Task Analysis, Cognitive Task Analysis, Cognitive Work Analysis: What's the Difference?

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TASK ANALYSIS, COGNITIVE TASK ANALYSIS, COGNITIVE WORK ANALYSIS: WHAT'S THE DIFFERENCE?

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The term cognitive task analysis (CTA) has been appearing in the human factors literature with increasing frequency. Others have used the term cognitive work analysis (CWA). Is there a difference? Do either of these methods differ from traditional task analysis (TA)? If so, what advantages can CTA/CWA provide human factors engineers? To address these issues, the history of work analysis methods and the evolution of work are reviewed. Work method analyses of the 19th century were suited to manual labor. As job demands progressed beyond the physical, traditional TA was introduced to provide a broader perspective. CTA has since been introduced to increase the emphasis on cognitive task demands. However, CTA, like TA, is incapable of dealing with unanticipated task demands. CWA has been introduced to deal with complex systems whose demands include unanticipated events. The initial evidence available indicates that CWA can be applied to industry-scale problems, leading to innovative designs.

INTRODUCTION

During recent years, the term cognitive task analysis (CTA) has been appearing in the human factors literature with increasing frequency. Others have used the term cognitive work analysis (CWA). Is there a difference? Do either of these methods differ from traditional task analysis (TA)? If so, what advantages can CTA or CWA provide to human factors engineers? To answer these questions, the history of task analysis and the evolution of human work will be briefly reviewed. To anticipate, this paper will argue that CWA differs substantially from TA and also from CTA, and that these differences lead to unique benefits that have important practical implications for human factors designers and researchers.

HISTORICAL OVERVIEW

Although human factors is generally considered to have been born during World War II, TA has a longer history dating back to the early days of industrial engineering. The work methods analyses pioneered by Frederick Taylor at the end of the 19th century (see Hammond, 1971) were a primitive but seminal form of TA. Taylor's concern with trying to maximize production led him to ask the question, "What is the best way to do this job"? For instance, one of his studies focused on the shoveling and handling of pig iron. Taylor systematically examined the effect of shovel size on production, and found that if the shovel was designed to lift 21.5 lbs of material then daily tonnage would be maximized. He also adapted the size of the shovel to the unique characteristics of different materials to be lifted. These design modifications, which resulted from systematic work methods analyses, cut the cost of shoveling by half. This and other applications of systematic work methods analyses were very successful in maximizing production by identifying "the one best way" to perform the task.

Taylor's seminal development of work methods analysis was therefore readily adopted in many industrial contexts (although later, his ideas were justly criticized for their mechanistic view of human workers). However, as the shoveling example shows, the initial application of work methods analysis was centered around physically demanding, manual labor. This was consistent with most jobs of that time, but gradually the nature of human work began to evolve to a point where people's job responsibilities became more complex in nature, requiring more than just physical force. Thus, new methods were required to analyze the new types of demands being imposed on workers.

This led Miller (1953) to develop a broader method for conducting TA that describes task demands as a function of system inputs and outputs. Miller's original ideas were subsequently modified and extended, and were widely applied, especially in the military. Thus, Miller's work lead to traditional TA, as it is widely known in the human factors community (e.g., Meister, 1985). This class of methods has proven itself over time to lead to valuable insights that have direct implications for design, training, and selection.

The TA methods advocated by Miller represented a step beyond the work method analyses introduced earlier by Taylor. More specifically, they were intended to cover a much broader range of task demands. However, there is one sense in which these TA methods are identical to Tayloristic work methods analyses - they still primarily focused on "the one right way" to perform the task. That is, traditional TA attempts to identify a single temporal sequence of (primarily overt) behaviors, including decision points, for performing a task. This task description provides the normative way in which the task is to be performed.

This simple observation has enormous implications. The assumption that there is one right way to do the task is probably a good approximation for work domains where tasks are highly proceduralized. In fact, TA has been primarily applied to such domains. However, in more complex domains where more degrees of freedom are available, operators are forced to deal with discretionary tasks that can be solved in a number of equally acceptable ways. As a result, one finds that under these conditions, there is a great deal of variability in behavior. The same task can be accomplished via a large number of different sets of operator actions.

There are at least three factors which lead to variability in behavior: changes in initial conditions, unpredictable disturbances, and the use of multiple strategies. First, because it is often not possible to predict the exact state that the system will be in when a particular task will be performed, it is very difficult to anticipate what actions need to be carried out to achieve the desired goal state. Furthermore, it may not even be possible to anticipate what the instigating event requiring action will be (e.g., unpredictable faults in process control plants). In these situations, it is virtually impossible to conduct a traditional TA identifying a single sequence of behaviors. Second, in open systems that are subject to external disturbances, there will again be a great deal of variability in performance because the operator must counteract the disturbance to satisfy system goals. Since the disturbance is unpredictable, the operator's compensatory actions also cannot be predicted. Third, it has also been empirically demonstrated that the same task can be performed in very different ways, as a function of the strategies adopted by operators (Rasmussen, 1986). This means that behavior will vary as a function of the operators' preferred strategies, both within and across individuals. These factors will be more influential in complex and open-ended work domains where demands are primarily cognitive in nature. For example, in investigating how expert technicians trouble-shoot electronic equipment, Rasmussen (1986) found that no two sequences of actions were identical, even though subjects were performing the same task every time. Traditional TA cannot capture such rich behavior because the concept of "the one right way" becomes untenable.

COGNITIVE TASK ANALYSIS

With the increasing trends towards computerization and centralization of complex human-machine systems, the nature of work changed yet again. For example, in some systems, the role of the human operator changed from one of active controller, requiring primarily perceptual-motor skills, to a supervisor of automated equipment, thereby requiring more conceptual knowledge and cognitive skills. Thus, the evolution of work led to a greater demand for decision making and problem solving, thereby increasing the discretion and therefore the variability in operator behavior. Since traditional TA focuses on "the one right way", it is not very effective in capturing these cognitive components of work.

This led several researchers to develop novel methods, known as cognitive task analysis (CTA), that try to account for the variability in behavior caused by differences in knowledge and cognitive strategies. Examples of such methods include: critical decision method (Klein, Calderwood, & MacGregor, 1989), operator function modelling (Mitchell & Miller, 1986), and conceptual graph analysis (Gordon, Schmeirer, & Gill, 1993). Despite the common label, CTA, there are strong differences between these methods. Perhaps because CTA is a comparatively recent innovation, there is no agreed upon standard. However, these methods do share at least one property: they all focus on the tasks and actions required to achieve system goals. This is very important because it means that methods of CTA suffer from some of the same limitations as traditional TA methods.

Because CTA focuses on tasks, like TA, it cannot possibly hope to deal with situations that have not been anticipated by system designers (Vicente & Rasmussen, 1992). If one cannot anticipate the instigating event, how can one possibly know what tasks are even required, let alone identify the cognitive components of the tasks? Thus, while methods of CTA certainly overcome the lack of emphasis given to problem solving and decision making in traditional TA methods, they do not provide a basis for dealing with unanticipated events. Depending on the domain that one is designing for, this may or may not be acceptable.

COGNITIVE WORK ANALYSIS

As systems have become more complex in nature, the greatest threat to system safety has become events which are unfamiliar to operators and have not been anticipated by system designers (Vicente & Rasmussen, 1992). Neither TA nor CTA can deal with this type of demands. Thus, cognitive work analysis (CWA) was developed to fulfill this need.

As the name would indicate, CWA shifts the focus of analysis from tasks to include work domains as well. This distinction is an important one. In any work domain, many tasks need to be conducted, some of them unanticipated. Tasks are what operators do, whereas work domains are what operators act on. Tasks are event-dependent in that they are identified for specific classes of events, whereas work domains are event-independent in that they are the systems that operators have available to them, regardless of the event. By focusing on the functional structure of the work domain (in addition to tasks, strategies, and knowledge), one can design for unanticipated events (Vicente & Rasmussen, 1992).

Rasmussen (1986) has developed a framework for CWA that is the most coherent and comprehensive available. The focus of this framework is on identifying the constraints that shape behavior, rather than trying to predict behavior itself. Rasmussen's framework provides separate descriptions of different classes of constraints: (1) the functional structure of the work domain in which behavior takes place, (2) the generic tasks that are to be accomplished, (3) the strategies that can be used to carry out those tasks, and (4) the competencies required of operators to deal with these demands (organizational constraints are also addressed, but these will not be discussed here). Therefore, CWA can be viewed as a complement to TA and CTA in that it retains the benefits of each of these methods, but also adds the capability for designing for the unanticipated.

APPLICATIONS TO HUMAN FACTORS RESEARCH AND DESIGN

The framework for CWA just described is not just an academic pipe dream. It has led to important insights for both human factors research and human factors design. The relevance of CWA to research is discussed in Vicente (in press). Consequently, the focus here will be on discussing the applications of CWA to design in industry.

Unanticipated events play a significant role in the nuclear industry, thereby making it a prime candidate for CWA. Reviews of accident reports have made it clear that events that are unfamiliar to operators and that have not been anticipated by system designers pose the greatest threat to the safety of nuclear power plants (see Vicente & Rasmussen, 1992). Thus, it is absolutely critical that the control room interface support operators in adapting and improvising a solution to these challenging situations. As already mentioned, CWA tries to accomplish this objective by analyzing the structure of the plant itself, independent of the tasks that need to be performed. Basing the interface on such a representation can lead to a description of the objectives that are to be satisifed by the plant, and the various means (e.g., functions, subsystems, components) that are available to achieve those objectives, as well as the complex mappings between the two. This type of interface should provide operators with an informational basis for coping with unanticipated events.

These abstract ideas can be made more concrete by discussing the application of CWA to the nuclear industry implemented by Toshiba in Japan (Monta et al., 1991). Designers at Toshiba have adopted Rasmussen's framework for CWA to conduct a thorough analysis of the work domain. This CWA, in turn, has been used to design a prototype control room interface that is intended to support operators during unanticipated events. Because an important part of CWA involves analyzing the system itself (rather than just predicted operator actions), several of the Toshiba displays are innovative in that they represent the plant in novel ways that are not currently found in existing plant control rooms. For instance, the Toshiba design contains a representation of the plant in terms of the different functions of the Rankine heat engine cycle. It also contains representations of the plant in terms of the conservation laws of mass and energy. By basing the design of the interface on goal-relevant plant constraints, and not just normative sequences of behaviour, the design can help operators in situations for which there are no normative procedures. For example, the representations based on first principles provide a basis for reasoning with any type of disturbance, since the conservation laws always hold. The important work conducted by Toshiba thereby shows that CWA can in fact be applied to large-scale problems that are representative of those found in industry. It also shows that the application of CWA can lead to innovative designs.

In summary, while far from being widely adopted, CWA has been applied to significant research and design problems. It is important to point out, however, that CWA is not just relevant to the nuclear industry. Unanticipated events leading to variability in operator behavior can be found in an increasing number of domains. For example, work demands associated with flexible manufacturing systems are notoriously turbulent and unpredictable. In order to achieve effective performance in such systems, a design must support "agile", adaptive behavior. This, in turn, requires a method of analyzing the domain demands in a way that accommodates unanticipated events. It should not be a surprise, therefore, that CWA is beginning to be applied to the manufacturing domain (Kinsley, Sharit, & Vicente, 1994; Rasmussen et al., 1994). CWA has also led to the design of a very innovative and highly successful information system for retrieving fiction books from public libraries (Rasmussen et al., 1994). Thus, CWA is relevant to a wide variety of application domains.

CONCLUSIONS

The history of work analysis methods has reflected the evolution of human work. Taylor's work method analyses were best suited to the demands imposed by manual labor. As job demands progressed beyond the domain of the physical, traditional TA was introduced to provide a more comprehensive tool. TA has proven itself for domains whose demands are relatively proceduralized. CTA has been introduced as a means for providing greater emphasis to the cognitive components of task demands, and the different strategies that can result from such demands. However, CTA, like TA, is not capable of effectively dealing with unanticipated task demands. This has lead to an expansion in the scope of analysis, from focusing exclusively on tasks to the explicit investigation of the functional properties of work domains. Rasmussen's framework for CWA is a multi-layered framework that can be used in the design of complex industrial systems whose demands include unanticipated events. Although a great deal of testing remains to be done, the initial evidence available indicates that CWA can lead to truly novel and successful designs.

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