HTA as a framework for task analysis

A. Shepherd

Department of Human Sciences, Loughborough University, Loughborough
LE11 3TU, UK

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The motivation for this paper is to review the status of Hierarchical Task Analysis (HTA) as a general framework for examining tasks, including those for which cognitive task analysis methods might be assumed to be necessary. HTA is treated as a strategy for examining tasks, aimed at refining performance criteria, focusing on constituent skills, understanding task contexts and generating useful hypotheses for overcoming performance problems. A neutral and principled perspective avoids bias and enables the analyst to justify using different analytical methods and develop hypotheses as information is gained about the task. It is argued that these considerations are equally valid when examining tasks that are assumed to contain substantial cognitive elements. Moreover, examining cognition within the context of a broader task helps to situate cognition within the network of actions and decisions that it must support, as well as helping to establish where effort in cognitive task analysis is really justified.

1. Introduction

Hierarchical Task Analysis (HTA) is a term that encompasses ideas developed by Annett and Duncan (Annett and Duncan 1967, Annett et al. 1971, Duncan 1972, 1974). It explores tasks through a hierarchy of goals indicating what a person is expected to do, and plans indicating the conditions when subordinate goals should be carried out. Rather than setting out to establish a distinctive method of task analysis, the original work suggested general principles for guiding all task analysis projects. HTA has enjoyed substantial success in many practical applications. This is illustrated in Kirwan and Ainsworth (1992) who provide a number of case studies describing task analysis applications in which HTA features prominently. Despite its successes, it is often assumed that HTA is unsuited to dealing with cognitive tasks. This paper will review the status of HTA as a framework for conducting task analysis rather than as a method for modelling behaviour. In this respect the paper aims to demonstrate how even the analysis of cognitive tasks benefits from consideration of the wider task perspective that HTA offers.

Contributions to the task analysis literature have often described techniques rather than discuss fundamental issues. This has encouraged a ‘tool-kit’ approach where different methods are offered for use at the discretion of the analyst. A problem with this approach is that it relies on the analyst prejudging the nature of the task to be examined or the nature of the solution. This can lead to bias, error of judgement and unfocused work, unsuited to an applied setting. Identifying appropriate analytical methods should be part of task analysis and not a precursor to it. Thus Duncan (1972) argues that task analysis should be neutral with respect to solution. Viewing HTA as a distinct technique has tended to place it in the tool-kit
along with other methods that appear to do specific things, such as link analysis or time-line analysis or, indeed, methods of cognitive task analysis. Selecting task analysis methods should be governed by a principled examination of task demands and constraints identified through the course of the task analysis project. It will be argued that HTA provides such a framework of principles.

Debate about task analysis is hampered by a lack of agreement of the nature and purpose of task analysis. The word ‘task’ may be treated as a reference to human behaviour, the system goals for which people are employed, how context constrains the attainment of goals, or some interaction between these and other factors. ‘Task analysis’ may be treated as an investigatory tool or a method of modelling human behaviour. Task analysis may be seen as a specific and rigorous method or merely a guiding framework. ‘Task’ is seldom defined satisfactorily. One of the few definitions of ‘task’ is Miller’s (Miller et al. 1953:1): a task ‘is a group of discriminations, decisions and effecter activities related to each other by temporal proximity, immediate purpose and a common man-machine output’. This definition combines features of human behaviour and features of systems behaviour. It implies that there is a consistent set of behaviours for a given system’s goal. This is unlikely; human beings are adaptive in their behaviour and need to be because controlled systems are complex and unpredictable. The reference to ‘temporal proximity’ is also problematic, because it gives no indication of what this means—a minute, an hour, a day? Moreover, the ‘immediacy’ of the purpose is misleading, because behaviour is fashioned by higher order purposes as well as by more immediate considerations. Generally, such definitions are imprecise, and there is a tendency to use words interchangeably. Thus, in different approaches, ‘goal’, ‘task’, ‘action’ may mean the same (imprecise) thing; behaviour becomes confused with demands. Stammers et al. (1991:138) argue that ‘the ambiguity of what constitutes a task is probably one of its greatest strengths, as it provides a flexible framework within which the analyst can group user/operator actions to fit the task context and the overall objectives of the analysis’. While this ambiguity fairly reflects how task analysis is usually practised, it limits development of a more rigorous discipline.

This paper will adopt the perspective of a ‘task’ as a problem facing an operator, with task analysis serving to identify strategies by which the operator can be facilitated to solve the problem, by information design, task re-organization, training and any other human factor. Problems in experimental psychology, such as the ‘two-string’ problem, the ‘selection’ task, and the ‘Tower of Hanoi’ problem, each entail a goal to be met; a representation of an initial state; a set of response facilities with which to affect the state; and an environment or context that constrains the manner in which changes can be made. A specification of a problem is not synonymous with the behaviour that might be used to solve it, but clear problem specification is critical to a proper understanding of behaviour. This paper, therefore, distinguishes between task and the behaviour recruited to carry out the task.

The aim of this paper is to review the status of HTA and argue its relevance to analysing ‘cognitive’ tasks. This will be done by providing a justification for HTA as a framework for neutral examination of tasks. Its relationship to analysing cognitive task elements will be justified in terms of identifying occasions when cognitive analysis methods or cognitive modelling might be adopted, and in specifying the demands of the task such that it is clearer how cognition is recruited to meet task goals.
2. Justification of HTA

Annett and Duncan's (1967) ideas of task analysis included elements of task description, behaviour modelling, risk assessment, hypothesis generation and cost-benefit analysis, and were strongly influenced by systems thinking. HTA was justified in part by systems thinking itself, and in part by ideas in skills psychology emerging from systems thinking. A system is any complex of interrelated parts; systems come in many varieties and possess many different properties. A principal characteristic of a system is its function, that is, the purpose the system serves in its broader context. A second important feature is a specification of system components or sub-systems and how they fit together. A system can only be properly understood in terms of its sub-systems by indicating how information, energy resources and physical entities flow between them. Third, expanding a system description by redescribing its components in more detail implies that systems can be described in terms of a hierarchical structure. Generally, the level of detail with which a system should be described depends upon the purpose to which the description will be put. An important property is that if some parts of the system warrant detailed attention, they may be examined in greater detail than other parts of the system.

A hierarchy could be employed simply to describe a system at an appropriate level or it could be used to imply some degree of control. In a hierarchical control system higher levels in the hierarchy exert influence over the manner in which lower levels behave. This may be done in an authoritarian manner by passing, to the lower levels, the methods by which the lower level components must be controlled. A less stringent form of hierarchical control is one that is delegatory—sub-goals, rather than methods, are assigned to components along with the authority to achieve the sub-goals by whatever method the component deems to be appropriate. Here, the role of the superordinate is to indicate when each subordinate should act. In this form of hierarchical control higher order components maintain their control through monitoring the performance of subordinate components via feedback. At any level, a goal is met by manipulating its sub-functions, while the sub-functions, in turn, work by organizing their sub-functions. An analogy is with structured programming, where sub-routines call on sub-routines and so forth. A further hierarchical arrangement is simply descriptive. It implies no control whatsoever, but merely describes sub-goals in relation to one another in terms of their purpose.

Systems ideas were adopted to model human behaviour, especially in disciplines concerned with examining purposeful activity such as industrial psychology or ergonomics. Human beings are regarded as working purposefully but may not share goals with the systems in which they are employed due to a deliberate lack of cooperation, incompetence or because circumstances prevent effective performance. It is the role of human factors engineering and human resource management to ensure that human goals are consistent with the goals of the system in which they are employed. Task analysis is intended to support this objective.

The concepts of feedback and control are strongly represented in modelling human behaviour. Pursuit of a goal entails adapting behaviour to influence a controlled environment in order to attain that goal (Winston and Schmidt 1989). There are different forms of feedback that can exercise control over human activity, including monitoring limb movement, the feel of controls, the consequences of the action of tools on the environment and comments from other people concerning the outcome of actions. More generalized system feedback is often necessary to help the operator to perform at a strategic or planning level. Miller et al. (1960) proposed the
TOTE unit as a model to describe the relationship between action and feedback in controlling performance. The skilled operator: tests (T) the environment against a specified criterion; then, if the test indicates a mismatch, operates (O) to affect change; then tests (T) again to determine whether the discrepancy has now been overcome; then exits (E) when the match is accomplished; if the match has not been accomplished, then (O) is repeated. Annett and Duncan (1967) incorporated the ideas of feedback and control in their approach to task analysis, representing components as input (I), action (A) and feedback (F). Failure to carry out an operation successfully will be due to failure of handling I, A or F.

TOTE and I-A-F can also be compared to ‘production systems’ used in a number of cognitive modelling approaches (Anderson 1983). A production is a condition-action statement; the condition component corresponds to ‘T’ (or ‘I’ and ‘F’); the action component of the production rule corresponds to ‘O’ (or ‘A’). A particular production will be triggered when prevailing circumstances match the conditions component—when the condition consistent with a specified pattern is present the action should follow. With a production system, feedback can be dealt with simply by virtue of a different set of prevailing conditions warranting a different action. Clearly feedback is a crucial component of human goal-seeking performance since responses need adjustment in accordance with circumstances in the world. Moreover, it is clear that people can be helped to learn by manipulating feedback during training and helped to perform by providing extrinsic task feedback to help them to regulate their actions. Thus, a production system handles feedback elegantly, but not necessarily as usefully in terms of supporting human factors design. The more explicit statement of feedback in I-A-F and TOTE seems more practical.

A hierarchical skills model that embodies the features of feedback and control is attractive in that a variety of apparently complex behaviours may be represented by relatively simple structures. For a hierarchical model to work, its designer must indicate how components relate to one another to meet the conditions of their common goal. Miller et al. (1960) demonstrated that O (operation) could itself be represented as a collection of TOTEs by utilizing a planning component. Annett and Duncan (1967) similarly adopted the word ‘plan’ as the label for the co-ordinating unit in HTA, although it was only later (Duncan 1972, Shepherd 1976) that plans became necessary components in redescribing goals in HTA and their full benefits became apparent. The utility of the hierarchical description is further in evidence when one addresses the question of how much detail is sufficient in the description of behaviour. Annett and Duncan (1967) proposed the P × C rule as a means of focusing attention where it is warranted. If attainment of a particular sub-goal is deemed satisfactory in terms of the product of the probability of inadequate performance (P) and cost of inadequate performance (C), then nothing more need be done in terms of task analysis to help people to achieve that sub-goal. Thus, detail in HTA is dictated less by considerations of behaviour than by consideration of criticality in terms of the system under scrutiny.

HTA may be seen to represent different things. It may be regarded as a model of human behaviour in the manner just described; this would suggest that the control of observed behaviour corresponds to the hierarchical control implied by different plans in the hierarchy. Supporting this perspective is extremely problematical. It suggests the way in which sub-skills are organized and encoded and implies that plans may be treated as psychological entities. It implies that utilization of
information in the pursuit of specific goals is consistent, irrespective of circumstances, and that everyone organizes task data in the same way. It takes no account of the fact that the mental organization of task information would appear to change as people become more or less skilled.

An alternative view is that HTA relates to the strategy of examining a task within a practical project. If a goal is met to a satisfactory standard, then the behaviour of people contributing to that goal is assumed to be satisfactory with no further attention warranted. If system performance is judged to be unsatisfactory then contributing behaviours may warrant investigation. One method of investigating this behaviour is through some form of behavioural analysis, including cognitive modelling. Another method is to specify the goal in greater detail. HTA utilizes the strategy of redescribing into subordinate operations and a plan that governs the conditions when each subordinate should be carried out. An alternative to investigating behaviour or redescribing a goal is to propose a known solution to that class of problem.

This perspective of systematically examining tasks to establish hypotheses to enable goals to be accomplished, most fairly represents HTA in practice and is consistent in most respects with the original conception of HTA. Thus, HTA is far from an exclusive method and actually relies upon other methods and perspectives being adopted to enable completion. The need for a systematic strategy for task analysis becomes particularly important in large, multiple activity tasks, with which more focused methods, such as link analysis, time-line analysis or cognitive task analysis, could not begin to cope. These more focused methods need a framework to justify their application and to provide sensible boundaries within which they may realistically be applied.

3. Strategy in task analysis
A full task analysis can be a complex enterprise entailing many decisions and judgements carried out over a long period. Figure 1 sets out a process model of task analysis. A variation of this figure was proposed and discussed in Shepherd (1995). Working through this process results in the hierarchical structure of HTA.

3.1. The HTA framework
3.1.1. Box 1—Setting goals: Task analysis should focus effort in order to be effective and economical. Task analysis should proceed by identifying the main work goal associated with the problem, whether the analysis is prompted by an operational or human performance problem or by a desire to seek improvements to a system. There are several task analysis methods that assist this focusing, for example, the critical incident technique (Flanagan 1954).

3.1.2. Box 2—Observing constraints: As goals are discussed, so constraints associated with their attainment or their solution are encountered. Constraints are particularly important in practical projects as they affect the design options that might be adopted to realize goals. Constraints include detail about the work environment that are assumed to influence performance. They also include limitations on preferred solutions imposed by management and staff.

3.1.3. Box 3—Calculating criticality: Task elements need only be examined if they are judged to be critical. Criticality is a combination of the importance of a goal and
the reliability of its execution, for example the P × C rule (Annett and Duncan 1967). Analysts may make these judgements subjectively, or they may seek data to quantify their judgements.

3.1.4. Box 4—Ceasing redescription: An outcome of the criticality judgement in box 3 is that redescription can cease at this point. This provides one of the important economies in HTA.
3.1.5. **Box 5—Generating hypotheses**: If current performance is judged to be unsatisfactory the analyst may examine the operator-system interaction to establish a cause or a solution to the problem. Different project aims may require hypotheses to be stated in terms of potential causes or design suggestions to overcome the problem. Thus, the discipline of human error analysis tries to identify ways in which human performance might lead to error (Kirwan 1994). *Operational task taxonomies* or *guidelines* may be used to identify design hypotheses without requiring any detailed modelling of behaviour. In other projects where suitable design hypotheses are not obviously forthcoming, the analyst might try to model behaviour as a precursor to suggesting a solution to overcome performance weaknesses. Cognitive task analysis methods may be used to serve this end. In practice, a variety of such strategies may be entirely appropriate.

An important aspect of generating hypotheses is observing constraints. Constraints are identified in box 2 as each cycle of reviewing goals and sub-goals is undertaken. It is quite possible that no hypotheses consistent with these constraints is forthcoming. This will warrant redescription (§3.1.8) or challenging the constraints (§3.1.9).

3.1.6. **Box 6—Cost-benefit analysis**: If the analyst generates a design hypothesis, then there is a need to determine whether its potential benefits outweigh its costs. This may be done intuitively or may be done explicitly. Some form of *cost-benefit analysis*, suited to routine application within task analysis, needs to be applied quickly, efficiently and repeatedly. Of particular concern is that cost-benefits change as an analysis progresses and a greater number of opportunities for deferring costs present themselves. For example, justifying a training simulator in terms of the first relevant sub-goal to present itself, may be difficult, but as further opportunities to use the device emerge, so cost justification is demonstrated.

3.1.7. **Box 7—Recording the analysis**: Record keeping shows what progress has been made, how the task has been represented and what design hypotheses have been proposed. It may also be useful to record the hypotheses that have been rejected on cost grounds, since these decisions may be revised as new issues emerge. HTA is recorded through both diagrams and tables (Shepherd 1995). Diagrams are useful in showing task structures but do not show the greater detail of information collected and insights gained.

3.1.8. **Box 8—Redescription**: Design hypotheses, consistent with cost-benefit criteria, may fail to emerge from examination of the operator-system interaction. Moreover, the task may be judged to be too complex for fruitful application of a formal method of modelling. In these cases the analyst would try to examine the system in terms of its sub-systems. In HTA, exploring sub-systems is achieved through *redescription* by stating a set of subordinate operations and a ‘plan’ specifying the conditions when each is appropriate.

3.1.9. **Box 9—Challenging the constraints**: If no hypotheses can be established, the constraints may need to be challenged. At the outset of the task analysis project, management might have ruled out investing in new technology on cost grounds, thereby limiting the options that may be pursued in the task analysis. However, a suitable design hypothesis may not be forthcoming. The following example refers to
A case where management sought improvements to the skills of controlling an ageing batch process plant in order to improve productivity. A common requirement in process control is that a particular parameter is required to be maintained at a particular value by adjusting an associated parameter. For example, the formulation of a liquid in a vessel may drift off target over time and must be adjusted by the appropriate addition of a particular feed-stock. In older generations of plant there are still many instances where human operators are expected to carry out this sort of adjustment manually. The task analysis carried out within the constraint of current technology had to focus on training solutions. The skills identified included taking samples, calculating the adjustments to formulation, making the adjustment, then waiting to re-sample and further adjust if necessary. Despite the preferences of management, analysis of these task elements showed that there were no suitable training solutions to meet the standards required, because plant dynamics were not predictable and additional work demands required staff to direct their attention elsewhere during crucial stages. Therefore, the previously stated constraint on changing technology had to be challenged if any productivity improvements were to be forthcoming. To do this, the analyst moved up the hierarchy to a suitable level of description, challenged constraints, and sought different methods of operation that involved automation of control loops.

3.2. Analytical strategy and the hierarchical representation of the task
The result of following the processes of review and redescription set out in figure 1 is a hierarchy of operations and plans, recognized as HTA (as in figure 2). Essentially, this is a record of a process. Thus HTA does not need to be justified as a model of behaviour, even though there will be occasions when the analyst chooses to use this representation as a model of behaviour, in information requirements specification, part-task training design or the design of documentation, for example.

The above discussion has distinguished between task and the behaviour that will enable the task to be carried out. For a successful human-task interaction, task and behaviour will complement one another. Tasks or task affordances may be adjusted to suit the capabilities of behaviour; behaviours may be modified to meet the demands of tasks. Task analysis, it is suggested, is a process of examining the human-task interaction in order to establish methods to ensure an appropriate ‘fit’ to meet system requirements, or to identify reasons why there is not an appropriate fit in a given operational configuration.

4. Analysing cognition within the task analysis context
Cognition is a crucial aspect of behaviour in tasks especially in connection with those associated with supervision and control of complex automated systems and with human-computer interaction. That specialist cognitive task analysis (CTA) methods should be developed and used throughout the course of a practical task analysis project is becoming an orthodoxy, but it is one that should be challenged on the grounds of economy of effort and the need properly to understand cognitive task elements in the wider task context.

Preece et al. (1994:417) have drawn a distinction between CTA and HTA, representing HTA as ‘concerned with establishing an accurate description of the steps that are required in order to complete a task’ whereas the focus in CTA is to ‘capture some representation of the knowledge that people have, or need to have in order to complete the task’. They point out that some actions are physical, such as
pressing buttons, and some are mental or cognitive, such as deciding which button to press or when to press it. Despite their distinction, successful performance in all tasks depends upon the interaction between physical and cognitive elements. Moreover, in a practical project, if part of a task is not critical, then it does not warrant attention, no matter how interesting it is from a cognitive perspective. Rather than distinguishing between cognitive and non-cognitive task analysis one might more profitably consider how a general task analysis strategy accommodates tasks where performance is driven substantially by cognitive factors.

Figure 2. Part of the Hierarchical Task Analysis of supervising an underground railway system. Each of the operations recorded here is further redescribed.
Several earlier attempts at producing CTA methods use task decomposition, similar in structure to HTA, but entailing assertions about how parts of the task description are represented. Thus a GOMS analysis (Goals, Operations, Methods and Selection rules; Card et al. 1983) requires the analyst to identify the rules for selecting methods for organizing operators to achieve goals. TAG (Task Action Grammar; Payne and Green 1986) entails coding actions according to rules of syntax to facilitate making comparisons between human-computer interfaces, for example. TAKD (Task Analysis for Knowledge Description; Diaper 1989) entails utilizing rules for knowledge elicitation against task descriptions. In several respects there are similarities between HTA and each of these other approaches. HTA deliberately avoided adopting constraining notations in order to maximize flexibility and to ensure that task descriptions could be understood equally by operational personnel and human factors staff. However, such notations could be incorporated in HTA should the analyst choose to do so. Thus, in different task analysis projects, the analyst might recognize the benefits of standardizing levels of description (as in GOMS) or expressing operations according to a particular notation (as in TAG) or recognizing that an important implication of plans is that there is a declarative knowledge base that may be generated to facilitate people learning a new task (as in TAKD). This is not to claim that HTA does what these other methods seek to do, but merely to point out that common forms of description are employed in different methods and that HTA may also be adapted in these ways. The important point about CTA methods is that their authors are attempting to exploit principles of cognition in their choice of constraints on task descriptions regarding, for example, the means by which syntax is parsed or the manner in which declarative knowledge is compiled to acquire skill. These methods attempt to do different things from one another and should be used by the analyst for different purposes, as the task analysis dictates. Important benefits of incorporating CTA within the HTA framework are economy of effort and in ensuring that the examination of task elements is not carried out in a vacuum.

More recently, approaches to cognitive modelling in support of CTA have attempted to develop what Kjaer-Hansen (1995:43) describes as ‘unitary theories of cognitive architectures’. These are more global theories that aim to understand cognition in terms of the role of knowledge within the processes of learning, inference and decision-making in producing behaviour, for example, SOAR (Laird et al. 1987) and ACT* (Anderson 1983). From a performance perspective, the unitary theories would account for the manner in which information is acquired, stored, organized and retrieved to account for decision-making and performance across a range of task elements. This perspective is important because despite the fact that tasks can be described in terms of separate goals, cognition is more widely influential and HTA frequently demonstrates the need to account for behaviours that interact across the task hierarchy.

One may distinguish between cognitive task elements, representing the problems with which operators or users are required to cope, and cognitive skills, concerned with operating upon information gained from the environment in order to guide subsequent physical actions. There may be no simple mapping of cognitive task elements onto cognitive skills, yet it is essential that task elements must be identified before skills can be examined. Otherwise it is unclear what these skills must achieve and there is no guidance for evaluating whether or not skills have been achieved.
Physical task elements are usually observable, whereas cognitive elements must be inferred by their relation to the observable actions of the task. Systematic variation of subsequent physical action implies that a decision has been made. The analyst needs to reflect carefully on how task elements interact before modelling underlying cognitive skills. In a nursing context, for example, engagement with the patient during routine care may provide crucial information for dealing with a subsequent crisis. Therefore, decision-making and routine care tasks cannot sensibly be analysed without reference to each other.

4.1. **Inferring cognitive task elements**

Cognitive task elements can be inferred through HTA by stating plans. If different actions are consistently carried out in different circumstances, then a decision process can be inferred that can feature as an operation as part of a redescription, even though decision-making was not apparent through observation or through talking to the operator. Similarly, if following a period of apparent inactivity an operator is seen to respond swiftly and appropriately to an unforeseen set of circumstances, it follows that the operator was monitoring a signal. A common work requirement is to maintain the status of a system—a refinery operator may ‘maintain correct product specification’; a railway supervisor may ‘maintain train headways’. To carry out these tasks implies that the target is monitored and then action is taken to rectify any deficiency. Remedial action could entail referring the problem to a colleague or making a simple correction. Alternatively it could entail a combination of *diagnosis, rectification, compensation and recovery*.

By inferring cognitive task elements within the context of a general task analysis it is also possible to identify what it is supposed to achieve. A monitoring task or decision-making task may vary considerably in accordance with demands placed on the person carrying out the task. This may be illustrated by reference to the case of a railway systems engineer, employed to monitor the health of the railway system in terms of trains running to timetable and whether assets (trains, track, escalators, etc.) are functioning correctly. If a problem arises the engineer needs to decide on a course of follow-up action. The nature of this decision depends on the courses of action permitted by management. The task is undertaken in a central control room, with maintenance teams deployed to undertake the work at the affected site. The demands on monitoring and decision-making will vary in accordance with the organization of work. In one form of work organization versatile technicians may deal with all the technologies of the railway—mechanical, electrical, electronic. The systems engineer would undertake an initial diagnosis, then brief a maintenance team. The initial diagnosis cannot be complete, because the central control room only enables limited access to information; inspection of local conditions is also necessary and this must be done by the maintenance team when they reach the site. Therefore, the engineer’s task is one of reduction of uncertainty to facilitate the search that the team will need to carry out when it reaches the site. In a second form of work organization maintenance teams are not multi-skilled but specialize in particular technologies. Here, the engineer must deploy the team most likely to deal appropriately with the problem. Deploying any team is costly. Should it transpire that the initial judgement was wrong, then these costs will have been wasted and the next hypothesis selected. Moreover, the judgement of whom to deploy will be a function of availability, costs, likely search time, likeliness of solutions and the severity of the incident. These judgements will be far more demanding than the simpler hypothesis reduction
needed in the first form of work organization where teams were multi-skilled. A further variant is that contractors are used to deal with all maintenance; the systems engineer merely monitors the contractors' response to events. This entails noting incidents, then awaiting telephone calls from the contractors' management to say that their teams are responding. The engineer's job would then simply be one of quality monitoring to ensure that the terms of the contractors' contract are being observed. Each of these variants entails monitoring and decision-making, but associated cognitive skills will be trivial or complex in accordance with the decisions and actions that follow. The task must be first understood to anticipate the demands placed on cognition.

Just as consideration of actions generates cognitive elements, so identification of cognitive elements points to actions to be included in the task analysis. An operator may report that, after 'checking the melting point of a substance', a standard fixed procedure is followed; observation of several instances of the task may appear to confirm this fixed procedure. However, checking or any other information gaining activity implies at least two outcomes—the system status is satisfactory or it is unsatisfactory. The invariant routine observed may simply reflect a reliable system where the unacceptable outcome is rarely encountered. If, on the other hand, remedial action is never necessary, then the checking action can be ignored. The only occasions when checking a parameter is a legitimate part of a fixed procedure is when the outcome is recorded for use by somebody else, for example, quality control. Task analysis should establish the interaction between cognition and action before making assumptions about the nature of cognition or, indeed, the necessity for action.

4.2. Inferring cognitive skills

Identifying a cognitive element in task analysis implies an underlying cognitive skill. Sometimes this skill is only concerned with a single task element identified through the task analysis. However, sometimes a more general skill must be understood to deal with the interaction between several task elements. In the tasks associated with delivering neonatal intensive care, represented in figure 3, each of the 11 sub-operations entails cognition of some kind—judgement, planning, or problem solving. Operation 1 entails procedures, but these may vary according to the condition of the baby. Operation 2 entails diagnosis and planning. The diagnosis component may entail collecting information to enable the diagnosis and selection of treatment. As treatment is delivered it is possible that the current treatment/care plan ceases to be suitable and needs revision (operation 4). This implies that a judgement is made continually to assess the adequacy of the current plan, hence operation 3 is inferred. The remaining operations may be treated in a similar manner. If the cognitive skills associated with each task element were examined separately it would not reflect the proper nature of the task. If a carer is responsible for all of these task elements in the care of a baby, then information may be gained deliberately or incidentally at various stages, and possibly stored for later use. Information is threaded throughout all aspects of this task to support planning and problem-solving. The skills and expertise of care, or indeed any systems supervision and control task, would need to be understood in terms of a more general cognitive system involving memory, inference, problem-solving and planning. It is for the conscientious task analyst to recognize these inter-relationships between the skills underlying task elements to avoid an oversimplification of the problem.
4.3. Cognitive task elements in context

Discussion of the railway system engineer’s task in § 4.1 indicated the importance of considering subsequent action in characterizing a decision-making task. There are further factors that influence performance of a cognitive task element.

4.3.1. Goal context: Goal context refers to the wider goals within which a task element of interest resides. Figure 2 represents the task of supervising the operation of a railway system. This is a complex task in the sense that there are many different things to do, several of which are interrelated. The individual task elements are not necessarily complex in themselves. The job is to ensure that the railway is running safely: timetables and reasonable distances between trains are maintained; problems are identified and dealt with; information is communicated to interested parties around the railway network. Taking one example, ‘Assess all consequences of possible changes {2.1.2.2}’ is carried out to contribute to ‘Review opportunities and resources for improvement {2.1.2}’, which is part of ‘Maintain standard of railway services {2.1}’, which is part of ‘Maintain best service {2}’, which is part of ‘Carry out service control on the line {0}’. The performance of two people carrying out this task will differ if their wider goal contexts differ. Thus, a supervisor standing in to help overloaded staff will be operating in a different context to a signalling assistant. The supervisor may adopt a strategy that supports immediate systems goals as quickly as possible to resolve the immediate congestion; the signalling assistant, who will still be on hand to deal with the consequences of the action when the crisis is over, may choose to act in a way to minimize work during a subsequent recovery activity.

4.3.2. Frequency, predictability and coincidence: The task analysis should indicate where frequency and predictability of events affect performance. The plans in HTA specify the cues for action; the actual occurrence of events will indicate the frequency
and predictability of these cues. This influences the choice of human factors solution. Response to predictable events can be automated, or proceduralized—at least personnel will be well prepared for these events and be on hand to respond. An uncertain task brings stress from uncertainty and, combined with infrequency, limits opportunity for practice. Such tasks are also often critical, for example, diagnostic tasks. Taking a task out of context of time and expectation may destroy much of what is important about the task.

Where events are unpredictable, several might occur together, causing extra workload. The HTA structure indicates, through the plans, where these coincidences might occur. For example, in figure 2, ‘Make section available {1.3}’ could be required at the same time as ‘Establish availability of trains…{1.4}’, ‘Modify services {2.1.3}’, ‘Review suitability of decision support options...{2.2.3}’, and many other combinations, because they are all driven by events that might coincide. Unless job-design solutions include increasing the size of operating teams, the underlying cognition required to cope with these events in combination may be insufficiently robust. Plans in HTA, together with a record of events, will indicate the performance criteria to be met.

4.3.3. Priming: If the operator is oriented towards a set of circumstances by just having carried out activities that always herald the new task demand, then performance will be primed. Some priming is procedural in the sense that it prompts the operator what to do next, and is made explicit in plans. Some priming is informational in that attainment of previous goals may provide information to the operator, which will be of use in later activities. Thus a doctor or nurse engaged directly in administering care or treatment would have a more thorough working knowledge of the patient than a staff member not similarly engaged and this is likely to affect diagnostic strategy in dealing with any crisis that might subsequently occur. Examining diagnostic skill out of context may be inappropriate.

4.3.4. Decision outcome: The issue of decision outcome has already been discussed in § 4.1 in relation to the railway systems engineer’s task. A diagnostic problem where the operator must distinguish between which of several specialist maintenance technicians need to be alerted is very different to one where the operator is required to determine the course of remedial action in terms of which pieces of equipment need replacing, and is very different to a binary choice of keeping a system operating or shutting down.

4.3.5. Criticality: Task criticality, discussed in box 3 in § 3.1.3, relates to the criteria of performance to be observed in any study of cognition and to whether attention to this particular task element is, indeed, justified.

4.4. Evaluating cognitive skill
A final necessary link between CTA and a form of task analysis that records operational requirements, such as HTA, is that practical insights gained from CTA, either problem hypotheses or design hypotheses need to be evaluated. Such evaluation must be informed by task requirements in terms of work goals and system events. Specification for such an evaluation will be derived from a task analysis that records system demands, rather than simply through modelling cognition.
5. Conclusions

The paper has considered two interrelated themes: (1) the justification of Hierarchical Task Analysis as a framework for analysing tasks, rather than as a method for modelling behaviour; and (2) the treatment of cognitive task elements within this framework.

The word ‘task’ is defined in terms of stating the problem that people with system responsibilities are charged with resolving. Thus task is treated as complementary to behaviour and not synonymous with it. Task analysis, it is suggested, is a process of examining the human-task interaction in order to establish methods to ensure an appropriate ‘fit’ to meet system requirements, or to identify reasons why there is not an appropriate fit in a given operational configuration.

Many developments in task analysis have added to the plethora of methods, requiring analysts to decide which methods to apply on different occasions. It is argued that making such choices should be integral to task analysis and not a precursor to it. A task analysis framework is presented that relates the various stages of decision-making encountered in a practical project, including identifying the task to be analysed, exploring constraints on solutions, exploring behaviours, cost-benefit analysis, and task redesignation. Working through this framework results in the hierarchy of operations and plans that characterizes Hierarchical Task Analysis. Thus, Hierarchical Task Analysis is justified as a general task analysis strategy rather than as a method for modelling behaviour.

All performance entails an interaction between cognition and action, so it is difficult to understand why some tasks are assumed, from the outset, to warrant a specialist form of cognitive task analysis, while others are not. Cognition should be treated within a general task framework, such that it can be understood in relation to action. Should a specialist method of cognitive task analysis or cognitive modelling be required in examining any particular aspect of task behaviour, then this will become clear as the task analysis develops. Identifying cognition within the context of a neutral task analysis will situate it within a task goal, it will indicate the extent to which task elements are carried out alongside other demands, it will indicate which activities influence performance by having gone before and which choice of actions will follow. Moreover, considering cognition within the context of a real task will indicate whether effort to examine it in detail really is justified.

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