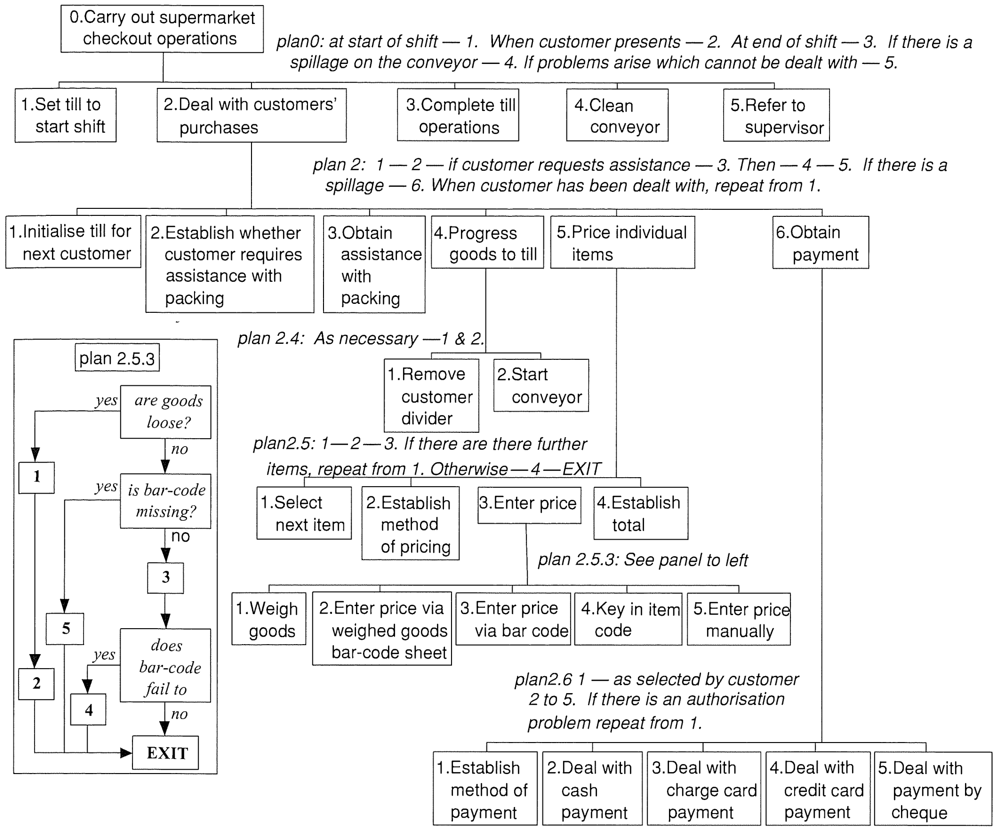

FIG. 2.1. Analysis of a supermarket checkout task in diagrammatic form (from Shepherd, 2001).

the tabular format is more economical of space and facilitates the recording of supplementary notes, queries, and recommendations. Individual operations are normally numbered with 0 standing for the top-level goal, in effect the title of the task, and with suboperations being numbered in the order of description (which is not necessarily the same as the order of execution). Thus operations 1, 2, and 3 would be the three principal suboperations of task 0; and 1.1, 1.2, and 1.3 would be the three suboperations into which operation 1 is decomposed and 2.1 and 2.2 would be the two suboperations into which operation 2 is decomposed. Each additional digit indicates a new level of decomposition. In the diagrammatic form, a vertical line descends from the superordinate operation to a horizontal line covering the set of suboperations into which it is expanded.

Plans are implicit in the decomposition structure, but they can be made more explicit by adding the appropriate algorithm to the diagram as in the example shown in Fig. 2.1. A succinct way of presenting four basic types of plan in the diagram was employed by Annett et al. (2000), using the symbols > to indicate a sequence, / to represent an either/or decision, + to represent dual or parallel operations, and : to represent multiple operations in which timing and order are not critical. This is shown in Fig. 2.2.

The lowest or most detailed level of decomposition, often being the most important level of description, is typically indicated in the diagram by an underline or some other feature of the box and may be similarly indicated in the table by a typographic variant such as boldface. The tabular layout can be facilitated by the use of the Outline system in Word™, and I have

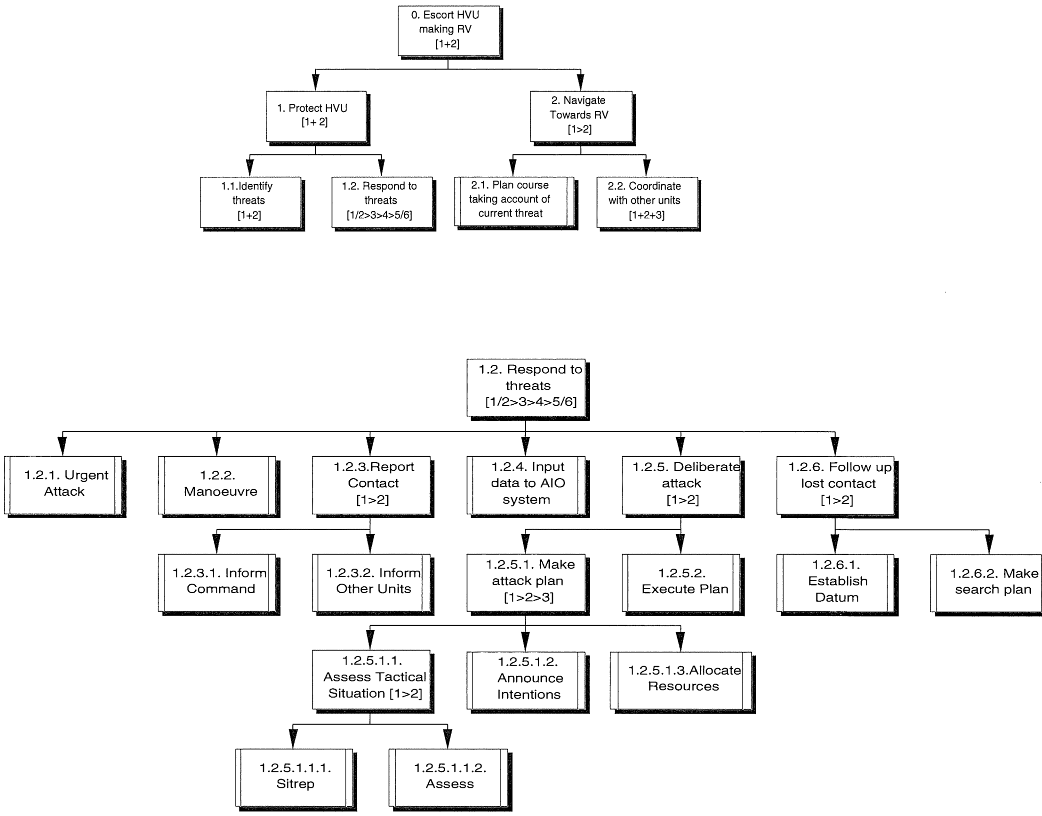

FIG. 2.2. Principal tasks of an ASW team (top section) and the further analysis of 1.2, Respond to Threats (lower section) (from Annett et al., 2000).

used another program, Inspiration™ (see Fig. 2.2), which is effectively a graphical form of an outline system, as a convenient, easily modifiable form of recording both diagrams and tables with ample scope for additional plain language notes.

Illustrative Examples. The first example shows a supermarket checkout task from Shepherd (2001), whose book is illustrated with a number of examples, and the second example (from Annett et al., 2000), using the alternative notation already referred to, is based on the analysis of a naval command and control team task. Shepherd's analysis identifies training needs and indicates where special training might be needed. The analysis from Annett et al. identifies operations in which teamwork is particularly critical and was used to develop an objective method of assessing teamwork.

The diagram in Fig. 2.1 shows the supermarket checkout task as comprising five principal sub-operations, one of which (#2) is further broken down into six more of which #4 is further decomposed into two more and #5 into four and #6 into five sub-operations one of which (#3) is redescribed in five sub-operations. Note that the box for each operation contains no more than a brief title, which stands for both the goal and the principal action involved. Table 2.2 gives a verbal description of selected operations together with notes concerning training. The table gives full numerical labels such that operation 2.5.3 (enter price) is identified as at the third level of decomposition and is itself finally redescribed as five suboperations that are listed at the bottom of the table. These can also be identified in the diagram as operations 2.5.3.1 to 2.5.3.5.

TABLE 2.2
Analysis of the Supermarket Checkout Task in Tabular Form (From Shepherd, 2001)

Operations and Plans	*Exp.*	*Notes*
0. Carry out supermarket checkout operations		
Plan 0: At start of shift—1. When customer presents—2. At end of shift—3. If there is a spillage on the conveyor—4. If problems arise which cannot be dealt with—5. Refer to supervisor.		
1. Set till to start shift	No	Demonstration as per induction programme.
2. Deal with customers' purchases	Yes	Ditto
3. Complete till operations	No	Ditto
4. Clean conveyor	No	Ditto
5. Refer to supervisor	No	Note that supervisors are not always at their desk. Review methods of communication.
2. Deal with customers' purchases		
Plan 2: 1–2—if customer requests assistance—3. Then—4—5. If there is a spillage—6. When customer has been dealt with, repeat from 1.		
1. Initialise till for next customer	No	
2. Establish whether customer requires assistance with packing	No	Some operators lack skill in asking customers whether they require help.
3. Obtain assistance with packing	No	
4. Progress goods to till	Yes	
5. Price individual items	Yes	
6. Obtain payment	Yes	
2.4. Progress goods to till		
Plan 2.4: As necessary—1 & 2.		
1. Remove customer divider	No	
2. Start conveyor	No	
2.5. Price individual items		
Plan 2.5: 1—2—3. If there are there further items, repeat from 1. Otherwise—4—EXIT.		
1. Select next item	No	
2. Establish method of pricing	No	Training required for more rapid identification on nonbarcoded items.
3. Enter price	Yes	
4. Establish total	No	
2.6. Obtain payment		
Plan 2.6: 1—as selected by customer 2 to 5. If there is an authorization problem, repeat from 1.		
1. Establish method of payment	No	Training required to help operators distinguish between different types of card.
2. Deal with cash payment	No	More training required to identify forged notes and coins.
3. Deal with charge card payment	No	
4. Deal with credit card payment	No	
5. Deal with payment by check	No	
2.5.3. Enter price		
Plan 2.5. See panel at left.		
1. Weigh goods	No	
2. Enter price by means of weighted goods barcode sheet	No	
3. Enter price by bar code	No	
4. Key in item code	No	
5. Enter price manually	No	

Note. From Shepherd (2001).

Figure 2.1 also shows the plans. The plan for 0 comprises a simple procedure, operations 1, 2, and 3 with two conditional operations, 4 and 6. The plan for operation 2.5.3 is described in the form of an algorithm that contains three tests (Are goods loose? Is bar code missing? Does bar code fail to read?). A tabular version can contain the same information with the addition of notes relating to features of the task of special interest. Although the tabular version is in some respects easier to read, the diagrammatic version shows the hierarchical structure, and this can be helpful in understanding the interdependencies of sections on the overall task.

Figure 2.2 shows selected parts of the diagrammatic form and Table 2.3 shows selected parts of the tabular form of a task carried out by the anti-submarine warfare (ASW) team in the operations room of a warship. The purpose of the analysis was to be able to identify and provide objective measures of key team skills.

The team comprises the Principal Warfare Officer (PWO), the Active Sonar Director (ASD), and the Action Picture Supervisor (AcPS), who are also in touch with other individuals and teams, notably the Officer of the Watch (OOW) and the Missile Director (MD). The upper section of Fig. 2.2 shows the overall aim of the team, which is to escort a highly valued unit (HVU; e.g., a troopship) to a rendezvous (RV; operation 0) while identifying (operation 1.1) and responding appropriately to (operation 1.2) submarine threats. The lower section of Fig. 2.2 shows that to identify threats (1.1) the team must, at the same time, scan for possible threats (1.1.1) and classify threats (1.1.2), of which more than one could be present at any given time. The plan for 1.1 is indicated by the notation [1 + 2], where 1 and 2 identify the two suboperations and the + symbol indicates they must be done in parallel. Classification (1.1.2) requires a decision as to the apparent immediacy of the threat followed by a process of checking and investigation.

Table 2.3 shows extracts from the tabular form, including three operations, 1.1, 1.2, and 1.1.2.2. Because the aim is to identify and provide a way of measuring critical teamwork skills, the analysis contains detailed notes on the goal, how goal attainment might be measured, and what kinds of teamwork activities are believed to be involved in attaining the goal.

Step 5: Recheck Validity of Decomposition with Stakeholders

Stakeholders, especially those unfamiliar with HTA, sometimes change their minds as the analysis proceeds. By thinking about the task they may realise that events do not always occur in a standard way or that something that has never been known to happen just could. For this reason an iterative process is recommended wherever possible, with the full analysis being developed over a series of interviews and by cross-checking between sources such as training manuals and experienced operators. The process of cross-checking not only provides the best guarantee of the reliability of the completed analysis but encourages the stakeholders to develop a sense of ownership of the analysis and consequently to share responsibility for recommendations arising from the results.

Step 6: Identify Significant Operations in Light of Purpose of Analysis

In any decomposition method, a decision must be made about the level of greatest detail required, that is, when to stop the analysis. It is common in decomposition methods used by large organisations, such as the military, to adopt a fixed number of levels, such as *job, task,* and *sub-task,* but this means that some parts of the task may be described in excessive detail whereas others require more. As a general rule the recommended criterion (the stop rule) is to stop the analysis of any given operation when the probability of performance failure multiplied by the cost to the system of performance failure ($p \times c$) is acceptably low. Where no data exist,

TABLE 2.3
Extracts From the Tabular Form of the ASW Team Task Analysis

	1.1. Identify Threats
Goal	Identify and classify all ASW contacts.
Measure	Contacts identified and classified as quickly and accurately as possible.
Teamwork	Team compiles information from various sources. PWO monitors and directs team.
Plan	[1 + 2] Scanning all sources for information on potential threats is continuous (1.1.1). Classification procedures (1.1.2) follow identification as soon as possible.
	1.2. Respond to Threats
Goal	To respond appropriately to an identified threat according to classification.
Measure	Response according to plan for force, without hesitation once relevant information is available.
Teamwork	PWO selects appropriate response based on information provided by team in accordance with standard operating procedures (team plan) plus range and bearing.
Plan	If threat is immediate (e.g., torpedo), go to urgent attack (1.2.1) otherwise execute (1.2.3) to (1.2.5). If contact is lost go to (1.2.6).
	1.1.2.2. Chart Check
Goal	To establish whether contact classified as possub lo 1 represents a known feature such as rock, wreck, or pipeline.
Measure	Procedures correctly executed, conflicts resolved, and other units informed.
Teamwork	Sonar operator passes information to ASD, who confers with PWO. PWO calls for "chart check poss. sub. BRG/RG." OOW plots position to agreed margin of error. ASD directs SC to investigate location; AcPS inputs data to system; EW and radar teams check returns on that bearing; OOW and MD check bearing visually. All report results of checks.
Plan	If chart check negative go to (1.2). If information is inconsistent go to (1.1.2.3).
	1.1.2.3. Investigate Possub
Goal	To confirm possub classification
Measure	Correct procedures and priority to search; optimal use of assets.
Teamwork	Correct procedures according to team plan.
Plan	If possub confirmed go to (1.2).

Note. From Annett et al. (2000).

values of p and c may be estimated. The rationale for this general rule is that the analysis is essentially a search process aimed at identifying significant sources of actual or potential system failure, so when no more sources can be identified then clearly the analysis should cease. However, modifications to this general rule may be made in certain circumstances. For example, when the analysis is part of the design process, it may be desirable to stop at a level that is device-independent, that is, at a purely functional specification of the component operations, leaving open specific implementation in terms of equipment or language (see Lim & Long, 1994; Ormerod et al., 1998). Another stopping rationale is when the aim of the analysis is to identify certain features of the task. For example, Crawley (1982) used a form of HTA referred to as Overview Task Analysis (OTA) in a study of air traffic control. The analysis was stopped at tasks that could be readily identified and judged by controllers as being particularly demanding or especially satisfying, thus providing a basis for deciding whether automation should be considered. As shown in the previous section, Annett et al. (2000) analysed naval ASW command team tasks in sufficient detail to identify certain types of team work such as operations that critically depended on intra-team communication or discussion, active collaboration, or the synchronisation of actions. The analysis formed the basis for a behaviourally based scoring system, thus enabling instructors to supplement their comments and advice by reference to objectively measurable features of teamwork.

Step 7: Generate and, if Possible, Test Hypotheses Concerning Task Performance

HTA is principally carried out on the assumption that it is a tool to be used by a specialist who is looking for particular classes of problem and has a range of optional recommendations available. The analysis provides a means of generating hypotheses concerning the likely sources of actual or potential failure to meet overall task goals and to propose appropriate solutions. It must be clearly understood that HTA as a method includes neither a set of diagnostic categories nor a set of acceptable solutions to the problems identified. These will depend on the predilections and technical capabilities of the analyst. HTA simply provides an efficient procedure for identifying sources of actual or potential performance failure. However, as a useful source of guidance, Reason's (1990) classification of human error, based on Rasmussen's (1983) taxonomy of skill-based, rule-based and knowledge-based performance, may be helpful in this context. The analyst is prompted to develop hypotheses to account for failures and to propose practical solutions, but these are to be regarded as hypotheses that should be put to the test because this is the only guarantee that the analysis is valid. Several broad classes of specialist interest may be distinguished. These include system design and operator training.

Task Design. The traditional concerns of human factors and ergonomics are questions such as allocation of function, manning, and interface design. The basic concept of an operation, being essentially that of a *function,* can be applied equally to a human or machine operator and to constraints such as the physical effort and information processing demands of the task. The analysis specifies the design of both the physical and the cognitive tasks, the latter being our primary concern in the present context. Consideration of the input, action, and feedback components of critical operations often provides useful clues about actual or potential problems and hence of possible solutions. Input problems may range from sheer legibility at Rasmussen's skill level, through to the recognition and interpretation of complex patterns at the knowledge level, which are the essential precursors of decision making.

Action problems likewise may range from the accessibility and effort requirements of controls through fixed routine procedures to the use of complex strategies, some following closely specified plans and others relying on sophisticated heuristics. Feedback problems are commonly underestimated, and this may be partially due to the use of action language ("do *x*") rather than goal-directed language ("achieve state *x*") in describing tasks. Too often the feedback that indicates successful goal attainment is ignored, perhaps because of the implicit assumption that all statable actions are simple and can be executed without error. The operator's failure to appreciate or to learn the significance of feedback can often be a major source of error that can be exacerbated if, as in so many process control type tasks, there is a significant temporal lag between the control action, such as reducing the temperature of a vessel, and feedback, such as change in chemical composition of the product as shown in a subsequent laboratory test. The problem may become even more severe in cases in which a control action has multiple effects that may be registered at different times and locations and may even interact with other operations.

The goal structure, essentially the plans, of a task also provide important clues to potential or actual performance failures. Consider the three main classes of plan identified in an earlier section. A simple sequence or routine procedure may create few problems if it is short and frequently practised but may otherwise be liable to memory failure, one of the commonest forms of human fallibility (Reason, 1990). The second type, selective rule or decision, clearly implies the existence of a repertoire of rules or strategies to deal with possible contingencies. The analysis should specify what these are if rule-based errors (Reason, 1990) are to be avoided. Examples include both applying the wrong rule and applying the correct rule to the wrong object or just using an inadequate rule. The third category of plan, dual task or time-sharing, provides opportunities for errors of inattention, distraction, and sheer physical or mental overload. Identification of these types of error, some of which ought to be apparent during the initial data collection phase, is probably the most important step to their elimination through techniques for providing various kinds of support, such as checklists, decision aids, equipment redesign, and automation.

Training. Questions relevant to training may include course content, training method, and often both. Training is often considered only when a new system is about to become operational. In a project for the British Army, Annett (1991) recommended the use of HTA at an early stage of system development as a means of choosing between types of training equipment, such as simulators, part-task trainers, embedded trainers, and weapons effects simulation as alternatives to classroom work and on-the-job experience. The choice of trainer was based principally on the characteristics of critical operations and plans identified by the analysis but also took into account the context in which training could be implemented. The recommendations were embodied in an algorithm that proposed the optimal training medium for each operation. For example, critical recognition and control skills typically require practice in high-fidelity simulations but can also be learned in a part-task trainer, whereas investigation and planning skills may be practised in a simple mock-up or, if more complex, in a simulation that provides a realistic range of problems.

USES OF HTA

HTA has been used in a wide variety of contexts for the full range of problems that confront human factors practitioners. Shepherd (2001) cites a range of examples, including simple procedural tasks, such as changing a printer cartridge, using a word processor, and carrying out the supermarket checkout task, through fine motor skills of minimal access (keyhole) surgery to air traffic control and management tasks. In a survey of 30 task analysis studies in the defense industry, Ainsworth and Marshall (1998) found two cases of its use in system procurement, seven for manpower analysis, nine for interface design, five for operability assessment, and two instances of its use in specifying training.

The final (seventh) step in the HTA procedure is to formulate and test hypotheses about possible solutions to the critical performance problems emerging from the analysis. As indicated, different kinds of solutions may be possible, such as changing the design or the task procedure or selecting operators or providing them with special training. As part of the original Hull research project, Duncan (1972) described the use of HTA in the design of training for process control operators in the petrochemical industry. His account is particularly valuable for the thorough discussion of the process of forming hypotheses and proposing solutions based on the analysis and current instructional theory. Other uses include assessing workload and manning requirements. Penington, Joy, and Kirwan (1992) used HTA to determine staffing levels in the control room of a nuclear plant. Fewins, Mitchell, and Williams (1992) described the use of a version of HTA to identify 56 critical tasks in the operation of a newly commissioned nuclear power station for the purpose of assessing the workload. The cognitive task problems identified by the analysis were dealt with by a combination of interface design, staffing levels, and automation. Crawley (1982) used an abbreviated version of HTA to identify critical air traffic control tasks to assess their suitability for automation. Command and control tasks typically involve team work, and HTA-T has been used to identify critical team functions (Annett et al., 2000; Annett & Cunningham, 2000). Shepherd (2001) also outlines HTA applications to production teams, supervision of an automatic railway, and collaboration between members of medical teams.

HTA has been used for the purpose of hazard assessment and error prediction. Baber and Stanton (1994) describe a method, Task Analysis For Error Identification (TAFEI), for designing error-tolerant consumer products that combines HTA with State-Space Diagrams (SSDs). HTA is used to describe human activities and SSDs to describe how the product will behave, that is, how it will move from one state to another; the aim is being to ensure that the design does not involve transitions to undesirable or hazardous states. Reed (1992) also describes the use of HTA in nuclear power plant operation specifically to assess the safety of the operator–machine interface in the handling of hazardous materials. Penington (1992) used a hierarchical analysis in a hazard and operability (HAZOP) study of oil rig drilling operations.

HTA has been recommended as a precursor to systematic design by Lim and Long (1994) in their Method for Usability Engineering (MUSE). Because most new designs begin as alternatives to extant designs, Lim and Long suggest that the HTA of an extant system (or systems) is a convenient way of generating a generalised task model containing the essential functional requirements of the proposed new system and demonstrating their implications for the human user. Ormerod (2000) also advocates a modified version of HTA, called the Sub-Goal Template (SGT) method, as part of the design process. The decomposition proceeds down to the level at which the specification of an operation is independent of any specific equipment or interface design. This approach frees the designer to consider a range of design possibilities.

The principle of hierarchical goal decomposition has become widely used in a number of well-known HCI methods. Some, like GOMS (Goals, Operators, Methods, and Selection rules) by Card, Moran, and Newell (1983), appear to have been developed for the specification of human–computer interaction tasks quite independently of HTA. Others, such as KAT (Knowledge Analysis of Tasks; Johnson & Johnson, 1991) and TAKD (Diaper 2001; Diaper & Johnson, 1991) explicitly incorporate the essentials of HTA into an extended methodology. In these latter cases the theory of knowledge structures is exploited as a means of determining the transfer potential (or "generification") of certain classes of tasks. Extensions of the principles underlying HTA raise an interesting general point.

This chapter has presented HTA as a "complete" route for proceeding systematically from problem to solution, but others have viewed HTA as a "front end" procedure, or the first stage in a number of distinct methods targeted at specific types of problem. In a broad view, most human factors problems span three domains—the machine or external system, the human agent, and the set of functional relationships between these two, that is, the task itself. HTA is essentially a specification of the functionality of a goal-directed system, or, to put it very simply, it provides the recipe for getting something done. However, getting something done depends not just on the recipe but the variable properties of the environment within which the "thing" has to be done and the often limited, but also variable, capabilities of the agent. To get at the heart of a problem, whether it be of task design or remediation, each of these aspects has to be modelled. If HTA is a procedure for modelling the functionality of the task, additional information and constructs are needed to model the nature of the machine environment and the capabilities of the agent. TAFEI does this by using SSDs to model the properties of the machine environment, and KAT provides a way of modelling the knowledge structures of the agent. Significant developments of the original principle underlying HTA such as these surely deserve their unique designation, and no doubt the future will bring more.

USABILITY OF HTA

It is reasonable to expect that the same standards of usability should apply to the methods used by human factors specialists as they apply to the objects of their studies. Ainsworth and Marshall's (1998) survey found a good deal of variability in the application of HTA. For example, only half the studies specified a stop rule, a third did not use diagrams, and only a minority of cases reported their recommendations and how they were derived from the analysis. Ainsworth and Marshall suggest that training in the use of HTA is somewhat variable, and it appears that some practitioners take shortcuts, neglecting some of the important steps outlined in this chapter. They also note that "it appeared that the most insightful analyses were undertaken by analysts who had the most human factors experience" (p. 1617/p. 89).

Stanton and Young (1998) surveyed the use of 27 methods used by members of the Ergonomics Society who were also on the Society's professional register. These included methods such as checklists, questionnaires, link analysis, predictive human error analysis, repertory grids, keystroke level models, and HTA. Although the response rate was low, the consensus view was that HTA was useful but requires more training and practice than most other methods. HTA is sometimes seen as very time consuming, which is certainly true when applied thoroughly to seriously complex tasks. In a study by Stanton and Stevenage (1998), 9 engineering students were given up to 4 hours training and practice in 11 of the most commonly used methods, including HTA. A week later they were required to use each method to evaluate the design of a car radio cassette player and were asked to judge each method on its perceived acceptability, auditability, comprehensiveness, consistency, theoretical validity, use of resources, and usefulness. Time to complete each evaluation was also recorded. The main finding was that HTA was, both objectively and subjectively, the most time intensive of the methods. The students also showed a preference for observation and interview over the more structured methods such as HTA.

Patrick, Gregov & Halliday (2000) carried out a study in which a small sample of students received training in four of the main features of HTA, that is, the decomposition of operations and sub-operations, the definition of operations in terms of objectives, the $p \times c$ stopping rule, and the construction of hierarchical diagrams and tables. They were then required to draw up an analysis of either painting a door or making a cup of tea. Their analyses were then scored on 13 criteria dealing with the principal features of the method. Overall performance was found to be poor, particularly in respect to the students' ability to construct an adequate hierarchy. A second study using the same population and tasks but with enhanced training generated analyses of higher quality, although still not without problems. These results confirm the conclusions reached by Ainsworth and Marshall (1998) and Stanton and Young (1998) that HTA is far from simple and takes both expertise and practice to administer effectively.

Evidence from these studies is suggestive rather than conclusive. However, careful attention to the basic steps summarised in Table 2.1 is recommended as the best guarantee of validity and reliability. In particular, keeping the purpose of the study in sight throughout is crucial to the validity of the analysis, and this is supported by continuing to insist that the stakeholders are clear about the system values and outputs by which performance is to be judged. The ultimate test of validity lies in step 7, the empirical test of the hypotheses on which the recommendations are based. Sadly, such results are rarely, if ever, reported. Reliability rests principally on the skills of the analyst in extracting and cross-checking data from various sources (step 3) and on consultation with stakeholders in step 5. A good analyst will always pursue and try to resolve apparent disagreement between informants or inconsistencies in the data. In this way reliability can be maximised. There are many practical reasons why direct evidence of the validity and reliability of HTA, in common with other analytical methods, is scarce, but perhaps the best evidence that HTA has been found a valuable tool lies in its continued use in a wide variety of contexts over the past 30 years.

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