Cognitive Work Analysis

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Cognitive work analysis is a framework for analyzing complex socio-technical systems. A socio-technical system is one that relies heavily for its overall functionality on the social processes of communication and cooperation.

This framework, which incorporates a set of analytic tools for exploration of different types of work capabilities and constraints, may seem overly complicated to some, but there is an intuition behind it that gives sense to it. In our everyday lives or our work life, we are aided and also constrained by the properties of the workspace or work domain, the structure of that work domain, the objects it contains and the functionality of those objects. If we are to design for human work, we need to develop a functional work structure that both supports and constrains work in effective and robust ways.

There are also cognitive capabilities and constraints that shape the work of both individuals and as groups. Because this analytic framework focuses on the cognitive aspects of work, the emphasis is on the functional capabilities and constraints associated with cognitive states and cognitive processes involved in executing work tasks, with cognitive strategies that may be used, and with the types of cognitive processing (the skills, rules and knowledge) that may be used to execute cognitive processes.

Many cognitive capabilities and constraints are associated with social organization. Collaboration and coordination between people, teams or organizations as facilitated by cognitive transactions in the form of communication activities such as discussions or

advisories and exchange of information products such as plans or analyses provide important capabilities and impose significant constraints as do organisational structures, requirements for oversight and requirements for special forms of expertise.

Adaptive activity within large-scale socio-technical systems

A suggested in Figure 1, the design focus in cognitive work analysis is on supporting and encouraging adaptive activity. Furthermore, that focus is on adaptive activity within large-scale socio-technical systems. We might imagine that we could tackle this problem holistically but the problem is too large and we need to break it up in some way. Within cognitive work analysis, we do that by considering the four classes of capabilities and constraints identified in the outer ring of labels of Figure 1;

- those associated with the structure of the work domain and work tasks,
- those associated with cognitive processes and cognitive strategies used in transition between cognitive states,
- those associated with individual work task assignments and cognitive modes, and finally,
- those associated with group coordination and collaborative style.

The inner labels of the graphic offer another way to characterize the capabilities and constraints within a socio-technical system;

- the upper half covers those associated with the work,
- the lower half covers those associated with agents,
- the left half covers those associated with organization, and
- the right half covers those associated with activity.

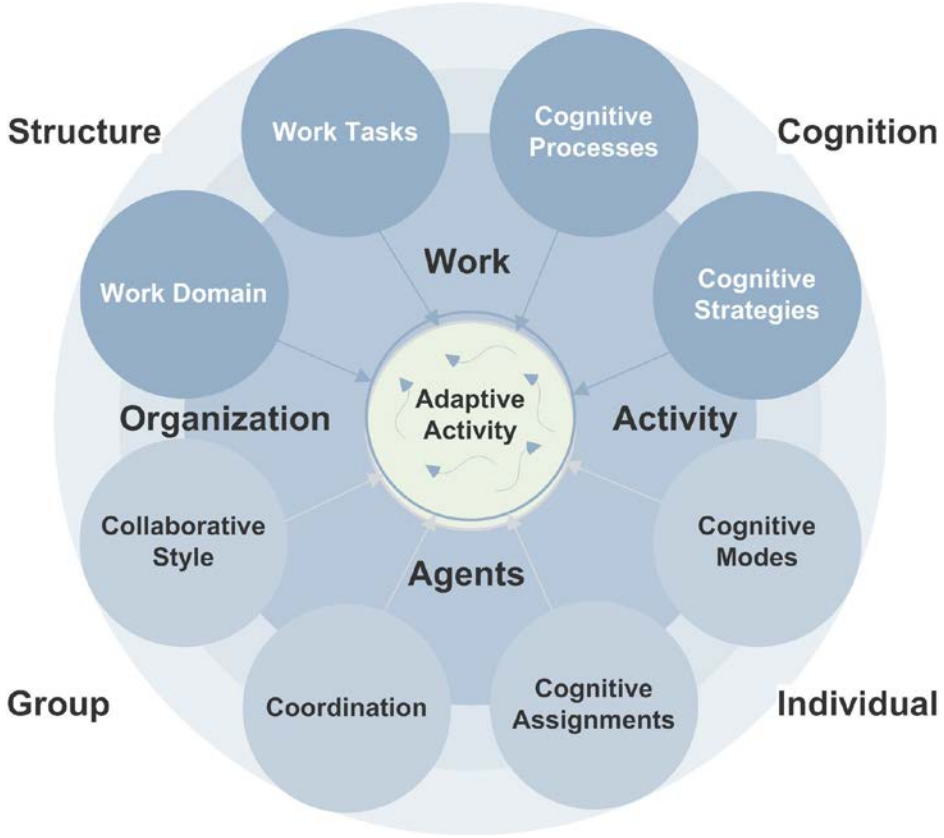

Figure 1: Cognitive work analysis assesses the capabilities and constraints that shape the cognitive work associated with adaptive activity

Cognitive work analysis is a multi-stage framework

Cognitive work analysis is a multi-stage framework in which each stage deals with one or more of these sets of capabilities and constraints, while cognitive work analysis, in its entirety, deals with all of them. As shown in Figure 2, cognitive work analysis can be parsed into six stages;

- the capabilities and constraints associated with the work domain,
- the capabilities and constraints associated with work organization,
- the cognitive states associated with cognitive work tasks (states such as being aware that something is present, understanding what it means, or knowing what to do about it) and the cognitive processes used to transition between cognitive states (for

example, the process used to transition from being aware that something is present to understanding what it means),

- the cognitive strategies that may be used to execute cognitive processes,
- the cognitive modes (skills rules and knowledge) used in execution of cognitive processes or strategies, and
- the capabilities and constraints associated with social organization, especially those associated with management and distribution of work and with communication and coordination.

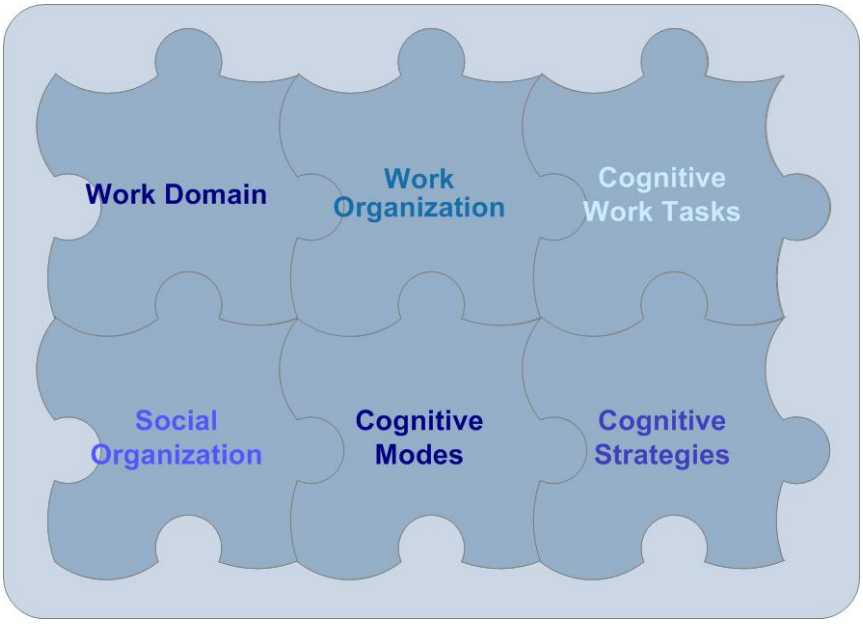

Figure 2: Cognitive work analysis is a multi-stage, integrated framework

Different treatments of cognitive work analysis identify different numbers of stages and give them different names. Table 1 compares the different stages as described by Vicente (1999) to those I have described here. However, there is no substantive difference in the analytic content between the different treatments. Rather, differentiation of analytic content by reference to stages is a pragmatic device that serves to aid organization of analytic workflow and description of the analytic work. Additionally, the names of the stages and the allocation of analytic content to various

stages have evolved as analysts have sought better ways to organize their workflow and to describe what they are doing.

Table 1: Comparison of stage names from Vicente (1999) with those of this tutorial

Name of Analysis (This Tutorial)	Representational Product (This Tutorial)	Vicente (1999) Chapter Titles
Work Domain Analysis	Abstraction-Decomposition Space	Work Domain Analysis
Work Organization Analysis	Work Task Scratch Pad Work Task Docket	
Work Task Analysis	Decision Ladder Cognitive States & Processes Table	Control Task Analysis
Cognitive Strategies Analysis	Annotations on a Decision Ladder Cognitive Strategies Table	Strategies Analysis
Cognitive Modes Analysis	Annotations on a Decision Ladder Cognitive Modes Table	Worker Competencies Analysis
Social Organization Analysis	Network Diagram Staffing & Transactions Dockets	Social Organization & Cooperation Analysis

Table 1 further identifies the representational products of each stage. These, too, vary to some extent between treatments although the abstraction-decomposition space as the representational product of work domain analysis and the decision ladder as the representational product of work task analysis (or control task analysis) are well-established and will be found in any reasonably complete treatment of cognitive work analysis.

There has been a tendency to number the stages in a convenient sequence. I have done this from time to time in my earlier expositions of cognitive work analysis but I now think it misleading. It will imply to some that cognitive work analysis is a sequential process that should follow the numbers. Nothing could be further from the truth. In my work, I am guided by the nature of the analytic problem. More often than not, I start

with work domain analysis, and then follow my best judgment from there. However, I occasionally start elsewhere and I often find myself undertaking two or three of the different stages in parallel. Furthermore, I engage in so much iteration between stages that it would be very difficult for me to identify any sequence even after the fact.

Cognitive work analysis by stages

I will now outline each of the stages in more detail.

Work domain analysis

A work domain is an intentional-functional-physical space in which work can be accomplished. The term *intention* refers to purpose and the term *function* refers to an activity-independent capability (potential) to accomplish something specific. Work domain analysis identifies the activity-independent capabilities and constraints that support and shape work. It does so at different levels of functional abstraction and to different degrees of decomposition.

The product of this stage of analysis is an abstraction-decomposition space, which is an activity-independent representation of both the intentional and the physical capabilities and constraints embedded in the work domain. An abstraction-decomposition space is a two-dimensional matrix (Figure 3). The vertical dimension is an abstraction hierarchy extending over the five levels of system purpose, domain values, domain functions, technical functions, and physical objects. The horizontal dimension is a decomposition hierarchy extending over the number of levels identified during analysis as relevant to an understanding of the functional structure of the work.

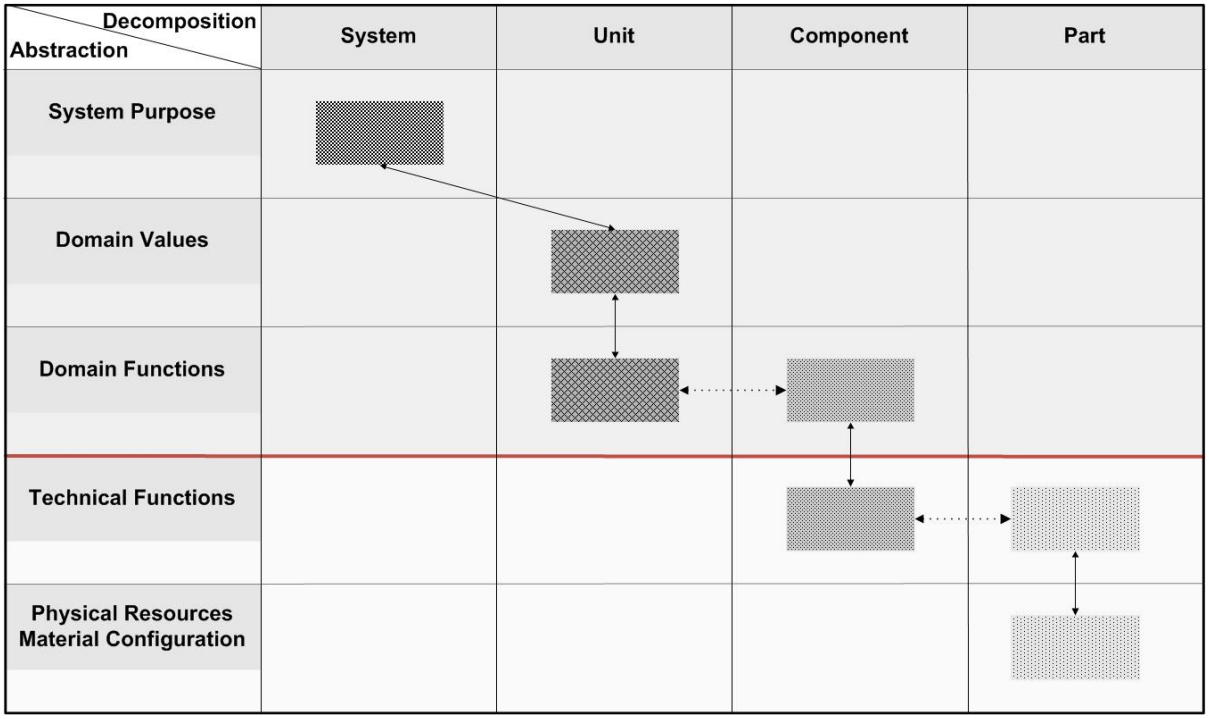

Figure 3: The standard two-dimensional format of an abstraction-decomposition space

Work organization analysis

As noted above, work domain analysis identifies the activity-independent capabilities and constraints that support and shape work. However, the execution of work involves activity and the remaining stages of cognitive work analysis focus on various dimensions of that activity.

Work can be described in terms of work situations (the situational contexts for work), domain functions (device-independent functional descriptions of capabilities and constraints essential to satisfying the domain purpose) and work tasks (what is to be accomplished by goal directed activity within the work domain). Work organization analysis identifies the work tasks that rely on the domain functions identified in work domain analysis and identifies the work situations in which those work tasks are typically activated.

Work situations are different phases of work or different situational contexts that influence the pattern of work. For example, Naikar, Moylan and Pearce (2006) have

identified a sequence of work situations for an airborne surveillance team as *on ground not in aircraft (pre-mission)*, *on ground in aircraft*, *en route to station*, *on station, en route to base*, *on ground in aircraft*, and *on ground not in aircraft (post-mission)*. Similarly, work situations for a process control plant may be described in terms of *startup*, *routine operations*, *shutdown*, *maintenance operations* and *emergency operations*. Notice that the first example if of a series of work situations that unfold sequentially. The work situations of the second example do not unfold sequentially. More generally, work situations may be classified in terms of temporal sequence or location or both.

It can be useful to start this analysis by entering the work tasks, inferred from the domain functions of the abstraction-decomposition space, into a scratch pad as shown in Figure 4. A separate scratch pad can be used for each work situation. External entities that can impact the way work is done should also be noted even if they are not to be included in the design or redesign of the system. In Figure 4, I show a scratch pad for a generic work situation with placeholders for work tasks within operational work. Figure 4 also shows that an analysis of this operational work will need to take some account of the executive and of external support.

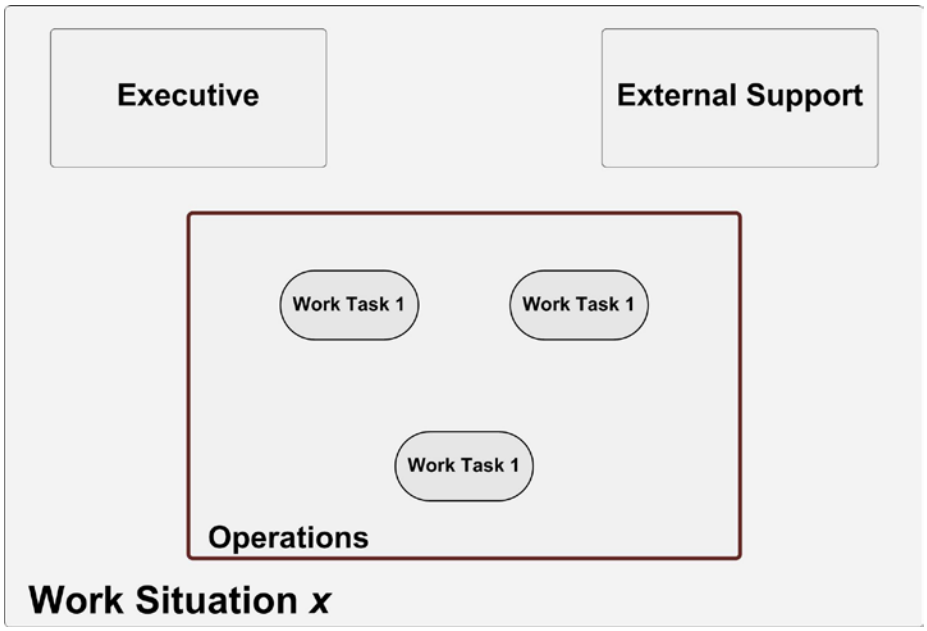

Figure 4: A situation-specific scratch pad for representing the organization of operational work

The final product of this stage of analysis is a matrix referred to as a work task docket (alternatively, a contextual activity matrix, Naikar el al, 2006) as shown in Figure 5. This docket identifies work tasks that will be required to satisfy the domain functions identified in the abstraction-decomposition space and will show how those work tasks are distributed over work situations.

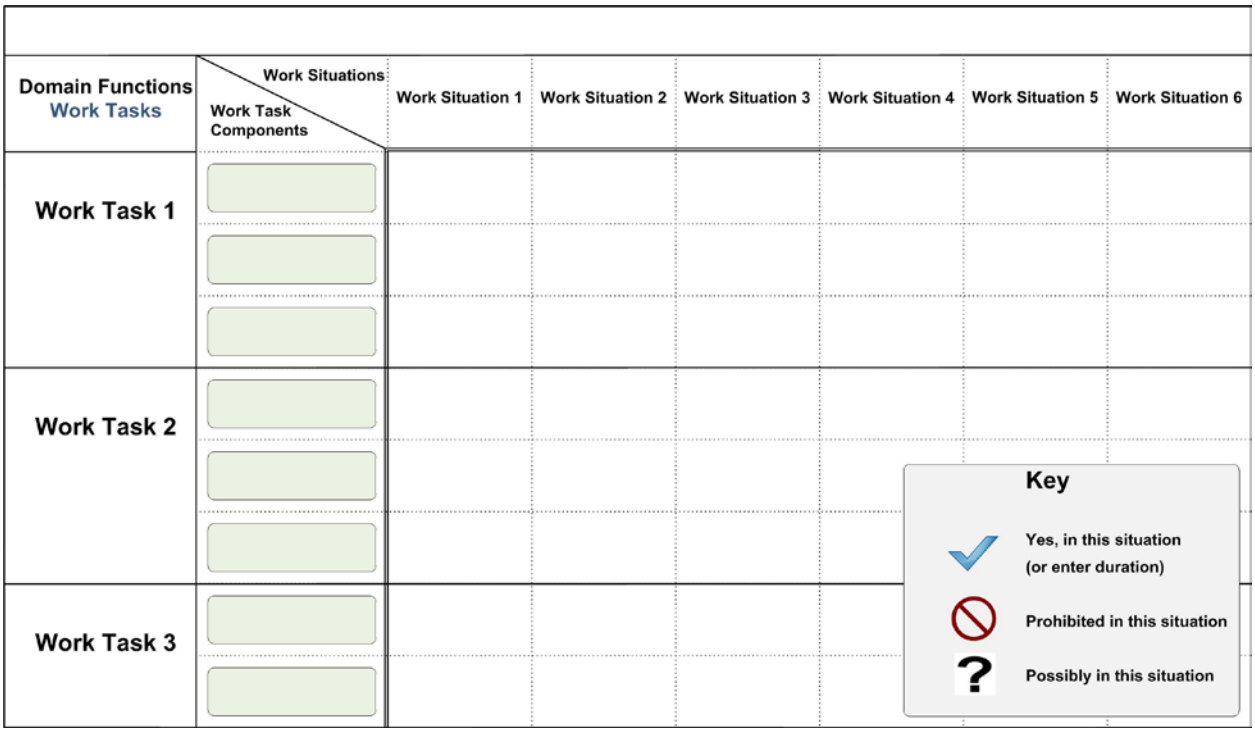

Figure 5: A work task docket of work situations and work tasks associated with specific domain functions

Work organization analysis, at least as a stand-alone stage, is a relatively new feature of cognitive work analysis. For example, Vicente (1999) does not discuss a work organization stage. However, because Cognitive Work Analysis is an extensive framework, Naikar, et al (2006) have promoted work organization analysis as an organizing structure between the analysis of the work domain and the analyses of cognitive activity and include it in an activity analysis stage that also includes work task analysis. I see it as sufficiently important to the framework to set it apart as a distinct analytic stage.

Work Task Analysis

A work task is something to be accomplished (e.g., resolution of a problem, development of a plan, a decision). A cognitive work task is executed by use of cognitive processes that transform cognitive states as the work task is executed. Work

task analysis results in a description of work tasks in terms of transitions between cognitive states as generated by cognitive processes.

The product of this stage of analysis is a work task trajectory mapped onto a decision ladder template. A decision ladder template (Figure 6) depicts all generic cognitive states and cognitive processes that could be involved in execution of a work task. A cognitive state is a condition of being (e.g., the state of being alert, the state of being aware of the situation, the state of being certain or uncertain, the state of knowing something) while a cognitive process is an activity (e.g., the process of seeking information, the process of formulating a plan).

Vicente (1999) refers to this stage as control task analysis. To many, the term *control* will imply moment-to-moment adjustments in a closed-loop feedback activity such as maintaining an automobile in the center of a lane. I doubt that Vicente (1999) intended that implication and I suggest that the best way to avoid it is to substitute a more appropriate term. That is why I refer to this stage as work task analysis.

I also avoid the common strategy of associating work tasks with goals and of labeling decision ladders with goal designators. As I note above, a work task is something to be accomplished. For example, the disarming of an explosive device is a work task. In identifying a work task in this way, the goal is implied and any further elaboration is redundant.

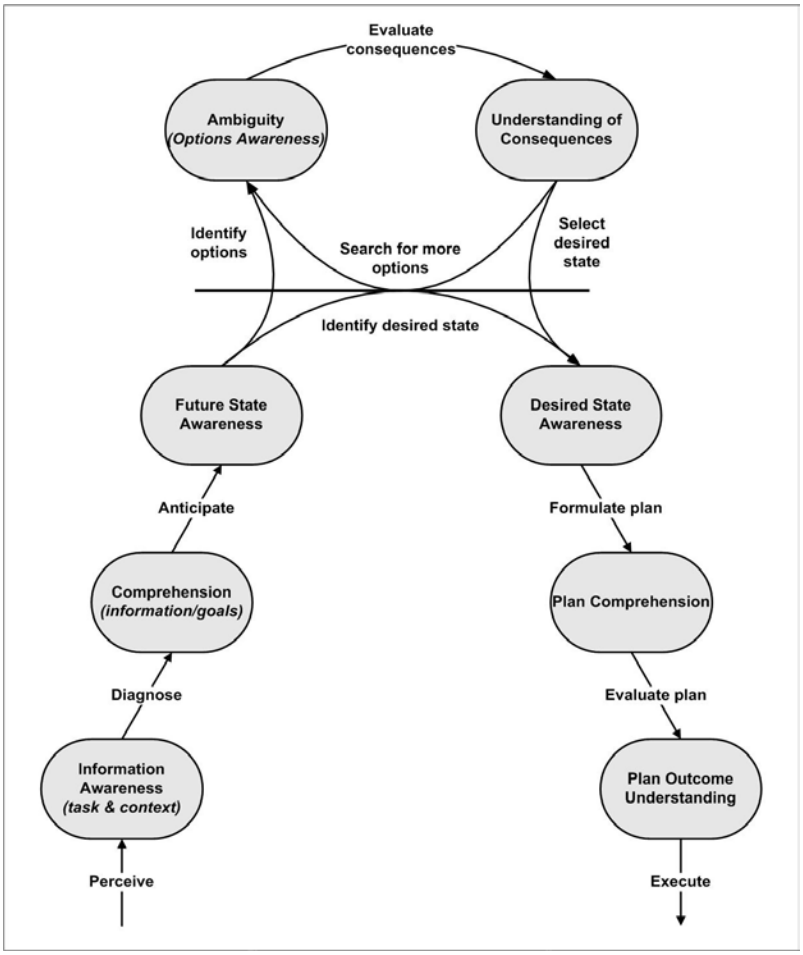

Figure 6: A decision ladder template with cognitive states depicted as ovals and cognitive processes depicted as arrows

Cognitive Strategies Analysis

A cognitive strategy is a generic pattern or, alternatively, a behavioural prototype for a work task or a component of a work task. It is a way of transforming one cognitive state into another and is therefore a class of cognitive process. In contrast to work task analysis, cognitive strategies analysis develops more detailed descriptions of the way in which one cognitive state can be transformed into another.

To illustrate, the right-hand leg of the decision ladder in Figure 6 identifies the cognitive process of *evaluate plan*. If our knowledge elicitation effort reveals that a particular work task does employ this process, we may want to identify one or more

strategies that might be used in execution of that process. Klein (1998) observes that experts will often use mental simulation. In contrast, a novice may ask a more experienced person or may follow guidelines. These alternatives constitute three different generic strategies that could be employed in execution of that same cognitive process.

A cognitive strategy may be a generic method of executing a single process (as in the example above) or a generic method of executing multiple processes.

Cognitive strategies analysis identifies the actual and potential strategies that are or could be used in execution of a work task and also the reasons that a particular strategy might be selected in preference to other possible strategies. Particular strategies might be preferred because of task demands such as the amount of time, memory load, or level of knowledge. However, all work tasks must support realisation of the values identified in work domain analysis. Strategies that result in violation of those values should be discouraged. Problematically, there may be a conflict between the preferences shaped by task demands and the constraints imposed by the values.

The analysis should identify the range of possible strategies rather than the strategies actually used. If workers avoid potentially valuable strategies because they impose unacceptable demands we might find that we can resolve that problem by designing effective support for such strategies.

Cognitive strategies analysis results in a description of the cognitive strategies that might be used to execute cognitive processes identified in work task analysis. While it is possible map the alternate strategies onto a decision ladder, a two-column table offers a more convenient representational format (Table 2). The first column identifies the potential strategies with sufficient detail to clarify how the strategy is executed. The second column specifies the circumstances under which a particular strategy may be preferred.

Table 2: A template for a cognitive strategies table

Cognitive Strategies	
Strategy	**Reasons for Selection**

Cognitive Modes[1] Analysis

An action mode is a particular means of accomplishing something. A cognitive mode is, therefore, a particular style of cognitive processing. Cognitive work analysis focuses on cognitive modes of three types[2];

- a skill-based mode of cognition, which has no conscious processing between perception and action and results in highly automated and integrated patterns

[1] Following Vicente (1999), I have previously referred to this stage as cognitive competencies analysis (e.g., Lintern, 2009). However, a competency is a capability to perform a task to a certain level of effectiveness, which is not what is assessed in this stage.

[2] In contrast, for example, to Kahneman (2011) who refers to two modes, identified in his work as system 1 (corresponding to skill based) and system 2 (corresponding to knowledge based).

performed in real time and coupled directly to the environment in a continuous perception-action loop,

- a rule-based mode of cognition, guided by sets of procedural instructions or familiar perceptual properties that specify sequences of actions, and
- a knowledge-based mode of cognition, grounded in conscious and explicit reasoning based on a symbolic mental representation of relevant capabilities and constraints.

Cognitive modes analysis identifies the modes used with various cognitive processes or strategies in the execution of a work task. Cognitive processes and cognitive strategies do not typically involve only one level of cognitive mode but rather may rely on a combination of two modes or on all three.

The product of this stage of analysis is a description of the activity elements associated with the different modes of cognitive processing. As in cognitive strategies analysis, it is possible to annotate a decision ladder with the appropriate information but an adaptation of the two-column table developed for cognitive strategies analysis offers a more convenient representational format (Table 3). As before, the first column identifies the potential strategies (or, alternatively, other work task elements such as cognitive processes or clusters of cognitive processes). The second column specifies the cognitive modes associated with particular strategies or work task elements.

Table 3: A template for a cognitive modes table

Work Task	
Process or Strategy	**Cognitive Mode(s)**

Interim Summary

At this point in the tutorial, only the stage of social organization analysis remains. However, there is no need to first engage with each of the analytic stages in the sequence I have introduced them here. The sequence I have used for introducing the stages is merely a tutorial device that helps conceptualize the relationships and flow of the important analytic ideas.

Recall that earlier in this tutorial I noted that progression through the stages is not a sequential process that follows any particular order. There will be much iteration to this point. Later analyses will generate ideas and insights that will inform earlier analyses and thus create a need to return to and modify the results of the earlier analyses. In general, it is best to start with the stage that helps you enter the problem and for which you have the most readily accessible information. You might work on that

stage until you have gone far enough so that you can move on to other stages one by one, gradually extending and strengthening each until you have a coherent whole[3].

This tutorial offers one illustrative trajectory of the process. To this point, I have explained the role of work domain analysis in mapping out the resources, capabilities and constraints of the work domain and have explained the role of work organisation analysis in laying out the organisation of work tasks. I have also explained the role of work task analysis in identifying the cognitive states that will be activated during execution of a work task and the cognitive processes that will generate the state transitions. Cognitive strategies analysis can then be used to identify a range of generic methods for executing some of the cognitive processes, and cognitive modes analysis can be used to identify the mode levels at which each of the cognitive processes is executed.

An analysis and design effort that follows this trajectory will develop a catalogue of essential but individual work units together with the resources, procedures and modes to execute each of them. The integrated results of the work task analysis, the cognitive strategies analysis, and of the cognitive modes analysis will inform the design of technological, procedural and training supports for each of the work tasks that make up these work units, and will guide decisions about essential levels of worker skill and essential types of expertise needed for execution of the work tasks given the cognitive supports that will be provided.

One job remains, that being to assemble these work units into an integrated and coherent work system. That is the job of social organisation analysis.

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[3] In speaking of this, I am reminded of my college classes in calculus. Each year provided a foundation for the next year where the concepts and methods of the previous year were enriched and extended.

Social Organization Analysis

Within a work environment, social organization refers to the way in which work is distributed, coordinated and managed. Social organisation analysis identifies how work can be shared between workers, how it can be distributed temporally and spatially, and how it can be supported and guided through the hierarchical levels of an enterprise.

Social organization analysis is concerned firstly with organizational structure and distribution of work. Organizational structures will necessarily be based on needs for authority, oversight, strategic guidance and reporting, and on the size of the organization. For large enterprises, structures will need to be designed at several levels of scale, for example at the scale of the whole organization, at the scale of individual business units within the organization, and at the scale of work teams. It is unlikely that a particular organizational structure will work for all business units or all teams. Additionally, the work teams must be structured to accommodate the nature of the work. Skill levels and experience needed for work components, needs for assistance, and requirements for specialty expertise must all be considered.

Once a structure is in place, work units are coordinated through collaboration between peers and collaboration between management and workers; the lateral connectivity that supports essential collaboration (and sometimes, competition) between peers and the vertical connectivity that supports essential manager-worker coordination. There will also be needs interaction, information access and product delivery across the boundary of the organization. The supporting coordination processes are primarily communication events of various types. Social organization analysis identifies the generic properties of characteristic communication events that maintain social organization within a work domain.

Social organization analysis results in a description of the organizational structures and of the coordinative work processes that support collaboration between peers within a team or work group at any of the hierarchical levels within an organization. It also develops a description of the overall organizational structure and of the coordinative

work processes that support interactions between the hierarchical levels within an organization such as those between a team leader and team members or between management and workers. Processes that support organizational integration such as statements of intent by senior management, rules, processes and procedures that guide the organization, and worker support processes such as those that may be provided by human resource or administrative support departments constitute important elements of the vertical connectivity that supports organizational integration. Finally, social organization analysis takes account of interactions with entities external to the organization, interactions such as acquisition of information and promulgation of plans and reports.

To begin summarizing the information acquired by the social organization analysis, it can be useful to return to the work organization scratch pad of Figure 4. As a result of the analyses that have been conducted since the work organization analysis, it should be possible to think about which work tasks can be undertaken with a particular skill set and level of expertise. A set of closely linked tasks that demand a common skill set and level of expertise can be viewed as a module of work.

The prior analyses will also have generated ideas for technological support for these work tasks and so it may now be possible to propose staffing levels. Where the work demands within a module exceed what can be handled by one person, staffing numbers can be increased to the appropriate level. The nature of the work will suggest how the work might be distributed among workers and that will lead to development of an appropriate teaming structure. For example, it may be preferable to give different workers responsibility for different components of a work module or it may be preferable to have the different workers take care of complete jobs within that work module. The nature of the work and the way in which it is distributed will have implications for communication demands within a work module.

Additionally, it will be useful to assess the communication demands with external agencies and to that end, it will be necessary to articulate to at least some degree the

functional structures of those entities and the sorts of roles they play in shaping the work within the organizational entity that is being analyzed. Figure 7 shows an elaboration of Figure 4 that depicts how these constructs might be represented.

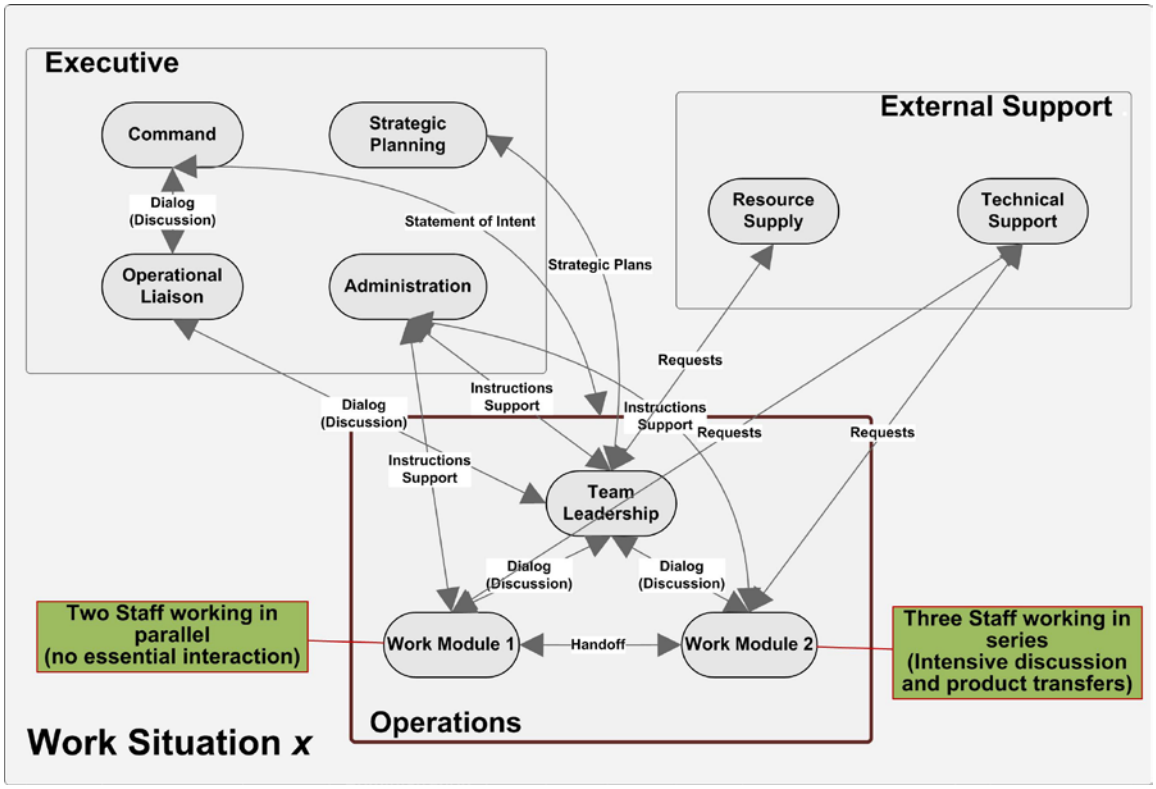

Figure 7: A situation-specific scratch pad for analysis of the social organization of work

The final product of this stage of analysis is a matrix referred to as a social transactions docket (Figure 8). This docket focuses on the transactions (i.e., the communication events) that have been identified in the social organization scratch pad. It is these transactions that are specifically responsible for coordinating the work. The social transactions docket identifies and characterizes the agents (both internal and external) involved in transactions associated with work tasks. Separate columns are used to characterize the transactions in terms of demand (its complexity), dimension (whether the agents are collocated or not and whether the interaction is in real time or otherwise temporally displaced) and resources that might be used to support the transactions.

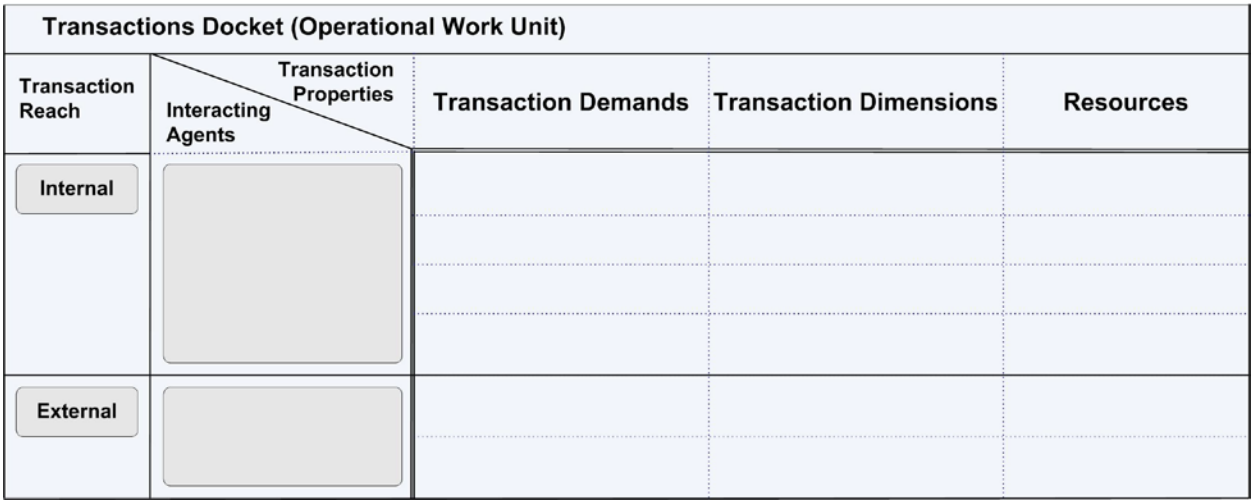

Figure 8: A social transactions docket showing agents associated with work tasks, and demand, dimensions and resources associated with transactions

Concluding discussion: Why cognitive work analysis?

The foundational assumption of cognitive work analysis is that workers in a complex system operate with a large number of capabilities and within a large number of constraints. Workers remain free to employ these capabilities as they act flexibly within the constraints and are free, therefore, to adapt to unanticipated situations. The purpose of cognitive work analysis is to identify and map out those capabilities and constraints so that design efforts can take explicit account of them.

The scale-up problem

Cognitive work analysis is framed as a systems approach to the analysis and design of the socio-technical aspects of complex, large-scale systems. The systems perspective of cognitive work analysis promotes identification of 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.

Most human factors and cognitive systems engineering design efforts suffer from the scale-up problem. They have been developed to focus on limited aspects of systems and do not offer any formal means of tracing relationships between different subsystems or, if the method is applied piecemeal to several subsystems, of maintaining an integrated account of these independent analysis and design efforts. Cognitive work analysis resolves this problem by using an abstraction-decomposition space to represent the system as a whole and by then using it as a book-keeping artefact to maintain traceability to the various work elements examined in other analytic stages.

The point-of-view problem

An analytic and design effort that focuses on a particular part of a system suffers from the point-of-view problem. That analytic and design effort may improve performance locally but the new design intervention could negatively impact whole system performance via unintended interactions. Largely by development of the abstraction-decomposition space and then by linking the elements of the other analytic products to it, the analyst can alternate as needed between macro and micro views; moving opportunistically back and forth between an overview of the system and a detailed examination of selected elements. By representing the whole system, work domain analysis offers a means of tracking potential interdependencies between subsystems so as to limit the risk engendered by designing a system from a single point-of-view.

The task-artifact cycle

Cognitive Work Analysis also provides a means of breaking the task-artifact cycle. The term, *task-artifact cycle*, refers to the co-evolution of tasks and artifacts. We are now in an age when revolutionary advances in technology have the potential to transform work practice but new technological designs typically fail to take full advantage of those new technological opportunities because they are guided by analysis of current work practice and are thus constrained by it. Technical solutions are developed for problems experienced in the execution of tasks but those technical solutions then

constrain the way tasks are executed. Cognitive work analysis breaks the co-evolutionary link between current and future work structures by mapping the structural constraints of the envisioned work domain as a foundation for the design of a new form of work practice not constrained by current technology or by current work practice.

Concluding remark

It is often said that cognitive work analysis is time-consuming and labor intensive, the implication being that it is more time-consuming and more labor intensive than other cognitive systems engineering frameworks. However, that is true only because it is used in the analysis of complex and extensive systems. Any rigorous and comprehensive analysis of a large scale system is necessarily time-consuming and labor intensive. More to the point, cognitive work analysis is unique in its capacity to support comprehensive and detailed analyses of the socio-technical aspects of large-scale systems. Cognitive work analysis will not always be appropriate for analysis of small, contained systems or for independent analyses of parts of systems but for analysis of large-scale sociotechnical systems, it adds a unique capability to our human factors and cognitive systems engineering tool set.

References:

Kahneman, Daniel (2011).Thinking, Fast and Slow. New York: Farrar, Straus and Giroux.

Klein, Gary (1998). Sources of power: how people make decisions. Cambridge, Massachusetts: MIT press.

Lintern, Gavan (2009). The Foundations and Pragmatics of Cognitive Work Analysis: A Systematic Approach to Design of Large-Scale Information Systems. Cognitve Systems Design [Downloaded 11 Nov, 2012 from www.CognitiveSystemsDesign.net].

Naikar, Neelam; Moylan, Anna and Pearce, Brett (2006). Analysing activity in complex systems with cognitive work analysis: concepts, guidelines, and case study for control task analysis. Theoretical Issues in Ergonomics Science, 7 (4), 371-394

Vicente, KH (1999). *Cognitive Work Analysis: Towards safe, productive, and healthy computer-based work*. Mahwah, NJ: Lawrence Erlbaum Associates.