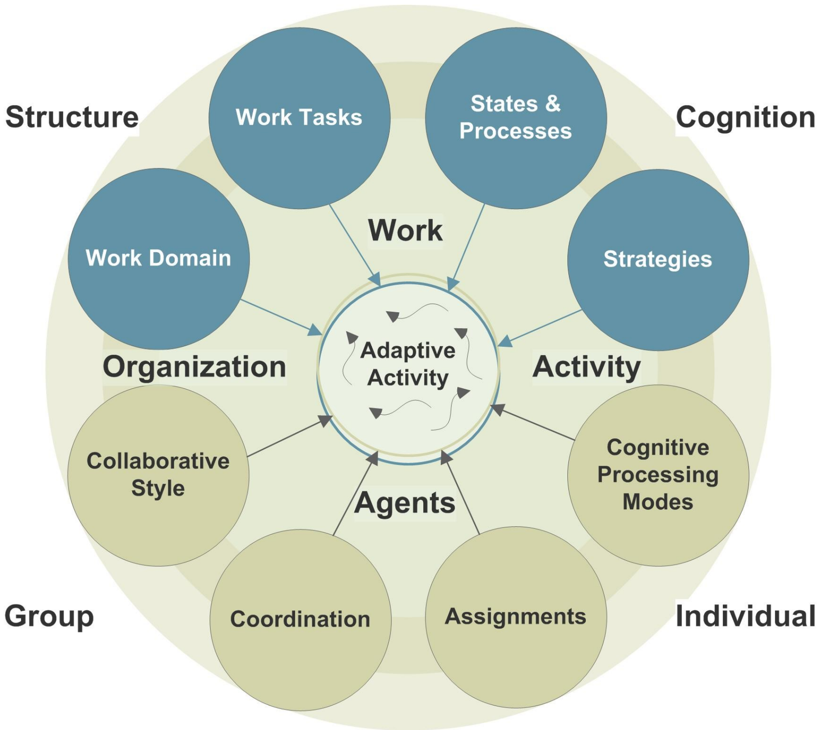
The Foundations and Pragmatics of Cognitive Work Analysis

A Systematic Approach to Design of Large-Scale Information Systems



Gavan Lintern

Cognitive Systems Design

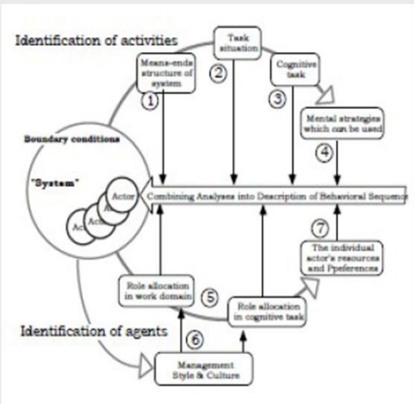
www.CognitiveSystemsDesign.net

Edition 1.0

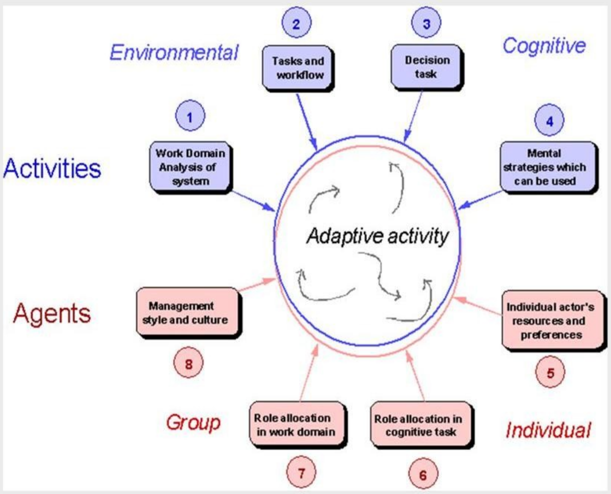
Cover Graphic

My inspiration for the cover graphic evolved from a figure developed by Penny Sanderson and published in Sanderson, Naikar, Lintern and Goss (1999). Penny had been influenced by other figures from Rasmussen, Pejtersen and Goodstein (1994) and Vicente (1999). These figures capture the fundamental idea behind Cognitive Work Analysis; that we must orient socio-technical design towards supporting adaptive human activity. That orientation requires consideration of four sets of constraints; those provided by the structure of the work domain and work tasks, those provided by cognitive processing and cognitive strategies used in transition between cognitive states, those associated with individual work task assignments and cognitive processing modes, and those associated with group coordination and collaborative style. The inner ring of labels parses the space in terms of work constraints (upper half), agent constraints (lower half), organizational constraints (left half), and activity constraints (right half). Each stage of Cognitive Work Analysis deals with one or more of these sets of constraints and Cognitive Work Analysis, in its entirety, deals with all of them.

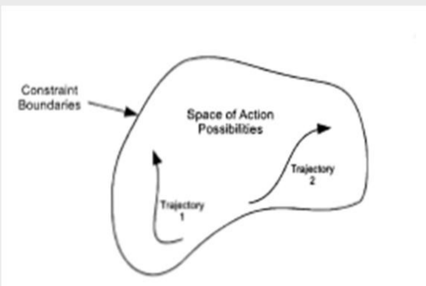
The three images below are the ones from the named publications that inspired development of the cover graphic.



Rasmussen et al (1994)



Sanderson et al (1999)



Vicente (1999)

Table of Contents

Preface

I offer this book as a free download from my website at www.CognitiveSystemsDesign.net. I suppose, if I had thought it might be as popular as Dan Brown's "The Da Vinci Code ", I may have been tempted to market it commercially, but the fact is that this is a specialist topic and even if the book is wildly successful in this topic area, it will gain relatively few readers. I value readership above the rather paltry royalties that might accrue and so I hope to encourage readership by making this book as accessible as possible.

I request that you direct others to my website for their copy rather than giving it to them directly. If everyone adheres to that request, I will be able to track how many copies are in circulation and thereby assess whether this project has been successful and whether I should do it again for another topic. However, feel free to break this rule if your colleague would otherwise experience difficulty or delay in downloading a copy.

I was first attracted to the electronic self-publishing route because it is difficult and time-consuming enough to write a book without the further complications of negotiating with a publisher and the delays that accompany printing and marketing.

Electronic self-publishing has a further significant advantage; I can change the book at any time and at no particular cost. I will be adding chapters and appendices as time goes by and when I do, I will identify what I have changed so that you will be able to go straight to the new material.

One useful feature of electronic publishing, at least in the Portable Document Format, is that PC users can access the dictionary meaning of any word via http://dictionary.reference.com by right-clicking on that word and selecting “Look Up” from the drop-down menu. I assume Mac users can do this as well but I am not clear on how they can do it.

When you read this in Portable Document Format you may use the hyperlinks in the Table of Contents to jump directly to a desired chapter. Hyperlinks are indicated by a light-blue underline. The Portable Document Format also obviates the need for an index. Use the search function to find references within the book to any term. I have included page numbers in the Table of Contents primarily for the convenience of those who will want to read a paper copy.

Acknowledgments

I can never ponder issues related to socio-technical systems without reflecting on ideas I have discussed with Peter Kugler. Our conversation on these issues commenced in 1988 and continues today.

I struggled in my early encounters with Cognitive Work Analysis and was assisted considerably at that time through conversations with Cathy Burns and Kim Vicente.

I have had many long and detailed conversations with Neelam Naikar and Penny Sanderson, not always devoted to issues in Cognitive Work Analysis but always engaging and productive.

Wide-ranging discussions with Iya Whitely (nee Solodilova) and Anne Bruseberg continue to guide me into new areas.

I have been concerned for many years about the gulf between Cognitive Task Analysis and Cognitive Work Analysis and have sought to bring ideas from the first into the practice of the second. My ongoing conversations with Cindy Dominguez, Laura Militello and Gary Klein have helped enormously.

I have also become concerned in recent years about the seemingly insurmountable barriers between Cognitive Engineering and Systems Engineering. My ongoing conversation with Steve Deal has helped me frame ideas about how to attack those barriers.

This book would not have been possible without the support and forbearance of my wife, Miyuki Chikamatsu and my daughter, Anna Lintern.

Chapter 1

Introduction

Cognitive Work Analysis is notoriously difficult for those who encounter it for the first time. It is a complicated and expansive system of analysis, differing in scope and strategy from much of what currently goes on in cognitive engineering. There is little to do about this; the system is what it is for good reasons. Given that state of affairs, we need cohesive, pedagogical accounts of this analytic framework to guide beginners through their early efforts. Vicente (1999) has made good progress in this regard but much remains to be done. In this book I take a different but complementary approach to that taken by Vicente to introduce beginners to Cognitive Work Analysis.

I seek to resolve two issues. Cognitive work analysis remains difficult to understand and to execute because we have not made the foundational theory behind it sufficiently explicit and also because we have not been sufficiently tutorial in our approach to explaining it. In believing that these two things go together, I outline the theoretical basis for this framework of analysis and then offer a tutorial example that shows how the concepts can be applied. In future editions of the book, I will offer further tutorial examples as appendices.

Although I offer some refinements of Cognitive Work Analysis, there is nothing fundamentally new in this book. Rather, this is an effort to assemble the important ideas of Cognitive Work Analysis into a treatment that encourages solid understanding via a process of establishing specific concepts as knowledge anchors and then expanding that knowledge into a comprehensive system.

The Title of the Book

I have chosen the title of this book with deliberation. The book is centrally about Cognitive Work Analysis. The *foundations* are specifically the theoretical foundations. In chapter 2, I offer a brief account of several theoretical positions that establish a context for Cognitive Work Analysis. I do not necessarily want to claim that these theoretical positions have guided the development of Cognitive Work Analysis but that rather the assumptions on which those positions are based and the observations that have emerged from them are consistent with and offer support for the framework. In succeeding chapters, I outline the specific theoretical assumptions for each of the analyses that make up Cognitive Work Analysis.

I have chosen to insert the word *pragmatics* into the title because, ultimately, Cognitive Work Analysis is a practical framework for developing a coherent and comprehensive description of the important properties of work. My dictionary, Houghton Mifflin (2000) defines pragmatism as a *practical, matter-of-fact approach to assessing situations or solving problems*.

Words

Words can be difficult. Many have multiple meanings and scientific and engineering usages often extend beyond the definitional boundaries contained in dictionaries. Vicente (1999) offered definitions for many of the troubling words he uses. I have gone back to those definitions time and time again. Many of the criticisms of Vicente's book have emerged from failure to understand how he was using specific terms; a failure that is inexcusable given that he defined the meanings of those terms explicitly. I also devote some effort in this book to defining my terms. Redefinitions of words first defined by Vicente will typically be clarifications rather than adjustments in meaning but I also add a few important terms to the lexicon of Cognitive Work Analysis.

In converging on a word meaning, I rely heavily on Wiktionary.org, Dictionary.com and Houghton Mifflin, 2000, but explain further when these references offer multiple meanings or where words have crept into common scientific usage with a meaning not implied by any dictionary. I avoid any usage that cannot be found in a pedigreed dictionary. I neither invent new meanings for words nor accept invented words or invented meanings unless there is a sound reason, as explicated by the inventor, for that term.

I abhor the current tendency in science and technology to sprinkle acronyms extensively throughout a narrative. Acronyms can make even simple ideas difficult to assimilate. Indeed, they require a reader who is new to the material to learn a new language. The practice of naming the acronym in its first use does not help very much. A reader will not necessarily remember it, especially if there are many other acronyms in an extended discussion. Many times, a reader will gloss over an acronym as something only half understood. I see no excuse for them and in this book I tolerate only those acronyms that are in general and widespread usage.

Chapter Titles

I have been troubled for some time by the misinterpretations of Cognitive Work Analysis that abound in the literature, for example, Lind (2003) on Work Domain Analysis, Cummings (2006) on the temporal implications of Work Domain Analysis, and Hollnagel and Woods (2005) on the Decision Ladder and the Abstraction Hierarchy. There is, it seems, no end of mischief that can be created by those who fail to understand.

As all readers of this book know, or at least will soon know, Cognitive Work Analysis has several analytic stages. It has occurred to me that the critiques of Cognitive Work Analysis noted above were encouraged by Vicente's strategy of using the names of the analyses for the titles of chapters in which he explained that analysis. I draw that conclusion because, without exception, those critics failed to show any understanding of the assumptions underlying that stage of the analysis they were critiquing and typically focused on analytic details. Not one of those critics offers even a glimmer of understanding of what is to be achieved in that analytic stage.

Although names of analytic stages seemed appropriate as chapter titles in 1999, I now think that a chapter title that identifies the purpose of the analytic stage will serve us better. I suggest that such a strategy will make it more difficult for critics to focus on peripheral issues. I map the correspondence between Vicente's chapters on analytic forms and the ones I use here in Table 1.1. As will be evident from Table 1.1, I have adjusted the stage sequence offered by Vicente (1991) and have added one stage. The additional stage, Stage 2 in my treatment, comes from a development by Naikar, Moylan, and Pearce (2006) of a Contextual Activity Matrix to depict the relationship of Work Problems to Work Situations.

The reasons behind my selection of each specific chapter title as a descriptor of what is to be achieved by the analysis described in that chapter will, I hope, become evident early in each of the respective chapters. I retain only two of the analysis titles used by Vicente (1991). The reasons that I have chosen the particular analysis titles that I have will also, I hope, become evident early in each of the respective chapters.

Vicente (1999) Chapter Titles	Lintern (2009) (this book) Chapter Titles	Lintern (2009) (this book) Name of Analysis
1. Work Domain Analysis	1. Functional Work Structure	1. Work Domain Analysis
	2. Partitioning & Organization of Work	2. Work Organization Analysis
2. Control Task Analysis	3. Cognitive States & Processes	3. Cognitive Transformations Analysis
3. Strategies Analysis	4. Cognitive Strategies	4. Strategies Analysis
5. Worker Competencies Analysis	5. Cognitive Processing Modes	5. Cognitive Processing Analysis
4. Social Organization & Cooperation Analysis	6. Work Coordination	6. Social Transactions Analysis

Table 1.1: Correspondence between Vicente' (1999) chapter titles and the chapter titles and names of the respective analyses as used in this book

A Niche for Cognitive Work Analysis

Some of the negativity towards Cognitive Work Analysis emanates, I believe, from a failure to understand what those of us who use Cognitive Work Analysis are trying to do. Most techniques of Cognitive Engineering are aimed at identifying and working on points of leverage, for example, on developing cognitive support tools in the form of such things as decision aids and planning support. In contrast, the framework of Cognitive Work Analysis was developed for a much larger problem; the design of large-scale socio-technical systems. Despite the value of other cognitive engineering strategies, they deal only with segments of the design problem for a complex socio-technical system. I do not intend that remark to be pejorative; many design assignments in cognitive engineering require precisely that form of intervention. My specific claim here is that Cognitive Work Analysis occupies a niche in the design world that is often not appreciated by those who focus on points of leverage or on the development of a cognitive support tools.

A long-standing complaint within Human Factors is that we (Human Factors practitioners in general) are brought into the design of large-scale systems only after human integration problems have become apparent. It is commonly argued that the expense of correcting these problems could be avoided if we were consulted earlier, possibly during concept development and then throughout the remainder of the design cycle. In the past, I have been skeptical. While I was confident that we could have avoided the sorts of common problems that were emerging, it was never clear to me that we would not have introduced other serious issues. We had no comprehensive analytic framework for addressing issues in concept development and then proceeding systematically through the human systems integration issues in the design of a complex socio-technical system. Only when I became acquainted with the framework of Cognitive Work Analysis did I begin to build confidence that I could, if invited early into the design process, contribute as an equal an effective partner.

I also wonder if the emphasis within Cognitive Work Analysis on representation introduces some negativity. Crandall, Klein and Hoffman (2006, p 107) note that knowledge elicitation has received more attention that knowledge representation within the general field of Cognitive Task Analysis. I suspect that formal education plays some role in determining enthusiasm for representation. The engineering disciplines employ representation extensively and systematically in many forms to impart understanding. In contrast, representation is employed less often within the behavioral sciences and then in an improvised and impromptu fashion.

From my own background in Psychology, my initial reaction to Cognitive Work Analysis was that it was *only* about representation (and therefore insubstantial). I adjusted that thought rather rapidly as I read further but continue to believe that Cognitive Work Analysis is largely about representation. However, I no longer use the pejorative *only* when I offer that view. I have come to believe firmly in the power of a theoretically motivated and well organized set of representations for assimilating, archiving and transferring knowledge.

Finally, Vicente (1999) emphasizes the activity-independent property of the Abstraction-Decomposition Space, the representational product of Work Domain Analysis. I suggest that this notion of activity independence troubles many people. Both Cognitive Psychology and Systems Engineering are process or activity oriented disciplines. Cognitive theories are typically framed as a series of processes or activities and Functional Analysis in Systems Engineering typically results in a representation of functional flow rather than a representation of functional structure.

Gibson (1979) is one in psychology who has taken this notion of activity independence seriously. I recall that his approach troubled me as I work through the first two chapters of his *Ecological Approach to Visual Perception*. My first thought was that this was *only* about the structure of the world and that there was no psychology in it. Again, note the pejorative *only*. However, one should not judge Gibson prematurely as I did then and, I suspect, as many others do. One has to get through the complete argument to appreciate its elegance.

By the time I encountered Rasmussen's work, I had assimilated Gibson's argument and did not for a moment cast the same aspersion. I do recall thinking that Rasmussen's distinction between structure and process was much like Gibson's. If we were to take the critics seriously, we would have to assume that Gibson and Rasmussen are alike in that they have built a flawed conceptual structure from a fundamental misunderstanding of the nature of the world. I happen to think otherwise, that each in their own way, immersed in a conceptually challenging and somewhat distracting intellectual culture, somehow came to remarkable insights about the way we need to conceptualize complex human environments.

Rasmussen was concerned with how to integrate multiple, diverse technical capabilities with human capability at many levels of organisation into a cohesive socio-technical system. As I note above, he was largely concerned with representation. Although he mentions the manner in which he collects data to populate his representations, those methods do not constitute an innovative contribution. In addition, while there is some discussion of how to use these representations for design, that too remains relatively undeveloped. Many others who employ the framework of Cognitive Work Analysis have made contributions in these other areas but my emphasis in this book is on the representational framework although I will, in a later editon of this book, devote a chapter to the design problem.

Chapter Summary

First and foremost, this book is a tutorial. It will have served its purpose if you, as reader, generate insights that help you understand what Cognitive Work Analysis is about. I seek to help you generate those insights by linking theory to illustration. Each of the chapters devoted to method outlines the theoretical basis for that method and then illustrates the method with an example that I hope will be easily understood by all. Additionally, I link the successive stages explicitly and illustrate how each stage not only provides information for design but also sets up the next stage.

Chapter 2

Theoretical Perspectives

The Nature of Theory

Opinions on what constitutes a theory are diverse. Sometimes I see summaries of structure, as derived through the application of taxonomic methods, characterized as theory. Sometimes those summaries incorporate relational statements as might be derived through the application of ontological methods. Indeed, an Abstraction-Decomposition Space, which is the representational product of Work Domain Analysis, is developed through use of ontological methods. The Abstraction-Decomposition Space is not, however, a theory, although I will later argue that the way we build one is guided by a pragmatic theory of reasoning.

In addition, I have occasionally encountered the opinion that Gibson's ecological approach is not a cognitive theory because it does not posit an internal cause-effect mechanism. I take issue with that opinion on two counts. I suspect that the author of a comment like this is demanding a linear action-reaction event such as a cue striking a billiard ball and that behavior shaping constraints will not serve. In addition, some appear to take Gibson's view that much cognitive activity unfolds beyond the central nervous system as a claim that there are no cognitive structures or processes within the central nervous system. That is, however, an incorrect reading of Gibson. His discussion of resonance to information is just one example of his concern with internal cognitive processes[2.1].

Given this sort of uncertainty, it is worth offering an opinion on what sort of properties a theory for Cognitive Work Analysis should capture. My dictionary (Houghton Mifflin, 2000) defines a theory as a set of statements or principles devised to explain a group of facts or phenomena or that can be used to make predictions about natural phenomena. This will do for the current purposes, although let's be cautious with the reference to *explanation;* there can be dissension about what constitutes an explanation versus a description. However, I conclude from this definition that by use of theory, scientists seek to make sense out of regularities they observe in natural phenomena.

2.1 The view that resources and processes external to the body can be characterized as cognitive has far more currency today (e.g., Hutchins, 1995; Hollan, Hutchins & Kirsh, 2000).

Also note the use of the word *devised* in the definition. A theory is not a statement of fact but rather an imaginative construction. The test of a theory is not whether it is true versus false but whether it helps us understand the world in useful ways. Despite being an imaginative construction, theories can be powerful. The theory of gravity, for example, is a relatively simple statement that takes account of a diverse set of natural phenomena. Despite its simplicity, it has remarkable power. There is presumably no one reading this book who doubts that gravity will have its way on every location of our (and every other) planet. We believe that for locations we know, for places we have never been, for places we will never visit and even for places we have never even heard about.

There is a tendency, within behavioral science, to envy physicists. They study (or at least used to study) observable and a regular phenomena. Such envy is unnecessary: Cognitive Work Analysis is based on observable and regular behavioral phenomena that can impart considerable power to our analysis and design activities.

Foundational Perspectives

The foundational perspectives I outline in this section did not necessarily guide developments in Cognitive Work Analysis, but the concepts they have established represent core assumptions for an analysis and design strategy based on Cognitive Work Analysis.

Situated Cognition

The ethnographic research by Hutchins (1995), Jordan (1989), Lave (1988), Lave and Wenger (1991), Saxe (1991), Scribner and Fahrmeier, (1982) and Suchman (1987) offers profound insights. It reveals how adept workers can be at cognitively restructuring their work environment. Invariably, the work practices that evolve are cognitively economical and robust, typically more so than work practices prescribed by those who do not actively participate in the work.

I have reviewed a portion of this work for its relevance to aviation (Lintern, 1995). One lesson to be taken from it (for aviation and more generally) is that workers are both physically and cognitively active, reshaping how they think about their work environment as they develop their own work practices. The conceit of managers, and also of many designers, is that they know how the work should be accomplished and they need to instruct workers in the proper procedures. The ethnographic research on situated work practice reveals that conceit to be shallow.

In thinking about this issue, I reflect on developments in Artificial Intelligence. There are an enormous number of computationally-based support systems that would seem to offer huge advantages to current practices. Diagnostic systems for medical practitioners can serve to illustrate. These have been under development for decades but are still struggling to find their way into common usage within the medical profession. It is not unusual to hear the accusation that medical practitioners are too arrogant to embrace technology that might replace some of their skills. I suspect otherwise; that these systems do not mesh well with the cognitive strategies and work flow of medical practitioners. From that perspective it would seem that it is the designers of these systems who are overly arrogant.

Implications for analysis and design. The research in Situated Cognition indicates that we need to be very careful if we, as designers, specify cognitive strategies or work flow. The existing strategies and processes will have evolved over considerable time to be robust and effective. To change them without fully understanding the potential repercussions is to risk disaster. Furthermore, workers are adept at modifying strategies to accommodate the demands of new systems. Thus, we should ensure we understand how practitioners or experts go about their work (strategies, modes of cognitive processing) so that we can design supports for their work practices without imposing awkward strategies and we should resist the temptation to over-design systems (we should permit workers to finish the design, Vicente 1999).

Distributed Cognition

Within the work environment of ship navigation in confined waters, Hutchins (1995) reiterated many of insights to be drawn from Situated Cognition but added a particularly evocative and succinct description of distributed cognition. Up to that time, distributed cognition was a somewhat fuzzy concept that even experts in the field would debate.

Hutchins proposed that a ship navigation team, together with accompanying navigational artifacts and procedures, is a cognitive system that performs the computations underlying navigation. It is a distributed cognitive system because various elements of the computations are carried out over time and in different locations. The results of early computations are passed to another location and then integrated in further computation. Hutchins argued that this navigation system has cognitive properties that differ from the cognitive properties of the individuals within the system and that the cognitive potential of the navigation team depends as much on its social organization as on the cognitive potentials of its members. Thus the navigational system performs computations that need not necessarily be within the grasp of all (or even any) of its members.

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.

Implications for analysis and design. Most, if not all socio-technical systems we design will be distributed. As revealed in the illustration offered by Hutchins (1995), there is need for coordination between the distributed subsystems. We need to examine how people coordinate (share information, communicate, work collaboratively) and then we need to ensure that our designs support the essential modes of coordination.

Requisite Variety

Vicente (1999) appeals to the law of requisite variety in arguing that the complexity of a technological support needs to reflect the complexity of the work. Ashby (1957, p207), in framing this law, proposed that *only variety can destroy variety*, here taken to mean that only variety can control variety. In other words, a control system must incorporate as much variety as the system it controls. Alternatively, the functional scope and granularity of a work space must match the operational complexity of the work.

The law of requisite variety warns us against seeking to reduce control complexity by simplifying displayed information. Hollnagel and Woods (2005, p 85) also warn against this, but mis-characterize Ecological Interface Design as a strategy that reduces complexity. An ecological interface, when properly designed, will give selective information access at the level of complexity required for the anticipated control problem. An ecological interface does not continuously display all information at the most detailed levels as for example does a Single-Sensor/Single-Control strategy, but rather displays patterns that can be selectively interrogated to reveal information for the control problem at the essential level of detail.

A pentagon display for a social system governed by human intentions (Figure 2.1) offers a simple illustration. Five dimensions that contribute to the global construct are represented by individual spokes of the pentagon. The measures of those dimensions are normalized to show a symmetric figure under normal or desirable conditions. Where a particular measure reflects an abnormal or undesirable condition, the spoke for that measure generates a distortion in the figure. That distortion will be noticed readily and the offending dimension identified. The relevant spoke can then be interrogated (via mouse click, for example) to foreground more diagnostic detail about the issue. By this means, requisite complexity is avoided until it becomes relevant and only that portion of the requisite complexity needed for the current situation is displayed. Nevertheless, the entire requisite complexity for the system is available.

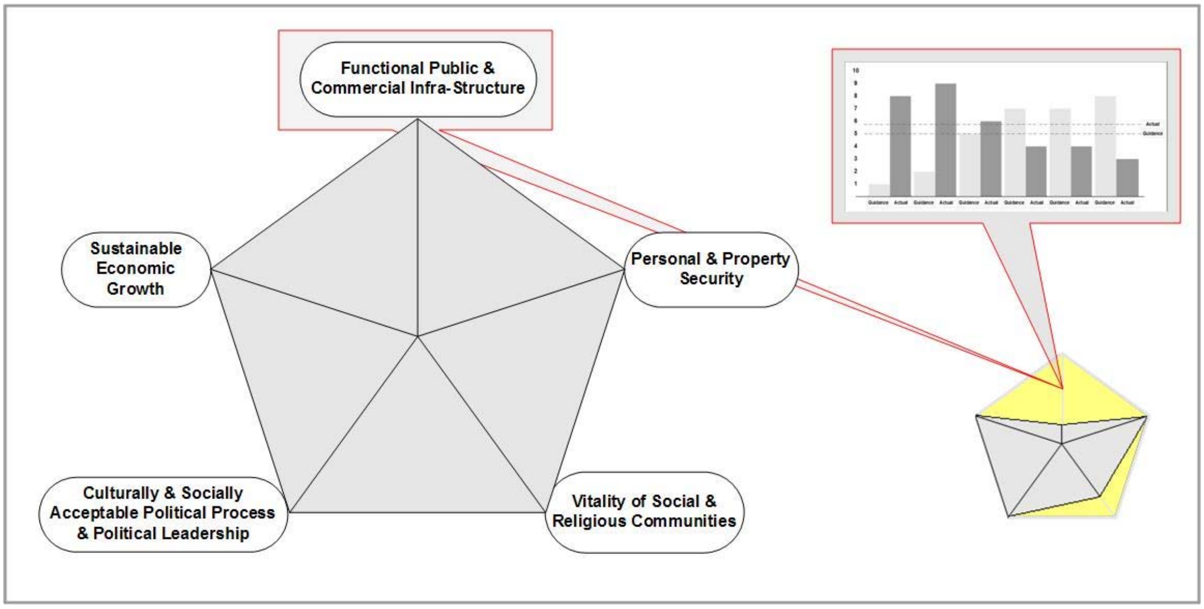


Figure 2.1: A pentagon representation for a social system governed by human intentions (assessment of progress in building a civil, democratic society): the outset of the pentagon at bottom right shows a distortion for Functional Public & Commercial Infra-Structure, the details of which can be displayed in a histogram that compares values for desirable and actual supply of Electricity, Gas, Telephone, Water, Gasoline and Public Transport.

Implications for analysis and design. In development of complex socio-technical systems, we need to ensure that the information potentially available to a worker matches the requisite variety of the work to be undertaken and we need to ensure that workers can find and assemble the constellation of information needed for the problem at hand.

Ecological Psychology

The foundational insight of Ecological Psychology is that cognition is tied up in the reciprocity between an organism and its environment. As with Situation Cognition and as stressed particularly by Hutchins (1995) and his colleagues (Hollan, Hutchins & Kirsh, 2000), much of cognition occurs in the world rather than in the head. As noted above, some critics of Ecological Psychology have taken this to be a claim that nothing relevant to cognition happens in the head, although I remain mystified how any reasonably competent reading of Gibson can lead to that conclusion.

The theory of affordances is a major contribution from Gibson that is relevant to our work. An affordance is a relationship between properties of an organism and matching properties of its environment. It is a relationship between capability and opportunity. In an explanation of the relevance of affordances to interface design (Lintern, 2000), I drew on work by Warren and Whang (1987) who discussed the relationship between shoulder width and aperture width as a passing-through affordance. Indeed, an affordance is always a relationship. Where the dimensions of that relationship can be quantified, it can be expressed as a dimensionless ratio.

Thus, an affordance-based fuel gauge compares the distance that needs to be traveled to the distance that can be traveled with currently available fuel. Depending on which way the ratio is constructed, a value of more or less than one will signify that you can (or cannot) get to your destination. This strategy removes from the operator the computation that is required when fuel and distance are presented separately. Gibson's affordance claim is that this is analogous to the way we operate in the world.

I suspect that many take an ecological display to be one that is pictorial or richly graphical. However, for a display to be ecological, it needs to be more than that. It needs to incorporate within its graphics a depiction of structure of the work environment in terms of the affordances essential to the work.

Implications for analysis and design. An affordance establishes meaning by revealing the reciprocity between information and action. We need to ensure that the information potentially available to a worker is meaningful and we can do that by examining how workers use information or, in other words, by analyzing their affordance structure. Also, recall that the law of *requisite variety* implies that the functional scope and granularity of a work space must match the operational complexity of the work. The law emphasizes that the degree of complexity must be equivalent but does not emphasize that the semantic structure of the workspace must match the semantic structure of the work. The appeal to the concept of affordances corrects that neglect.

Self Organization

Self-organization is a process in which the internal organization of a system, normally an open system, increases in complexity without being guided or managed by an outside source. Self-organizing systems typically (though not always) display emergent properties.
http://en.wikipedia.org/wiki/Self-organization [Accessed Nov 16 2007]

Theories that posit a mental image, a mental model or a mental schema as a formative cause of cognition eschew self-organization (e.g., Johnson-Laird, 1983). In contrast, others argue that an understanding of self-organization is central to understanding cognition. Peter Kugler and I have summarized the basic concepts for this latter view in Lintern and Kugler (1991) and Kugler and Lintern (1995).

Self-organizing systems can transition through a non-linear region into a different (and sometimes, unexpected) organizational form. As explained by Prigogine and Stengers (1984), an adjustment of a control parameter can generate critical fluctuations that cast the system into a new energetic mode. In the case, for example, that the change in the control parameter is serving to inject more energy into the system, a point is reached at which the system must reorganize to dissipate that energy. The term *dissipative structure* is often used to characterize the new organizational form.

The patterns of locomotion for a horse offer an illustration. As the rider nudges the horse into increasing its speed, the horse will initially increase the rates of limb motion but at some critical point will transition into a new, more efficient mode (e.g., canter to gallop). As is true of all nonlinear systems, equine locomotion is mostly linear. However, it is at the nonlinear transitions that interesting things occur. It is invariably true that nonlinear systems can appear linear if one takes a restricted view.

Those who promote self-organization as an explanation of cognition typically emphasize the role of local interactions in the development of patterns and might offer self-organization as a bottom-up, emergent view in contrast to the top-down view of mental imagery as the shaping influence on cognition. Some caution is needed here. While local constraints play an important role in self-organization, it is the interplay between local and global constraints that generate the new patterns.

This means that cognitive emergence owes as much to the functional layout of the environment as it does to the local interactions of individuals with each other and with artifacts. The cognitive architecture determines the way information flows through the system. This architecture encompasses the functional structure of the physical environment, the social organization of the work place and the functional structure of individual minds. New cognitive capabilities emerge from activity undertaken within the constraints imposed by the cognitive architecture and are shaped by those architectural constraints.

Note also that it can be difficult to anticipate the form of organization that will emerge after transition through a nonlinearity. It is never possible to do that from an understanding of the underlying mechanism. However, those experienced with a particular system can typically anticipate the forms of organization that will emerge at least within the range of their previous experience. Experienced equestrians can certainly anticipate the form of organization that will emerge as a horse increases or decreases its pace.

Engineers abhor nonlinearities but biology cannot survive without them. In cognitive engineering, we have a subtle problem. We need to conjoin system components that have been designed with linearity as a design goal to other system components (i.e., the human operators) for which nonlinearity is fundamental. The techno-centric approach is to force linearity on our nonlinear human work force; to suppress the self-organizing tendencies of human systems. These self-organizing tendencies are, however, critical to the system effectiveness (Lintern, 2003). The human-centric approach we seek in cognitive engineering is to work with (even to celebrate and to leverage from) processes of self-organization to make our systems more effective.

Implications for analysis and design. In the design of a large-scale information system we must remain concerned with the functional properties that constrain (or-shape) the possibilities for courses of action and the informational interactions that stimulate emergent patterns of action. We need to examine how both intentional as well as technological properties establish a functional structure that can shape cognition. In addition, we need to understand how interactions between people and interactions between people and technological subsystems generate emergent patterns of behavior as the basis for social organization and teamwork within the workplace. Note that for new designs, anticipation of emergent behavioral patterns demands careful analysis of similar systems if they exist but may otherwise require systematic evaluation with a full range of realistic operational scenarios.

Cognitive Systems

A cognitive system is a one that performs the cognitive work of knowing, understanding, planning, deciding, problem solving, analyzing, synthesizing, assessing, and judging as those activities are fully integrated with perceiving and acting. A complex socio-technical system is an entity that does cognitive work and is therefore a cognitive system.

The claim that a complex socio-technical system does cognitive work expands the view of what is *cognitive* beyond the individual mind to encompass coordination between people and their use of resources and materials. This view is aligned with the theory of distributed cognition enunciated by Hutchins (1995) and further described by Hollan, et al (2000). A foremost claim of this theory is that distributed cognition is not a special type of cognition but is rather a characterization of fundamental cognitive structures and processes (Hollan et al, 2000). Thus, all cognition is distributed.

Traditionally, we are used to thinking of cognition as an activity of individual minds but from the perspective of distributed cognition it is a joint activity that is distributed across the members of a work or social group and across the technological artifacts available for support of work[2.2]. Cognition is distributed spatially so that diverse artifacts shape cognitive processes. It is also distributed temporally so that products of earlier cognitive processes shape later cognitive processes. Most significantly, cognitive processes of different workers interact so that synergistic cognitive capabilities emerge via the mutual and dynamic interplay resulting from both spatial and temporal coordination among distributed human agents.

A distributed cognitive system is one that dynamically reconfigures itself within its functional constraints to bring subsystems into functional coordination. Many of the subsystems lie outside individual minds; in distributed cognition, 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

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2.2 Research in Situated Cognition and Ecological psychology focuses primarily on individual interactions with environment or artifacts but their foundational ideas are consistent with this distributed view.

involves many people and diverse artifacts in the performance of cognitive work is therefore properly viewed as a cognitive system.

A cognitive system is a thinking (or intelligent) information system. However, the enhanced intelligence is not generated by the activity of intelligent technological functions as many in the discipline of Artificial Intelligence want to claim, but emerges from the coordinated collaboration of distributed human agents via their interactions with each other and with functionally heterogeneous technological artifacts. In the sense that collaboration between human agents and their use of technological artifacts is coordinated, effective, robust and meaningful, the cognitive system is intelligent.

It is sometimes argued that computer-based agents can be employed to reason about the beliefs of human participants in teams. However, computer-based agents follow programmed rules, they do not reason. More generally, people reason but technological devices do not. Two people in coordination can possibly reason more effectively than either in isolation, and if they (as a coordinated dyad) avail themselves of the opportunities presented by technological devices that can compute logical relationships, find and organize information, and probably offer a number of as yet unimagined supporting functions, these entities (the two people together with their technological devices) constitute a reasoning system. Heterogeneity (people with different capabilities, the availability of diverse functional resources) will enhance the potential of the system to perform complex cognitive work.

Implications for analysis and design. Note that heterogeneity does not ensure more effective performance of a cognitive system. It is our job as designers to promote effective cognitive performance by assembling and configuring the requisite functional resources and the requisite collaborative supports. The recommendations offered within the implications for analysis and design for each of the preceding discussions of Situated Cognition, Distributed Cognition, Requisite Variety, Ecological Psychology and Self Organization suggest the means for accomplishing this.

Work Centering: Whence the Images

Most, if not all scientific developments emerge from an image that is acquired informally through natural interaction in the world. Theorizing in behavioral science has traditionally derived formative images from some sort of well-known mechanism. Most recently, the digital computer has played a central role, but appeals to formal logic and mathematical relationships have also been influential.

The rational choice strategy for decision making is one such logical-mathematical strategy. The theory of rational choice posits that decision makers first identify options for action and then define dimensions of evaluation, weight each dimension, rate each option on each dimension, multiply the dimensional weightings, total up the scores and select the option with the highest score. Klein (1998) notes that he entered his early decision research committed to the assumption that he would find evidence of option comparison. Only after confrontation with evidence that suggested otherwise could he divert his attention from that idea and develop the concept of recognition-primed decision making.

Klein's work on recognition-primed decision making, now held in high regard, involves a radical move that attracts little comment. Klein rejected decades, possibly even centuries, of reliance on logical and technological images in favor of a work-centered image, one drawn from the way that experienced operators conceptualize their work. Quite independently, it seems, Rasmussen had already made this move and researchers in Situated Cognition were actively working through it.

I have heard it said that Cognitive Engineering is no more than good Human Factors or good applied cognitive science. I reject that observation and do so primarily because of this move. Human Factors is guided predominately by theoretical images derived from technology and logic. In contrast, Cognitive Engineering is work-centered not only in practice but also in theory. We are no longer deriving formative images from mechanism (e.g., the computer) but from ethnographic descriptions or analyses of cognitive work.

Implications for analysis and design. To be work-centered means to be concerned, first and foremost, with what must be accomplished. A work-centered approach rejects ideas that have the human agent subservient to the technology (*man is best when doing least*, Birmingham and Taylor, 1954) or imply a parity between the human agent and the technology (the *team-player* analogy for interaction of humans with automation, Dekker and Woods, 2002). Cognitive Systems Engineers must first understand the nature of the work (what must be accomplished, how it is accomplished, how it might be accomplished in the future) and then set about designing technological supports and organizational configurations to enhance the conduct of that work.

A Theory of Work Practice

Developments in Cognitive Work Analysis have been guided by a largely unstated theory of work practice. While each of the theoretical perspectives outlined above can be considered a theory in its own right, and each contributes to how we might understand a theory of work practice, none constitutes a comprehensive theory of work practice. That theory of work practice needs to characterize the structure within which work is accomplished and the processes with which it is accomplished. The theory that underlies Cognitive Work Analysis does that and I will outline it throughout the early sections of the next six chapters in this book.

Chapter Summary

I sometimes hear the claim that we cannot predict human behavior. While that is true for specific details, there are certain aspects of human behavior that are predictable. For example, if you and I meet for dinner at a restaurant, I will not be able to predict what you order from the menu, but I can predict with good reliability that you will order something and also the upper and lower boundaries of how much you will eat. To illustrate with another example, an architect can design a family home without knowing the specifics of what will be done in that home. S/he knows enough about human behavior at the level of description required for architectural design to do what is necessary. One of the critical but unstated assumptions of cognitive engineering is that we can predict human behavior at that level of description required for design of cognitive support tools and cognitive systems.

The foundational perspective I outline in this section draws on certain observable and regular behavioral phenomena that can inform cognitive design. Theories or conceptualizations of Situated Cognition, Distributed Cognition, Requisite Variety, Ecological Psychology, Self Organization, Cognitive Systems, Work Centering and Work Practice strengthen our conceptualization of the regularities of human behavior. In this chapter, I suggest that each has specific implications for analysis and design.

The practice of Cognitive Work Analysis is also based on observable and regular behavioral phenomena of the sort that can inform cognitive design. It would be useful to connect the theories and conceptualizations I have discussed in this chapter to the practice of Cognitive

Work Analysis but that would make for a scholarly and detailed treatment, which is not my purpose here. Rather, I introduce these ideas to set them as context for the later discussion and I hope, if you are puzzled by any particular elements of my approach, you will be able to reflect on the ideas presented in this chapter in order to understand the rationale.

Chapter 3

The Framework of Cognitive Work Analysis

Cognitive Work Analysis is a multi-stage analytic framework for identifying the human-relevant work constraints in a socio-technical system. The development of this framework was motivated by the assumption that the potential for action by workers in a complex system is specified by behavior-shaping constraints that define a field within which action can take place. The analysis focuses on identifying and representing those constraints.

Work Constraints

Different Treatments of Cognitive Work Analysis (e.g., Rasmussen et al., 1994; Vicente, 1999) identify different numbers of stages for the framework essentially because the different forms of analysis can be grouped in different combinations. There are, however, no substantive differences between the different treatments. I identify six stages that I have found convenient for the analysis of complex information systems. In addition, I have adjusted some of the names of the stages and names of the analyses undertaken within the stages so that they signify more specifically what I am trying to accomplish in my analysis of complex information systems and how I proceed. You also should feel free to organize the different analyses in the way that suits you and suits your domain of analysis as you gain experience in Cognitive Work Analysis.

Six Stages of Cognitive Work Analysis

Stage 1: Functional Work Structure (Work Domain Analysis). In chapter 4, I discuss the functional (activity-independent) structure of work in terms of:

- An Abstraction Hierarchy extending over the five levels of Domain Purpose, Domain Values and Priorities, Domain Functions, Physical Functions and Physical Objects, and
- A Functional Decomposition extending over the number of levels identified during analysis as relevant to an understanding of the functional structure of the work.

The product of this stage of analysis is an Abstraction-Decomposition Space, which is an activity-independent representation of the the functional structure of the work domain.

Stage 2: Partitioning and Organization of Work (Work Organization Analysis). In chapter 5, I discuss the Partitioning and Organization of work in terms of:

- Domain Functions, as identified in the Abstraction-Decomposition Space,
- Work Situations, which are the various situational contexts in which work takes place, and
- Work Tasks, which are the distinctive outcomes to be achieved.

The product of this stage of analysis is a Contextual Activity Matrix.

Stage 3: Cognitive States and Processes (Cognitive Transformations Analysis). In chapter 6, I discuss the Work Tasks identified in the Work Organization Analysis in terms of:

- Cognitive States established during task execution, and
- Cognitive Processes used to effect the transitions between states.

The product of this stage of analysis is a suite of Decision Ladders.

Stage 4: Cognitive Strategies (Strategies Analysis). A Cognitive Strategy is a category of task procedure that transforms an initial Cognitive State into another Cognitive State. In chapter 7, I discuss the Cognitive Strategies that can be used to execute the Cognitive Processes identified in the Cognitive Transformations Analysis in terms of:

- The categories of task procedure that could be used to transform an initial Cognitive State into another Cognitive State, and
- The reasons that a worker may select one strategy in preference to another or may transition between strategies during execution of a Cognitive Process.

The product of this stage of analysis is a detailed description of potential strategies that can be used to execute the Cognitive Processes identified in the Cognitive Transformations Analysis and a description of the factors that will prompt selection of one strategy over another.

Stage 5: Cognitive Processing Modes (Cognitive Processing Analysis). In chapter 8, I discuss the modes of Cognitive Processing that may be employed in execution of Cognitive Strategies in terms of:

- A Skill-Based mode of cognition, which has no conscious processing between perception and action,

- A Rule-Based mode of cognition, which is guided by sets of procedural instructions that specify sequences of actions, some of which may be conditional, leading to branches or halts in the sequence, and
- A Knowledge-Based mode of cognition, which is grounded in conscious and explicit reasoning, and
- The reasons that a worker may use one level of Cognitive Processing versus another or may switch opportunistically between levels during execution of a Cognitive Strategy.

The product of this stage of analysis is a detailed description of the activity elements associated with the different modes of cognitive processing.

Stage 6: Work Coordination (Social Transactions Analysis). In chapter 9, I discuss Work Coordination in terms of:

- The social and collaborative processes that can facilitate peer-to-peer interaction, and
- The social and collaborative processes that can facilitate management-worker interaction and organizational integration.

One product of this stage of analysis is a Social Transactions Matrix, which is an adaptation of the Contextual Activity Matrix developed in Stage 2. A Social Transactions Matrix maps agents (either human or technological or some combination) to Work Tasks and maps Work Tasks to Transaction Demands and Transaction Modes. A second product is a Transaction Network in which the transactions between agents (either human or technological) are identified and characterized in terms of fundamental or generic properties relevant to design.

The Products of Cognitive Work Analysis

The products of Cognitive Work Analysis are knowledge representations 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 Acquisition 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, performative) that shape human action in a work domain.

A Distinction Between Function and Process

Cognitive Work Analysis examines both function and process[3.1]; Work Domain Analysis identifies functions while Cognitive Transformations Analysis, Strategies Analysis, Cognitive Processing Analysis and Coordination Analysis explore the diverse processes of task flow, task coordination, social organization and cognitive processing. Work Organization Analysis provides a bridge between function and process at a high level of description. It maps the functional properties identified in the Work Domain Analysis to potentially important work processes. These are the work processes that are further examined in the later stages of the framework.

There is no principled reason for distinguishing function and process. Indeed, there is no principled reason for analyzing a large-scale socio-technical system through stages as is done in Cognitive Work Analysis. However, problems of this sort are often so large that they can be unmanageable absent some sort of partitioning strategy. The distinctive stages provide natural conceptual boundaries for a pragmatic strategy of parsing the design of a large-scale socio-technical system into more manageable problems. The function-process distinction together with the analytic stages provide natural boundaries.

This function-process distinction is also useful because function and process have different implications for design. Function identifies how physical resources should be instantiated within the workspace. In contrast, process might be accomplished in different ways (e.g., explicit procedures, training, or computerized agents).

Emphasis on the Prototypical

The term, *prototypical*, is used by Rasmussen et al (1994) to imply the generic nature of the properties described. Vicente (1999) does not use this term but rather refers to known, recurring classes of situations. This emphasis on known, recurring classes of situations (the prototypical) is a central feature of Cognitive Work Analysis. The goal is to describe the work domain and the work in terms of generic constraints rather than specific terms. For example, the problem of arranging a business trip to a distant city is one that faces many of us. How do you go about planning such a trip? The strategies you describe would have to be

3.1 Some disciplines (e.g., biology) equate function and process. Elsewhere, building on Vicente (1999), I have argued that for the framework of Cognitive Work Analysis, it is useful to think of function as a structural property and process as an action property (Lintern, 2008).

generic or prototypical because neither the city of origin nor the destination have yet been specified . Specific details could be added later when a particular trip is to be planned.

Do not take this emphasis on known, recurring classes of situations as a dogmatic requirement that you should never, while involved in an analysis, reflect on specifics. There can be an informative interplay between the prototypical and the specific; each contributing to an understanding of the other. Vicente (1999) is explicit:

> *studying current practice can shed a great deal of light on intrinsic work constraints. However, the analysis of current practice should be viewed as one of several possible means to investigate work constraints, rather than an end in itself [p 102].*

Nor do I suggest that cognitive engineering should always aim to describe work in prototypical terms. A good number of important insights and useful design solutions have emerged from applications of Cognitive Task Analysis that have resulted in detailed, specific descriptions. Those of us who prefer the framework of Cognitive Work Analysis can glean much from those insights.

Do remember however that there is an important reason to prefer prototypical descriptions. That reason aligns closely with Suchman’s treatment of plans as situated actions (Suchman, 1987). Much in the future is unpredictable and detailed plans constrain us to that which is predictable. The implication of Suchman’s work is that in preference to developing specific plans for which the details have to be adjusted when a plan encounters reality, it is better to develop a plan as a structure that can accommodate unanticipated events and that can further help us develop specific adaptations to those events in real time. In the design of complex systems, there are many things we cannot anticipate but the prototypical nature of our analytic products permits them to remain relevant and useful even so. In Rasmussen's terms, by emphasizing prototypical design, we permit the workers to finish the design when they encounter specific challenges.

What is a framework?

Cognitive Work Analysis is a framework and not a method (Vicente, 1999). A framework is a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality. More abstractly, it is a skeletal support to be used as the basis for something being constructed (Houghton Mifflin, 2000). A method is a means or manner of procedure, especially a regular and systematic way of accomplishing something (Houghton Mifflin, 2000). A framework is not a recipe, a tool, a process or a model.

Frameworks are used extensively in other disciplines. For example, the Department of Defense Architecture Framework, used in the acquisition and development of major military systems, is used extensively within Systems Engineering.

Cognitive Work Analysis is a framework because it embodies a set of assumptions, concepts and values as a basis for analytic methods (the practices) which result in a schematic (skeletal) description of the system under development.

Frameworks are used in design because they aid assimilation of complex sets of concepts, practices and metrics. They depict interconnections, interactions and interdependencies with a clarity that is difficult to achieve by other strategies. They organize and codify what can be known about a system to be designed in a manner that supports efficient archiving and economical knowledge transfer between members of a design team. The intent of Cognitive Work Analysis is to deploy these advantages of taking a framework approach in design of cognitive work systems.

More on a Theory of Work Practice

In extending the ideas I forwarded towards the end of Chapter 2 on a theory of Work Practice, I propose that the functions of a domain are best understood in terms of activity-independent constraints as represented in an Abstraction-Decomposition Space, and that the work processes can be characterized in terms of Work Tasks, Cognitive Transformations (cognitive states, cognitive processes), categories of cognitive task procedures (Strategies), modes of Cognitive Processing (Skills, Rules, Knowledge) and coordinative work processes (processes of peer to peer interaction and processes of management). I will expand on these ideas at the beginning of the chapters devoted to each of the stages of analysis.

Chapter Summary

In this book, I present the framework of Cognitive Work Analysis as a six-stage analytic framework for identifying the human-relevant work constraints in a socio-technical system.

Although my treatment of Cognitive Work Analysis differs from treatments provided by others in terms of number of stages and in names of stages and methods, these are adjustments rather than a radical reconceptualization of the framework. I offer these adjustments primarily to improve consistency and understandability. I have long been troubled by the fact that names of some stages and of some the methods of analysis do not accurately reflect the specific purpose of that stage or that method of analysis. I anticipate that the treatment I offer here will especially help those new to Cognitive Work Analysis to assimilate the ideas.

Cognitive Work Analysis is a framework, which means that it offers a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality. It emphasizes the prototypical; the generic nature of cognitive properties or cognitively-relevant properties of the work domain. In contrast to other frameworks for cognitive design, it distinguishes function and process. Its analytic products are knowledge representations of the work domain, of individual and collaborative activities undertaken in the work domain, and of processes involved in the execution of those activities.

Chapter 4

The Functional Structure of Work

The activity-independent constraints on work can be described to different degrees of decomposition in terms of both intentional and physical constraints. A description in these terms offers a functional description of the work domain as a work environment that supports and constrains the processes of work. The functional structure of work is identified by the use of Work Domain Analysis and mapped onto an Abstraction-Decomposition Space.

Reprise from Chapter 3

Stage 1: Functional Work Structure (Work Domain Analysis). In this chapter, I discuss the functional (activity-independent) structure of work in terms of:

- An Abstraction Hierarchy extending over the five levels of Domain Purpose, Domain Values and Priorities, Domain Functions, Physical Functions and Physical Objects, and
- A Functional Decomposition extending over the number of levels identified during analysis as relevant to an understanding of the functional structure of the work.

The product of this stage of analysis is an Abstraction-Decomposition Space, which is an activity-independent representation of the the functional structure of the work domain.

Functional Work Structure

A function as used in Cognitive Work Analysis is a capability. A sensor, for example, provides a capability to monitor the status of an area or event. In ecological terms, a function is an affordance, a property of the work environment that supports purposeful action or a constraint that guides it.

In general use, the term *function* has diverse meanings. Following Vicente (1999, p 6), I use it to signify what something does or is used for, which corresponds to one of the several definitions offered by Wiktionary. Vicente defines a function as a goal-relevant structural property of a work domain that supports realization of the purposes for which the work domain was designed. This statement should be interpreted carefully. Sometimes workers use devices in ways not intended by the designer but nevertheless use them to support realization of the purposes for which the work domain was designed. In other circumstances, the Domain Purpose may have changed radically, in which case no device supports realization of the original purpose. Nevertheless, even in that case, the system is being used for an intended purpose and so devices can be legitimately said to have functions. I take Vicente's definition as permitting these interpretations.

By this definition, a function is a structural property of a work domain and is activity independent. A work domain has a functional, activity-independent structure, which is identified and mapped into an Abstraction-Decomposition Space by the application of Work Domain Analysis.

Illustration; A Hobby Carpenter's Workshop

The development of an Abstraction-Decomposition Space is motivated by a particular theory of problem solving. Consider the following scenario.

> As a hobby, a home carpenter has built several pieces of furniture over the past couple of years. The first few pieces were unattractive and fragile and have already been disassembled so that the timber used in them could be recovered for other projects. The more recent pieces were better and are now being used in the home. Our hobby carpenter is now enjoying the process more and is more satisfied with the result and satisfaction was, after all, the primary reason to take up this hobby. He attributes his progress largely to his recent purchases of a wider array of more useful woodworking tools (although he may yet purchase one or two more) and also to his improving skill with them.
>
> He now wants to reorganize his workshop, which has grown and evolved haphazardly as he has become more enthusiastic about building furniture. He works in a small, dark corner of a home garage that has also become, over several years, the storage area for unwanted household items. His tools are stored in a box when not in use, his spare timber is stacked in different places throughout the garage, and he must climb over boxes to access power outlets.
>
> When working on a piece of furniture, he spends an inordinate amount of time sorting through his toolbox to find the particular tool he needs. Often, he settles

for the first tool that will fulfill the required function rather than continuing the search for the tool that will best satisfy it. He does not have enough room to lay out the pieces of a complex job but rather must pile them on top of each other. As a result, he occasionally forgets how far he has progressed with the different pieces and sometimes duplicates a piece, thereby wasting time and material. He frequently has to shift his work site so he has enough body room to work on a piece of wood from a required angle. He often finds, part way into a job, that he does not have the piece of timber he needs and then, inconveniently, he has to go to the supply store to get it.

He needs more working space, better lighting, more convenient access to power, and better organized storage for tools and lumber. He wants at least half the garage for his woodworking and he wants that side of the garage that has the power outlets. He wants to display his tools on a pegboard so that he can, at a glance, locate the required tool. He wants to sort his timber and store it in a manner that he can, when planning a new piece of furniture, glance over it to select what he needs and then to identify what he will have to purchase on the next trip to the supply store.

I have used this simple narrative to build the Abstraction-Decomposition Space shown in in figure 4.1.

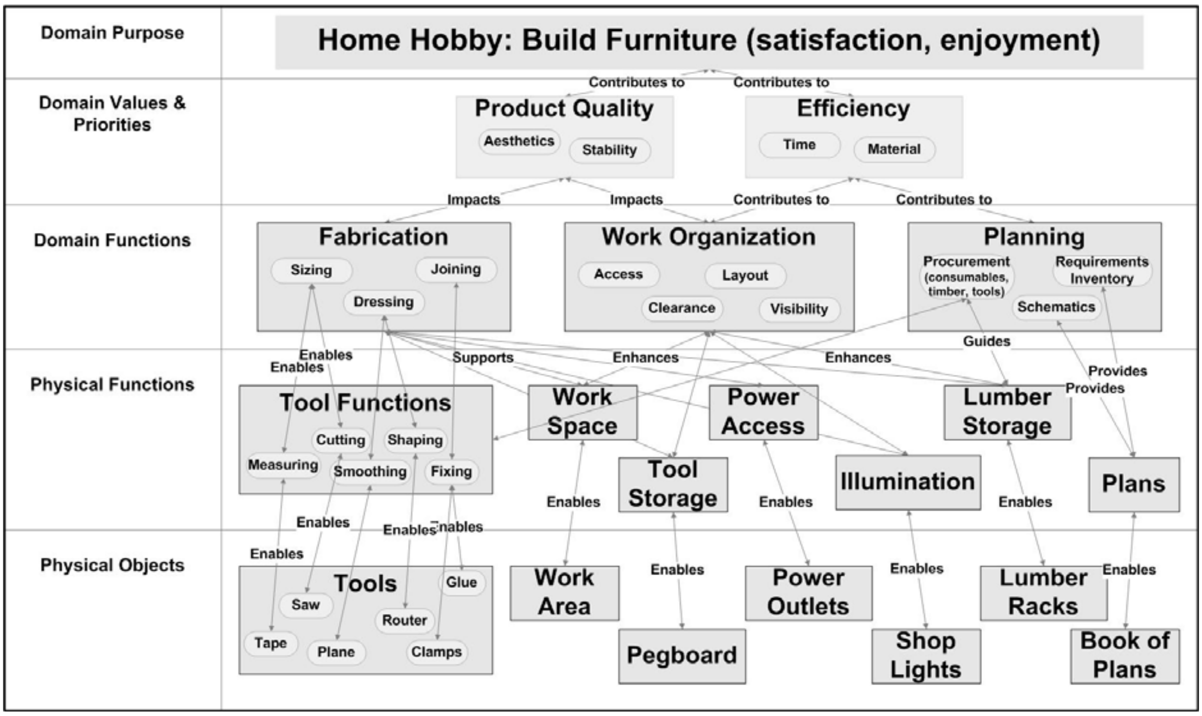

Figure 4.1: An Abstraction-Decomposition Space for a hobby carpenter's workshop

The **Domain Purpose** is identified as the desire to build furniture as a hobby. Satisfaction and enjoyment are important elements of this **Domain Purpose**.

Our hobby carpenter expresses concerns within the narrative about **Domain Values**; the quality of the product (aesthetics, stability) and efficiency (time, material).

At the **Domain Purpose** level, he believes his woodworking capabilities are good but poor organization (visibility, layout, access, clearance) has been impacting the quality of his work. Additionally, the inadequate organization of his workshop has been imposing inefficiencies; in particular, his work efficiency suffers because he spends a good deal of time searching for tools and working his way into difficult places to connect his power tools to a power outlet. He has often lost precious woodworking time when he has had to go to the supply store because he was unable to fully anticipate his purchasing needs for timber. Figure 4.1 identifies the functionality that will help resolve these issues.

At the **Physical Function** and **Physical Object** levels, he has had a good set of tools that has provided him with most of the tool capabilities he has needed but a pegboard will help him lay them out in full view so that he can quickly and easily locate and identify a tool that will satisfy any functional need he has at any time. A more open work area will allow him to lay pieces of his work out on the floor and to move more freely around his working area with sufficient room to work from any angle. He will gain clear access to power points and will install shop lighting to illuminate his work directly. He plans to build racks to store the timber; a sufficient number to hold all the types and dimensions of timber he is likely to need so that he can see at a glance whether he has what is required for an upcoming job.

In developing the Abstraction-Decomposition Space, it can also be useful to decompose functions at the different levels. Figure 4.1 shows several decompositions embedded graphically within nodal boundaries. Not all functional nodes are yet decomposed but the decompositions of the nodes linking tools as **Physical Objects** to **Domain Purpose** is illustrative. Tools as **Physical Objects** (saws, planes, clamps, routers, etc.) enable specific **Physical Functions** (cutting, smoothing, shaping, fixing, etc.) which, in turn enable **Domain Functions** (sizing, dressing, joining, etc.). These **Domain Functions** impact product quality at the **Domain Values** level. This decomposition might indicate a need for a small number of additional tools.

This example illustrates how adherence to the structure of an Abstraction-Decomposition Space can support the design of an efficient and effective workspace. By reviewing an

Abstraction-Decomposition Space that corresponds to the current unsatisfactory workshop, our home carpenter can mentally review the issues and ponder possible enhancements. He can then revise the Abstraction-Decomposition Space to correspond to a more satisfactory space. With that new form in mind, he can then set about reorganizing the physical space and acquiring the additional **Physical Objects** that are required.

A workspace that reflects the structure of an Abstraction-Decomposition Space offers our hobby carpenter more than just an efficient workspace; it is also a problem-solving space. On entering that space, he can quickly ascertain whether he needs to purchase more timber and possibly another tool or two for a project in the planning stage. And then, later, while he is actively working on a project, he can search through the physical resources now laid out in full view to find the tool that will satisfy the **Physical Function** needed to accomplish a **Domain Function** (e.g., a plane to smooth a piece of timber, thereby dressing it).

Work Domain Analysis

Work Domain Analysis, the first stage of Cognitive Work Analysis, identifies the activity-independent constraints of the work domain.

Work Domain Analysis results in an Abstraction-Decomposition Space, which is a two-dimensional space with five levels of abstraction assigned by convention to the vertical dimension and several degrees of decomposition assigned by convention to the horizontal dimension (Figure 4.2).

Those cells in Figure 4.2 that contain entries form a diagonal from upper left to bottom right. In principle, it should be possible to populate every cell of this two-dimensional space but in practice, only the cells that follow the upper right to lower left diagonal provide useful information for design. The lower left cell offers the most evocative example. For the hobby carpenter's workshop described above, the physical object at a whole system of description is *a hobby carpenter's workshop*. While that is a valid description, it does not provide useful information for the design problem.

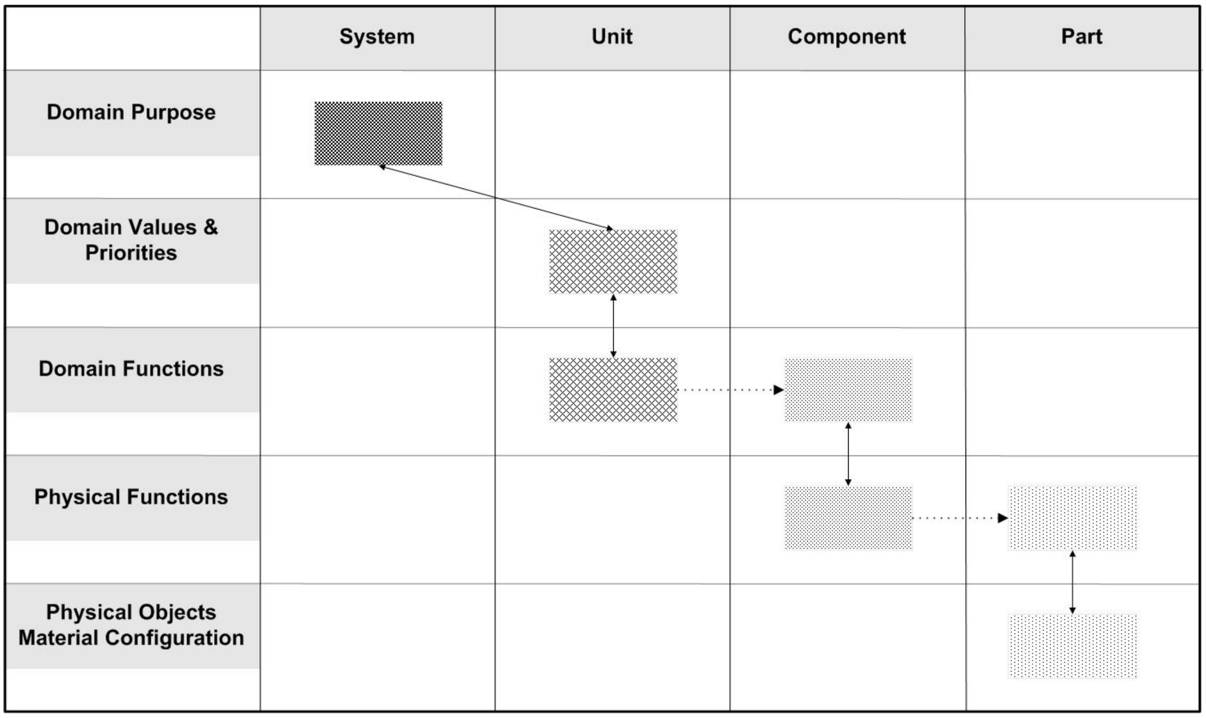

Figure 4.2: An Abstraction-Decomposition Space is a two-dimensional space with five levels of abstraction and several degrees of decomposition

There is no rule to specify which of the cells need to be populated. This varies with the nature of the problem and the extent of the analysis. It is not even necessary to populate cells in every row. In some design problems, you may be concerned with conceptual design rather than physical implementation and might therefore be interested only in the top three rows. More generally, you come to understand which cells you need to populate as you gain more experience.

The format shown in Figure 4.2, while useful for a tutorial, is not otherwise useful because it leaves a considerable amount of page space unoccupied. I prefer the strategy shown in Figure 4.1, where I have sub-functions nested within the appropriate functional node. When the decompositions go from system to the unit to component to part as in Figure 4.2, I typically represent these as graphically nested through that sequence.

Five Levels of Abstraction

The five levels of abstraction are[4.1]:

- **Domain Purpose** is the overarching intention that the work domain was designed to satisfy. A purpose is a property of a domain (not of an actor) and is relatively permanent. It is to be contrasted with a goal, which is a state to be achieved or maintained by an actor at a particular time. Goals are attributes of actors (not domains) and are dynamic. A Domain Purpose may be multi-dimensional and can be identified with questions such as what will domain experts want to achieve with this domain and why is a system being designed for that domain
- **Domain Values and Priorities** are the principles, standards, or qualities to be maintained during execution of work in the domain. They can be identified with questions such as what are the values that shape how domain experts will use this system to satisfy the purpose, what abstract properties help domain experts establish priorities with respect to Domain Purpose, and what are the guiding concerns for domain experts? What considerations guide what domain experts do and, most significantly, what considerations constrain how they set priorities and allocate resources? Properties of balance, conservation, preservation, minimization and maximization are important, e.g. the safety-productivity trade off. Policies and legislation (e.g. Rules of Engagement, Geneva Convention) are typically manifestations of underlying values (e.g., the sanctity of human life).
- **Domain Functions** are those functions sufficient to execute the work that will satisfy the **Domain Purpose** as constrained by the **Domain Values and Priorities**. **Domain Functions** are those work domain functions that must be realized, regardless of how they are physically implemented, to satisfy the **Domain Purpose**. Although some

4.1 There is considerable variation in the literature regarding the labels given to the top three levels of abstraction. The upper three levels point to intentional properties while the lower two levels point to physical properties. Most commonly, the top level is identified as Functional Purpose. I have have avoided that label because the two words *function* and *purpose* have similar meanings. In the past, I have preferred to identify this level as System Purpose and sometimes System Mission. System and mission are, however, not quite the right words. In some usages, the word *system* refers to physical entities and their organization while *mission* has event-dependency connotations. Xiao, Sanderson, Mooij, & Fothergill (2008) have identified this level as Domain Purpose which, in my opinion, is precisely what we mean here. In this book I follow their lead in labeling the top three levels as domain descriptions.

form of technological support is essential, the description at the third level of abstraction is silent on the means (**Domain Functions** are device independent). The realization of **Domain Functions** will be constrained, however, by values or priorities.

- **Physical Functions** are those functions realized by activation or use of technical devices or physical sub-systems (the physical elements of the system). I often characterize this fourth level of abstraction as **Technical Functions and Contextual Effects.** I add the reference to **effects** when I am concerned with the influence of the environment (e.g., weather). Effects are conceptually similar to functions but it sounds strange to suggest that natural events (e.g., weather) have functions.
- **Physical Objects and Material Configuration** are those physical devices and sub-systems within the work domain, useful for the conduct of work, that have material existence. They are identified by their names, appearances and locations. The physical properties of environmental systems that might impact the work domain can also be described here.

From the bottom to the middle level of the Abstraction Hierarchy, means-ends relations link Physical Objects to Physical Functions and Physical Functions to Domain Functions. From the middle to the top level, they link Domain Functions to Domain Values and Domain Values to Domain Purpose. In many cases, a constellation of properties at a lower level will be required to satisfy any specific property at the next highest level.

Levels of Decomposition

There is no specified number for degrees of decomposition. The number of degrees of decomposition is determined by that found useful by domain experts and is identified by reference to knowledge acquisition protocols. The illustration of the hobby carpenter's workshop offers a useful example. For the purpose of building furniture, it is useful to identify individual tools and their functions but it would not be useful to decompose tools into their components although for tool repair (a different work domain) it would be useful to decompose tools into their components.

Abstraction: The Fundamentals

An Abstraction Hierarchy, as developed via Work Domain Analysis, is a stratified hierarchy defined by means-ends relations between adjacent levels. There are different types of Abstraction Hierarchies, which I describe in Appendix A. It is the means-ends structure that distinguishes the type developed via Work Domain Analysis. A means-end relation identifies the resources (the means) that are available for a worker to achieve a work product (the end). A series of means-ends relations links resources across levels of abstraction in a functional chain. Figure 4.3 shows a minimal means-ends Abstraction Hierarchy. The furnace is the physical resource that enables the physical function of heating and the heating function is the resource that enables realization of the value of comfort.

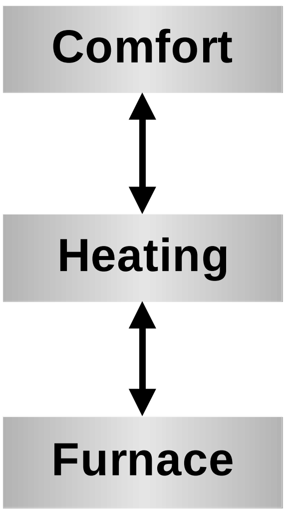

Figure 4.3: A minimal Abstraction Hierarchy showing the means-ends relationships between a furnace, heating and comfort

The relationship shown in Figure 4.3 is often described by a Why-What-How rule as depicted in the second and third columns of Figure 4.4. This is to be read as:

- What do we wish to achieve - *we wish to heat our home*
- Why do we wish to achieve it - *because that will enhance our comfort*
- How can we achieve it - *by use of the furnace*

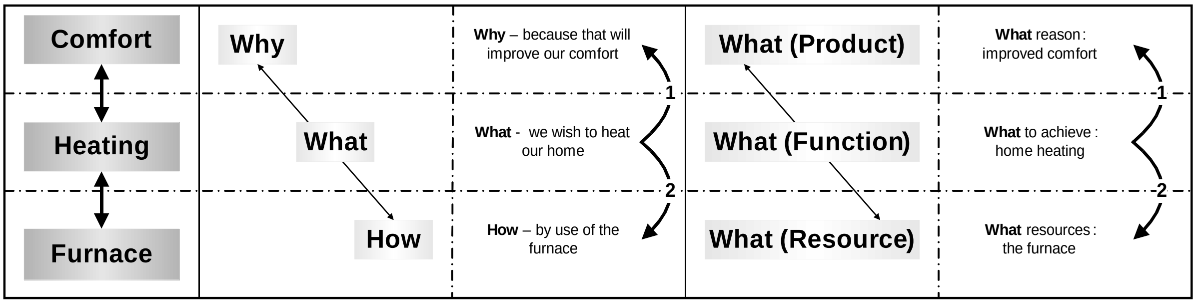

Figure 4.4: The Why-What-How rule contrasted with the What-What-What or Product-Function-Resource rule

I do not, however, favor the use of this Why-What-How rule. *Why* implies a goal which, according to Vicente (1999), is a task property rather than a work domain property. In general discussion, a *why* query will sometimes be answered with a statement of purpose, but at other times will be answered with a statement of goal and sometimes with a cause-effect explanation. *How* implies activity as well as resources. In general discussion, a *how* query will most often be answered with an activity description that may or may not include a reference to a resource. Thus the implications of the Why-What-How rule are not fully consistent with the activity-independent nature of an Abstraction-Decomposition Space.

The Abstraction-Decomposition Space is a *what* space and so I prefer what might be called a What-What-What rule or a Product-Function-Resource rule as depicted in columns 4 and 5 of Figure 4.4**:**

- What do we wish to achieve or what function do we wish to realize – *home heating*
- What is the reason or what is the desired product - *improved comfort*
- What resources will we use- *the furnace*

A means-ends relation is a proposition, much like the proposition in a Concept Map, although Concept Maps do not impose an activity-independence restriction. Those who build Concept Maps typically label the linking statement. That strategy is not normally used for Abstraction-Decomposition Spaces but Xiao et al (2008) have used it to such good effect that I now also use it. Figure 4.1 offers an illustration. I particularly like this strategy because it makes an Abstraction-Decomposition Space more readable. I have not, however, adjusted all of the Abstraction-Decomposition Spaces I reproduce in this book to conform to that strategy primarily because of the amount of time that would take to revise those I have used here that are from my earlier work.

It is occasionally argued that the Abstraction Hierarchy is not a hierarchy because it permits many-to-one mappings (of means-ends relations) from a higher to a lower level. It is also sometimes argued that the Abstraction Hierarchy is a network. These claims are based on a misunderstanding of the nature of hierarchies and I deal with them in Appendix A.

The Controversy of Means-Ends Relations

Lind (2003) has argued that the activity-independence restriction on the meaning of means-ends relations is inappropriate and that the usage of this concept should take account of the diverse meanings for means-ends relations, many of which incorporate references to causality and activity. From dictionary.com, *means* refers to an agency, instrument, or method used to attain an end (a telephone is a means of communication) or to an available resource. This is an activity-independent usage consistent with the usage in Work Domain Analysis. Note this carefully; the failure to understand or acknowledge the activity-independent nature of the Abstraction-Decomposition Space is a source of considerable confusion within discussions of Work Domain Analysis.

Decomposition

Figure 4.5 shows how we might decompose the three levels of abstraction introduced in Figure 4.3.

Decomposition is relatively straightforward, at least in conceptual terms, and I will not discuss it to any great extent. There is, however, one issue that is worth noting. Decomposition at the level of technical systems is straightforward. In fact, technical systems are assembled out of parts and so decomposition is conceptually at least, the reverse of the assembly process. In contrast, the higher levels of abstraction within an Abstraction-Decomposition Space reference biological or human properties that are realized via processes of growth and development rather than technological processes of assembly. Their decomposition is not as straightforward. For example, in Figure 4.5, comfort is decomposed into physiological, psychological and financial stability but these are not as independent as that decomposition implies. Can we imagine psychological stability without financial stability or financial stability without psychological stability? In a strict sense, properties of human and biological systems are not decomposable.

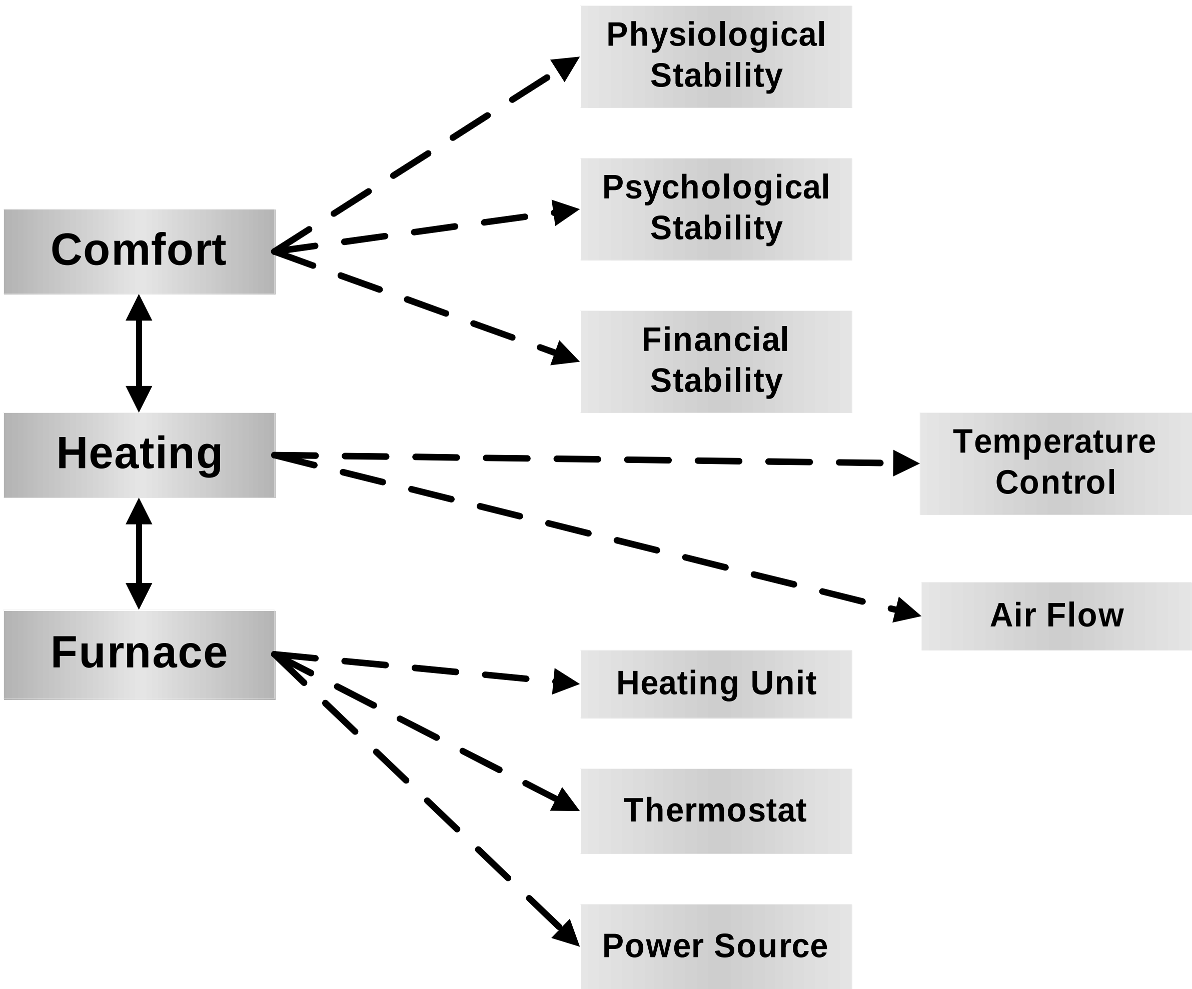

Figure 4.5: Decomposition at three levels of abstraction

Work Domain Analysis: Other Illustrations

At first pass, many find Work Domain Analysis counter intuitive and the Abstraction-Decomposition space impenetrable. I will provide two further illustrations of Abstraction-Decomposition spaces as appendices, which I will add to this book in the near future. These are Abstraction-Decomposition Spaces of two markedly different systems, an iPod and a theatrical production. In particular, I have used these illustrations to emphasize the meaning of the Product-Function-Resource relationship in the means-ends scheme.

I will also include in the appendices a comparison of a home cooling system, which is predominantly a technical system, and a library, which is predominantly a social system.

Additionally, do not forget Neelam Naikar's forthcoming book (see page vi) which will focus on this topic.

Special Topics in Work Domain Analysis

Interdependency

One of the major concerns in reasoning through a complex problem or knowledge-intensive issue is that there can be subtle interactions between seemingly independent constraints. For example, a military plan for resolution of an issue might be developed on the basis of availability of certain resources that, if made available, would compromise another critical mission. One of the more important contributions of the Abstraction-Decomposition Space is that it depicts inter-dependencies between functional areas that will often be viewed as independent.

The airborne surveillance example of Figure 4.6, inspired by the work of Naikar and Sanderson (2001) serves to illustrates. This fragment of an Abstraction-Decomposition Space shows that the Domain Purpose is to protect national security through an air defense capability. Early warning against an air attack has a high Value as does safety of the platform against destruction by the enemy. These Values are supported by independent sets of means-ends links through Domain Functions, Physical Functions and Physical Objects. In normal Systems Engineering practice, each of these functional areas might be assigned to different Integrated Product Teams and the team responsible for building the detection system might not recognize that the decisions they make could compromise the stealth profile and thereby compromise the important Value of platform safety.

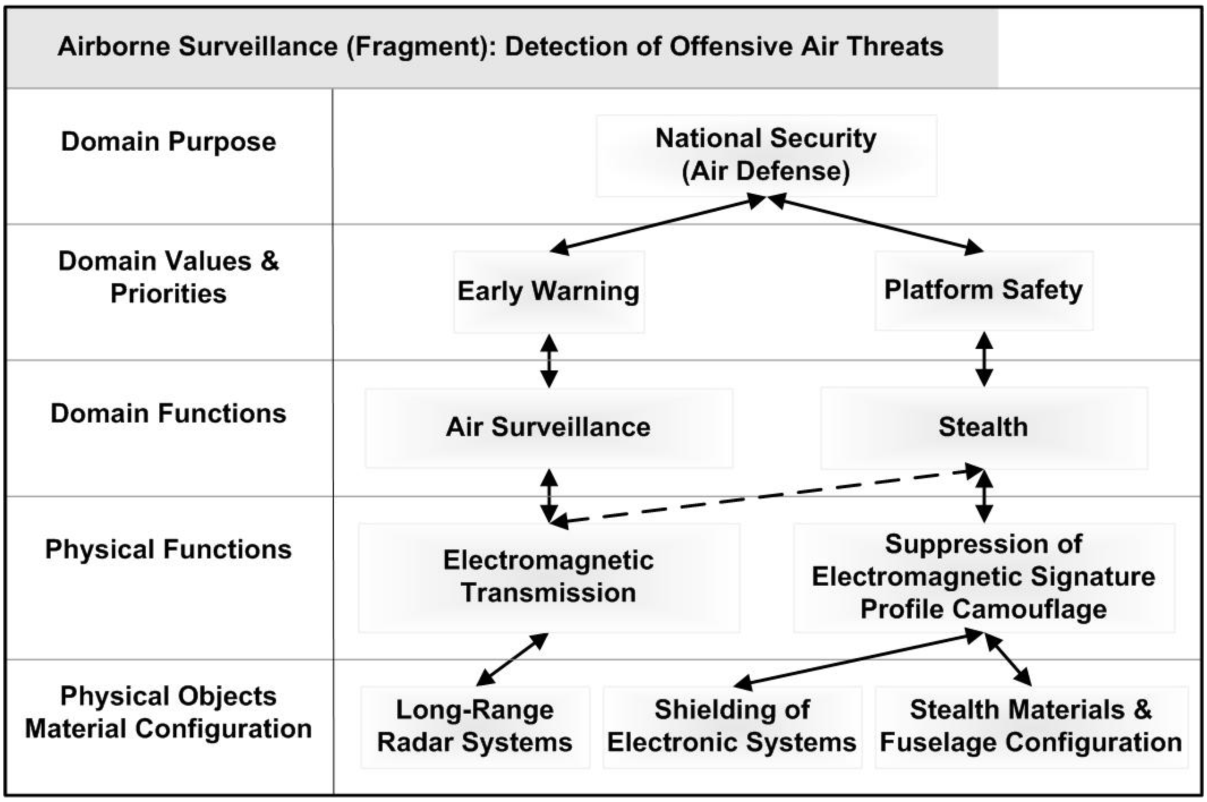

Figure 4.6: A fragment of an Abstraction-Decomposition Space for an airborne surveillance system showing an interdependency between distinctive subsystems

The home cooling example of Figure 4.7 offers a further illustration. The comfort of a home is maintained both by an active process (heat exchange) and by a passive process (obstruction of thermal transmission). This illustration is based on an actual example in which the cooling system of a domestic residence shut down on hot days activated when the system overloaded. The initial diagnosis was that the compressor of the air conditioner had insufficient cooling capacity for the home but the subsequent calculations revealed that its capacity was more than adequate for the volume of air that had to be cooled. That calculation was, however, based on the specified values of roof and wall insulation. Subsequently, it was ascertained that the builder had failed to use any insulation in the walls and had not fully satisfied the specifications for roof insulation. Although this problem revealed itself in the functionality of the heat exchange, the problem lay in the functionality of the thermal transmission.

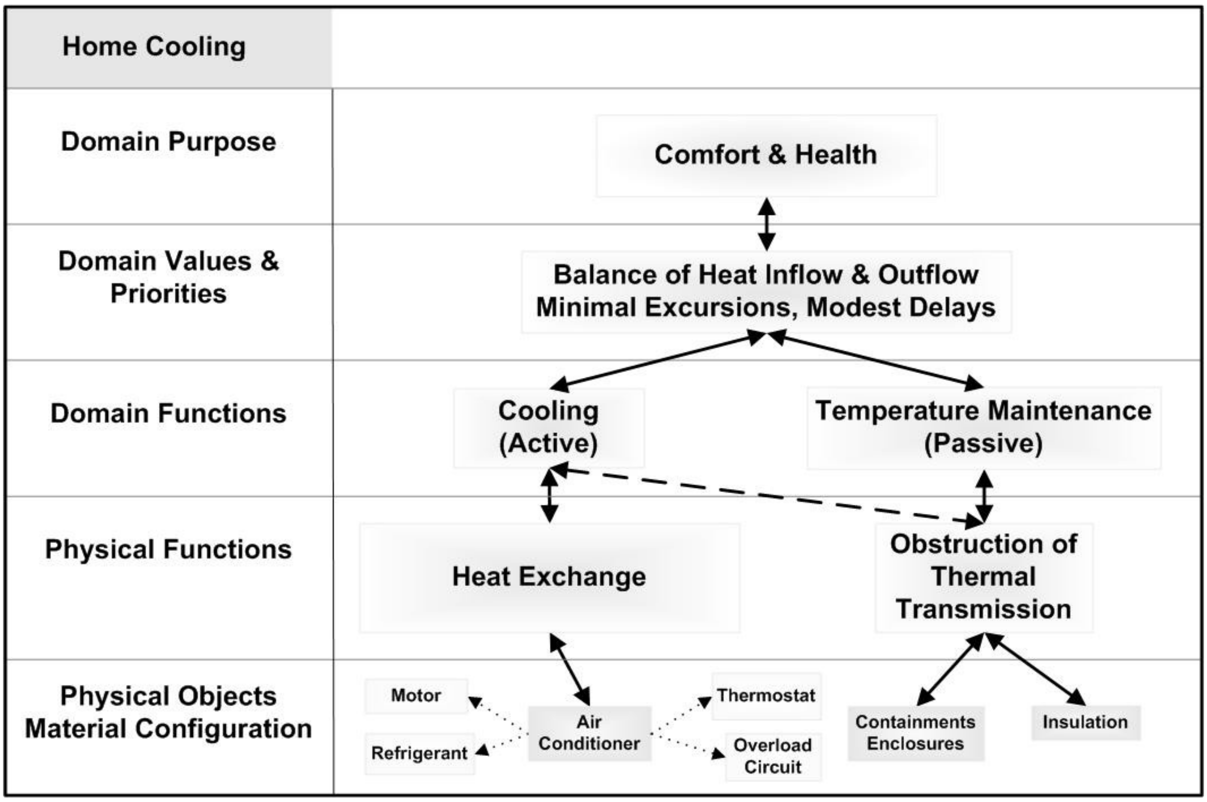

Figure 4.7: A fragment of an Abstraction-Decomposition Space for a home cooling system showing an interdependency between distinctive subsystems

Terms for entries in the Abstraction-Decomposition Space

I offer the somewhat humorous example of Figure 4.8 as an illustration of the importance of words in the development of an Abstraction-Decomposition Space. Each of the levels of abstraction can be viewed as a complete but alternate description of the system under analysis. The descriptions at different levels should be encapsulated in different language. My example of Figure 4.8 suggests that this is not always easy. The same word can have diverse meanings and, most troubling for the Abstraction-Decomposition Space, can be applied at different levels of abstraction. The terms used in an Abstraction-Decomposition Space should be level-appropriate and should distinguish the levels.

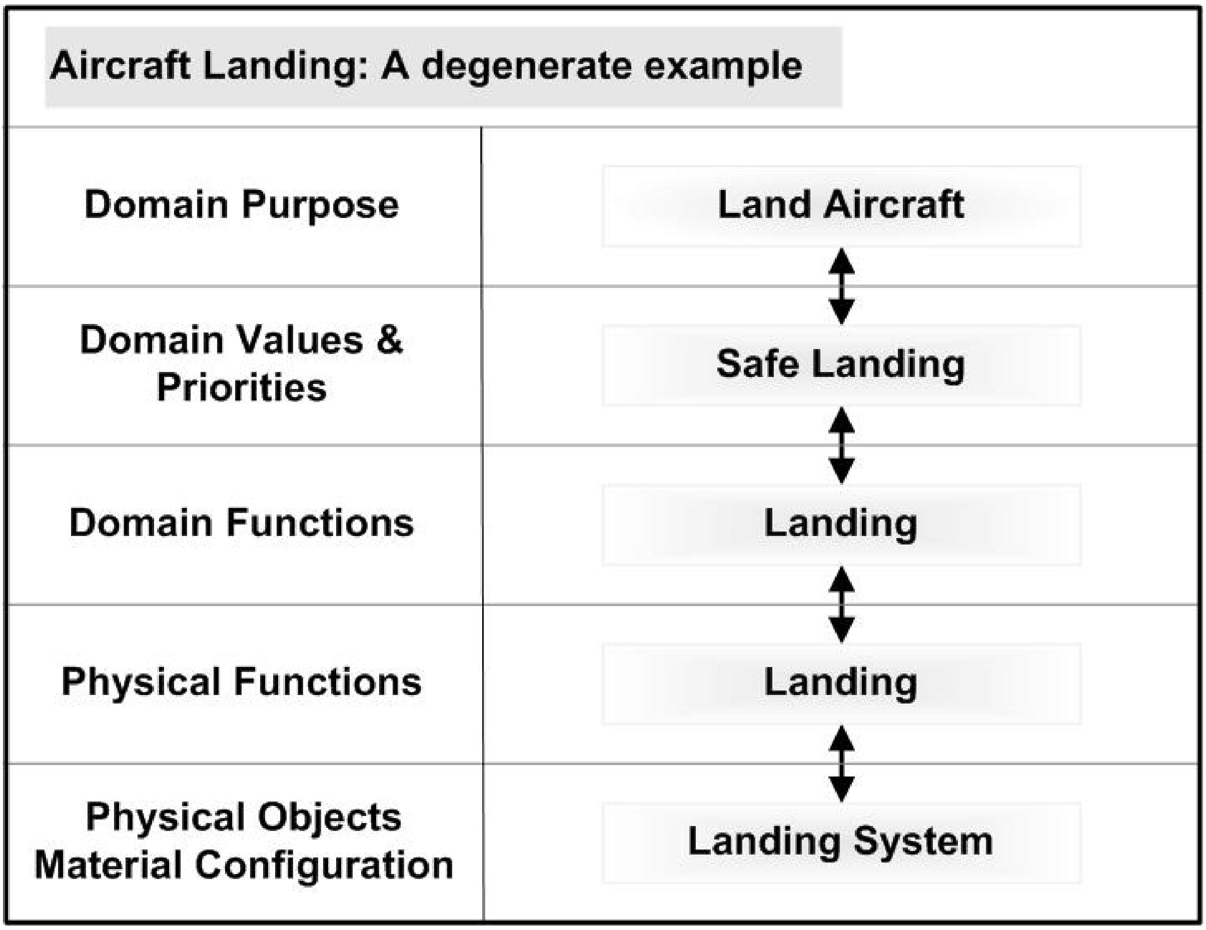

Figure 4.8: An Abstraction-Decomposition Space for aircraft landings in which the terms are not level-appropriate and do not distinguish the levels

It is often a challenge to identify terms that are level-appropriate and that distinguish the levels. For example, is a pump an object or function? A pump, in fact, is an object that pumps. While this example suggests that it is legitimate to have the same word at different levels of abstraction, I suggest you avoid that. You might, in this example, name the object as a pump and then develop a different description for its function, something such as fluid flow. When faced with this dilemma, I sometimes find at least at the bottom to levels of abstraction, that my technical knowledge is not up to the task of finding adequate descriptions for Physical Functions. I have less difficulty with the upper three levels. My own professional training is in psychology and I imagine that my colleagues with professional training in engineering could possibly experience the reverse challenge.

Indeed, the development of a comprehensive Abstraction-Decomposition Space for a large socio-technical system requires close collaboration between members of different professional disciplines and also close collaboration with subject matter experts. The prime intent of the Abstraction-Decomposition Space, which is rarely stated explicitly, is to provide a comprehensive, detailed and meaningful description of the work domain. You should not imagine this is easy. The development of an Abstraction-Decomposition Space is not a straightforward translation of work domain data. More than anything else, it is like writing a difficult paper where you struggle over the placement and expression of ideas and struggle with how they fit together. I find myself editing and re-editing as I keep checking and rechecking for both external and internal consistency. I keep questioning whether the structure and terminology of my Abstraction-Decomposition Space accurately reflects the meanings contained in the source data, whether they conform to the meanings of abstraction, decomposition and means-ends as those concepts are defined for Work Domain Analysis, and whether the words I have used are sufficiently discriminatory and evocative.

The success of Work Domain Analysis depends critically on use of terms in the Abstraction-Decomposition Space that are evocative, meaningful, level appropriate and distinctive.

Abstraction-Decomposition as a Theory of Reasoning

The foundational assumption for work domain analysis is that human reasoning is based on navigation through an Abstraction-Decomposition Space.

It would seem axiomatic that resolution of a problem would require that the problem solver be cognizant of the purpose of the system in which the problem is observed, the values and priorities that need to be considered within use of the system, the physical resources available for problem resolution, and the uses to which the available resources can be put (i.e., their functionality). In a complex knowledge domain, it is likely that the problem solver would need to decompose some of these elements to fully understand how they would contribute to resolution of the problem. The theory that lies behind Work Domain Analysis is based on the assumption that domain experts reason in this manner when they resolve knowledge-based problems within their domain of expertise.

The statement above, *the uses to which the available resources can be put*, implies a means-ends relationship between resources and functionality. A physical device (**Physical Object**) such as a sensor provides a functional capability. Similarly, functional capabilities support realization of **Domain Values and Priorities** and, in their turn, **Domain Values and Priorities** support realization of **Domain Purpose**. This hierarchical scheme (first shown in this chapter in Figure 4.1) conforms to the usual strategy in Work Domain Analysis, as inspired by Jens Rasmussen, of distinguishing P**hysical Functions** (directly realized through activation of **Physical Objects**) from **Domain Functions** established to support realization of **Domain Purpose**. In this scheme, **Domain Functions** are not linked directly to **Physical Objects** but are linked to them via **Physical Functions**. **Domain Functions** are sometimes characterized as device-independent functions.

Reasoning by reference to the form of hierarchical structure illustrated in this chapter is conceptualized as a navigational trajectory through an Abstraction-Decomposition Space. That trajectory is not characteristically systematic. An expert might start anywhere in the Abstraction-Decomposition Space and might wander through it opportunistically, collecting information as the need becomes apparent. The same expert, on the next exposure to a similar problem, might employ a different trajectory. All that is required is that the essential information be collected, at least *implicitly*, for the development of an expert solution.

I introduce the concept of *implicit* to take account of the fact that experts might remember information from previous experiences and in some circumstances, might not even be aware of how that information influences their reasoning. Additionally, information about purposes, values and priorities may have become entrenched by indoctrination or training. Experts may have tuned their strategies to take account of that information without necessarily being cognizant of it during reasoning events. In these sorts of circumstances, an expert is unlikely to visit, at least explicitly, all essential nodes of an Abstraction-Decomposition Space.

Note that an Abstraction-Decomposition Space is an activity-independent representation. It can be likened in this regard to a map, which is a familiar type of generic, activity-independent representation that supports resolution of a straightforward problem (i.e., navigation through an unfamiliar area). A map supports activity but none of its elements describe activity. Similarly, an Abstraction-Decomposition Space provides information that can support activity but it does not contain activity descriptions. The theory on which Work Domain Analysis is based describes the hierarchical structure for the support of reasoning but does not describe the reasoning process itself.

In summary, the claim is that there is a natural structure to expert reasoning and that it is best described by an Abstraction-Decomposition Space that links the different levels of hierarchical abstraction through means-ends relations and that reveals functional constraints and physical resources at different hierarchical and decomposition levels. If this claim is valid, it should be possible to map reasoning protocols onto the appropriate Abstraction-Decomposition Space. I offer an illustration of this idea in Appendix B.

Work Domain Analysis: How to Proceed

In all the Work Domain Analyses I have done, I have relied heavily and sometimes exclusively for source material on operational, design and training documents. I sometimes supplement that material through discussions with subject matter experts and for an upcoming project, I plan to gather the relevant information exclusively from subject matter experts. In large part, the choice of where you get your data is determined by availability although it does have to be a source that is likely to provide the sort of information that will help you fill out each of the five levels of the Abstraction-Decomposition Space to an operationally relevant level of decomposition.

I always start by first identifying the Domain Purpose and then developing a simple Abstraction Hierarchy over about 30 to 60 minutes, relying on what I already know about the system. For a future system, I typically work down from Domain Purpose and for an existing system go directly from Domain Purpose to Physical Object level. Once I have developed a simple Abstraction Hierarchy, I start elaborating and extending it in the decomposition dimension with information from my document analysis or my interviews with subject matter experts.

I move between levels frequently, adding functional nodes as they come to me or as I find them in the documents or interview records and developing decompositions as their value becomes apparent. Parts of functions are often named in documents. I allow the naming of one or two parts of a function or object to stimulate a search, either in that document or elsewhere, for the remaining parts.

Once I have a good number of functions at each level, I start inserting and naming means-ends links with the aim of establishing means-ends relations as meaningful propositions but taking care to conform to the activity-independence restriction. As noted above, I have started taking this step of naming the means-ends links only in recent months.

All through the development of an Abstraction-Decomposition Space, I am continually editing; moving functions up or down a level, adjusting names of functions or links, and adding or removing links between functions.

I then start reviewing what I have for internal validity. Do the propositions conform to a meaningful narrative both from the bottom to the top and from the top to the bottom? There should be continuous means-ends linking in both directions and every function at each of the intermediate levels must be linked to the levels above and below; there must be no orphan functions. The goal is to be able to read the Abstraction-Decomposition Space as a narrative. To that end, it must have internal continuity, grammatical conformity, conceptual clarity and conceptual consistency.

It is normally quite challenging to execute a good Work Domain Analysis but it becomes even more challenging if you know very little about the system you are analyzing. I have known some details of every system I have analyzed and I have used that knowledge to start the process. You need to know at least a little about the human dimensions of the system and also about its technical dimensions. My background is in behavioral science, which offers a good basis for developing the top three levels of the Abstraction-Decomposition Space, but I typically find it more challenging to identify terms and decompositions that are appropriate for the lower two levels.

Be warned. This is hard. I am not sure anyone finds it easy but I certainly do not. As I noted above, for me it offers challenges similar to those of writing a scientific paper. I struggle with assembling and organizing the concepts and then, many times, I think I have it right but my review tells me I have not. Even now, with more than 20 years of experience in writing scientific papers, I struggle with first formulating and then organizing ideas and then, once I have a decent draft, I edit and review numerous times. I suspect that 20 years of experience with Work Domain Analysis will have me saying the same thing about building Abstraction-Decomposition Spaces. However, one strategy that has helped me enormously to write scientific papers is that of developing a structured outline early in the process. I have co-opted that strategy to my development of an Abstraction-Decomposition Space by initiating the process with a 30- to 60-minute exercise in developing a simple Abstraction Hierarchy as I have described above.

Design Implications

An Abstraction-Decomposition Space is not a design or even a design specification but rather a design artifact. It organizes information in a systematic manner that will support design. For example, it can be used to specify the information requirements of a work domain. Each node in an Abstraction-Decomposition Space points to information (either directly or indirectly) that must be provided within the workspace, although different stakeholders (staff members, operators) will need access to different constellations of that information at different times. This information will reveal to the workers the essential functional properties (purposes, values, resources and opportunities) of their work area. Ultimately, functions identified as nodes in the Abstraction-Decomposition Space must be linked to a design object.

Finally, as we will see in succeeding chapters, the Abstraction-Decomposition Space provides guidance for the development of the next stage of Cognitive Work Analysis, Work Structure Analysis.

Chapter Summary

Work Domain Analysis, the first stage of Cognitive Work Analysis, is a specific method for analyzing the means-ends structure of the Work Domain. It results in an Abstraction-Decomposition Space; an activity-independent representation of system elements at different levels of abstraction and detail. The elements at different levels of abstraction are connected by means-ends relations.

Work Domain Analysis leads into Work Structure Analysis, the second stage of Cognitive Work Analysis, which associates the activity-independent Domain Functions identified by Work Domain Analysis with activity-dependent Work Situations and Work Tasks identified by Work Structure Analysis which, in turn leads into Cognitive Transformations Analysis, Strategies Analysis and Cognitive Processing Analysis, the third, fourth and fifth stages of Cognitive Work Analysis, all of which examine different aspects of the activity-dependent constraints identified by Work Structure Analysis.

Chapter 5

The Partitioning and Organization of Work

The organization of cognitive work can be framed in terms of situations and tasks. Work Situations are different modes (e.g., startup, operation, shutdown) of work or different situational contexts that influence the choice of a pattern of work.

Work Situations and Work Tasks are identified by the use of Work Organization Analysis and mapped onto a Contextual Activity Matrix.

Reprise from Chapter 3

Stage 2: Partitioning and Organization of Work (Work Organization Analysis). In this chapter, I discuss the Partitioning and Organization of work in terms of:

- Domain Functions, as identified in the Abstraction-Decomposition Space
- Work Tasks, which are the distinctive outcomes to be achieved, and
- Work Situations, which are the various situational contexts in which work takes place.

The product of this stage of analysis is a Contextual Activity Matrix.

Work Organization

Work is organized as distinctive tasks to be accomplished or problems to be resolved. Following the definition of task offered by Crandall, Klein & Hoffman, (2006), Work Tasks are viewed in the broad sense as outcomes "people are trying to achieve" (ibid, p 3] rather than in the narrow sense as a sequence of discrete activities aimed at achieving a particular goal. The Crandall, et al view of task corresponds closely to Vicente's (1999) definition of a Control Task.

The context within which tasks are undertaken (Work Situations) influences how they are accomplished, for example tasks undertaken in crisis or danger will often be executed differently and may even satisfy different goals than the same task undertaken in normal or benign conditions. This dimension of work organization is treated more fully in a discussion of the subsumption concept later in this chapter.

Illustration; A Home Carpenter's Workshop (Continued)

Consider, again, the home carpentry scenario.

> In completing a project, our home carpenter realizes the three Domain Functions (Fabrication, Work Organization, Planning) identified by the Work Domain Analysis.
>
> He completes the work in two phases; a Project Preparation phase and a Project Execution phase.
>
> He commences Project Preparation with Project Planning. He may have a requirement for a specific piece of furniture in the home, in which case he will search for a suitable plan. Alternately, he may initiate the project by consulting a book of plans to identify a worthwhile project. He will examine the plan to generate a list of requirements (timber, consumables, tools). He will then match that list of requirements against what he has already in his workshop and will identify any items that must be purchased. As part of this process, he will review his inventory of tools and will consider whether he will have to purchase one or two more tools to do this project properly.
>
> Early in the Project Preparation phase, he also starts to distribute timber, tools and consumables required for the project around the periphery of his work space. In earlier times, there was a good deal of work required in this phase to organize the workspace by moving boxes to clear a space and to locate the timber and consumables that he already had on hand. However, with his workshop now organized as he wants it, all of this unproductive, frustrating effort has been eliminated.
>
> He completes the Project Preparation phase with a trip to the hardware store to purchase any items he needs that he does not already have. On projects in which he does a good job with identifying purchase needs in the Project Preparation phase, all purchasing is done in one trip. Only when he is careless does he have to take a second trip.
>
> Ideally, the Project Execution phase is given over to building the piece of furniture. In his earliest attempts, our home carpenter's approach to completing the Work Tasks of measuring, sizing, shaping and finishing was haphazard. With

experience, he has become more systematic, completing each of these Work Tasks in the order of measuring, sizing, shaping and finishing before moving on to the next so that finally he is ready to assemble, clamp and glue to complete the project.

Our home Carpenter has also learned over time that mental review of the project during the Work Task of laying out the timber, tools and consumables pays off in the Project Execution phase. He has become aware, for example, that he measures and cuts timber with more confidence if he has thought through the plan carefully before he starts that measuring and cutting.

I have used this narrative to build the Contextual Activity Matrix shown in in Figure 5.1.

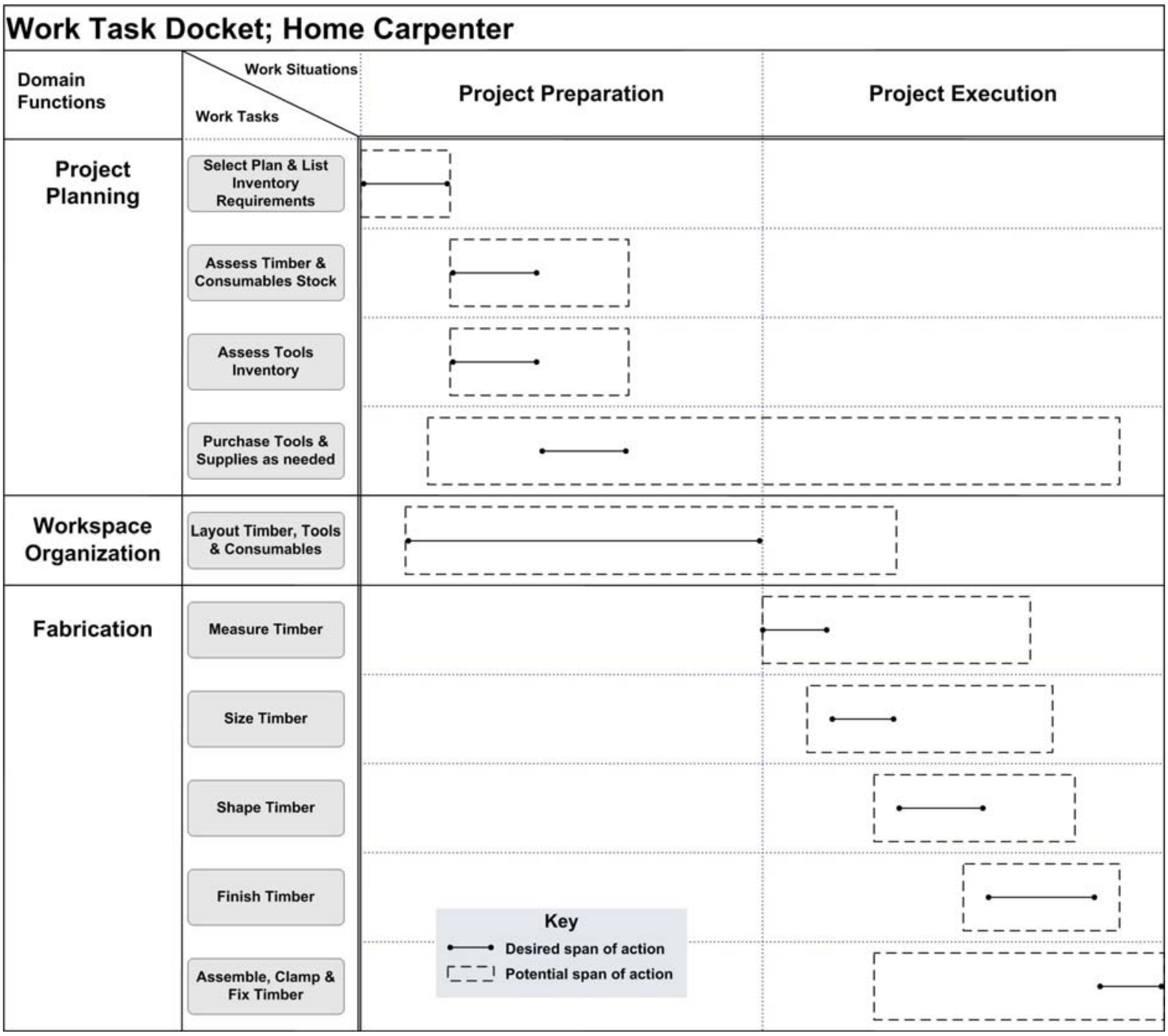

Figure 5.1: A Contextual Activity Matrix of Work Situations and Work Tasks associated with Domain Functions for home carpentry

The Work Tasks undertaken by our home carpenter are shown on a vertical axis of Figure 5.1 and are crossed with Work Situations. The Work Situations shown in Figure 5.1 establish a context for the carpentry Work Tasks and thereby influence their conduct.

The Contextual Activity Matrix (Figure 5.1) shows the desired span of action (designated by a solid horizontal line) and a potential span of action (designated by a dashed outline). In a well ordered project, our home carpenter would be able to adhere to the constraints of the desired span of action. Any failure to do so would disrupt realization of Values identified in the Abstraction-Decomposition Space. In particular, Work Tasks that extend unexpectedly across the boundary between Work Situations have the potential to be particularly disruptive. Given that the workspace is now reasonably well organized, the causes of any such failure should be readily apparent and should represent a learning experience for our home carpenter.

Work Organization Analysis

Work Organization Analysis, the second stage of Cognitive Work Analysis, identifies the prototypical Work Tasks undertaken to satisfy the Domain Functions of the work domain and the Work Situations in which those Work Tasks are accomplished. Work Tasks are characterized by the distinctive outcomes to be achieved. They segment the work according to content independently of operational modes. Work Situations are characterized by the various situational contexts in which work takes place. They segment the work according to operational modes independently of content.

Work Organization Analysis results in a Contextual Activity Matrix, which associates the activity-independent Domain Functions from the Abstraction-Decomposition Space with activity-dependent Work Tasks and associates Work Tasks with Work Situations in which those Work Tasks may be accomplished.

Figure 5.2 is an amalgam of ideas based on interviews with subject matter experts within several different projects and is therefore a notional Contextual Activity Matrix for command of battlefield operations. Two Domain Functions have been drawn from the notional Abstraction-Decomposition Space; Strategic Planning and Tactical Planning. The Work Situations are those of Theater Command and Operational Command. Theater Command is responsible for Strategic Planning and Operational Command is responsible for Tactical Planning. These two command centers are in different locations.

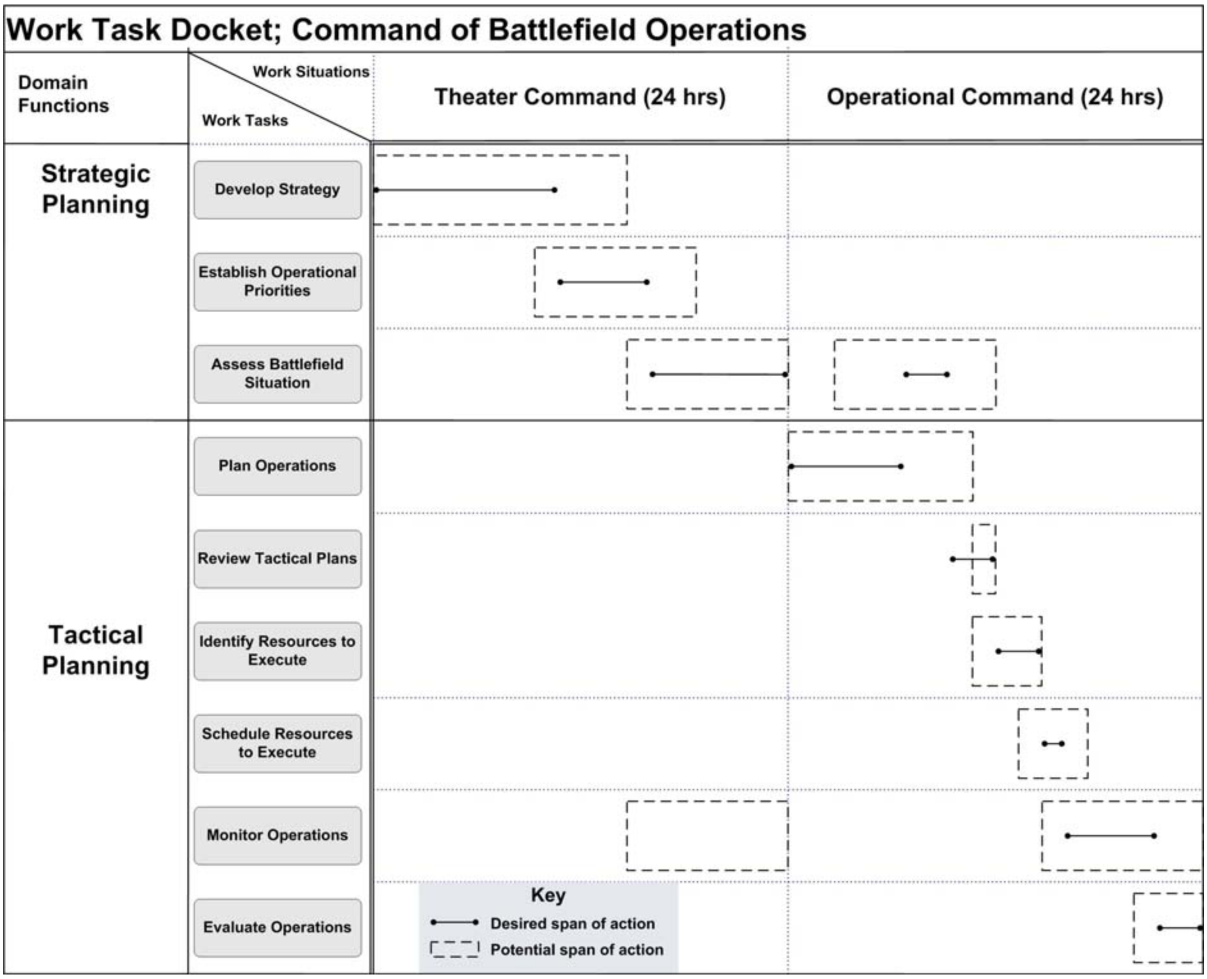

Figure 5.2: A Contextual Activity Matrix of Work Situations and Work Tasks associated with Domain Functions for command of battlefield operations

Each command center is responsible for a set of Work Tasks which will consume all available resources in each 24-hour cycle if their completion time equals the desired span of action. On some occasions, one or more Work Tasks will not be completed within the desired span of action as indicated by the depicted potential span of action. In such cases, the completion of other Work Tasks may be compromised or extra personnel will be co-opted to accommodate the overload.

Two Work Tasks, Assess Battlefield Situation and Monitor Operations have entries in both commands. While the Work Task of Assess Battlefield Situation is the prime responsibility of Theater Command, it is recommended that Operational Command also devote some attention to it to ensure that Operational Command staff understand the rationale for strategy and priorities. The Work Task of Monitor Operations is the exclusive responsibility of Operational Command but Theater Command staff typically find it difficult to ignore operational progress and will tend to monitor it especially when a significant action is in progress. Conceivably, that unauthorized monitoring would assist staff in Theater Command in the development of strategy and possibly should be authorized.

Work Organization Analysis: Other Illustrations

I plan to continue the development of both the iPod and the theatrical production illustrations mentioned in Chapter 4 as complete illustrations of the framework of cognitive work analysis, proceeding from work domain analysis through Work Organization Analysis, Cognitive Transformations Analysis, Strategies Analysis, Cognitive Processing Analysis and Social Transactions Analysis. I will include these analyses in the forthcoming appendices.

A Special Topic in Work Organization

Subsumption

The discussion above of the relationship between Work Situations and Work Tasks draws inspiration from a discourse on subsumption offered by Clancey, Sachs, Sierhuis and van Hoof (1998). Subsumption is a hierarchical structure in which activities at a subordinate level are subsumed under a super-ordinate activity. Clancey et al (1998) argue that human activity is subsumed within and shaped by context and that most activity is shaped by loosely coupled constraints between several levels of hierarchically nested contexts.

The relationship between the super-ordinate and subordinate activities is one of supervisory management; the super-ordinate activity initiates, monitors and terminates the subordinate activity but beyond that, the subordinate node is autonomous (the super-ordinate activity manages rather than controls the subordinate activity).

Figure 5.3 depicts the scheme as it conforms to the Contextual Activity Matrix of Figure 5.1. Building furniture as a hobby constitutes the overall context, termed a work frame in the discussion provided by Clancey et al (1998). The Work Situations of Project Preparation and

Project Execution, as subordinate work frames, are subsumed within the context of the the *building furniture* work frame and influenced by it. The Work Tasks are are, in their turn, influenced by the Work Situations under which they are subsumed, with two of them extending across both Work Situations. The subsumption implication of continuing a Task into a different Situation is that it may constitute the same activity in many respects but it is being executed from a different frame of reference. Properties of activity such as work intensity and attention to detail may be shaped differently by the different frames of reference.

Figure 5.3: A subsumption diagram of Work Situations and Work Tasks for building furniture as a hobby

The subsumption diagram does not assume a Work Task sequence. Our home carpenter indicated that he used to switch frequently between tasks as it seemed appropriate at the time. Only after some experience with this work did he settle into a relatively stable pattern. However, this pattern is not firmly fixed. He may still switch between Work Tasks as the need arises. The subsumption hypothesis comfortably accommodates this sort of adaptive behavior.

Work Organization Analysis: How to Proceed

Work Organization Analysis commences from an understanding, at a high level of description, of how someone organizes and proceeds with their work. A simulation interview in which an expert narrates how her/his work team progresses through a typical job offers a good start.

Work Situations. The subject-matter expert may volunteer the information you can use to distinguish Work Situations or you may have to probe for those. Look for situations that have the expert working at a different intensity, in a different place, at a different conceptual level (e.g., overview versus detail) or a markedly different constellation of Work Tasks. Any one of these could indicate a difference in Work Situation.

From the narrative provided by our home carpenter, it was possible to identify Project Preparation and Project Execution as different situations. I have elsewhere identified formulation, development and refinement of the problem as distinctive Work Situations for reasoning through an issue (Lintern, 2008). Naikar, Moylan and Pearce (2006), in the analysis of an airborne surveillance and early warning system, have identified "on ground not in aircraft", "on the ground in aircraft", "en route to station", "on station", "en route to base", "on ground in aircraft" and "on ground not in aircraft" as a sequence of Work Situations through which a surveillance team progresses during an air mission.

Work Tasks. Work Organization Analysis is often referred to as Activity Analysis in work domain terms. The reference to work domain terms signifies that the Work Tasks can be identified with the aid of the Abstraction-Decomposition Space developed within Work Domain Analysis. Work Tasks should correspond to decompositions of Domain Functions and Physical Functions identified in the Abstraction-Decomposition Space. I have explored the idea that Work Tasks should be associated exclusively with decompositions of either Domain Functions or Physical Functions but have concluded that to restrict Work Tasks to an association with one or the other of these levels of abstraction over-constrains the Work Organization Analysis.

Work Tasks should be identified at a useful level of description. Allow your expert to guide you in this matter but be sensitive to the possibility that s/he may offer descriptions that are unnecessarily or insufficiently detailed. The decompositions of Domain Functions and Physical Functions in the Abstraction-Decomposition Space can also guide you in terms of ensuring appropriate level of detail for your Work Tasks.

In my Work Organization Analysis, I sometimes find Work Tasks that are not anticipated by the Work Domain Analysis. When that happens, I review my Abstraction-Decomposition

Space and typically discover that I have missed those elements that are now becoming evident[5.1].

Although each Work Task in Figure 1 is neatly nested within a single Domain Function, that may not always be the case. For illustration, consider that our home carpenter might purchase supplies from a hardware store that would measure and size the larger pieces of timber. In that case, some of measuring and sizing would be associated with Project Planning. Note from the narrative, however, that the home carpenter's approach to decisions related to measuring and sizing is different across the two Work Situations. He is more confident with measuring and sizing if he can leave those Work Tasks until after the transition from Project Preparation to Project Execution.

Design Implications

Cognitive support tools that assist with execution of specific work tasks must be available within the applicable Work Situation. In the case of our home carpenter, that does not appear to be a particular problem because the workshop, or at least the home, is the site of both Work Situations. However, such is not the case for Airborne Surveillance and Early Warning System analyzed by Naikar, et al (2006). Some Work Tasks are initiated before the surveillance crew is in the aircraft and others are completed after they leave it. In development of this system, it would not do to focus only on the cognitive support tools that will be required in the aircraft.

A Contextual Activity Matrix can also reveal the potential for resource conflicts or team overload as illustrated in my Contextual Activity Matrix for command of battlefield operations.

Primarily, Work Organization Analysis guides the remaining stages of Cognitive Work Analysis. It identifies the Work Tasks that are to be subjected to an analysis of cognitive transformations, of strategies and of cognitive processing. It also provides a base for analysis of Coordinative Work Processes where the Contextual Activity Matrix is further developed by assigning agents to work tasks and by identifying coordination links between agents.

5.1 As a general rule, you should anticipate that you will have to iterate between the stages of Cognitive Work Analysis as you proceed.

Chapter Summary

Work Organization Analysis, the second stage of Cognitive Work Analysis, is a specific method for analyzing the prototypical Work Tasks undertaken to satisfy the Domain Functions of the work domain and for analyzing the Work Situations in which those Work Tasks are accomplished. The product of this stage of analysis is a Contextual Activity Matrix.

Work Organization Analysis supports the the third, fourth and fifth stages of Cognitive Work Analysis by identifying the Work Tasks that are to be subjected to an analysis of cognitive transformations, of strategies and of cognitive processing. It also provides a base for analysis of Coordinative Work Processes in the sixth stage of Cognitive Work Analysis.

Chapter 6

Cognitive States and Processes

Each Work Task can be described in terms of the Cognitive States established during task execution and the Cognitive Processes used to effect the transitions between states. These Cognitive States and Processes are identified by the use of Cognitive Transformations Analysis, the third stage of Cognitive Work Analysis, and are mapped onto a Decision Ladder.

Reprise from Chapter 3

Stage 3: Cognitive States & Processes (Cognitive Transformations Analysis). In this chapter, I discuss the Work Tasks identified in the Work Organization Analysis in terms of:

- Cognitive States established during task execution, and
- Cognitive Processes used to effect the transitions between states.

The product of this stage of analysis is a suite of Decision Ladders.

Cognitive Transformations

Cognitive Transformations Analysis assumes that tasks are accomplished, problems resolved and decisions made via transformations between Cognitive States as induced by Cognitive Processes. 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 planning).

In a physical system, a state is a condition described in terms of phase, form, composition, or structure (e.g., ice is the solid state of the chemical compound, H2O, and water is its liquid state). A physical process acts on a state to change it (e.g., the process of cooling transforms water into ice). Cognitive States and Processes can be viewed similarly. There can be no state transition in a physical system without an intervening process (Figure 6.1). In the realm of cognition, processes are often not accessible to conscious awareness, in which case they are said to be implicit.

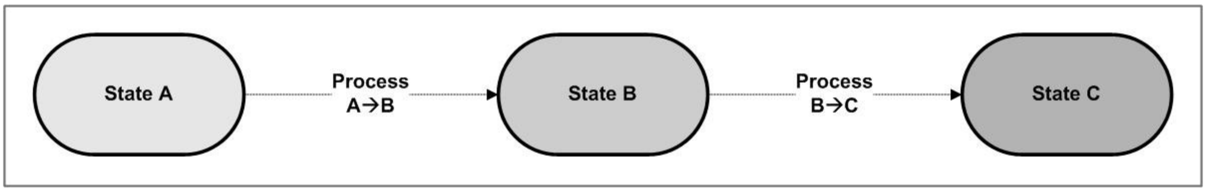

Figure 6.1: States change by the action of intervening processes

Illustration; A Home Carpenter's Workshop (Continued)

Consider, again, the home carpentry scenario. While it would normally be necessary to analyze all Work Tasks in the manner I demonstrate below, I have selected three from the previous chapter to illustrate the concepts. I have focused on one Work Task that is predominantly a decision task, another that is predominantly a situational analysis and diagnosis task and a third that is predominantly a planning, scheduling and execution task.

> **Work Task: Select Plan and List Inventory Requirements.** Our home Carpenter has recently been puzzling over whether he should use a different type of joint to the one most commonly featured in his book of plans. His plans typically specify use of a simple butt joint (Figure 6.2, left) that is formed by screwing the end of one piece of wood to the end of the other. While this is simple to do, it is neither elegant nor stable. He wonders if he should substitute a mortise and tenon joint (Figure 6.2, right) which is more difficult and time-consuming to make but is stronger and more elegant. He has the skill to make a mortise and tenon joint but each joint will consume extra time and effort. Is the added stability and elegance worth the extra time and effort?

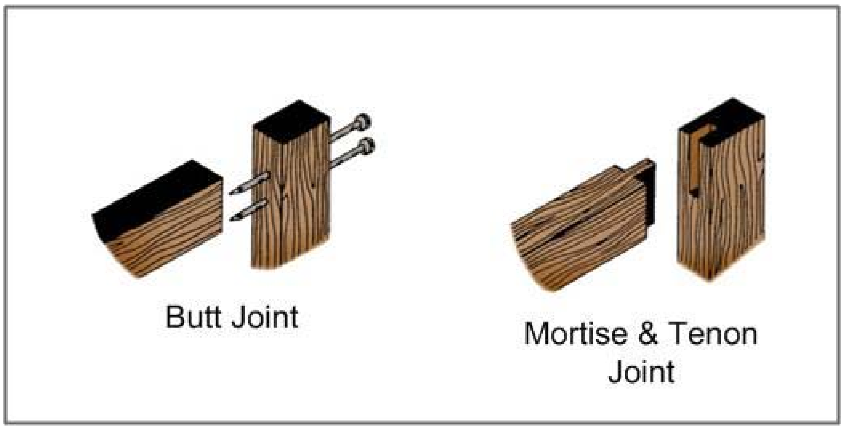

Figure 6.2: Butt joint (left) and mortise & tenon joint (right)

Work Task: Assess Timber and Consumables Stock. Before assessing his timber and consumables stock, our home carpenter reviews the project plan in his home office and lists all requirements. He then goes into his workshop to check what he actually has against what he needs. If he needs glue, for example, he will take the cap off his glue container and look into it to identify how much glue is left. By reflecting on how much glue he needed for previous projects of this approximate size, he will then judge whether the amount of glue remaining is sufficient for the upcoming project. Given the perishable nature of glue, he does not want to purchase a new container of glue unless he is will need it for the upcoming project. Neither does he want run out of glue before the project is finished. He makes a careful judgment on this issue, erring on the side of purchasing more glue if there is even a slight possibility he will need more before the project is finished because the expense of the trip to the store and the wasted time exceeds the actual cost of the glue. He assesses other requirements similarly.

Work Task: Size Timber. Having measured and marked all required pieces of timber and laid them out in a pattern that conforms approximately to the plan, our home carpenter first cuts pieces to length. He starts at one side of his layout, selecting the first piece, choosing first to size the end that has the smallest piece to be removed, which he has found to be good practice because short pieces of timber can be hard to clamp onto his workbench. He clamps the selection onto his workbench with the end to be cut extending beyond the bench to give clearance for the saw blade. He selects the appropriate power saw and places his feet so he is in a stable stance facing the line to be cut. He lines the blade up carefully with the pencil line he has used to mark the cut, with the inside edge of the blade on the outside of the line to ensure that the groove made by the blade removes only excess timber. He moves the saw forward so that the tip of a tooth is almost touching the first point of the cut. He powers up the saw, steadies it, and then moves it forward slowly and steadily so that it bites into the timber, taking care that he maintains a straight line across the end of the piece to complete the cut. When finished, he moves the blade away from the timber and turns the power off. He releases the clamps and resets the piece to size the other end.

I have used this narrative to build State-Process diagrams for each of the three Work Tasks.

Figure 6.3 shows the State-Process diagram for the Work Task of deciding whether to change the type of joint specified in the plan to one that is more stable and more elegant. Our home carpenter appreciates (Cognitive State) that the specified butt joint lacks stability and elegance. He reflects (Cognitive Process) on potential alternatives and becomes aware (Cognitive State) that the mortise and tenon joint is a potential alternative. He compares (Cognitive Process) the relative merits of the mortise and tenon versus the butt joint. He is aware (Cognitive State) that the mortise and tenon will require more time and effort but will result in more stable and elegant joint. He therefore decides (Cognitive Process) to substitute mortise and tenon joints wherever butt joints are called for in the plan and imagines (Cognitive Process) the adjusted plan as a mental image (Cognitive State).

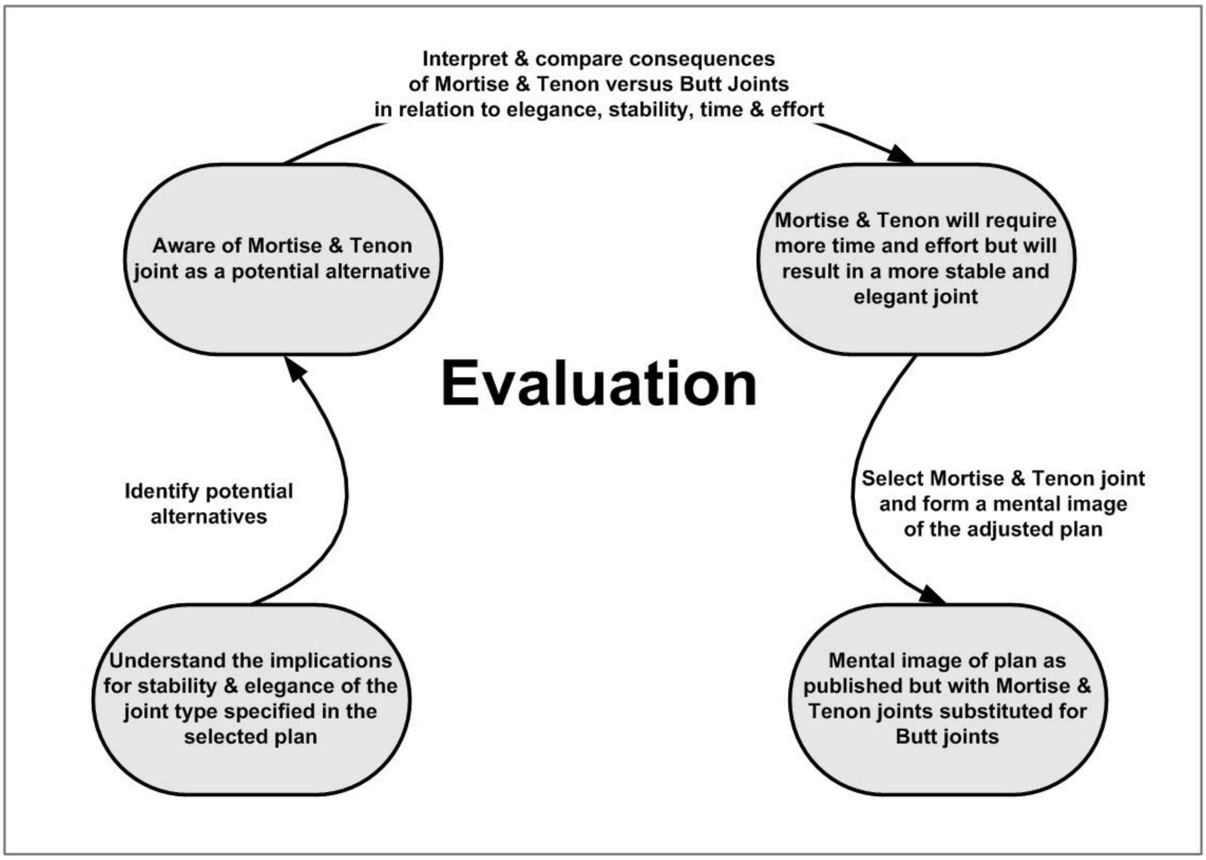

Figure 6.3: State-Process diagram for the carpentry Work Task of deciding which type of joint to use

Figure 6.4 depicts a State-Process diagram for the Work Task of assessing supplies against the Requirements List. Glue is the specific item considered here. Our home carpenter reviews (Cognitive Process) his Project Requirements List and thereby becomes aware (Cognitive State) that he needs to assess how much glue he has over from the previous project. He locates the glue container and removes the cap to peer into it (Cognitive Process) to see how much is left. He is now aware (Cognitive State) of the remaining amount and compares (Cognitive Process) that remainder to how much he used on a previous job of this size. That comparison allows him to understand (Cognitive State) whether he has enough glue for the upcoming project.

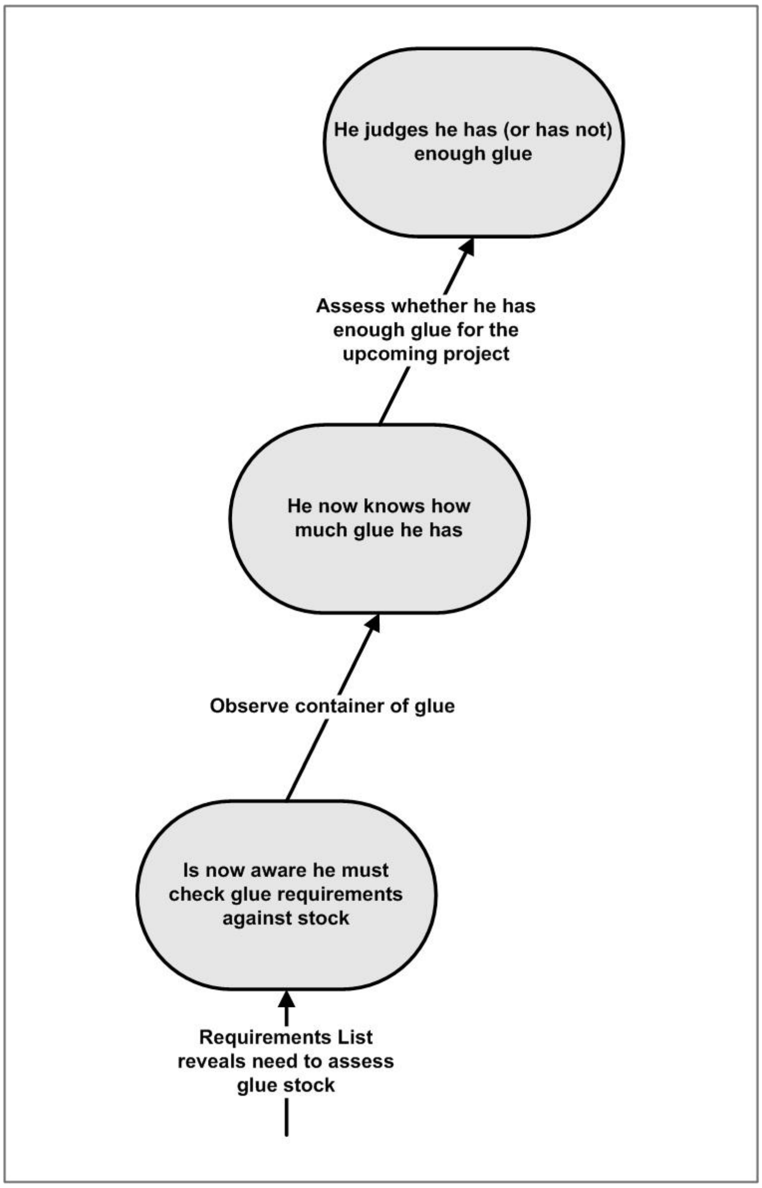

Figure 6.4: State-Process diagram for the carpentry Work Task of assessing glue stock

Figure 6.5 depicts a State-Process diagram for the Work Task of the Sizing the length of a timber piece. Our home carpenter has already measured and marked the timber and is already aware (Cognitive State) of the desired end result. He identifies (Cognitive Process) the excess timber to be removed at each end of the piece to be sized and understands (Cognitive State) that he must cut through the timber at each of the two lines that mark the desired length. He mentally simulates (Cognitive Process) the procedure of clamping the piece, picking up the power saw, setting the saw blade to position, starting the power saw and cutting smoothly through the timber. As a result of the mental simulation, he is satisfied that he knows (Cognitive State) the required procedural steps. At that point he executes (Cognitive Process) the procedure.

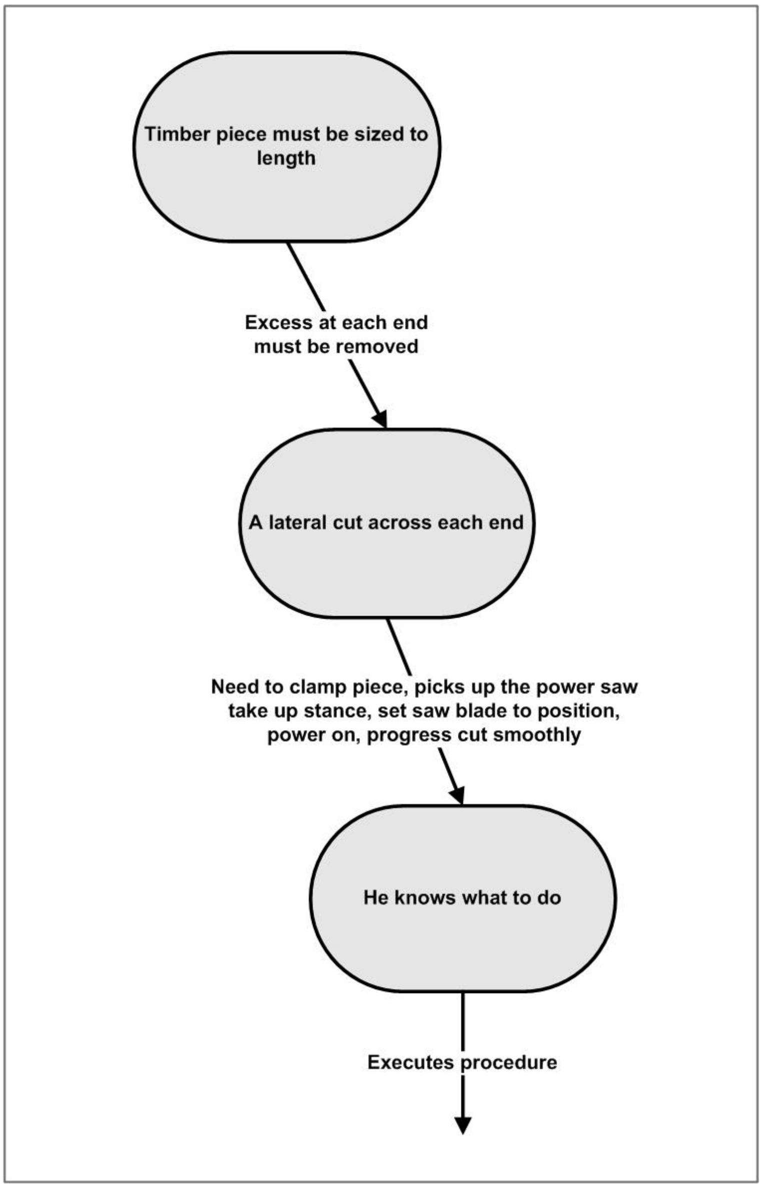

Figure 6.5: State-Process diagram for the carpentry Work Task of sizing the length of timber

Cognitive Transformations Analysis

Cognitive Transformations Analysis, the third stage of Cognitive Work Analysis, identifies the Cognitive States and Cognitive Processes that might be used to accomplish Work Tasks as identified in the Contextual Activity Matrix. The Decision Ladder is the representational form for depicting these Cognitive States and Cognitive Processes (Figure 6.6). States are shown as nodes (ovals) between Cognitive Processes (directed, labeled arrows).

A Decision Ladder might be read as follows:

> By detecting a need for action, the worker becomes alerted to a potential issue. Having been so alerted, s/he observes information and data in order to become fully aware of the dimensions of the situation. S/he will then diagnosis or analyze that information in order to identify the current system state. Now being fully aware of the current system state, s/he may interpret its consequences and then identify a different system state that will achieve the goal of the current Work Task.
>
> Alternatively, it may be more difficult to interpret the consequences of the current system state and to identify alternate system states that would achieve the goal of the current Work Task, in which case the worker would divert through the evaluation loop to resolve the ambiguity. S/he would ascertain and thereby become aware of the potential states and then interpret and compare their diverse consequences. S/he is now likely to be aware of the consequences of potential states and would choose the one that s/he judges to result in the most desirable outcome. If ambiguity remains at this point, s/he will cycle through the evaluation loop again.
>
> Having settled on a desirable system state, the worker will identify what has to be changed in the current system state to achieve the desired system state. When s/he understands that, s/he will construct a procedure to effect desired change. S/he will then have a set of procedural steps in mind and will coordinate the actions they specify.

The Decision Ladder is a template rather than a model. Thus, I said above that a Decision Ladder depicts the Cognitive States and Cognitive Processes that *might be* rather than *are* used. Note this carefully. Most who criticize the use of the Decision Ladder fail to appreciate that it is a template and not a model. Also note that the State-Process diagrams I developed above by reference to the carpentry narratives depict State-Process trajectories that might have actually been used. I developed those as a tutorial introduction to State-Process depictions but to fully conform to the template requirement, I should in principle now identify other states and processes that the carpenter could use to accomplish these work tasks.

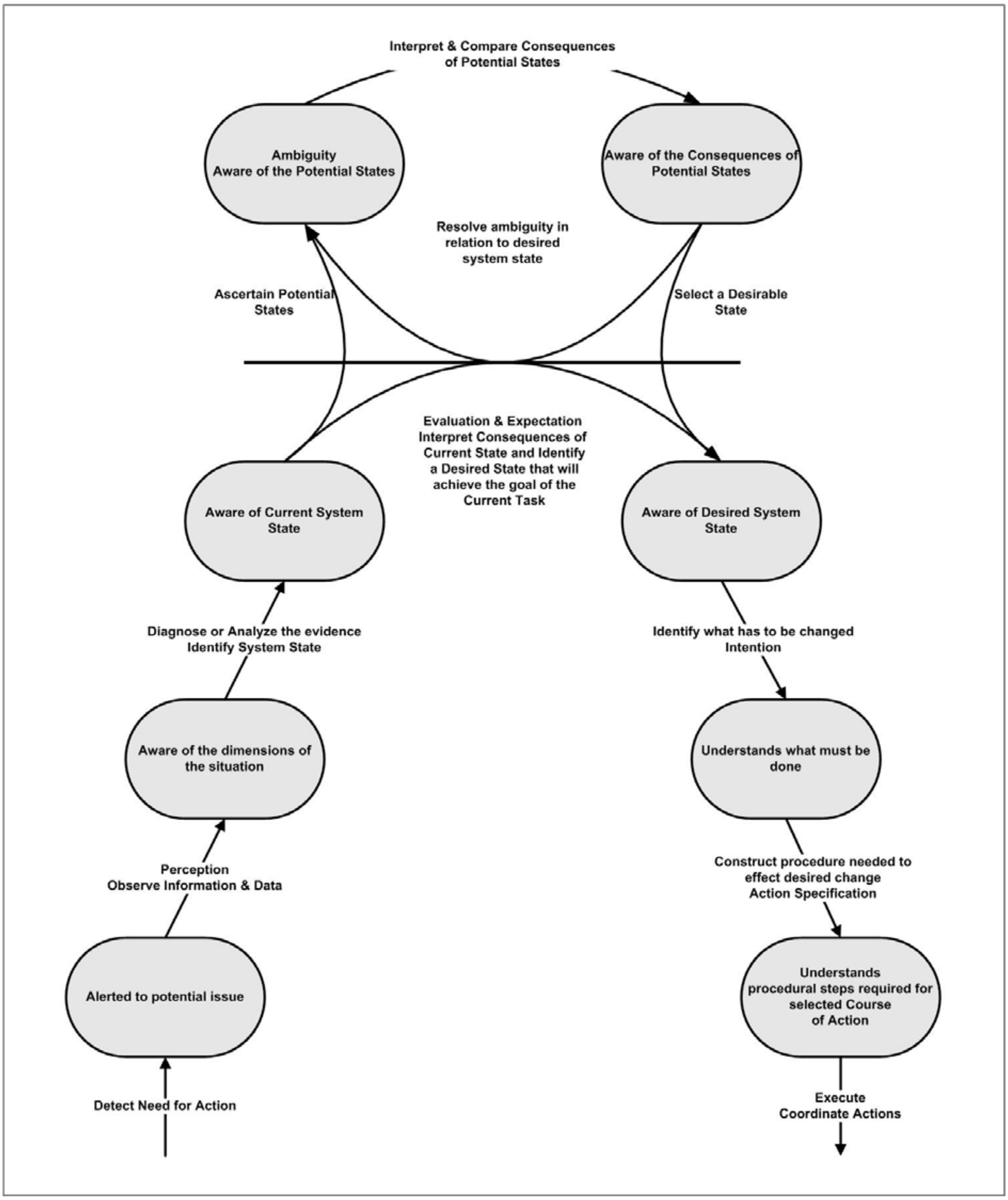

Figure 6.6: A Decision Ladder template depicting all Cognitive States and Cognitive Processes that might be used to accomplish any conceivable Work Task.

You may have already noticed that the three Work Tasks I developed from those carpentry narratives, when assembled as shown in Figure 6.7 and in comparison to Figure 6.6, follow the basic form of the Decision Ladder. This is not, however, a genuine Decision Ladder because it incorporates three Work Tasks. A genuine Decision Ladder maps the potential Cognitive States and Cognitive Processes for only a single Work Task.

As depicted in (Figure 6.8), a task has three phases; Situation Analysis and Diagnosis, Evaluation, and Planning, and Scheduling and Execution.

The Decision Ladder representation does not imply a cognitive decision theory that assumes a linear, canonical sequence of information processing starting from detection of a need for action, progressing through decision processes of evaluation and selection, and finishing with execution. Rather than specifying that these Cognitive States and Processes must be traversed in a canonical sequence or even that they are always activated, the theory on which the Decision Ladder is based specifies that these Cognitive States are potentially available and identifies the classes of Cognitive Process that are needed to transition from one state to another.

Process links that generate state transitions are not confined to the perimeter of the Decision Ladder; any potential Cognitive State can, in principle, be accessed via an appropriate Cognitive Process from any other Cognitive State. Several alternate transition links are shown in Figure 6.9. The Cognitive Work Analysis literature generally refers to links that do not follow the perimeter of the Decision Ladder as *shortcuts*, a possibly unfortunate characterization because it implies precedence for transitions that do follow the perimeter. Here I dispense with that term and also the associated terms, *leap* and *shunt* and talk only of state transitions, thereby avoiding the implication of a canonical sequence of Cognitive States and Cognitive Processes.

Additionally, within the literature, the form of a shortcut referred to as a leap describes a direct association between two Cognitive States. There is an implication of a state transition with no intervening process. I find that implication disconcerting (in the physical world at least, state transitions require an intervening process) and I prefer to characterize the type of cognitive event that appears to be process free as one in which the process is implicit. This strategy aligns the theoretical argument underlying the Decision Ladder with a body of research and theory on human expertise that distinguishes implicit from explicit knowledge.

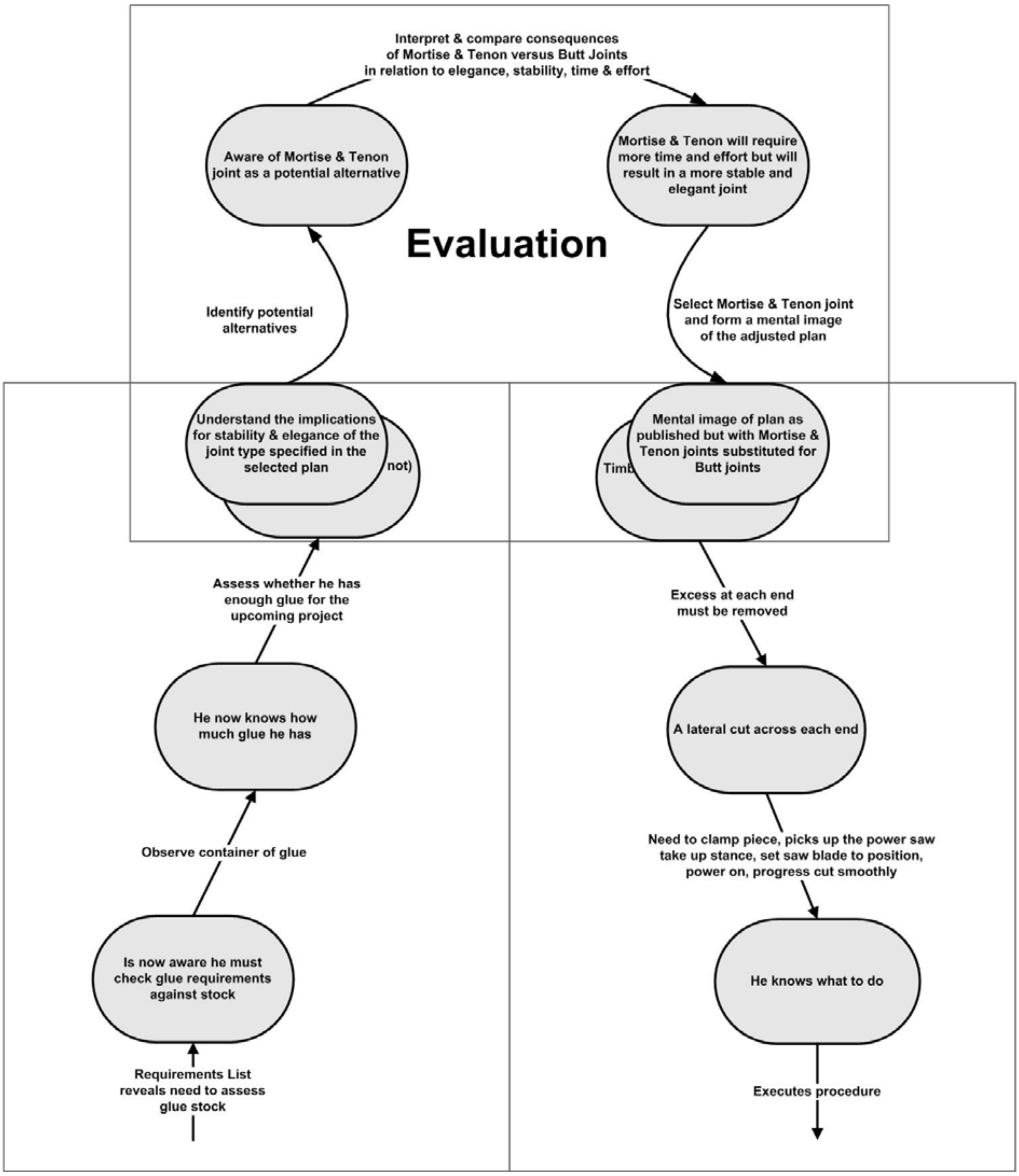

Figure 6.7: State-Process trajectories for three Work Tasks developed from the carpentry narratives, assembled into the basic form of a Decision Ladder

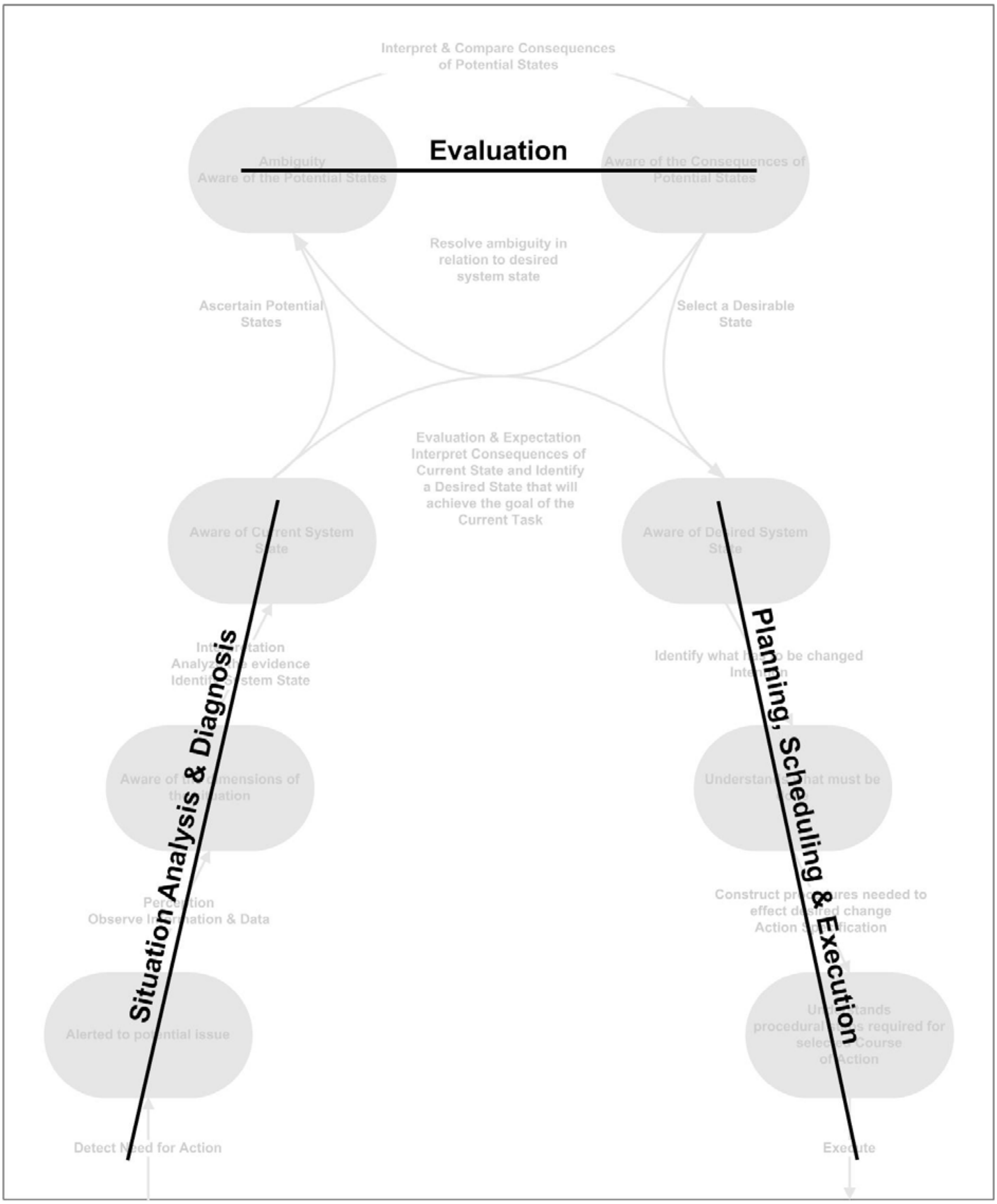

Figure 6.8: A Work Task potentially has three phases; analysis, evaluation and planning

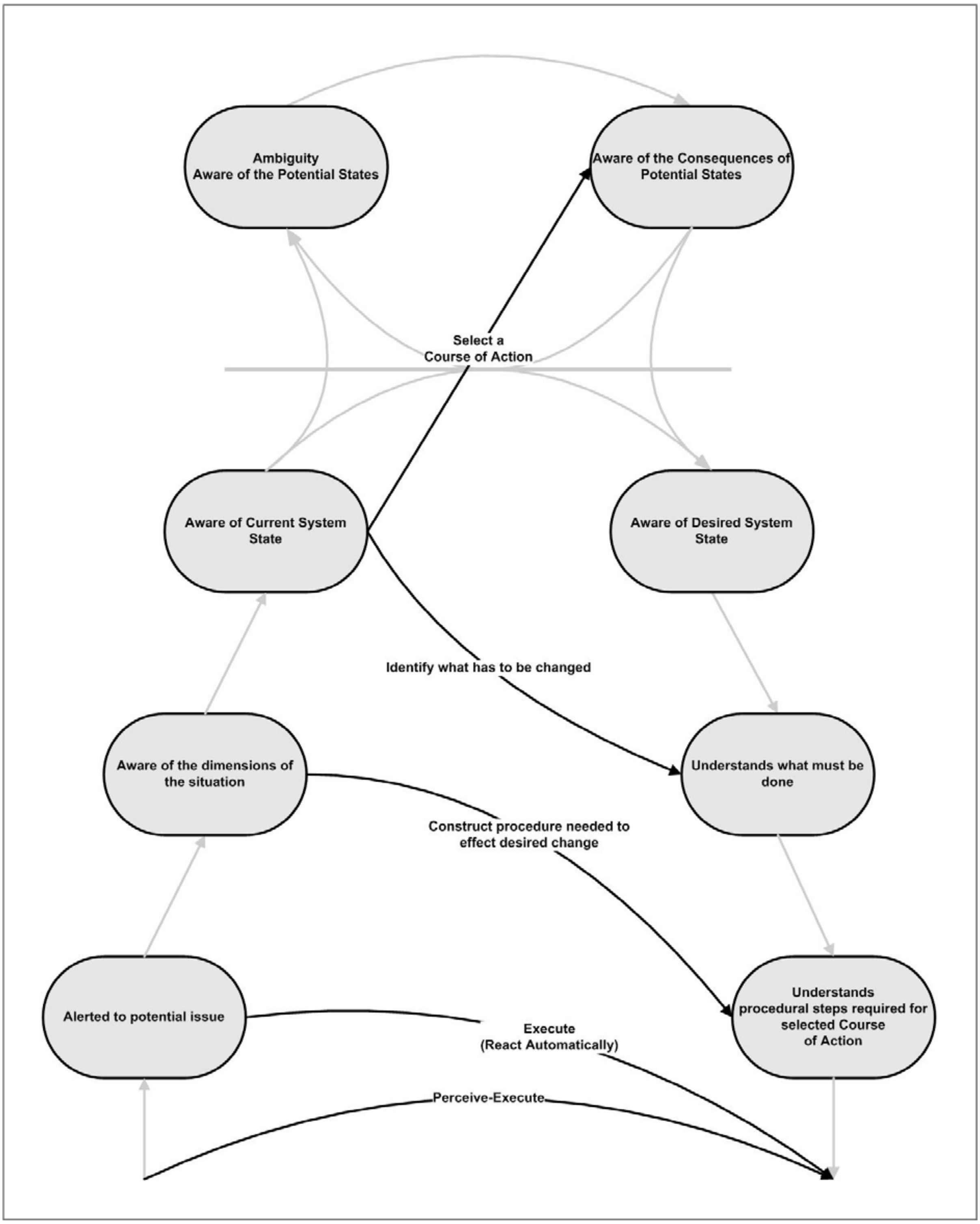

Figure 6.9: Examples of alternate process links that can generate state transitions

The Decision Ladder format I present in Figure 6.6 is an adaptation of the standard format (Figure 6.10) used by Rasmussen (1986), Vicente (1999) and many others. I developed the format shown in Figure 6.6 to resolve several concerns I have had about semantic confusions induced by the standard form shown in Figure 6.10 as follows:

- The standard format codes a state as an ellipse (or a circle) and a process as a rectangle. Beginners have considerable trouble keeping this straight because, I suspect, a box implies stasis. In contrast, an arrow implies action and so I use an arrow in the revised format to code process.
- The state and process labels in the standard format are succinct in the extreme and can be difficult to interpret. I have extended these descriptions to clarify what is meant at different points in the template. I recognize that there is a fine line between being too succinct and too verbose but I believe that for a tutorial at least, some expansion of the original descriptions is warranted.
- Some of the labels in the standard format are misleading. For example, a state node towards the upper left of the template is designated as *system state*. By a literal reading, a system state is a physical state but the states mapped onto the Decision Ladder template are Cognitive States. However, this particular node represents the *cognitive awareness* of the system state and is therefore fully consistent with the intent but those who read a Decision Ladder for the first time often miss that distinction.
- Some of the labels in the standard format are ambiguous. States should be identified by nouns and processes by verbs. The process at the bottom left of the standard format is identified as *activation*, which is a noun. Additionally, the state identified as *alert* towards the bottom left of the standard format could be either a verb (I alert you) or a noun (you are alert). I remove these ambiguities in my adapted format.

I have developed this new format specifically to help those unfamiliar with the Decision Ladder read it more easily.

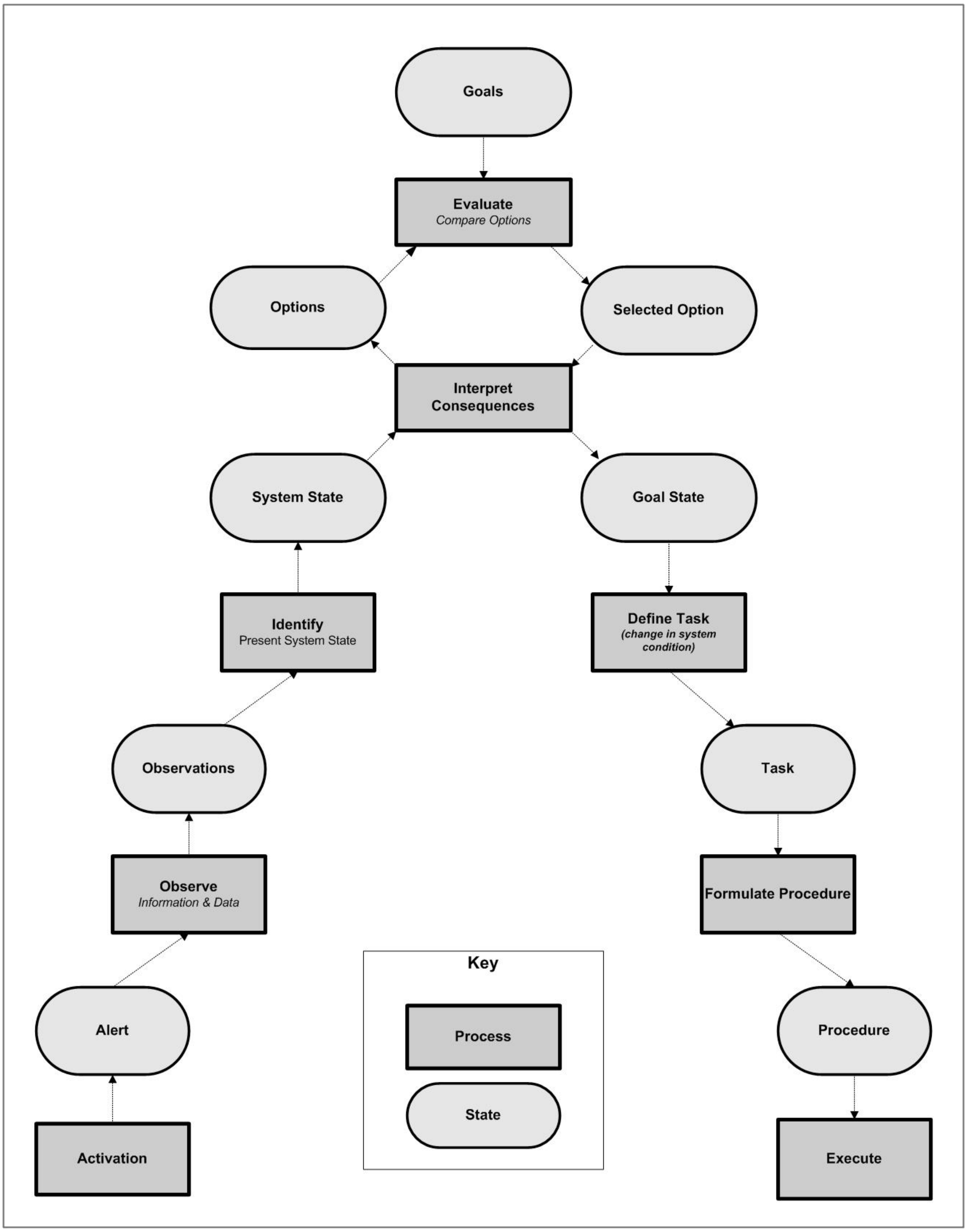

Figure 6.10: The standard form of the Decision Ladder as used by Rasmussen (1986), Vicente (1999) and many others

Cognitive Transformations Analysis: Other Illustrations

I will provide further illustrations of Decision Ladders as an appendix which I will add to this book in the near future. One of these Decision Ladders is constructed around the narrative supplied by a targeteer experienced in planning air attack missions for time sensitive targeting. Another is of a driver responding to a highway traffic jam that resulted from an accident. I have also mapped onto Decision Ladders a number of Recognition-Primed Decision scenarios from Klein (1989) and Klein & Calderwood (1991). In addition, I will continue the iPod and the theatrical production illustrations first mentioned in Chapter 4.

Cognitive Transformations Analysis: How to Proceed

Much of the information already gathered in the previous stages of Cognitive Work Analysis will be useful. Use the Abstraction-Decomposition Space to identify the available resources and the Contextual Activity Matrix to identify the Work Tasks. Scenario simulations will help you ascertain how subject matter experts might execute the Work Tasks. Typically, subject matter experts will want to decompose the Work Tasks as identified in the Contextual Activity Matrix into more specific subtasks as I have done above with the home carpenter narratives.

You will find that those you interview will discuss their work most naturally in terms of activity statements. You can focus your attention on the process elements of the Decision Ladder by adapting the process descriptors in figure 6 (e.g., exploration of "Detect Need for Action" could possibly be advanced by asking a question such as "what makes you first realize that you need to do something?") You do not have to force your subject matter experts to discuss states in any detail; you can generally infer those from the process descriptions, with possibly minor clarifications from your subject matter experts.

Remember that the Decision Ladder is used to map Cognitive States and Cognitive Processes that might be used rather than those that are used. Explore possible ways of doing each of the subtasks with your subject matter experts and take note of the different Cognitive States and Cognitive Processes to which they refer. Do not constrain the discussion to only those that are mentioned first in the narrative. Also remember that workers, when questioned about how they do something, will often respond with a description of a formal or mandated process.

Ensure you go beyond that to identify how the work is actually done and also how it might be done under different circumstances.

Also remember that the Decision Ladder is a template rather than a model and its form is not intended to represent a set trajectory for resolution of a work problem. Workers are flexible and will generate different trajectories at different times. In particular, narrative descriptions provided by a subject matter expert can start anywhere on the Decision Ladder and visit states via process in any order. Nor is it likely that any specific narrative will visit all possible Cognitive States or employ all possible Cognitive Processes.

Design Implications

The intent of Cognitive Transformations Analysis is to identify Cognitive States and Cognitive Processes that might be supported through design; that is, those for which some form of supportive cognitive technology could facilitate the work.

Every Cognitive State and every Cognitive Process involved in execution of a Work Task is a candidate for assistance with some form of technological support. You should examine the Decision Ladder to see where that support might be useful and then contemplate the design possibilities. How it is possible to get from the identification of a potential need to the specification of a design solution is a topic that will be covered in Chapter 10. Note that the first edition of this book (Version 1.0) will not include Chapter 10.

As an illustration of how the Decision Ladder can help identify a design need, reflect again on the home carpentry scenario and the associated state-process diagrams.

- For the Work Task; Select Plan and List Inventory Requirements, our home carpenter decided to use a different type of joint than the one indicated in his plan. We could question whether he might have used another type of joint beyond the one he selected. To that end, a plan book that identified the different types of joints that could work for the selected project and that summarized the relative costs and benefits, could help our home carpenter first to identify the potential alternatives and then interpret and compare the consequences of using the different joints.
- For the Work Task; Assess Timber and Consumables Stock, the effort required to ascertain the quantity of remaining glue by removing the cap of the glue container

and peering into it could be eased by making the container transparent so that the level of glue could be seen at a glance.

- For the Work Task; Size Timber, our home carpenter had to be extremely careful to ensure that his cut across the timber was straight. A saw guide that would keep the saw blade tracking in a straight line would be useful.

These design possibilities are mapped onto the relevant state process diagrams in Figure 6.11.

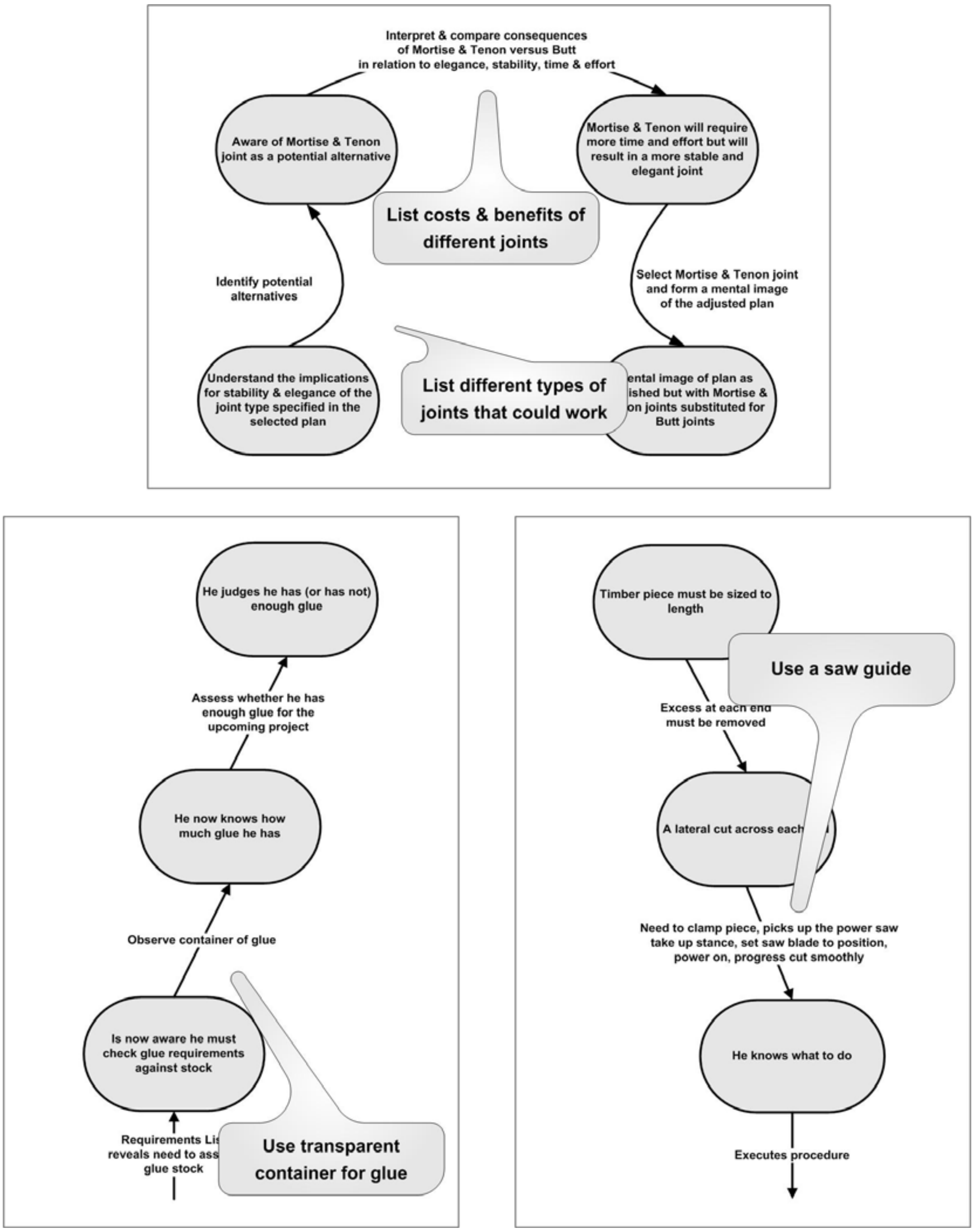

Figure 6.11: Use of State-Process diagrams to identify design needs

In addition to identifying design needs, Cognitive Transformations Analysis guides two of the remaining stages of Cognitive Work Analysis. It identifies the Cognitive Processes that may be performed with different Cognitive Strategies in different modes of Cognitive Processing.

Chapter Summary

Cognitive Transformations Analysis, the third stage of Cognitive Work Analysis, identifies the Cognitive States and Cognitive Processes that might be used to accomplish Work Tasks as identified in the Contextual Activity Matrix. The product of this stage of analysis is a suite of Decision Ladders.

Cognitive Transformations Analysis supports the the fourth and fifth stages of Cognitive Work Analysis by identifying the Cognitive Processes that are to be subjected to an analysis of strategies and of cognitive processing.

Chapter 7

Cognitive Strategies

Strategies Analysis, the fourth stage of Cognitive Work Analysis, identifies the Cognitive Strategies involved in a specific Cognitive Process as identified in the Cognitive Transformations Analysis described in the previous chapter. A strategy is a category of cognitive task procedure that transforms one cognitive state into another.

Reprise from Chapter 3

Stage 4: Cognitive Strategies (Strategies Analysis). A Cognitive Strategy is a category of task procedure that transforms an initial Cognitive State into another Cognitive State. In this chapter, I discuss the Cognitive Strategies that can be used to execute the Cognitive Processes identified in the Cognitive Transformations Analysis in terms of:

- The categories of task procedure that could be used to transform an initial Cognitive State into another Cognitive State, and
- The reasons that a worker may select one strategy in preference to another or may transition between strategies during execution of a Cognitive Process.

The product of this stage of analysis is a detailed description of potential strategies that can be used to execute the Cognitive Processes identified in the Cognitive Transformations Analysis and a description of the factors that will prompt selection of one strategy over another. A table offers the best representation for this information although simple strategy diagrams can be used to depict the potential strategies.

Cognitive Strategies

A Cognitive Strategy description is a description of process rather than merely an identification of process as accomplished within the Cognitive Transformations Analysis. It constitutes a description of the way in which one cognitive state can be transformed into another. Typically, diverse strategies will be available to effect a transition between two specific cognitive states. Furthermore, a worker may shift unpredictably and opportunistically between available strategies during execution of a cognitive process aimed at inducing a cognitive state transition.

Illustration; A Home Carpenter's Workshop (Continued)

Consider, again, the home carpentry scenario. While it would normally be necessary to analyze all Cognitive Processes in the manner described below, I have selected two from the previous chapter to illustrate the concepts.

> **Cognitive Strategy: Assess whether there is enough glue for the upcoming project.** For this cognitive process, our home Carpenter has typically inspected the amount of glue in the container and matched that against an estimated amount that he had used in similar size job previously. He wonders if he should do this more carefully. Each plan in his plan book provides an estimate of the amount of glue that will be needed. He has ignored that in the past but now wonders if he should follow it. Alternately, he wonders if he should calculate the amount of glue he needs by counting up the number of joints, estimating the surface area to be glued in each joint and making an adjustment for the type of timber. This latter strategy will require a good deal of research to ascertain how much glue is needed for a unit of surface area and how that differs with variations in timber type.
>
> **Cognitive Strategy: Interpret & compare consequences of Mortise & Tenon versus Butt in relation to elegance, stability, time and effort.** For this cognitive process, our home Carpenter settled on the use of the Mortise and Tenon joint as a snap decision. It was the only other joint he had experience with and he could readily assess its relative benefits and costs. He wonders if he should do this more systematically. Should he search on the World Wide Web to find recommendations or should he research the basic structural principles of a variety of joint types and infer from that knowledge the most suitable for his current project.

I have used this narrative to build strategy diagrams for each of these two Cognitive Processes.

Figure 7.1 shows a strategy diagram for assessing whether there is enough glue for the upcoming project. Our home carpenter has previously done this by a snap judgment in which he observed how much glue was in the container and then used his experience to assess whether that was enough for the upcoming job. Two other strategies are diagrammed in Figure 7.1. Our home carpenter might follow the recommendation in his book of plans or he might calculate the required amount by carefully assessing the dimensions of the joint and how well the type of timber he is using accepts the glue.

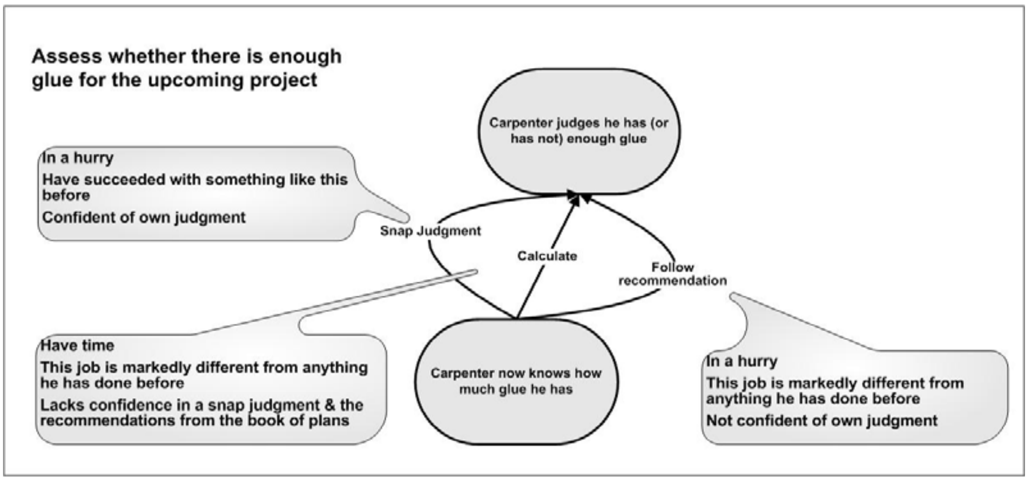

Figure 7.1: Alternative strategies for assessing whether the amount of glue on hand is sufficient for the upcoming job with reasons for selecting one strategy versus another

Figure 7.2 shows a strategy diagram for comparing the consequences of joint types in relation to elegance, stability, time and effort. Our home carpenter has previously settled on the use of the Mortise and Tenon joined as a snap decision. Two other strategies are diagrammed in Figure 7.2. Our home carpenter might follow any recommendation he can find on the World Wide Web or he might research the basic structural principles of joint construction and identify the most suitable joint type from that knowledge.

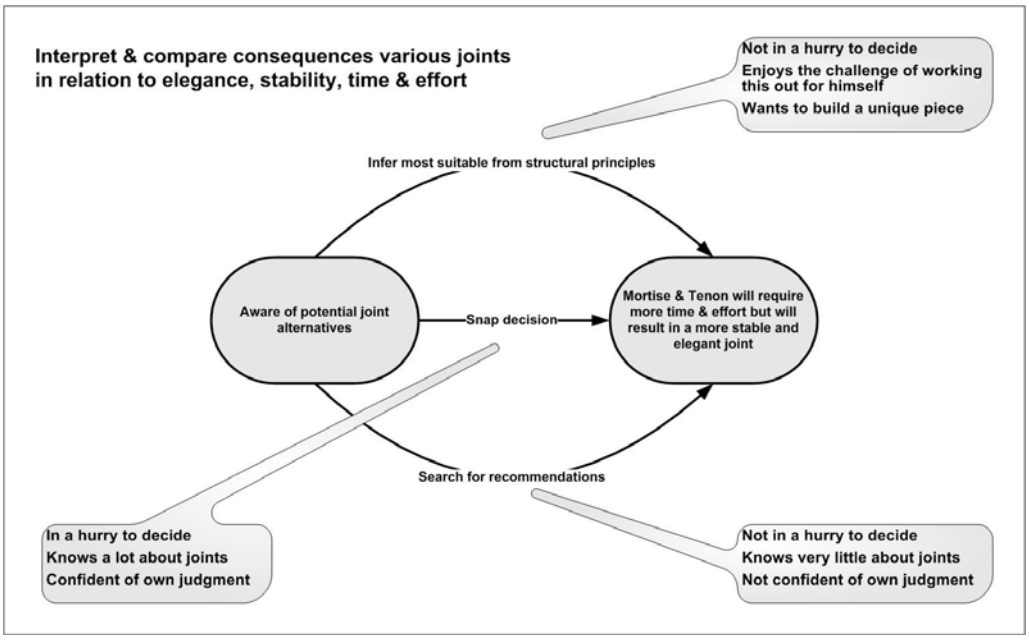

Figure 7.2: Alternative strategies for interpreting and comparing consequences of various joints with reasons for selecting one strategy versus another

Strategies Analysis

The Decision Ladder names Cognitive Processes but says nothing else about them. This fourth stage of Cognitive Work Analysis, Strategies Analysis, identifies the Cognitive Strategies that might be used to execute those Cognitive Processes.

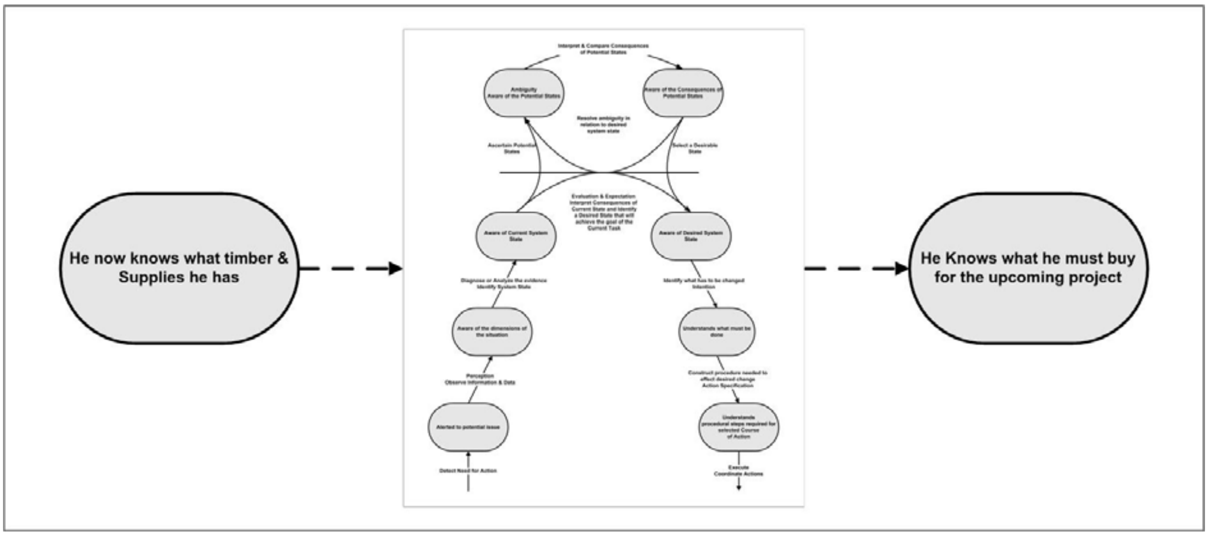

Figure 7.3: Cognitive Processes to be subjected to Strategies Analysis are identified from the Decision Ladder

The types of Cognitive Strategies that could be used vary considerably and can encompass multiple Cognitive Processes according to the nature of the domain, the types of work problems and the types of Cognitive Transformations being undertaken.

The following example draws inspiration from BookHouse, a library catalog interface described by Rasmussen et al., (1994). The Work Task of finding a suitable book in a library might be accomplished as depicted in Figure 7.4 by:

- bibliographic search (a user's needs are matched to author, date of publication, edition or typography, as entered into the database at the time of cataloging),
- analytic search (a user's needs are matched to keywords, as entered into the database at the time of cataloging),
- analogic search (a user's needs are matched to indexed attributes such as genre and content of story line), or

- browsing (a user scans available items to find items that match the current intuitive need.

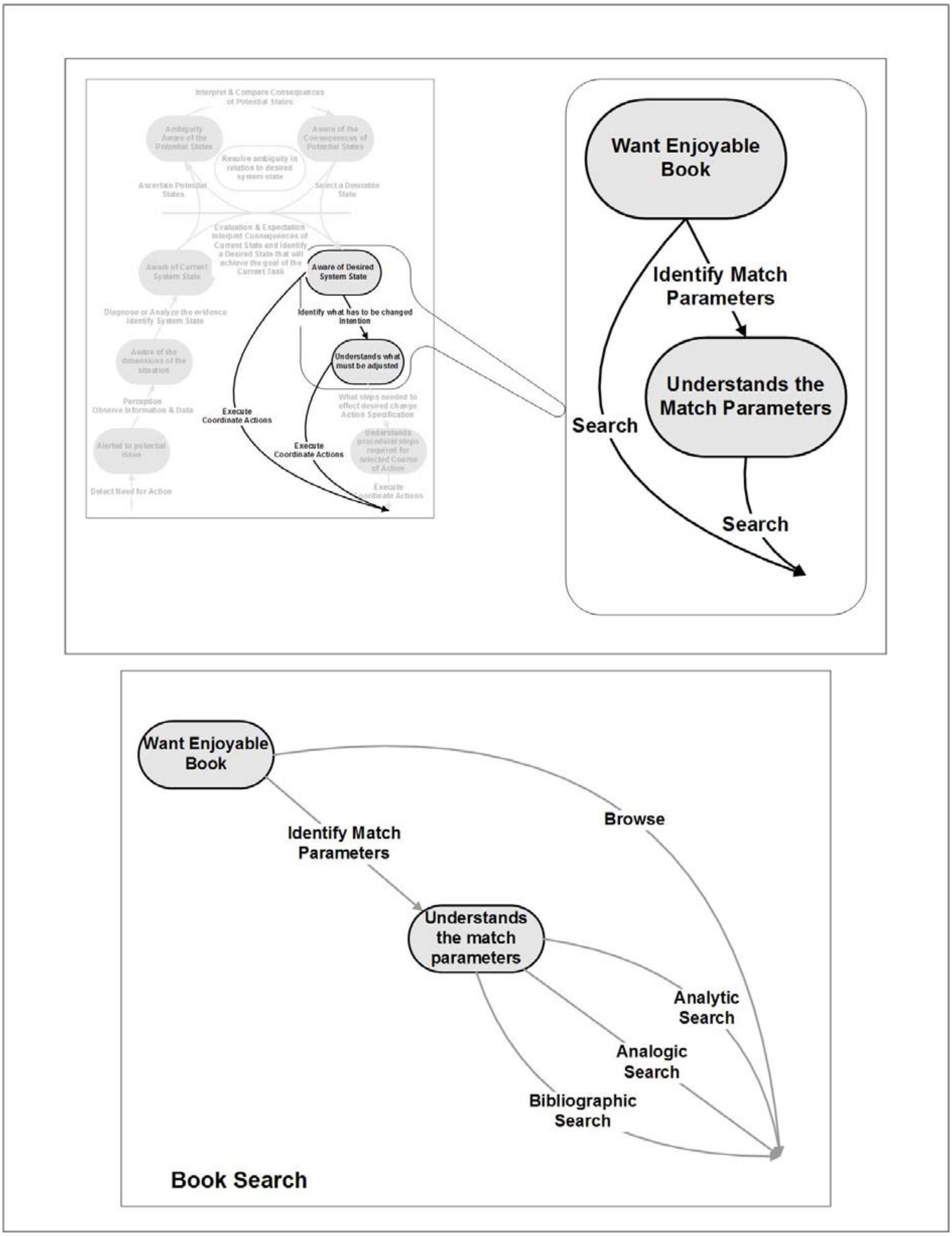

Figure 7.4: Potential library-search strategies (top panel highlights the relevant segment of the Decision Ladder and the bottom panel identifies four potential strategies)

The top panel of Figure 7.4 highlights the relevant segment of the Decision Ladder and the bottom panel identifies the four potential strategies. As illustrated in the top panel, the Desired System State is to be in the possession of an enjoyable book. The library patron might immediately start scanning the shelves which is depicted in the bottom panel as the *browse* strategy. Alternately, the patron may think about the type of book that would satisfy the Desired System State and in doing so, would identify a set of match parameters. The ensuing search would follow a bibliographic, analytic or analogic strategy as determined by the type of parameters that have been identified.

Typically, diverse strategies will be available to effect a transition between two specific cognitive states. Furthermore, a worker may shift unpredictably and opportunistically between available strategies during execution of a Cognitive Process aimed at inducing a Cognitive State transition.

Strategies Analysis: How to Proceed

The most effective way of identifying strategies is through methods of knowledge acquisition that accesses the expertise of experienced workers. Focus on the work tasks for which you have constructed Decision Ladder. Your earlier discussions with subject matter experts may have already uncovered one or more Cognitive Strategies for some cognitive transformations.

Be aware that strategies are often implicit, that is, the subject matter expert is not always aware of their particulars. You may need a special technique to uncover this information. The Critical Decision Method from Cognitive Task Analysis (Crandall, Klein and Hoffman, 2006) is a good procedure for this. In the execution of this method, an interviewer elicits information about cognitive processes within a specific challenging incident. An operational expert is asked to describe decisions s/he made during an incident and also to 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 exploration of alternative actions. A number of specific probes are recommended for the final to sweeps but you should feel free to tune these probes to your specific purpose, in this case to identify alternate strategies.

The results of your analysis will be names and brief descriptions of alternate strategies that might be used to achieve a transition in Cognitive States. Map those into a figure as I illustrate above (e.g., Figure 7.1 & Figure 7.2) or into a table as I illustrate below (Table 7.1 & Table 7.2). Your figure or table should name the alternate strategies and provide some detail about the types of situational factors that influence their use.

Cognitive Process **Assess whether there is enough glue for the upcoming project**	
Strategy	**Reasons for Selection**
Perception-action pairing; inspect the amount of glue in the container and matched that against an estimated amount used previously in similar size job	In a hurry Has succeeded with something like this before Confident of own judgment
Use the estimate from the plan book	In a hurry This job is markedly different from anything he has done before Not confident of own judgment
Calculate the amount of glue required by taking account of the number of joints, the surface area to be glued, and the characteristics of timber	Have time This job is markedly different from anything he has done before Lacks confidence in own judgment & the recommendations from the book of plans

Table 7.1: Alternative strategies for assessing whether the amount of glue on hand is sufficient for the upcoming job with reasons for selecting one strategy versus another

Design Implications

The goal is to develop support for the range of useful strategies rather than to promote one as the preferred strategy. In reviewing your figures or tables, you should consider how challenging the alternate strategies are to execute, how effective they are in accomplishing the work and how well-suited they are to the situational constraints within which they are used. You may already have gleaned some of that from your subject matter experts but you may also have to draw on your own knowledge about effectiveness of strategies from the literature on this topic. Remember that by tapping different different Cognitive States and Processes, different strategies impose different cognitive demands. Assess each strategy as a distinct cognitive event.

Cognitive Process Interpret & compare consequences various joints in relation to elegance, stability, time & effort	
Strategy	**Reasons for Selection**
Snap decision	In a hurry to decide Knows a lot about joints Confident of own judgment
Search for recommendations	Not in a hurry to decide Enjoys the challenge of working this out for himself Wants to build a unique piece
Infer most suitable from structural principles	Not in a hurry to decide Knows very little about joints Not confident of own judgment

Table 7.2: Alternative strategies for interpreting and comparing consequences of various joints with reasons for selecting one strategy versus another

If you succeed to this point, you should be able to assess rather easily whether any specific strategy needs some sort of technological or procedural support or possibly should be discouraged in favor of a different strategy. Some strategies are best left alone, but for those for which some intervention is desirable, the next step, to design that intervention, is more challenging. There may be a hint towards an appropriate intervention within the description of the strategy or in observations about why it may be difficult to execute or how it may fail. You might also find that some guidance in the literature on design of support for various cognitive activities.

Chapter Summary

Strategies Analysis, the fourth stage of Cognitive Work Analysis, identifies the Cognitive Strategies involved in a specific Cognitive Process as identified in the Cognitive Transformations Analysis. A strategy is a category of cognitive task procedure that transforms one cognitive state into another. The product of this stage of analysis is a suite of diagrams or tables that name and describe the alternate strategies that might be used to transition from one Cognitive State to another and that record some details about the types of situational factors that influence the selection of one strategy over another.

Strategies Analysis supports the fifth stage of Cognitive Work Analysis by identifying the Cognitive Strategies that are to be subjected to an analysis of Cognitive Processing Modes.

Chapter 8

Cognitive Processing Modes

Cognitive Processing Analysis, the fifth stage of Cognitive Work Analysis, identifies the different modes of cognitive processing (Skills, Rules or Knowledge) at which Cognitive Strategies are executed.

Reprise from Chapter 3

Stage 5: Cognitive Processing Modes (Cognitive Processing Analysis). In this chapter, I discuss the modes of cognitive processing that may be employed in execution of Cognitive Strategies in terms of:

- A Skill-Based mode of cognition, which has no conscious processing between perception and action,
- A Rule-Based mode of cognition, which is guided by sets of procedural instructions that specify sequences of actions, some of which may be conditional, leading to branches or halts in the sequence,
- A Knowledge-Based mode of cognition, which is grounded in conscious and explicit reasoning, and
- The reasons that a worker may use one mode of Cognitive processing versus another or may switch opportunistically between modes during execution of a Cognitive Strategy.

The product of this stage of analysis is a detailed description of the activity elements associated with the different modes of cognitive processing.

Cognitive Processing

In the execution of any Cognitive Strategy, a worker may interact with the system by use of different modes of cognitive processing characterized in terms of Skills, Rules or Knowledge or some combination of them. As depicted in Figure 8.1, the Skill-Based mode of cognition involves a perception-action association in which a pattern of meaningful information, once recognized implicitly, automatically stimulates coordinated action. The Rule-Based mode of cognition replaces the implicit recognition and perception-action pairing with explicit recognition and an established action plan. The Knowledge-Based mode of cognition replaces it with a decision following reasoning through a set of knowledge.

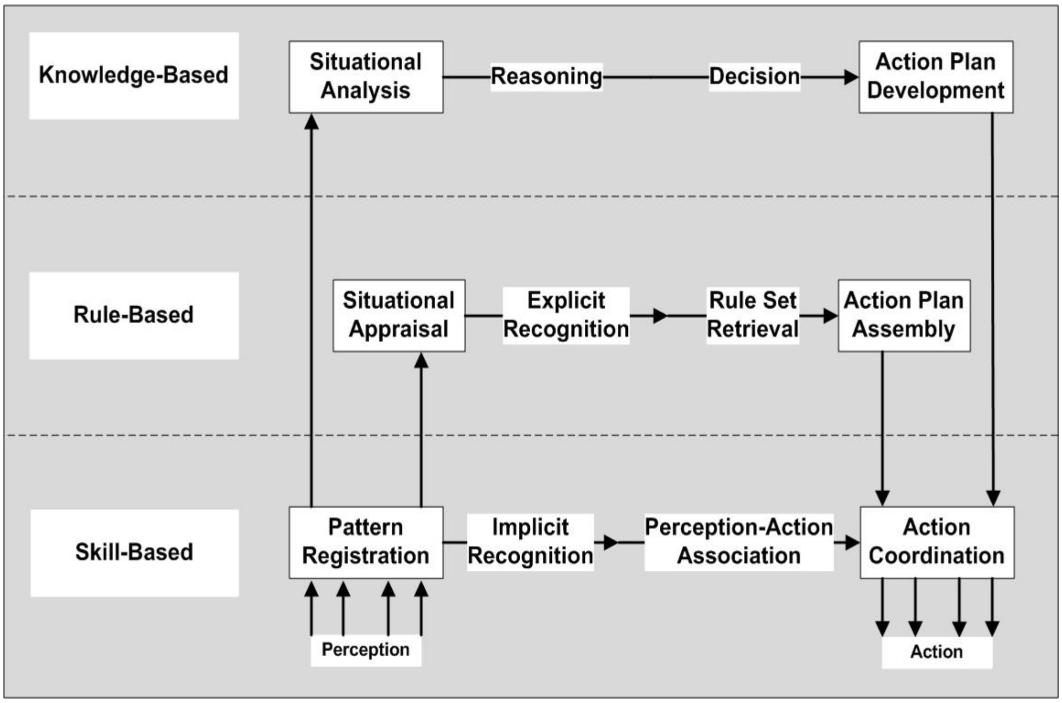

Figure 8.1: Cognitive processing can be Skill-, Rule-, or Knowledge-Based

Illustration; A Home Carpenter's Workshop (Continued)

Consider, again, the home carpentry scenario. While it will normally be necessary to analyze all potential Cognitive Strategies in this manner, I use those discussed in the previous chapter to illustrate the concepts.

Cognitive Strategy; Assess whether he has enough glue for the upcoming project: three potential strategies were identified for for this Cognitive Process; a perception-action pairing where our home carpenter inspected the amount of glue in the container and matched that against an estimated amount that he had used previously in similar sized job, use of the estimate from his plan book, and calculation of the amount of glue required by taking account of the number of joints, the surface area to be glued, and the characteristics of timber.

Cognitive Strategy; Interpret & compare consequences of Mortise & Tenon versus Butt in relation to elegance, stability, time & effort: three potential strategies were identified for for this Cognitive Process; a snap decision, use of a recommendation found by search on the World Wide Web, and reasoning and inference based on knowledge of the basic structural principles of joints.

I have used these elements of the carpentry scenario to annotate the strategy diagrams developed for the previous chapter with activity elements associated with the different modes of cognitive processing.

Figure 8.2 repeats Figure 7.1, which was annotated with the reasons for selecting one strategy versus another but is here annotated with the activity elements associated with the different modes of cognitive processing for each of the potential strategies:

- A snap judgment uses Skill-Based Processing in the form of assessing the quantity of glue remaining in the glue container, recalling the amount used on previous jobs and matching the assessed remainder with an amount used in a previous similar job;
- The use of an estimate from the plan book requires both Rule-Based and Knowledge-Based Processing in the form of applying the plan book recommendation to the job (Rule-Based) and estimating the quantity of glue remaining by comparing the measured height of glue in container to the container volume specified on the label (Knowledge-Based); and
- Calculation requires Knowledge-Based Processing in the form of generating a research strategy, reading and assimilating information about joint types and timber characteristics, calculating the total amount of glue needed for the current job (by counting the number of joints to be made, measuring the total surface area to be glued and factoring in the glue absorbent characteristics of timber) and estimating the quantity of glue remaining by comparing the measured height of the glue in container to the container volume specified on the label.

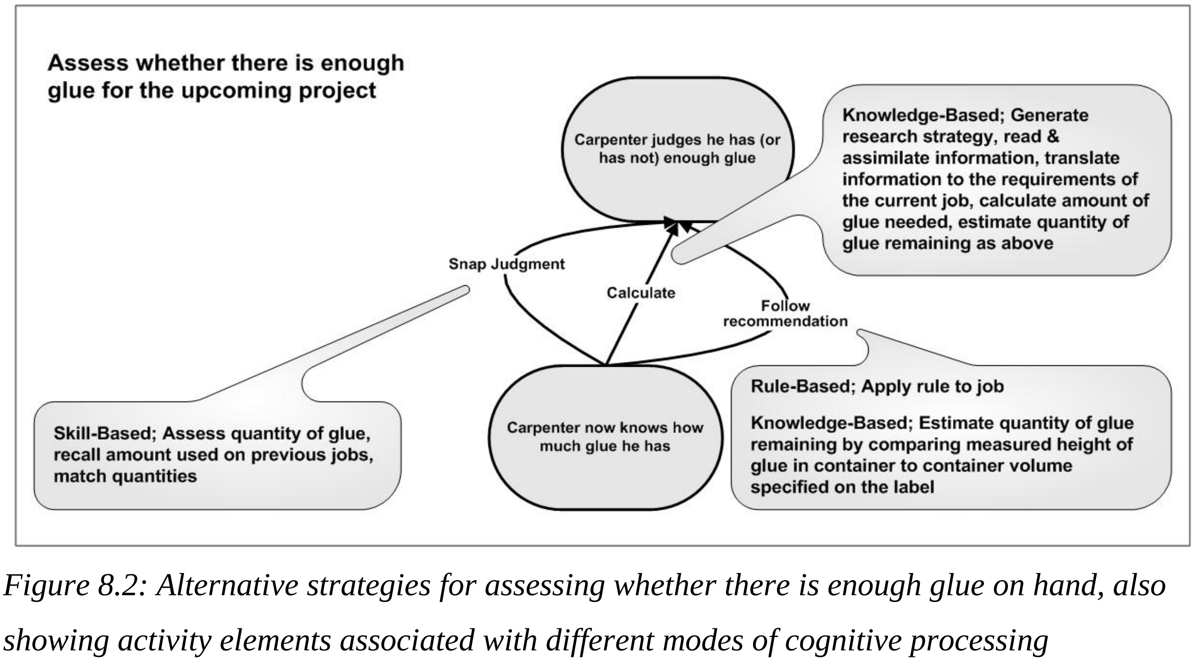

Figure 8.2: Alternative strategies for assessing whether there is enough glue on hand, also showing activity elements associated with different modes of cognitive processing

Figure 8.3 repeats Figure 7.2, which was annotated with the reasons for selecting one strategy versus another but is here annotated with the activity elements associated with the different modes of cognitive processing for each of the potential strategies:

- A snap decision uses Skill-Based Processing in the form of selection based on prior experience (selected joint was suitable before) and mental simulation of the process of constructing the joint and and of its appearance and stability;
- A search for recommendations requires both Knowledge- and Rule-Based Processing in the form of generating a search strategy, identifying useful documents from search results, selecting a joint from recommendations as seems appropriate (Knowledge-Based) and ensuring that any constraints published with the selected recommendation do not preclude its use with the upcoming job (Rule-Based); and
- Inference from structural principles requires both Knowledge- and Skill-Based Processing in the form of generating a search strategy, identifying useful documents from search results, reading and assimilating information, translating information to the requirements of the current job, designing a suitable joint (Knowledge-Based), and mentally simulating construction of the joint, its appearance and its stability (Rule-Based).

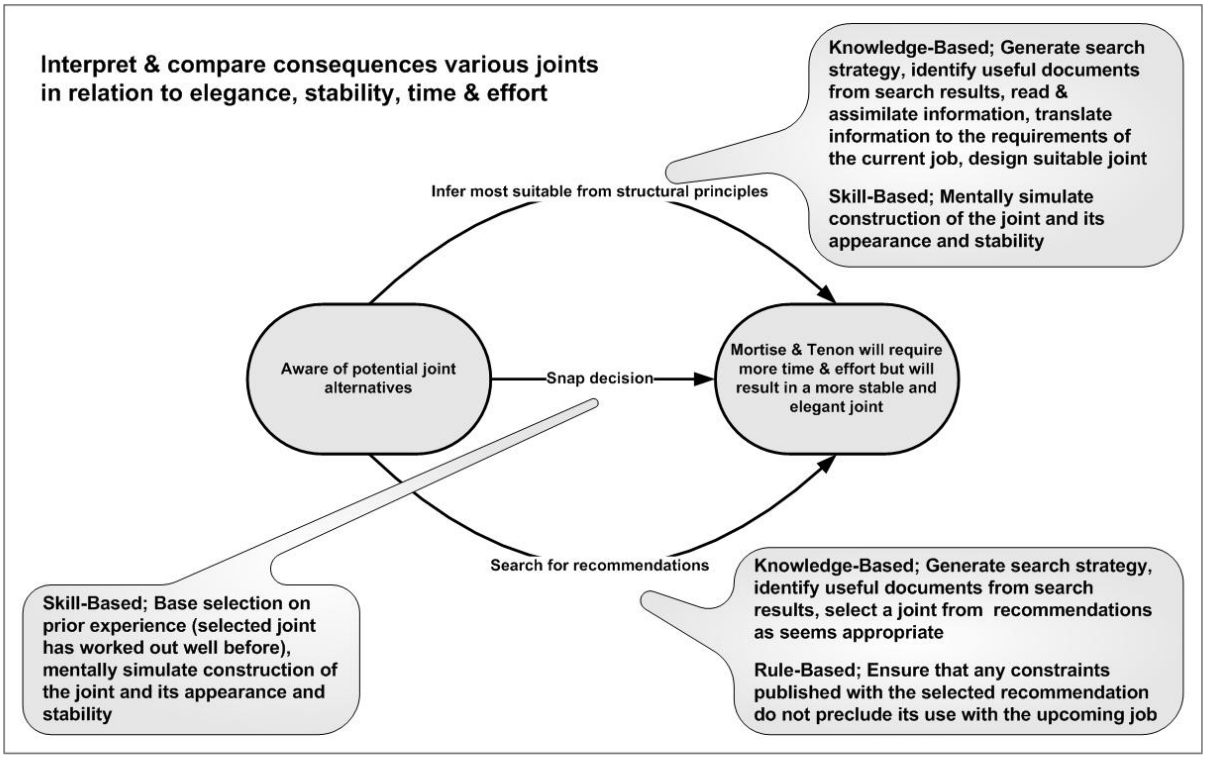

Figure 8.3: Alternative strategies for comparing effectiveness of various joints, also showing activity elements associated with the different modes of cognitive processing

Cognitive Processing Analysis

Cognitive Processing Analysis, the fifth stage of Cognitive Work Analysis, identifies the modes of cognitive processing involved in resolution of a work problem. It results in a summary of the information processing undertaken at the Skill-, Rule- and Knowledge-Based modes in the execution of a cognitive process.

A perceptual pattern is registered in all three modes of of cognitive processing, which leads to coordinated action.

In the Skill-Based mode, a pattern is recognized implicitly and the coordinated action is automatic; there is no conscious processing between perception and action. Lane following by the driver of an automobile, where positioning in the approximate center of lane is guided by the implicit perceptual symmetry of the lane markings on either side of the automobile, offers an example. In general, Skill-Based behavior is guided by perceptual information in the form of space-time patterns that have become ingrained by extensive experience or practice.

In the Rule-Based mode of cognitive processing, the pattern is first appraised and then recognized explicitly. On being recognized, it is associated with a familiar action plan either recalled from previous experience or retrieved from an electronic or paper document. The coordinated action is executed with full conscious awareness of the procedural steps to be taken. Such procedures are typically constructed in advance of the required behavior and their use does not demand reasoning. Decisions to advance, to branch or to halt are typically determined by perceptually-referenced rules.

In the Knowledge-Based mode of cognitive processing, the pattern is again recognized explicitly. That recognition induces analysis of the situation. Reasoning about the situation will follow analysis, a decision will be reached, and an action plan developed. That action plan will be implemented in coordinated action, again with full conscious awareness of the steps to be taken. The Knowledge-Based mode of cognition is grounded in conscious and explicit reasoning. It is the foundation for deciding, planning and problem solving and relies on access to and careful consideration of meaningful and diverse elements of information.

Proficiency with the three different modes of cognitive processing evolves in different ways.

Skills can be developed by coaching and by observation and behavioral modeling. They can also emerge from Rule-Based Processing (often supported by Knowledge-Based Processing) through the repetition of rules or procedures that are first employed to sequence the actions.

The inverse is also possible. Experts sometimes distill their skillful behavior into rule sets that then become an efficient and robust guide to execution of a complicated sequence of actions.

Knowledge-Based Processing emerges from the demands of resolving new knowledge-intensive problems. It becomes more effective as experts become more familiar with their domain and learn how to find and interpret information that can support resolution of a knowledge intensive problem. Where a particular Knowledge-Based problem is encountered over and over, workers will often develop a rule set as a summary of what has become a frequently-used pattern of Knowledge-Based Processing.

In all modes of processing, workers react to information, although the character of information is different for each of the modes. For Skill-Based Processing, that information is in the form of space-time patterns. For Rule-Based Processing, it is in the form of words or symbols that have come to be associated with specific activity. For Knowledge-Based Processing, it is in the form of semantics carried by complex perceptual patterns such as text, graphics or speech.

Skill-Based Processing can be effortless and efficient in the right circumstances. It does however proceed without conscious reflection and will not serve when there is a complicated and unfamiliar problem to be resolved. It can also be undesirable in tightly-regulated industries such as aviation or power generation where some prescribed procedures contain critical steps that cannot be omitted.

The effectiveness of Rule-Based Processing will depend on the accuracy and completeness of the procedural instructions that are being followed. In many cases, those procedural instructions are developed by managers or experts who have only passing familiarity with the details and context of the work. Procedures developed in this manner can be brittle; the steps they specify will often be incorrect or incomplete. Alternatively, they may be correct for most situations but incorrect for specific and unusual circumstances. The worker who encounters an incorrectly or incompletely specified step, or one that is inappropriate for the current context, can be diverted through an incorrect series of actions.

In contrast, procedures developed by experts as they proceed skillfully through a task are generally robust, for example, aircraft landing to procedures, which are generally developed by a pair of test pilots as they evaluate how best to land the aircraft. For any new aircraft type, test pilots will routinely exercise the aircraft through a range of flight regimes and, for landing, may have to work on procedures for short or otherwise primitive runways as well as for normal, hard-surface runways. Procedures developed by experts as they exercise the system are typically sensitive to context and are typically accurate and complete[8.1].

Work constraints and work experience influence the mode of cognitive processing that is activated. Workers gravitate naturally to Skill-Based Processing but can employ Rule-Based Processing when encouraged to do so through training or experience or when an appropriate rule set is readily available, especially if it is evident that Skill-Based Processing will be difficult to execute. They undertake Knowledge-Based Processing when the problem faced is unfamiliar or is possibly of a familiar type but contains unfamiliar details. It could be a problem well known in an abstract or general sense (e.g., the purchase of a home) but that poses details that need to be assessed and evaluated.

Much cognition is an opportunistic mix of Skill-, Rule- and Knowledge-Based Processing (again, the purchase of a home offers an applicable illustration) the balance of which will tip towards more Skill- and Rule-Based Processing as a worker gains experience.

Almost any reasonably complicated activity will require frequent and subtle transitions between modes of processing. Something like landing light aircraft manually by visual reference to the runway and its surround will demand skill-based processing in judgment of lineup of the aircraft with a runway centerline and in judgment of descent path, rule-based processing related to control of air speed, extension of flaps and extension of undercarriage, and knowledge-based processing in selection of landing runway (Table 8.1).

8.1 As an exercise in becoming aware of the dangers of developing procedures without being actively engaged in execution of the Work Tasks, reflect for a moment on something you have most likely done once or twice in your life; created for someone else a set of directions to travel a route with which you are familiar. You most probably did not have the opportunity to drive the route as you created your directions in order to ensure their accuracy. Did you make any mistakes? Would you have developed a more accurate set of instructions if you had created them as you drove the route despite the fact that the you were already quite familiar with that route?

Cognitive Processing \ Task	Final approach, landing a light aircraft
Skills	Use centerline & symmetry of runway to judge lineup Use horizon-aimpoint angle to judge glideslope
Rules	Lower wheels & extend flaps at recommended speeds & locations Maintain airspeed recommended for runway type
Knowledge	Ascertain optimum approach heading based on strength & direction of wind, & select most suitable runway based on published airport information

Table 8.1: Skills, rules and knowledge employed in final approach for landing an aircraft

More generally, the cognitive processing associated with any cognitive strategy is likely to involve a subtle and coordinated mix of the three modes. The role of each will be difficult to anticipate and will be discovered primarily by close examination of how each strategy is executed within a specific Work Task.

Cognitive Processing Analysis: How to Proceed

For Cognitive Processing Analysis, you must identify the types of information used in various strategies, how that information is transformed and how it is put to use. Focus on the strategies you have identified in the previous stage. For both Knowledge- and Skill-Based Processing, identify what information is used, how it is accessed, how it is transformed and how it is used. For Rule-Based Processing, identify procedures or activity sequences used to accomplish specific strategies. The most effective way of proceeding systematically with this analysis is to extend the methods of Knowledge Acquisition you have used in the previous stage of Strategies Analysis. In general, you should integrate the Knowledge Acquisition efforts from these two stages.

I noted in the previous chapter that strategies are often implicit, that is, the subject matter expert is not always aware of their particulars. This especially true with Skill-Based Processing. For this mode, you are unlikely to find anything that is useful in documents and you are an unlikely to get much from subject matter experts unless you approach this carefully. This is where the Critical Decision Method as described by Crandall, et al (2006) and as I described in the previous chapter, becomes most useful. It was developed to uncover information about implicit skills. In the use of this method, I devote the third sweep to probes that will identify strategies and the fourth sweep to probes that will explore the Skill-Based mode of cognitive processing. I also include probes related to the other processing modes to the extent I am dissatisfied with the coverage provided from document analysis or from less structured discussions with subject matter experts.

The results of your analysis will be names and succinct descriptions of activity for each of the modes used in the execution of a strategy plus identification of elements of the activities. Map the names and activity descriptions onto a figure as I illustrate above (e.g., Figure 8.2 & Figure 8.3) and the activity elements into a table as I illustrate in (Table 8.1). Additionally, annotate figures or tables with any insights you may have gathered regarding the reasons that a worker may use one mode of Cognitive Processing versus another or may switch opportunistically between modes during execution of a Cognitive Strategy. Remember that a strategy is typically executed at multiple modes of cognitive processing.

Cognitive Processing Analysis: Design Implications

Skill-Based Processing

Support the information aspect of Skill-Based Processing with familiar perceptual patterns and support the action aspect with capabilities that encourage direct manipulation.

Rule-Based Processing

Support the information aspect of Rule-Based Processing with familiar perceptual forms linked in procedural sequences that show a consistent one-to-one mapping between the work domain constraints and the information provided at the interface. Support the action aspect with manipulative capabilities that are linked directly to the perceptual form that is to stimulate the action. The use on a computer desk top of a trash can icon to identify a place for unwanted files conforms to the principle of familiar perceptual forms. The act of deleting a file by dragging it to that icon conforms to the principle of direct manipulation. In contrast, selection of a delete function from a menu violates both principles.

You may sometimes be asked to design procedures for Rule-Based Processing. Be careful with this. You should approach this problem by assembling a group of experts, current in the work domain of interest, to develop the procedures as they actually execute the Work Tasks.

Knowledge-Based Processing

Support the information aspect of Knowledge-Based Processing with an information resource that encourages workers to assemble a sparse but sufficient constellation of information for support of the current activity, whether it be making a decision, maintaining situation awareness, planning or anticipating the future. Your information resource will most likely need to contain a very large amount of information but any particular problem is unlikely to need more than a small subset of that information. The next problem is also unlikely to need more than a small subset of information but it will often be a different subset.

It is often said that we cannot have too much information. That may be true for information availability but it is not true for information use. A small subset of the right information will generally suffice. Thus, your information resource should enable its user to converge on, to select and to assemble that particular constellations of information relevant to the problem at hand.

Knowledge-Based Processing will lead to decisions, plans or reports that will most probably the published via Rule-Based action.

Cognitive Support Interventions

Develop interfaces that support the use of Skill- and Rule-Based Processing wherever possible and appropriate but also include support for Knowledge-Based Processing whenever necessary, for example during assessing, planning or adapting to complex and unexpected situations.

You may need to design a training module that will help workers develop expertise in the use of the different modes of cognitive processing. Realistic scenarios should also be developed to exercise all modes of processing as they are required for particular Work Tasks. Part training of processing elements can be used to good effect but ensure you do not decompose Work Tasks into trivial parts where the actual challenges to expert performance lie in assembling the different elements into a whole task (Lintern, 1989). Note the discussion above about how different modes of processing sometimes emerge from the exercise of other modes. Your training module will not always need to address the targeted mode of processing directly.

Chapter Summary

Cognitive Processing Analysis, the fifth stage of Cognitive Work Analysis, identifies the modes of cognitive processing involved in a specific Cognitive Strategies as identified in the Strategies Analysis. Cognitive processing may be Skills-, Rules- or Knowledge-Based.

Chapter 9

Work Coordination

Coordinative work processes are those that support collaboration between peers and coordination between management and workers. Work coordination is supported by physical and informational transactions. Although physical interactions (e.g., the transport of matter, the physical pressure associated with a handshake between peers) can be important in work coordination, my discussion in previous chapters and now in this chapter focuses on informational transactions.

Coordinative work processes are explored via a Social Transactions Analysis. The results of this analysis are summarized in an adaptation of the Contextual Activity Matrix introduced in Chapter 5 and detailed further in a Transaction Network.

Reprise from Chapter 3

Stage 6: Work Coordination (Social Transactions Analysis). In this chapter, I discuss Work Coordination in terms of:

- The social and collaborative processes that can facilitate peer-peer interaction, and
- The social and collaborative processes that can facilitate management-worker interaction and organizational integration.

One product of this stage of analysis is a Social Transactions Matrix, which is an adaptation of the Contextual Activity Matrix developed in Stage 2. A Social Transactions Matrix maps agents (either human or technological or some combination) to Work Tasks and maps Work Tasks to Transaction Demands and Transaction Modes. A second product is a Transaction Network in which the transactions between agents (either human or technological) are identified and characterized in terms of fundamental or generic properties relevant to design.

Social Transactions

A complex, socio-technical system is distributed and heterogeneous, comprising diverse human and technological functions. Such a system remains coordinated in part through the collaboration between peers and collaboration between management and workers; the lateral connectivity that supports essential work collaboration (and sometimes, competition) between peers and the vertical connectivity that supports essential manager-worker coordination.

I characterize collaboration and coordination in terms of transactions; the conduct or performance of some action. A social transaction is in an exchange or transfer between agents, either human or technological.

Within information systems, social transactions are predominantly virtual; a publication, a transmission or an exchange of information. Communication is central whether it is face-to-face or geographically distributed and whether it is concurrent or temporally distributed.

Concurrent face-to-face communication can be a conversation between two persons, a meeting between many or a presentation by one to many. Similarly, temporally and geographically distributed communication can be a conversation between two persons, a meeting between many or a presentation by one to many, but some form of communications technology must be employed. Additionally, any of these forms of communication might involve instructions and procedures from specialist teams to workers, advisories or guidance from management to workers or reports and advisories from workers to management.

Social Transactions can be characterized in terms of their demands (what needs to be accomplished) and their mode (how they are accomplished or how they might be accomplished). Additionally, for design purposes, it is useful to characterize transaction demands in terms of supporting technologies (what is used, what might be used) and the generic nature of each transaction (e.g., dialog, instruction, discussion, explanation).

We should also remember that social transactions can be physical; an exchange of equipment, supplies or currency or transportation of persons or goods, although the emphasis in this chapter is on information transactions.

Illustration; A Home Carpenter's Workshop (Continued)

Consider, again, the home carpentry scenario.

> When planning a job, our home carpenter settles into his home office to consult his book of plans from his personal library or searches on the Internet for a plan. He develops his requirements and then moved to his workshop to assess what he

has on hand. He annotates his requirements inventory and then moves back to his home office to prepare an acquisition inventory. He needs to do this carefully because his family situation generally results in his spouse picking up the required supplies from the store. He typically prepares a detailed requirements list and then telephones a store clerk he has come to know well to verify that all requirements are in stock. Once the clerk confirms that all requirements are in stock, he faxes his requirements inventory to the store. He would like to substitute e-mail for both the telephone and fax transmission but his trusted store clerk, admirably reliable and systematic on all other things, checks his e-mail infrequently.

He then discusses with his spouse, generally over dinner, when she might be able to pick the order up. This is often an extended discussion, especially if the requirements amount to more than a few items, because she needs check that the order is filled as specified when she picks it up. As reliable as s/he is, the store clerk occasionally neglects an item or provides the wrong brand or quantity.

Our home carpenter typically purchases tools by mail-order from an Internet-based supply. He prefers this method for shopping for tools because he can comparison shop and he can compare features in the comfort and peace of his home office. Particularly, he does not have to rely on the advice of sales clerks who typically know less than he does. He is, however, aware of mail-order scams and rarely places an order with a mail-order house outside of his small group of trusted suppliers. If he is tempted to purchase from a new supplier, he searches the Internet extensively for customer reviews, being careful to avoid reviews review sites that are also scams.

When he has the supply store size any of the timber, he sketches plans and dimensions, scans them into computer files, and e-mails them to the workshop attendant at the local supply store. Unlike the preferred store clerk, the workshop attendant checks his e-mail regularly and confirms that the message has been received. Generally the messages is undistorted but the workshop attendant occasionally queries particular specifications. Negotiation ensue by an exchange of e-mails.

At pickup, his spouse never checks the dimensions of the store-sized timber. To this point, the workshop attendant has never made a mistake.

I have used this narrative as a basis for adapting the home carpentry Contextual Activity Matrix from Chapter 5 (Figure 9.1). In this simple example, the carpenter is the agent responsible for most of the Work Tasks. However, as noted in the narrative above, his spouse is responsible for taking delivery of the required supplies from the local supply store and the store workshop attendant is sometimes it responsible for sizing the timber. Figure 9.1 shows the transaction demand for each work task and the transaction mode used to satisfy that demand.

Social Transaction Docket; Home Carpenter

Agent	Transaction Properties / Work Tasks	Transaction Demand	Transaction Mode
Carpenter	Select Plan & List Inventory Requirements	Research	Book (Personal Library), Internet
Carpenter	Assess Timber & Consumables Stock	Observation	Local, Physical Presence
Carpenter	Assess Tools Inventory	Observation	Local, Physical Presence
Carpenter or Spouse	Purchase Tools & Supplies as needed	Acquisition	Travel, Physical Presence, Internet
Carpenter	Layout Timber, Tools & Consumables	Manipulation	Local, Physical Presence
Carpenter	Measure Timber	Manipulation	Local, Physical Presence
Carpenter or Store	Size Timber	Manipulation	Local, Physical Presence
Carpenter	Shape Timber	Manipulation	Local, Physical Presence
Carpenter	Finish Timber	Manipulation	Local, Physical Presence
Carpenter	Assemble, Clamp & Fix Timber	Manipulation	Local, Physical Presence

Figure 9.1: A Social Transactions Matrix for a home carpenter that maps agents to Work Tasks and Work Tasks to Transaction Demands and Transaction Modes

The Transaction Demands are further elaborated as a Transaction Network Diagram (Figure 9.2) which shows transaction links between agents that interact. This diagram is annotated with the name of the supporting technology and a description of the generic nature of each transaction.

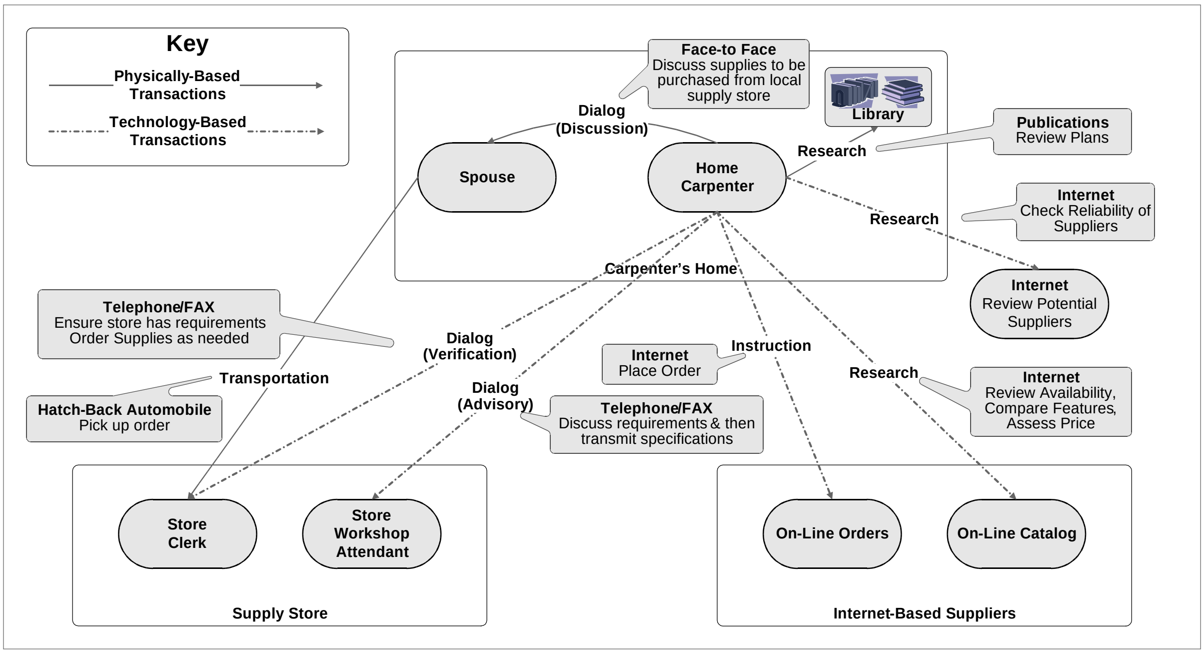

Figure 9.2: A Transaction Network for a home carpenter in which transaction links are associated with the supporting technology and the generic nature of each transaction

Social Transactions Analysis

Social Transactions Analysis, the sixth stage of Cognitive Work Analysis, identifies social and collaborative processes that support work; those that can facilitate peer-peer interaction and those that can facilitate management-worker interaction and organizational integration. The aim is to map the needs for collaboration (especially those for communication) between agents as they execute Work Tasks.

Social Transactions Analysis further characterizes collaborative processes in terms of generic properties that can inform design. The frequency and complexity of exchanges and the requirements for spatial proximity or concurrency are important. For example, demands for mutual understanding or shared situation awareness at a distance or displaced in time will have different requirements for technological support than the same demands within a face-to-face transaction as will planning for immediate action versus planning for future action. Properties such as dynamic versus reflective, verbal versus non-verbal and mutual versus command transaction will be significant.

One product of this stage of analysis is a Social Transactions Matrix, which is an adaptation of the Contextual Activity Matrix developed as the representational product for Work Organization Analysis. A Social Transactions Matrix maps agents (either human or technological or some combination) to Work Tasks and maps Work Tasks to Transaction Demands and Transaction Modes.

As I have illustrated in Figure 9.1, the first column is used to name the agent(s) responsible for work tasks as identified in the Work Organization Analysis while the third and fourth columns are used to specify the Transaction Demands and Transaction Modes at a generic level of description. As noted in the Chapter 5, the Contextual Activity Matrix developed in Stage 2 of Cognitive Work Analysis can be used to identify Work Situations and Work Tasks for a system now in use or for a future system. Similarly, the Social Transactions Matrix can be used to represent agent allocations, Transaction Demands and Transaction Modes for either existing or future systems.

To assist with recall of how the Work Tasks were distributed across Work Situations, I typically fade those indications as they were represented in the Contextual Activity Matrix and leave them in the background of the Social Transactions Matrix.

A second product of the Social Transactions Analysis is a Transaction Network Diagram in which the transactions between agents (either human or technological) are identified and characterized in terms of fundamental or generic properties relevant to design. As I have illustrated in Figure 9.2, a Transaction Network Diagram represents transaction links between agents and labels those links in terms of a generic property that describes the transaction in abstract terms. The diagram is also annotated with a brief description of what is to be accomplished by the transaction and, in the case of an existing system, the technological support now being used.

Special topics in Social Transactions Analysis

Management

Work Coordination for management is a special topic that I will add to this book soon. In my treatment of this topic, I will propose that there is a management team that can be assessed in much the same way as an operational team. The management team will, however, focus on different work products. They will plan the future course of their organization, remain sensitive to competitive or disruptive issues at an organizational level and remain sensitive to operations. They will also ensure that organizational intent and organizational values filter through the system without distortion.

In addition, I will reflect on management-worker interaction. The unschooled view has a large enterprise being organized by management directive. In fact, this style of management can be ineffective. It will consist either of a hierarchy of tightly-coupled management layers that result in micro-management (and instability) or else it will be a loosely-coupled hierarchy in which the activities of management and of operations have little mutual relevance or influence. Characteristically, this type of management is disengaged from operations and has a somewhat fanciful view of how operations unfold.

As observed by Weick & Sutcliffe (2001), effective management is mindful in that it pays attention to the complexity and subtlety of operational requirements. It takes account of how operations actually unfold versus how they might be thought to unfold. One particular role of management in this scheme is to set a context that will permit operational staff to develop effective and robust work processes in pursuit of the organization's goals. Mindful managers promote a permissive culture in which operational personnel are encouraged to provide meaningful information about operational complexity and to offer information that can guide development of effective management interventions. It could be said that the directives flow from operations to management rather than from management to operations.

In adding this topic, I will further develop these ideas and work through illustrations that take account of them.

Social Transactions Analysis: How to Proceed

In this stage of the analysis, you need to identify work-group structures and social transactions.

Base your analysis of work-group structures on the Work Tasks already identified in Work Organization Analysis and mapped into the Contextual Activity Matrix. Identify the authority and leadership structure. Also identify tasking assignments in relation to work tasks and, within those assignments, who is responsible for decision-making and planning. Do not forget either specialty tasks that require high levels of expertise or mundane tasks such as trash removal and personal maintenance.

For existing work groups, a method used by Klinger and Klein (1999) offers valuable guidance. For analysis of an emergency response team within a nuclear power plant, they identified macro-cognitive team functions such as communication of intent and maintenance of shared situation awareness and also meta-cognitive work-group functions such as collaborative monitoring of team effectiveness by use of probes such as “What tasks are not finished?”, “What are the essential handoffs and transactions?” and “Who are the key decision makers?”.

For future systems, the tabletop method used by Naikar, Pearce, Drumm and Sanderson (2003) can start you in the right direction. This method uses small groups of experts (generally no more than two in each group) to explore how the work demands imposed by realistic scenarios can be distributed across work-group members within different work-group structures (e.g., work-group size, number of levels of hierarchy). Operational staff, managers and engineers have different areas of expertise that can be useful for tabletop exercises.

Both forms of analysis can also be used to develop a record of transactions within the work group and also between the work group and external agents. You will need to code your interview data code it in terms of of generic properties that can inform design. Note actual or anticipated inefficiencies in the use of communications technologies. In undertaking the coding, it is preferable to work from audio or video records (or from verbatim transcripts) because they permit you to return and recode if you have failed to consider something important in preparation for data collection. Be aware that the coding will be time-consuming.

Social Transactions Analysis: Design Implications

The goal is to design effective structures for work groups and to provide them with support technologies that are concordant with their communications demands.

It will often be possible to enhance the effectiveness of existing work groups with straightforward adjustments. Klinger and Klein (1999), as a result of their analysis, 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). These inerventions 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.

For future systems, the results of the tabletop method can be used to design efficient structures for work groups. From the brief description I provide above, it may at first seem that the tabletop method contrasts different structures in order to decide which is best. That is not actually the intent. Tabletop analysis is intended as a qualitative exercise in exploring relevant dimensions of work groups (e.g., work-group size, number of levels of hierarchy) to assess their influence. With this sort of systematic knowledge in hand, it is possible to design an effective work group structure. Note that the final structure may not correspond to any of the structures examined in the analysis.

That final structure should be assessed in terms of how well it satisfies the Domain Purpose, the Domain Values and Priorities and the Domain Functions (Naikar, et al, 2003). A trade study based on work domain criteria can be used in the event there is more than one candidate structure.

The Transaction Network will have identified the generic properties of the essential communications in terms of physical structure (face-to-face versus geographically distributed) and style (command, instruction, advisory, simple, complex or creative interaction). Knowledge of these properties can be used to establish be desirable style of information exchange (push, pull, broadcast, interactive engagement) and the implications of that for technological support.

For example, e-mail might be excellent for exchanging information but it does not offer good support for a dynamic discussion. Nor does it serve well when an immediate response is required; a telephone exchange or a broadcast is likely to solicit a more immediate response. Additionally, we should not forget that some transactions require physical presence for the exchange or display of material items and it still remains unclear that technology can be substituted for physical presence for all types of discussions, in particular, those for which nonverbal information plays an important role. 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.

In addition, the work group structures that have been developed should be reviewed to ensure that any need for frequent and demanding transactions between agents can be supported adequately. Ideally, teams should be configured so that the number of transactions between agents is minimized and those transactions that are essential are economical.

Summary

Social Transactions Analysis, the sixth stage of Cognitive Work Analysis, identifies the social and collaborative processes that facilitate peer-peer interaction and those that facilitate management-worker interaction and organizational integration. The results of this analysis are represented in an adaptation of the Contextual Activity Matrix introduced in Chapter 5, identified here as a Social Transactions Matrix. It maps agents (either human or technological or some combination) to Work Tasks and maps Work Tasks to Transaction Demands and Transaction Modes. These social transactions are further elaborated in a Transaction Network in which the transactions between agents (either human or technological) are identified and characterized in terms of fundamental or generic properties relevant to design.

Appendix A

Hierarchies, Heterarchies and Networks

There is often confusion and disagreement about the nature of hierarchies and so it is worth pondering some of the basic concepts.

Hierarchies

A hierarchy is a system of ranking and organizing things in terms of a relationship, such as ‘is superior to’, ‘is part of’, or 'is taller than’. Entries in the hierarchy can be characterized as nodes. Nodes at a higher level of a hierarchy are designated as superior to nodes at a lower level and nodes at that lower level are designated as subordinate. Hierarchies are always:

- transitive — if *a* is superior to *b*, and *b* is superior to *c*, then *a* is superior to *c*
- irreflexive — no entry in the hierachy is superior to itself
- asymmetric — if *a* is superior to *b*, then *b* is not superior to *a*

There are several types of hierarchies:

- Abstraction: The superior node needs all of its subordinate nodes for its full realization and the subordinate nodes are required for realization of their superior node (Figure A.1a)
- Decomposition: The superior node is composed of its subordinate nodes and the subordinate nodes are parts of their superior node (Figure A.1b)
- Authority: The superior node has authority over its subordinate nodes and the subordinate nodes are submissive to their superior node (Figure A.1c)
- Classification: The superior node is a super-ordinate category of its subordinate nodes and the subordinate nodes are exemplars of their superior node (Figure A.1d)

Many hierarchies conform to the property of containment in which subordinate nodes are contained within a superior (or parent) noted as shown in Figure A.2. A classification hierarchy always conforms to this property and crossovers are never legal. For example, a tiger can never be classified as a canine and a fox can never be classified as a feline.

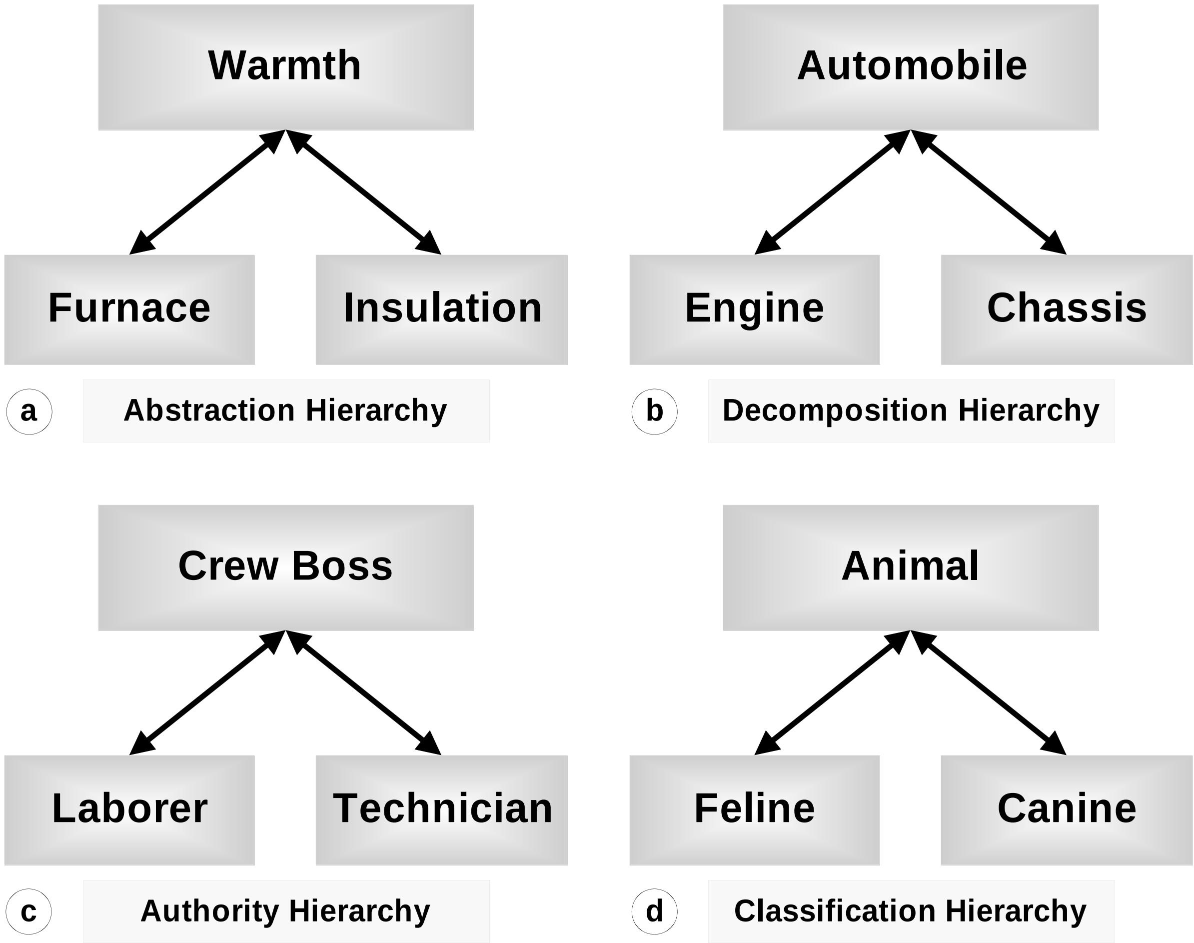

Figure A.1: Types of hierarchies

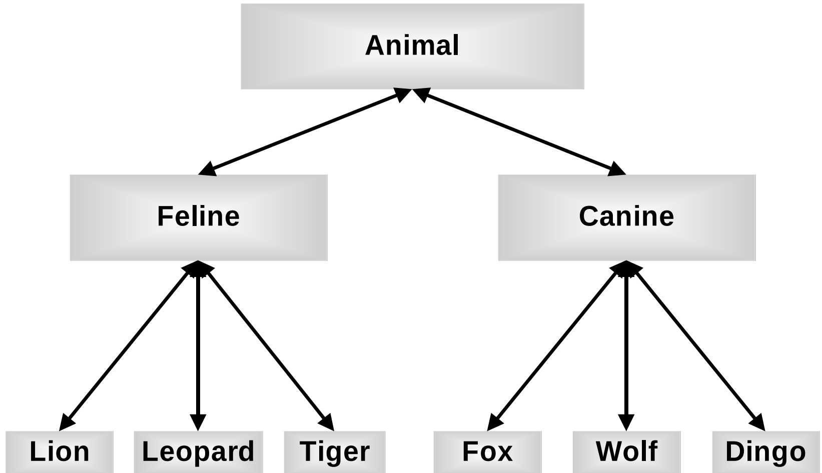

Figure A.2: Most hierarchies conform to the property of containment in which subordinate nodes are contained within a superior (or parent)

Containment is not, however, a necessary property of hierarchies. As shown in Figure A.3, an abstraction hierarchy does not conform to this property. Subordinate nodes will often have multiple superior nodes. This, indeed, is the property that enables us to take account of interdependencies between different functional areas. Relaxation of the containment property is crucial to effective use of an Abstraction Hierarchy in development of Socio-Technical Systems. This allows us to track multiple (often unintended and undesirable) effects of subordinate nodes.

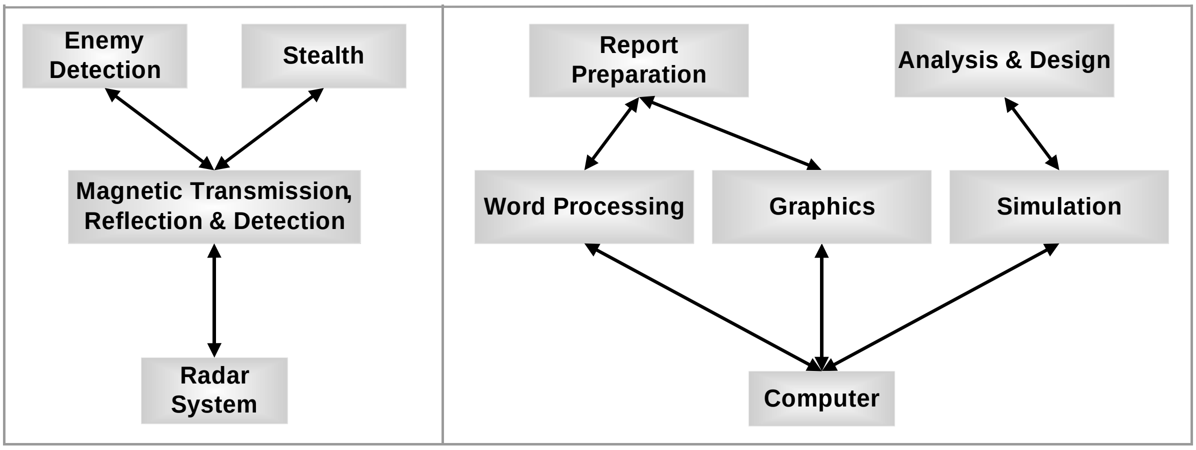

Figure A.3: An Abstraction hierarchy does not conform to the property of containment; subordinate nodes are not necessarily contained within a single superior (or parent) node

Heterarchies and Networks

A heterarchy is a network of elements that share the same level of a hierarchy. Each level in a hierarchy is composed of a heterarchy. A network is an interconnected heterarchy in which cords, threads, or wires cross at regular intervals, as in for example:

- a network of railroads
- an espionage network
- an extended group of people with similar interests or concerns who interact and remain in contact for mutual assistance or support

I cannot recall if this is a typo or if I actually meant regular. In future editions, I will replace this sentence with "A network is an interconnected heterarchy in which cords, threads, or wires link entities in some irregular pattern".

Summary

The failure to note the distinctive differences between hierarchies, heterarchies and networks has led to some confusion about the nature of the Abstraction-Decomposition space. Elm, Potter, Gualtieri, Roth and Easter (2003), for example, claim that the Abstraction-Decomposition space is a network and not a hierarchy. Make no mistake. The Abstraction-Decomposition space as I describe it in this book and as it is generally described by practitioners of cognitive work analysis, is a hierarchy. The two dimensions are different types of hierarchies. The decomposition dimension conforms to the property of containment whereas the abstraction dimension does not. The basic definition of a hierarchy does not impose the property of containment.

Appendix B

A Problem Solving Trajectory

If the foundational assumption for Work Domain Analysis (that human reasoning is based on navigation through an Abstraction-Decomposition Space) is valid, it should be possible to map reasoning protocols onto the appropriate Abstraction-Decomposition Space. The illustration I offer here is intended as tutorial example rather than as evidence for this claim. It illustrates what this claim means and further illuminates the conceptual nature of an Abstraction-Decomposition Space.

The illustration draws on a fictitious example in which a plan is developed for the air defense of a naval task force. The purpose of this system is to coordinate defenses against a possible attack from the air. Figure B:1 shows an Abstraction-Decomposition Space for a planning support system.

The scenario has a naval task force deployed off the coast of fictitious country that is known to be antagonistic. An air defense plan is to be developed to counter any offensive sortie launched by that country's known air assets.

The task force's air defense planner navigates through this problem by reference to information organized with reference to the abstraction-decomposition structure. The planner navigates through functional descriptions at different levels of abstraction or degrees of decomposition in an opportunistic sequence. One possible trajectory is shown in Figure B:2.

That trajectory first establishes the Domain Purpose, which is to coordinate the air-to-air and surface-to-air defenses of the task force. There is a possible threat from the adversary's fighter assets and so the trajectory identifies those assets at the level of Physical Resources and Constraints and then examines their threat potential at the level of Technical Functions, continuing into the level of the Domain Functions.

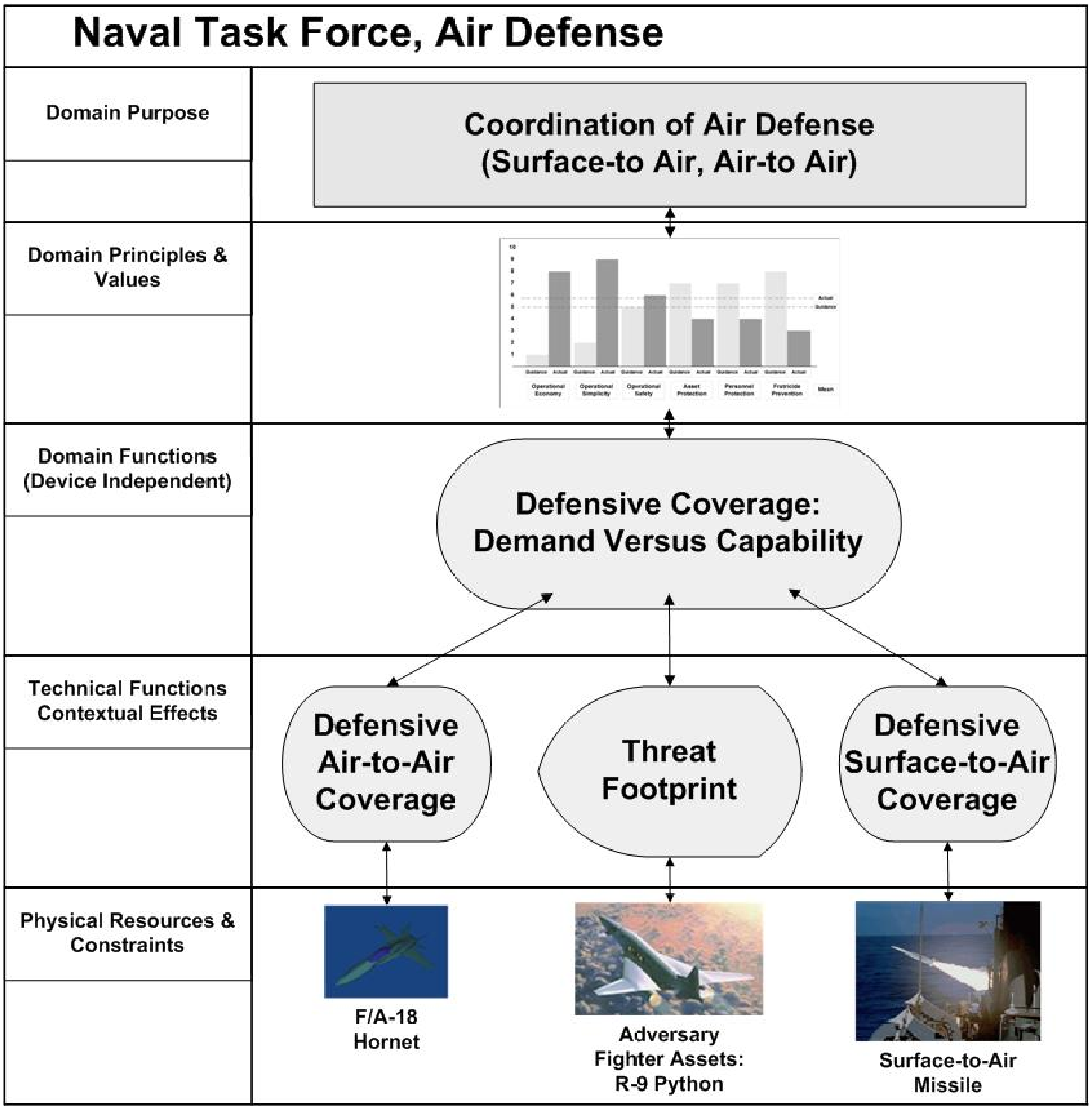

Figure B:1: A planning support space for Naval Task Force air defense

Given appreciation of the threat potential, the planner then identifies the defensive resources of the naval task force; first aircraft at the level of Physical Resources and Constraints and their capabilities at the level of Technical Functions, continuing into the level of the Domain Functions. Surface-to-air missiles and their capabilities are reviewed similarly. All capabilities are compared in terms of defensive capability versus demand for defensive coverage at the level of Domain Functions. Through consideration of the relative capabilities for the task force versus those of the adversary, the air defense planner develops a defensive strategy which s/he publishes as a defensive plan.

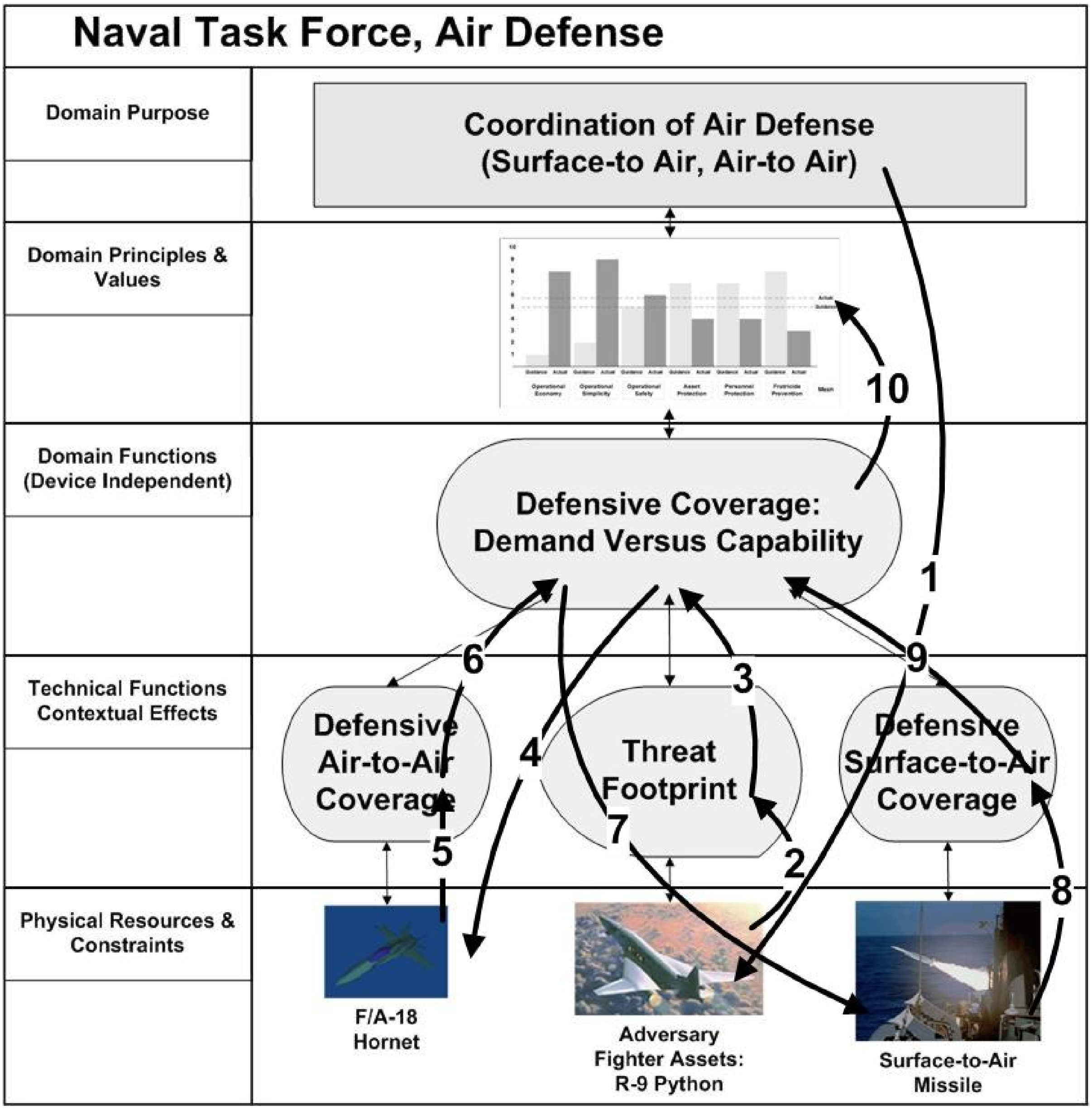

Figure B:2: A planning support space for Naval Task Force air defense showing one possible sequence for navigating through the information that will support the planning process

On publication, the plan is then assessed by a senior officer for its conformance to the priorities expressed for task force protection by the commander. The assessing officer should already be familiar with the priorities set by the task force commander and will either approve the plan as one that will be effective as it conforms to those priorities or else will send the plan back to the planning officer for revision.

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