# Analysis of Cognitive Work for Large-Scale Socio-Technical Systems

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**Abstract**. Large-scale socio-technical systems are cognitive systems and function as such through the individual and collaborative cognitive work of the humans in the system. As major systems have become more information intensive and more distributed, the difficulty of addressing cognitive challenges has become a troubling area for systems acquisition. The discipline of cognitive systems engineering has methods and tools that can be brought to bear on this problem. In this paper I outline two analytic frameworks that have been developed within cognitive systems engineering for design of cognitive work and illustrate how their tools and methods can be deployed to develop the cognitive content of products currently required by the US defense acquisition management framework. The strategy I propose for development of cognitively-relevant functionality of large-scale systems is to replace inadequate methods currently in use with the more effective and efficient methods from cognitive systems engineering.

## Introduction

Large-scale socio-technical systems are cognitive systems and function as such through the individual and collaborative cognitive work of the humans in the system. As major systems have become more information intensive and more distributed, the difficulty of addressing cognitive challenges has become a troubling area for Systems Engineering. The discipline of cognitive systems engineering has methods and tools that can be brought to bear on the challenge of designing system functionality that will support human participants as the undertake the essential cognitive work.

While the specialty area of Human Systems Integration is intended to resolve issues of cognitive design as well as other Human Factors issues, I generally find the cognitive design work undertaken within the framework of this specialty area to be unprincipled and insubstantial. In particular, insights generated over the past 20 years within the discipline of Cognitive Systems Engineering do not have any worthwhile level of visibility within Systems Engineering.

In this paper, I will describe some of those insights and outline some of the analytic and design methods that that will help us take advantage of those insights. I will commence by defining important terms and then outline important features of the practice of Cognitive Systems Engineering and discuss the distributed nature of cognitive systems. I will outline two popular frameworks for Cognitive Systems Engineering. While these two frameworks are viewed as competitive frameworks within the discipline of Cognitive Systems Engineering, I will argue that Systems Engineers will be better served by viewing them as complementary. Finally, I will illustrate how each of these frameworks can be fitted into existing Systems Engineering processes to contribute to the design of large-scale socio-technical systems.

# Cognitive Systems Engineering Frameworks

For those who are unfamiliar with the discipline of Cognitive Systems Engineering, its array of frameworks and methods can be confusing. Cognitive Systems Engineering frameworks offer different tools that can be brought to bear on the design of technological functionality for the support of human work. No single framework or method can satisfy all essential requirements in the development of large-scale socio-technical systems.

All Cognitive Systems Engineering frameworks take a characteristic approach (Figure 1). Essentially, the challenge is to first elicit knowledge about the work that must be supported (primarily through analysis of how the work is accomplished) and of the constraints of the work environment. That knowledge must then be represented or summarized in a form that supports the design effort. Finally, prototypes are built (often, computer-based models) and evaluated (often, human-in-the-loop simulation with the prototype). The final stages of this process (prototyping and evaluation) are already well-known in Systems Engineering and I will say no more about them in this paper. The first two stages of this process (knowledge elicitation and knowledge representation) offer ideas, not well-known in Systems Engineering, that have the potential to strengthen systems acquisition.

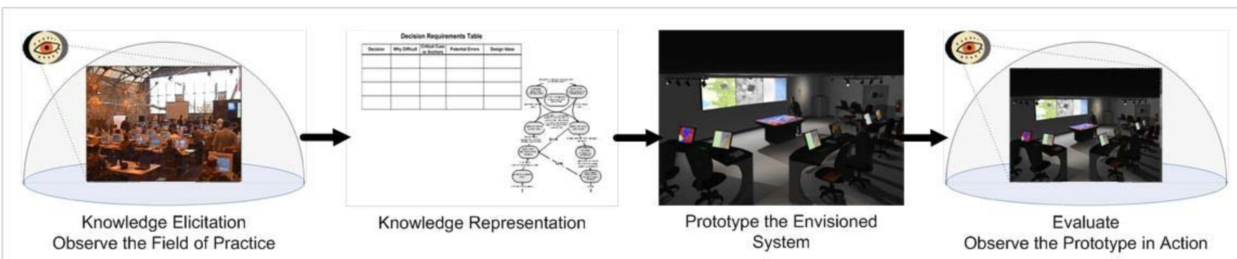


Figure 1: The cognitive design process

There are many methods for knowledge elicitation but all fall into one of four basic themes; document analysis, interview, observation or scenario simulation. The variations on these themes should not be neglected but I do not explore them systematically in this paper. The product of the knowledge elicitation phase is a detailed and specific description. The purpose of knowledge representation is to abstract that description in a manner that highlights the critical information and points to potential design solutions.

There are, as for knowledge elicitation, many methods for knowledge representation. Some are principled in the sense that they are guided by cognitive theory but others are unprincipled, being developed primarily to summarize information in a convenient way with an eye to the design problem. A principled representational form offers the benefit that it can be validated internally (the concepts and the relationships between them must be consistent with the guiding cognitive theory) but in application, the link to the design problem is often obscure. In contrast, those who develop representational forms without a connection to cognitive theory often do so with the design problem uppermost in their minds. There is a largely unrecognized challenge within Cognitive Systems Engineering to combine the strengths of these two approaches.

## Cognitive Systems are Distributed

Traditionally, we are used to thinking of cognition as an activity of individual minds but Hutchins (1995), and more recently, Hollan, Hutchins and Kirsh (2000), have argued that cognition is a joint activity that is distributed across the members of a work or social group and also across the available work artifacts. Cognition is distributed spatially so that diverse interactions with cognitive products and work artifacts shape cognitive processes. Cognition is also distributed temporally so that products of earlier cognitive processes can shape later cognitive processes. Most significantly, cognitive processes of different workers can interact so that new cognitive capabilities emerge via the mutual and dynamic interplay resulting from both spatial and temporal coordination among distributed human agents. A foremost claim of this view is that distributed cognition is not a theory about a special type of cognition but rather a theory about fundamental cognitive structures and processes (Hollan et al, 2000). Thus, all cognition is distributed.

A (distributed) cognitive system is one that dynamically reconfigures itself to bring subsystems into functional coordination. Many of the subsystems lie outside individual minds; interactions between people as they work with external resources are as important as the processes of individual cognition. Both internal mental activity and external interactions play important roles as do physical resources that reveal relationships and act as reminders. A distributed system that involves many people and diverse artifacts in the performance of cognitive work is therefore properly viewed as a cognitive system.

The theory of distributed cognition forces a shift in how we think about the relationship between minds, social interactions and physical resources. Interactions between internal and external processes are complex and unfold over different spatial and temporal scales and neither internal nor external resources assume privileged status. This view of cognitive systems as distributed is now accepted almost universally within Cognitive Systems Engineering and enables the generalization to teams and organizations of cognitive concepts normally used in discussion of individuals. Thus, we can speak comfortably of concepts such as a team mind and organizational knowledge.

## More on Cognitive Systems Engineering Frameworks

There are several major frameworks within Cognitive Systems Engineering that represent different ways of resolving a conceptually similar problem, that being to design systems for the support of cognitive work. They are frameworks rather than methods because they are global constructs that frame suites of methods and specific theoretical constructs. Within a systems acquisition context, these frameworks can be thought of as a Cognitive Systems Engineering tool set. The two dominant frameworks are those of Cognitive Task Analysis and Cognitive Work Analysis.

The primary titles of these two frameworks differ only in the second word, *task* versus *work*, and so it is useful to distinguish these two terms. A *task* is something to be achieved, in other words, an outcome (Crandall, Klein & Hoffman, 2006). *Work* is a constellation of responsibilities and activities which is specified in terms of behavior shaping constraints (Vicente, 1999). There is some dissension within the discipline of Cognitive Systems Engineering about whether we should be analyzing tasks or work, work being a more global construct than task.

Also note that both frameworks analyze tasks but for Cognitive Task Analysis that is the focus of analysis whereas for Cognitive Work Analysis it is only a part. One continuing sources of dissension between practitioners of the two frameworks is a disagreement about what constitutes a task. In promoting the framework of Cognitive Work Analysis, Vicente (1999) defines task to mean actions that can or should be performed to achieve a particular goal. He argues that instead of analyzing tasks we should be analyzing control tasks, which he defines as goals that need to be achieved, independently of how they are to be achieved or by whom. However, as noted in the previous paragraph, Crandall, et al (2006) define task as something to be achieved, which is not all that different to Vicente's definition of control task. Thus the dissension on this issue is based on a misunderstanding, which leaves only the dissension about whether we should focus on the analysis of tasks or whether we should focus on the analysis of work (which includes analysis of tasks) as the single substantive point of disagreement.

I will describe each of these frameworks in more detail in the two forthcoming articles of this series and will argue that Systems Engineers would do well to think of them as complementary rather than competitive frameworks.

## *Recognition-Primed Decisions & the Critical Decision Method*

The field research of Klein (1989) on expert decision making generated widespread interest in Cognitive Task Analysis. As more recently reported in Klein (1998), he was interested in understanding how operational experts applied rational decision methods in time-stressed and critical situations. At that time, rational decision methods in which decision-makers would assemble several options and then select the most appropriate through some sort of semiquantitative evaluation, were thought by many to be the basis of all decisions. Klein discovered that his operational experts rarely used a decision method that could be characterized as rational. Rather, they made decisions by recognizing and acting on familiar situational elements.

The result of this work was the Recognition-Primed Model of decision-making (Figure 2). As its name implies, decisions flow from recognition. One or more critical elements of a situation are recognized as being similar to something experienced previously and that recognition encourages development a course of action similar to one that had been effective on the previous occasion. Klein's operational experts did not, it seems, compare options at any point in the decision process.

Some variations on the recognition-primed theme have been observed. In some cases, an expert mentally simulates the likely outcome of an action prior to execution to confirm it will work . If that mental simulation indicates a positive outcome, the expert proceeds, but if not, s/he may refine the course of action or may discard it and review the situation in order to identify a more appropriate course of action.

The implication of this model for time-stressed, critical decisions at least is that, rather than being concerned with computational cognitive processes, we should identify the information that guides decisions, the sort of experience that builds expertise and the mental models that help people evaluate whether a planned course of action will be effective. The Recognition-Primed Model of decision-making constitutes a revolutionary departure from the received theoretical perspective on decision making and offers radically contrasting implications.

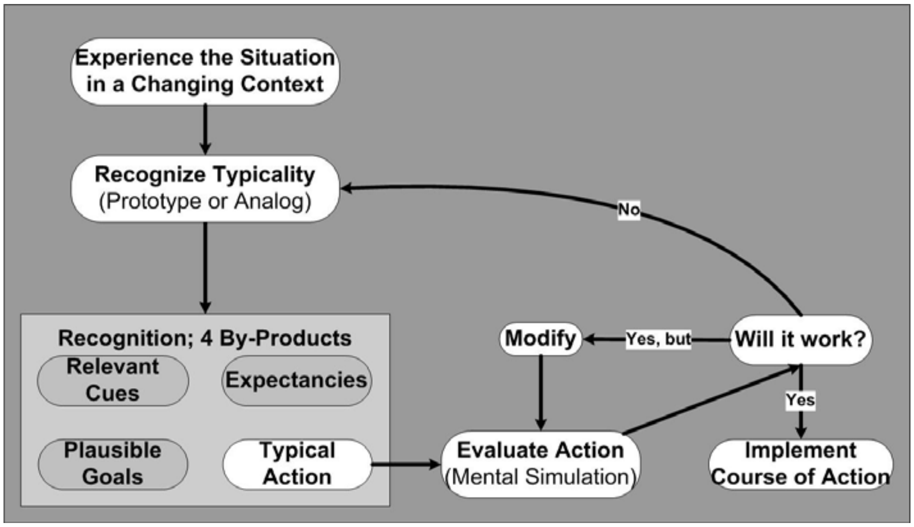


Figure 2: The Recognition-Primed Decision Model

Knowledge elicitation for Recognition-Primed Decisions uses a Critical Decision Method in which an interviewer elicits information about cognitive functions such as decision-making, planning and sense making within a specific challenging incident. An operational expert is asked to describe decisions s/he made during an incident and also describe the information and rules of thumb s/he used during the decision process. S/he is further asked to identify situational features that might have made decisions difficult and situational elements that characterized the incident as familiar. The interviewing team (usually two, an interviewer and a recorder) works through four sequential sweeps; incident identification, time-line verification, deepening and *what if* probes. Note that an operational expert is always asked to recount an actual incident.

Those with experience in this method see less value in asking about hypothetical incidents. The conceptualization of Recognition-Primed Decisions and the development of the Critical Decision Method for knowledge elicitation brought a new vitality to the analysis of cognition in operational environments. Much of what had gone before in cognitive science had proven to be of limited relevance to human work environments and, indeed, misleading. There had already been much discussion about cognitive behavior in the field, but Recognition-Primed Decision theory was the first conceptualization to bring with it a focused method of knowledge elicitation. This eminently pragmatic combination of conceptualization and method quickly became established as a powerful presence in applied cognitive research and became one of the motivating forces in the establishment of Cognitive Systems Engineering.

## *Macro-Cognition, Micro-Cognition, Meta-Cognition*

Several other techniques for knowledge elicitation have been developed as this framework has become established but possibly the most valuable development in recent times is the popularization of the concept of macro-cognition, the cognitive functions and processes employed in operational work settings. Figure 3 (left panel) depicts what is evocatively known as a macro-cognitive cheese wheel; macro-cognitive functions are represented in the upper half of the figure while macro-cognitive processes are represented in the lower half. Note that there is no canonical macro-cognitive cheese wheel; different operational contexts will demonstrate a different constellation of functions and processes.

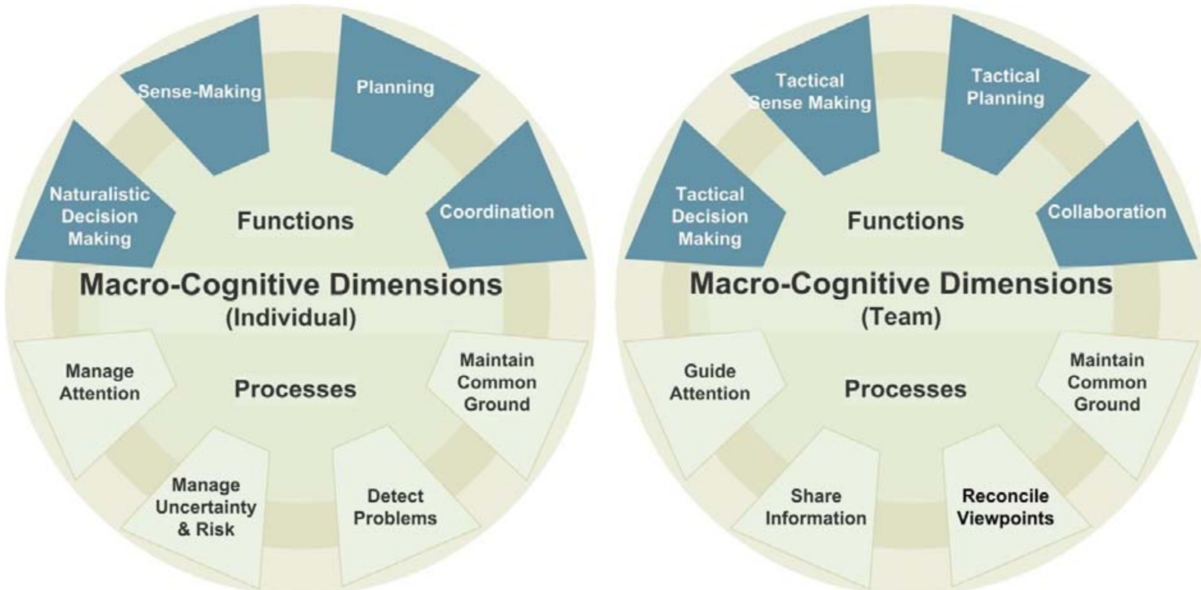


Figure 3: Illustrative macro-cognitive cheese wheels for individuals (left) & teams (right)

Macro-cognition is to be distinguished from micro-cognition, the cognitive functions and processes examined in cognitive research laboratories. Meta-cognition, a concept also invoked in the framework of cognitive task analysis, refers to the cognitive appraisal of own cognitive function.

## *Decision-Centered Design*

Cognitive task analysis is directed at developing cognitive support systems and at developing efficient and robust team cognition. The process, as depicted in Figure 4, has five steps, preparation for the interview, knowledge elicitation, representation of decision requirements, generation of design concepts and prototype design.

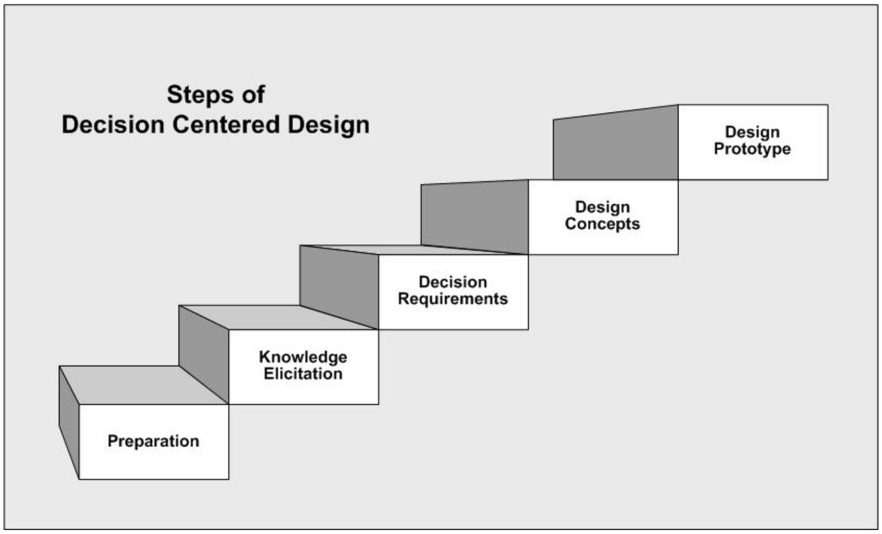


Figure 4: The steps of Decision-Centered Design

The form of knowledge representation generally used in Cognitive Task Analysis and Decision-Centered Design is a table with four to seven columns. The number of columns and their headings is adapted to the needs of the particular project but the example provided in Figure 5 is typical. The method of knowledge elicitation, often the Critical Decision Method, gathers the information required to populate this table, which is then used as a guide for generating design concepts and for designing a prototype.

| Decision | Why Difficult | Critical Cues or Anchors | Potential Errors | Design Ideas |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Figure 5: A Decision Requirements Table

## *Team Design*

The methods of Cognitive Task Analysis and Decision Centered Design, first developed for individual cognition, have been applied to teams. Macro-cognitive functions such as tactical decision-making, tactical sense making, tactical planning and collaboration are identified as are supporting processes such as guidance of attention, sharing of information, reconciliation of viewpoints and maintenance of common ground. Figure 3 (right panel) depicts a macro-cognitive cheese wheel developed from analysis of team decisions.

The work of Klinger and Klein (1999), who sought to improve the effectiveness of an emergency response team within a nuclear power plant, offers a cogent illustration on the value of this approach to the analysis of teamwork. By use of team probes such as "What tasks are not finished?", "What are the essential handoffs and transactions?" and "Who are the key decision makers?", they identified macro-cognitive team functions such as communication of intent and maintenance of shared situation awareness and also meta-cognitive team functions such as collaborative monitoring of team effectiveness.

As a result of this analysis, Klinger and Klein recommended that the layout of the emergency situation room be reorganized, that human roles and functions be clarified, and that staffing assignments be rationalized through consolidation of positions (thereby leading to a reduction in staff). Once implemented, these recommendations led to a dramatic improvement. There was noticeably less noise and confusion during exercises. Paradoxically, workload in this high intensity environment decreased despite the reduction in staffing. Furthermore, those responsible for key decisions were able to expand their time horizon and think ahead instead of continually reacting to events. Despite the fact that Klinger and Klein were responding to a work statement that requested recommendations for new technology to reduce workload, these marked improvements in the team effectiveness resulted entirely from non-technological interventions.

## *Cognitive Work Analysis*

Cognitive Work Analysis is a multi-stage analytic framework for identifying the human-relevant work constraints in a socio-technical system (Vicente, 1999) in the form of:

- The Hierarchical Structure of work in terms of the activity-independent constraints of the work domain at several levels of abstraction and decomposition (Work Domain Analysis),
- The Partitioning and Organization of work in terms of Work Situations and Work Problems (Work Organization Analysis),
- The Cognitive States typically established in the execution of work problems and the cognitive processes used to transition through states (Work Task Analysis)
- The cognitive strategies, defined as the categories of cognitive processes, used to transform one cognitive state into another (Work Strategies Analysis)
- The coordinative processes that support management and collaboration of work (Organizational Coordination Analysis), and
- Categories of human cognitive processing in terms of skill, rules and knowledge (Cognitive Processing Analysis).

The foundational assumption of Cognitive Work Analysis is that workers in a complex system operate within a large number of constraints. They remain free to act flexibly within those constraints and free, therefore, to act flexibly in response to unanticipated situations. The purpose of Cognitive Work Analysis is to identify and map out those constraints so that design efforts may take explicit account of them.

The products of Cognitive Work Analysis are knowledge representations (Figure 6) of the work domain, of individual and collaborative activities undertaken in the work domain, and of processes involved in the execution of those activities. These representations are developed from information gathered by use of cognitively oriented knowledge elicitation tools. The goal of Cognitive Work Analysis is to identify the basic sources of regularity or constraint, both contextual (technological, social, environmental) and human (intentional, perceptual, cognitive, active) that shape human action in a workspace.

### *Functional Interfaces, Functional Workspaces*

Although Cognitive Work Analysis is not a method of design, its analytic products can be used to support any design method. Those who undertake Cognitive Work Analysis typically adhere to the principles of Ecological Interface Design (e.g., Dinadis & Vicente, 1999). An ecological interface is one in which information is structured in a manner that reflects the structure of the cognitive work (Tufte, 1997) so that it is readily assimilated and so that there are natural transitions between information elements. An ecological interface reveals to the operator the operation of underlying system processes, the interactions between system states, and the constraints on control actions.

A conventional interface displays the status of sensed system states as independent parameters. The operator then has the task of integrating those parameters into a meaningful interpretation of system function, a task that is cognitively demanding and that may be impossible under tight time constraints. While an ecological interface presents more information than a conventional display, it does not overload the operator because that information is integrated across levels of abstraction and the display supports a natural and compatible navigation that allows the operator to converge naturally on currently important constellations of information. Thus, an ecological interface reduces complexity of activity but it does not do that by reducing the complexity of the information but rather by managing it.

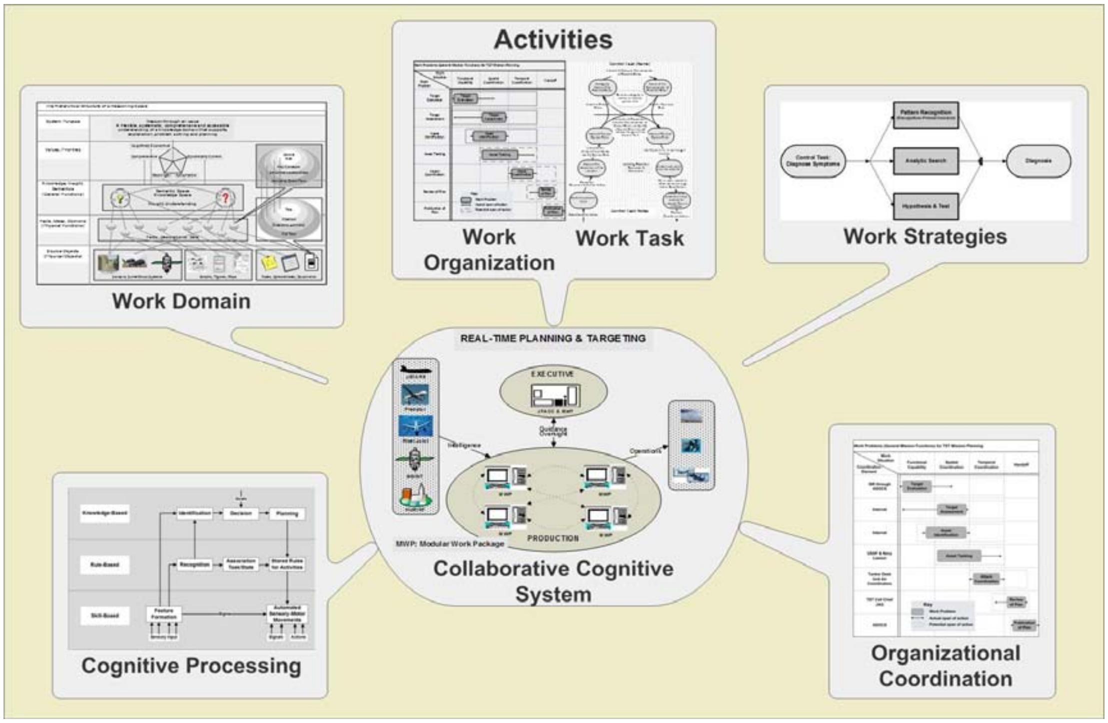


Figure 6: The stage products of Cognitive Work Analysis are theory-based representations that guide the design of cognitive systems

This strategy is commonly referred to as Ecological Interface Design because of its allegiance to the principles of Ecological Psychology. In my work, I have referred to this design process as Functional Interface Design (Lintern, Waite & Talleur, 1999) because the emphasis is on meaningful information that supports functional action versus data that must be interpreted. The most direct way of providing meaningful information is through display of affordances, where an affordance is defined as the ratio between what is required and what is possible (Lintern, 2000). For example, instead of showing fuel quantity, an affordance-based display will show the ratio between the distance that must be traveled and the distance that can be traveled given the remaining fuel. As might be obvious, if this ratio is not > 1.0, the required distance cannot be covered with the available fuel. The interpretation of such a display is direct and immediate.

In systems engineering however, we are less concerned with pieces of information than we are with constellations of information as they support cognition and action. Functional displays must be assembled into functional interfaces where the displays are not merely placed in a convenient arrangement but the information from the variety of sources is integrated to encourage seamless navigation to and foregrounding of that particular and specific constellation of information that bears on the current problem. As suggested above, the goal is not to reduce the complexity of the information space but to manage it in a manner that reduces the complexity of the activity or, at least, reduces the overhead work of finding and organizing within a complex set of information.

Additionally, if information is to be at all useful, it must lead to action. To that end, functional interfaces must be integrated with action support systems so that the interplay between analysis and execution is seamless. For example, a predictor display for aircraft control (Lintern, Roscoe, Koonce & Segal, 1990) will alert the pilot when action is required, will reveal the nature of the corrective action, and will show whether any action taken will return the aircraft to the desired flight path. This view of functionally integrated interfaces and controls leads naturally to the conceptualization of a functional workspace.

### *Cognitive Systems Design*

Within the context of large-scale socio-technical systems, interface (or workspace) design constitutes only a part of the problem and in that context I prefer to speak of Cognitive Systems Design. We know well that individuals as cognitive systems perform at diverse levels of effectiveness.  Furthermore, a committee of disparate individuals is also a cognitive system but many committees are not particularly effective; they often develop a mediocre product. Systems Engineers design distributed collaborative systems as in, for example, a net-centric command system. In the terms I describe here, a net-centric command system is a cognitive system. Whether by default or intent, we are designing cognitive systems and we should be designing good ones.

An effective cognitive system, whether it be an individual, a team or an organization, will make good decisions and plans and will execute courses of action in a timely and effective manner. That requires access to suitable information and to suitable action capabilities as would be provided by a well-configured functional workspace, but it also requires functional structures and coordinating capabilities that encourage effective cognition (and that discourage the opposite).  Team and organizational cognition emerge via the the coordinated collaboration of individuals and the effective use by participants of technological artifacts.  Design of such systems requires cognitively oriented analyses of information processing and coordinative functions. At the very least, where the individuals are geographically distributed, the communications systems must support the types of interactions that are essential to functional coordination.

## Frameworks for Cognitive Analysis; Tasks or Work?

Remarkably, interest in these two frameworks, Cognitive Task Analysis and Cognitive Work Analysis, emerged within the same time period. The work in the Cognitive Task Analysis commenced largely with the insights generated by Klein (1989).  It has, however, become evident that these early insights were addressing only a part of the problem and so Cognitive Task Analysis has continued to evolve over the past 20 years from that powerful insight about recognition-primed decisions. It currently constitutes a more comprehensive suite of methods that can be used to address diverse cognitive functions. In contrast, Cognitive Work Analysis was first presented as a comprehensive system (Rasmussen, 1986) and although considerable work has been undertaken throughout these past 20 years on refining it and extending its application areas, its structure  remains largely as it was first described.

At their inception, neither framework addressed design explicitly but considerable work has been undertaken through the past decade to address this neglect, resulting in the strategies of Decision Centered Design for Cognitive Task Analysis and Ecological Interface Design for Cognitive Work  Analysis.

Those working with the framework of Cognitive Task Analysis have developed innovative methods of knowledge elicitation but their approach to knowledge representation has been opportunistic. Many of these representations have been developed with an eye to linking directly to the design problem. In contrast, those working in the framework of Cognitive Work Analysis have been opportunistic in their approach to knowledge elicitation but the approach to knowledge representation has been more principled and systematic, with many of the representations reflecting the structure of underlying theory although linking less directly to the design problem.

As might be imagined from my earlier comment that those with experience in the use of the critical decision method prefer to work with actual rather than hypothetical incidents, Cognitive Task Analysis has largely been directed towards improving existing systems. In contrast, the literature on Cognitive Work Analysis emphasizes the design of future systems. Nevertheless, there is no principled distinction between the two frameworks on this dimension; those working within the framework of Cognitive Task Analysis do sometimes apply their methods to the design of future systems by generalizing lessons construed from their analysis of current systems while Vicente (1999), in his treatment of Cognitive Work Analysis, allows that the study of current practice can inform an analysis oriented towards the design of future systems.

Finally, the framework of Cognitive Task Analysis is geared towards identifying points of leverage for design and towards designing cognitive support systems. In contrast, the framework of Cognitive Work Analysis takes a comprehensive systems perspective in emphasizing the design of functional interfaces and cognitive systems.

None of the characterizations I offer here should be taken as criticisms. Each of these frameworks has particular strengths and while Cognitive Systems Engineers tend to be somewhat parochial, there is considerable potential benefit in bringing these two frameworks together. However, the primary purpose of this paper is to illustrate how these frameworks can support acquisition of complex socio-technical systems and it is that issue I turn to in the next article.

## Cognitive Engineering For Systems Acquisition

Behavioral scientists who work on the periphery of systems engineering or systems acquisition management have an unfortunate tendency towards advising systems engineers how to do systems engineering (e.g., Pew and Mavor, 2008). The engineering disciplines involved in systems acquisition have a plethora of processes and products and it is not the job of behavioral scientists to assess whether those processes and products are suitable for the job at hand. In contrast, it is appropriate that behavioral scientists comment on the behavioral issues involved in the human systems integration. In my view at least, the quality of the efforts directed at human systems integration is variable and, in relation to cognitive issues especially, the conceptualization is impoverished and outdated. It has been my intent, in this series of articles, to offer a stronger conceptualization.

In doing so, there is no need for me to suggest that the systems acquisition process needs new products. There are already several that would seem to require cognitive engineering input. The Department of Defense management acquisition framework, for example, calls for a human systems integration strategy, a manpower estimate report, an Information Support Plan and a training plan, which are obvious candidates for cognitive engineering input. It is not possible within the constraints of this paper to identify all of the ways in which the concepts and the tools of cognitive engineering might be employed within systems acquisition but in the following I will outline a selection of the ways in which each of the two cognitive engineering frameworks I have discussed might be used to address the design of cognitive support tools and workspaces, the design of teams and cognitive systems, and the design of training. All of these are relevant to at least one of the systems acquisition products identified above (see table 1).

From the decision-centered perspective, judicious application of knowledge elicitation tools will identify problem areas in current work practices and will isolate leverage points that offer opportunities for high-value (but often low-cost) interventions.

From the cognitive systems perspective, progression through the framework of cognitive work analysis will identify the functional structure of the work domain, the outcomes to be achieved, the definition of human work roles, the collaborative processes that facilitate transactions between people (and also between people and artifacts) and the cognitive tasks and strategies to be used in the execution of the work.

## *Cognitive Support Tools, Cognitive Workspaces*

Specifications for Cognitive Support Tools and Cognitive Workspaces will contribute at least to the human systems integration strategy and the Information Support Plan.

A decision-centered analysis might identify decision requirements, establish what might pose a cognitive challenge in making decisions, and develop design solutions that would resolve the challenges. The results of this analysis might be organized into a decision requirements table as shown in Figure 7 (adapted from from Crandell, Klein and Hoffman, 2006). The analysis is for the work of a weapons director on an Airborne Warning and Control System (AWACS).

**Cognitive Requirements (AWACS)**

| Cognitive Requirements | Difficulty | Solution |
|---|---|---|
| Detect and track primary threats | When monitoring multiple contacts, screen clutter can generate confusion & degrade situational understanding The weapons director must sustain her/his attention & monitor all displayed tracks to determine history & possible hostile intent while compensating for her/his own limited memory span | Symbols for flagging major threats (e.g., high, fast aircraft) |
| Estimate intercept geometry | Considerable screen distance between target aircraft & intercepting aircraft | Decision support system to estimate intercept geometry |

Figure 7: A fragment of a decision requirements table for an AWACS weapons director

The first cognitive requirement listed in Figure 7 is to detect and track primary threats. This task becomes difficult when the weapons director must monitor several contacts because screen clutter can generate confusion and degrade situational understanding. It is also difficult because the weapons director must sustain her/his attention and monitor all of the displayed tracks to determine history and possible hostile intent while compensating for her/his own limited memory span. The solution for these cognitive challenges lies in development of symbols for flagging major threats (e.g., high, fast aircraft).

The second cognitive requirement listed in Figure 7 is to estimate intercept geometry. The difficulty in satisfying this cognitive requirement lies in the fact that there can be a considerable screen distance between the target aircraft and the intercepting aircraft. The solution to this problem lies in development of a decision support system that will estimate the intercept geometry.

A cognitive systems analysis will overview the entire suite of information needs for the particular work domain under analysis. Figure 8 depicts an information workspace for military analysis of insurgent operations which shows, among other things, the values and priorities of the allied and insurgent forces, the information resources available to the planners, the defensive and offensive resources available to allied and enemy forces and a situation map (Lintern, 2006). The workspace is organized as a multi-panel format that permits seamless navigation to and selection of constellations of information from a larger information set by use of standard search, selection and manipulation tools such as a point-and-click and drag-and-drop.

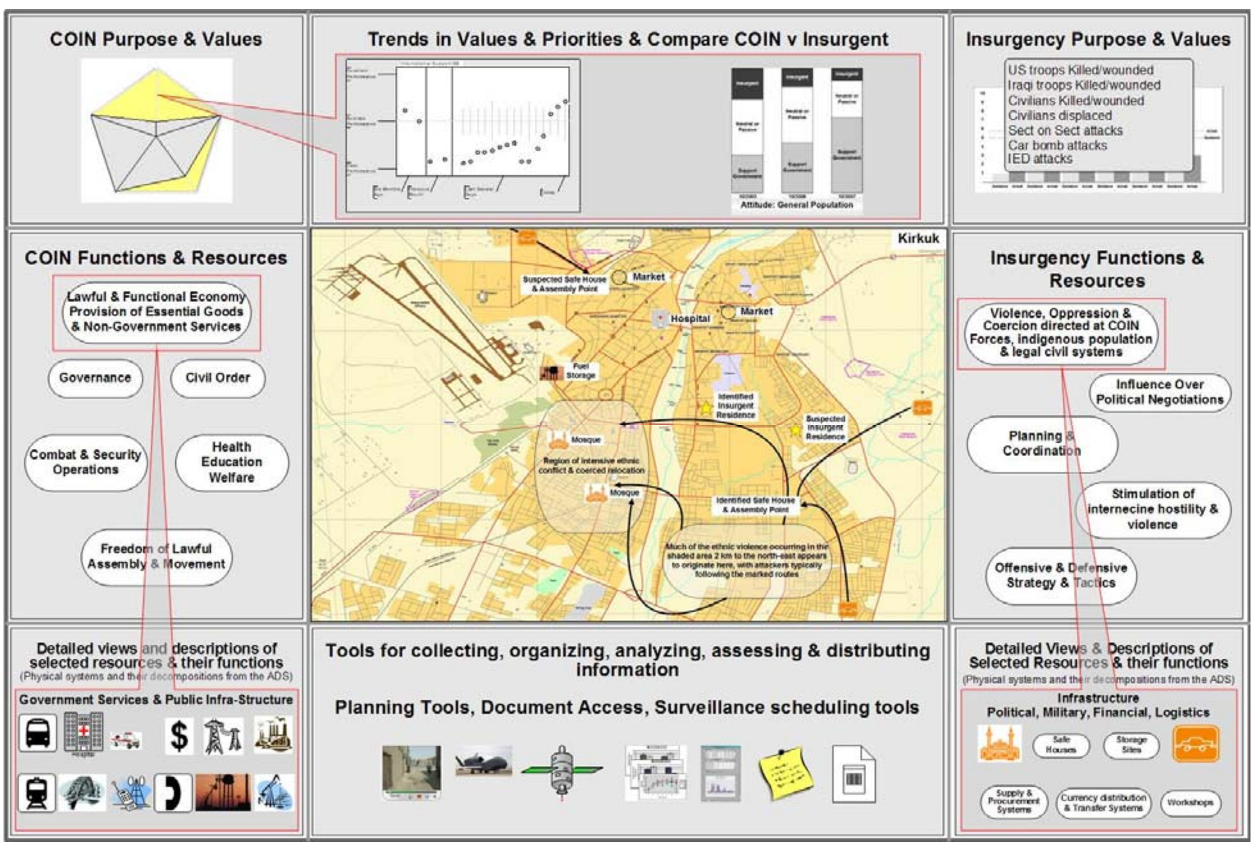

Figure 8: A prototype information workspace for analysis of insurgent operations

### *Teamwork, Cognitive Systems*

Specifications for design of teams and cognitive systems will contribute at least to the human systems integration strategy, the manpower estimate report and the Information Support Plan.

Following the decision centered framework, Klinger and Klein (1999), in an analysis of an emergency response team, sought to identify key decision makers and senior staff members with final responsibility for outcomes. They also sought to identify tasks that were often not finished and the essential transactions. They assessed how the various work products were used and how staff members assisted each other. From this analysis, Klinger and Klein clarified roles and developed recommendations for rationalizing work processes and work roles, which led to elimination of redundant tasks and redundant staff.

Following the cognitive systems framework, I have analyzed the targeting cell of an air operations Center and developed recommendations for restructuring the work to rationalize work packages and communications overhead, and for developing effective systems to support coordination with elements both inside and outside the targeting cell (Lintern, 2007). the current organization of the targeting cell has three persons assigned to assessing a target and planning an attack (a targeteer, a rerole coordinator and an attack coordinator), each whom deals with a part of the problem and then hands the result of their work to the next person in the sequence.

The analysis led recommendations for combining these different but inter-related work tasks into a single modular work package (identified in Figure 9 as the targeting officer) on the assumption that the individuals assigned to the different tasks had similar skills and authority. This type of design results in fewer transactions between workers and reduces communications overhead. As shown in Figure 8, high workloads can be accommodated through a flexible strategy of adding targeting officers to work concurrently on different targets as the need arises.

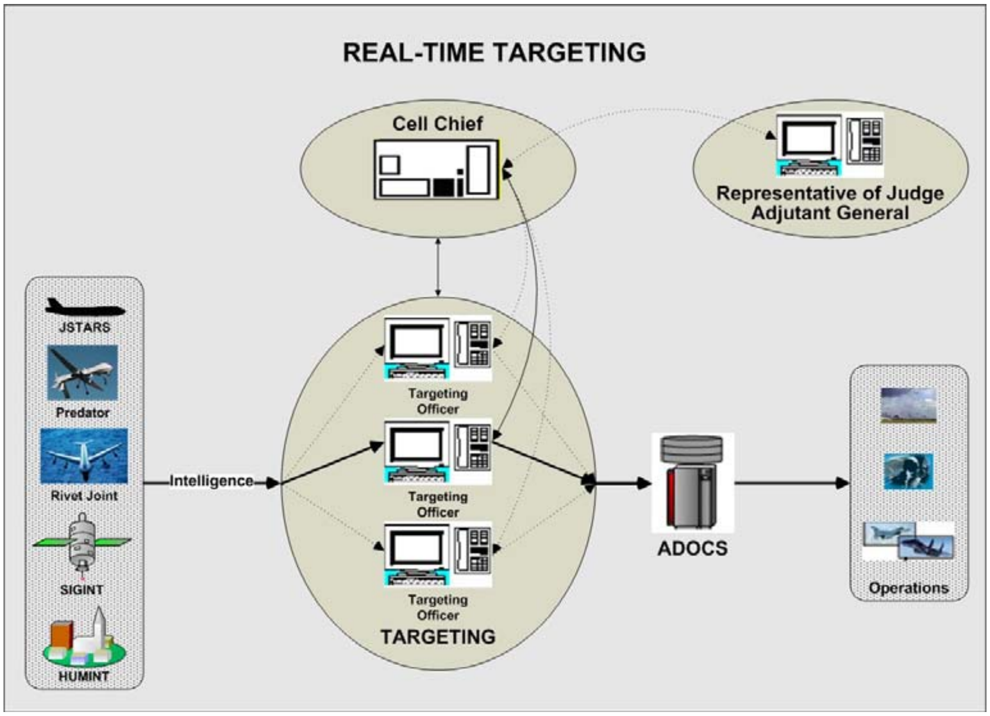


Figure 9: A modular work structure for the targeting cell of an air operations Center

There was a need, however, to identify command responsibilities and specialty skills to ensure that these were not folded into the modular work packages. Additionally, the analysis identified activities that, while not designated as contributing to work products, were nevertheless essential; such things as trash disposal, meal breaks and rest breaks.

This strategy rationalizes but does not eliminate the need for communication. The analysis identified the generic nature of the remaining communications in terms of physical structure (face-to-face versus geographically distributed) and style (command, instruction, advisory, simple, complex or creative discussion). The aim was to establish style of information exchange was desirable (push, pull, broadcast, interactive engagement) and the implications of that for technological support. While the dominant focus is on communications systems that connect geographically distributed workers, even face-to-face discussions might be enhanced with supportive technologies in the form of display systems that can be consulted during the discussion and recording systems that store records or summaries of the discussion.

## *Training Support*

Specifications for Training Support will contribute at least to the training plan.

A decision-centered analysis might lead to recommendations about how practice time-pressured decisions in order to build skill with recognition-primed decision making and how to design appropriate training scenarios for that effort. Additionally, recommendations based on that analysis would emphasize the explicit training of coordination, collaboration and information sharing skills and also team processes and team activities such as how members can support each other and how they might back each other up.

As outlined by Lintern and Naikar (2000), a cognitive systems analysis will overview the entire suite of training needs for the particular work domain under analysis. The results of this analysis will potentially be used to specify a suite of training technologies ranging from web-based learning systems through part trainers is up to full-mission simulators. Additionally, the analysis will point to the pedagogical requirements for structuring effective training interventions; such things as the use of problem-based learning (Liu, Williams & Pedersen 2002), part training (Wightman & Lintern, 1985), adaptive training (Lintern &Gopher, 1978) and augmented feedback (Lintern, 1980). In a particularly innovative study, Naikar and Saunders (2003) have demonstrated how the two frameworks can complement each other in the development of simulator-based training of technical skills for error management within the cockpit of a high performance aircraft.

## Summary

In this paper I have outlined a role for different cognitive tools for a small subset of the products required by the US defense acquisition management framework. A complete answer to the question of what support can be provided by Cognitive Systems Engineering for the development of standard systems acquisition products would require a more lengthy account than is possible here and so my intent was to demonstrate, by selective illustration, that the potential contributions of Cognitive Systems Engineering are specific but that they have to be targeted to the requirements.

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