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FOUNDATIONAL ISSUES FOR WORK DOMAIN ANALYSIS

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Lind (2003) has offered a critical analysis of Work Domain Analysis as executed in Cognitive Work Analysis. I review his critique and conclude that relatively few of his arguments have merit. Work Domain Analysis has a unique role to play within Cognitive Engineering. Although only some of the issues raised by Lind require resolution, consideration of those selected issues would be useful for the development of Cognitive Work Analysis.

INTRODUCTION

Work Domain Analysis is a phase of Cognitive Work Analysis, which in turn is a framework within the larger enterprise of Cognitive Systems Engineering¹. Lind (2003) has emerged as notable critic of Work Domain Analysis and argues that it suffers from both methodological and conceptual problems. In summary, he argues that the Abstraction-Decomposition space developed via Work Domain Analysis is incoherent and cannot perform the role promoted for it by Rasmussen, Vicente, and many others (including me), either in principle or in practice.

Lind is not alone in voicing his disapproval of Work Domain Analysis but, in contrast to many others whose critiques are little more than expressions of discontent, he has developed an explicit argument. His views are sufficiently cogent to be addressed and, given that they are devastating if valid, need to be addressed by those of us who rely on this analysis.

Lind's arguments are not relevant to Applied Cognitive Work Analysis (Elm, Roth, Potter, Gualtieri, & Easter, 2005), which does not lead to an Abstraction-Decomposition space and which, in fact, leads to a representation similar to that produced by Lind's Multilevel Flow Modeling. Elm, Potter, Gualtieri, Roth and Easter (2003) acknowledge their intellectual debt to Lind.

TERMINOLOGY

Vicente (1999) refers to the representational product of Work Domain Analysis as an Abstraction-Decomposition space but it is also known as an Abstraction Hierarchy or an Abstraction-Decomposition model. The term Abstraction Hierarchy is unsatisfactory because it encourages neglect of the decomposition dimension, which is essential to this analysis. I dislike characterizing this as a model because to many the word model implies properties that the result of this analysis does not capture, for example properties of causality and activity. That is not to argue that model is incorrect when used in this sense but only that it introduces avoidable ambiguity.

Abstract means to consider apart from concrete existence (Houghton Mifflin, 2000). There are numerous ways of abstracting a domain and the means-ends relationship as

captured within Work Domain Analysis defines one of them. Lind (2003) refers to part-whole as well as means-ends abstractions, but neither assembly from parts (composition) nor disassembly into parts (decomposition) constitutes a gradation from concrete existence and should not be characterized as an abstraction. To speak of a part-whole abstraction suggests a failure to grasp the essential nature of abstraction.

The belief that cognitive activity maps to an abstraction-decomposition structure in a specific and significant way is a foundation of Cognitive Work Analysis. Both Rasmussen and Vicente argue that experts navigate through an Abstraction-Decomposition space as they troubleshoot or solve problems. I suspect that much of the confusion and skepticism about Work Domain Analysis emanates from a failure in our Cognitive Work Analysis community to develop and stress this idea. I suggest that if we were to establish this idea beyond the cursory treatment given it by both Rasmussen and Vicente, the sense of Work Domain Analysis would become more widely apparent. I do not, however, focus on that issue in this paper.

I have long suspected that some of the skepticism I encounter regarding the Abstraction-Decomposition space results from confusion about what is meant by *hierarchy* and *network* and I take the opportunity here to clarify those terms.

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*. A node at a higher level of a hierarchy is designated as *superior* to nodes to which it is linked at a lower level and those lower-level nodes are designated as *subordinate*. A hierarchy is:

- transitive (if *a* is *superior* to *b*, and *b* is *superior* to *c*, then *a* is *superior* to *c*)
- irreflexive (no entry is *superior* to itself)
- asymmetric (if *a* is *superior* to *b*, *b* is not *superior* to *a*)

Most hierarchies conform to the property of *containment* in which subordinate nodes are strictly nested within superior nodes (Figure 1, left panel). Containment is not, however, a definitional property of a hierarchy and a functional abstraction hierarchy does not conform to it; subordinate nodes are not be contained by (linked to) only one superior node (Figure 1, right panel). Relaxation of the containment property allows us to track multiple (sometimes unintended and undesirable) effects of subordinate nodes and is crucial to effective use of means-ends relationships for design of socio-technical systems. For this reason, we should speak of *means-ends* rather than *means-end relations*.

¹ This analytic method is only one of potentially many ways to analyze the work domain; Burns and Vicente (2001) note, for example, that Multilevel Flow Modeling (Lind, 1994, 1999) is another.

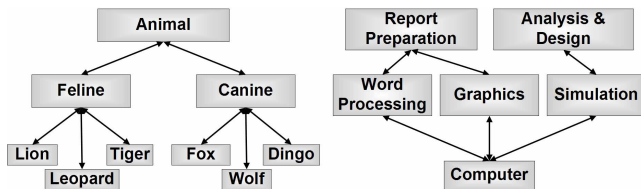


Figure 1; Hierarchies generally conform to the property of containment (left) but a functional abstraction hierarchy does not (right).

The classification hierarchy of Figure 1 (left panel) is an abstraction hierarchy of the type used as a foundation for Ayn Rand’s Objectivist Epistemology (Rand, 1979/1990). Work Domain Analysis is about functional abstraction and functional decomposition. In discussion, the term *functional* is often left implicit to avoid the repetition of a long and clumsy designation, but it should not be forgotten.

A *network* is an interconnected arrangement of elements. The nodes may be connected in either a regular or an irregular pattern (e.g., a railroad network, an espionage network, people who interact for mutual assistance). The definition of network offered by Houghton Mifflin (2000) implies that network nodes are specified at a single level of hierarchy. Thus, the term, *Functional Abstraction Network* (Elm, et al, 2005) distorts the concept of network.

ASSESSMENT STRATEGY

The most persuasive criterion for assessing an analytic method is effectiveness in support of a project. Unfortunately, the results of analysis are often not transformed into design and at other times, the link between a design and the preliminary analysis remains obscure. Assessment of an analytic method is particularly challenging when used predominantly in the design of systems to be fielded at some considerable time into the future. In that case, analysis must proceed in the absence of operational feedback and even after a system is fielded it may remain difficult to connect operational success or failure to the analysis that shaped the design.

Where analysis is directed at future systems, a critique of the principles and structure of the analytic method can be useful if it reveals one or more of the following problems:

- The method has no useful purpose even if done well,
- The method has a useful purpose but its foundational principles are unsound,
- An alternative analytic strategy can accomplish the same purpose more effectively,
- The principles are sound but practitioners do not apply them well so the method does not achieve its potential.

For Lind’s critique to have any value, it must establish that Work Domain Analysis fails on at least one of these criteria. I have concluded from my review of his papers that he believes the method has a useful purpose but that its basic principles are unsound. In what follows, I will first assess the merit of his argument in relation to that unsound-principles criterion.

UNSOUND PRINCIPLES?

Work Domain Analysis is, as the term implies, an analytic method. It must therefore be coupled with a design or development strategy to achieve a pragmatic result.

Ecological Interface Design is the preferred design strategy. Vicente (2002) has reviewed the contributions of Ecological Interface Design and has concluded that progress has been encouraging and that there is evidence both of applicability to a diverse set of operational domains and of technology transfer to industry. Vicente’s review shows explicit links between Work Domain Analysis and Ecological Interface Design for at least some of his examples. Other design work based on Abstraction-Decomposition analyses but outside the Ecological Interface Design realm by Naikar, Pearce, Drumm, and Sanderson (2003) and Naikar and Sanderson (2001) has also shown strong results.

Any *unsound-principles* argument needs to demonstrate how these projects achieved successful outcomes in spite of, rather than because of their reliance on Work Domain Analysis. Lind (2003) did not examine any of the projects reviewed by Vicente, nor did he assess the work of Naikar and Sanderson (2001). Doubtless, the work of Naikar et al (2003) was published too late to for him to evaluate in his paper, but it also undermines his critique. In the absence of any substantive argument that can discount Vicente’s conclusions or the relevance of the work by Naikar and Sanderson (2001) and Naikar et al (2003), I discount the *unsound-principles* argument.

Nevertheless, it would be useful to examine the content of Lind’s arguments in light of a less stringent criterion noted above; that the method does not live up to its potential because application of its principles is flawed. That exercise may serve to draw some value from Lind’s critique by making the principles more explicit. I am unaware of any alternative method for mapping workplace structure and therefore do not examine the possibility that there is a more effective alternative.

Lind (2003) identified several issues, some of which he characterized as methodological and others as conceptual. Following the sequence used by Lind (2003), I will address the methodological issues before the conceptual issues.

METHODOLOGICAL ISSUES

In this section, I paraphrase the more significant of Lind’s methodological issues as stated in his 2003 paper and offer my commentary. Note that my statement of the issues is not a quote but rather my summary of Lind’s concern.

Issue: There are no procedures or guidelines for knowledge acquisition.

Response, part a: In a design effort, we need to acquire knowledge and then represent or summarize it in a form that can support design. As noted by Burns and Vicente (2001), the primary thrust of expositions of Cognitive Work Analysis has been on representation. This could be seen as neglectful but Cognitive Work Analysis is part of the larger enterprise of Cognitive Systems Engineering, which has a plethora of Knowledge Acquisition methods. Practitioners of Cognitive Work Analysis select from those methods and, given their extensive treatment elsewhere, there seems little need to elaborate on them in formal expositions of Cognitive Work Analysis.

Response, part b: Many practitioners of Cognitive Work

Analysis discuss or at least identify their methods of knowledge acquisition. Rasmussen (1986) used interviews, observation and verbal protocols and described his use of those methods in detail. Naikar et al (2003) name document analysis, subject matter interviews and tabletop analysis. Naikar and Saunders (2003) name the critical decision method. I name document analysis and subject matter interviews (Lintern, 2006). Most other practitioners of Cognitive Work Analysis include some discussion of their knowledge acquisition methods in reports of applied work.

Issue: There is no process for building, revising, modifying and validating models.

Response: Processes for building, revising, modifying and validating models are always incomplete but Vicente has offered many details for Cognitive Work Analysis. His guidelines for constructing an Abstraction-Decomposition space are detailed (Vicente, 1999, pp 165-6). The processes and guidelines offered by Lind (1994, 1999) for Multilevel Flow Modeling are no more explicit or extensive. In addition, some in our community continue to develop and extend guidelines for different stages of Cognitive Work Analysis (e.g., Naikar, Hopcroft & Moylan, 2005).

Issue: There are no convincing arguments for the number of abstraction levels or part-whole levels. It is a strange coincidence that the number of levels (five) along the two dimensions is the same.

Response, part a: Pragmatically speaking, there are five levels of abstraction². The limits are anchored by the Why-What-How sequence. Purpose is the ultimate end and so represents the upper limit. Physical material represents the most basic means at the lower limit. Objects, functions, values and purposes are conceptually different and we further find it useful to distinguish physical (device-dependent) from purpose-related (device-independent) functions. These distinctions should not be considered inviolate because identification of more appropriate distinctions is always possible but they do seem to correspond to the way experts conceptualize their work. Note that this is a pragmatic issue (*the distinctions correspond to how experts think*) rather than a metaphysical one (*the distinctions do not reflect an inherent structure of the world*)³.

Response, part b: Except in Lind's own papers, I have never seen a claim of five decomposition levels and it is definitely not a principle of Work Domain Analysis. Levels of decomposition are selected based on knowledge acquisition protocols. Analysis extends to a level found useful for domain experts.

Issue: The inclusion of control systems in the Abstraction-Decomposition space is a controversial issue.

Response, part a: Lind attributes the controversy to incompatible statements made by Vicente and Rasmussen, versus Miller and Sanderson. He takes Miller and

Sanderson (2000) to task because they, in forwarding a claim that Work Domain Analysis cannot cope with biological systems, imply that process plants do not incorporate control systems. Miller (personal communication) has indicated that she and Sanderson had not meant to imply that and she now believes that the term *entangled* is a better descriptor for the biological control systems problem.

Response, part b: Lind takes Vicente (1999, p 9) to task because of Vicente's definition of a work domain as a *system being controlled, independent of any particular worker, automation, event, task, goal, or interface*. Lind takes this definition to mean that control systems should be excluded from a Work Domain Analysis but I take this definition more generally to mean that agency should be excluded from the analysis. Thus, control systems are not to be analyzed as causal loops within Work Domain Analysis. Control systems realize a function and that function, together with the appropriate decomposition should be included in the Abstraction-Decomposition space, but the causal loop must be investigated through some other form of analysis.

Response, part c: From my reading of Lind's papers, I understand that analysis of processes within a control system is the role he has set for Multilevel Flow Modeling. If that is the case, Multilevel Flow Modeling and Work Domain Analysis do not compete for the same ground and my email exchanges with Lind suggest to me that he would agree. Burns and Vicente (2001) also argue that these two analyses yield different information.

CONCEPTUAL PROBLEMS

The repository of concepts used to characterize the content of the five means-end levels is a major source of confusion

(Lind, 2003, p 73)

As suggested by the above quotation, many of Lind's issues relate to semantics. This is one point that I find telling. The confusion he expresses about the semantics that underpin Work Domain Analysis is understandable. Cognitive Engineers who practice Work Domain Analysis are, unfortunately, inconsistent in their use of words.

Vicente (1999) has made a systematic and disciplined attempt to clarify the semantics and his book remains the benchmark for defining relevant concepts. As one might imagine, others do not always follow Vicente precisely. In itself, this is not problematic because we should expect that usage of concepts would evolve as we develop this method, but many analysts depart from Vicente's terminology for no apparent reason, without explanation, and without acknowledging the departure. I am left with the impression that there is a troubling lack of discipline in our community regarding the meaning of terms and that relatively few are concerned by that state of affairs.

I find this attitude as troubling as Lind (2003) apparently does. He notes our use of the term *function* and argues that we do not recognize its multiple meanings. The same can be said of the term *process* and it is a further concern that there is overlap in some of these meanings between the two terms. Nevertheless, Vicente (1999) defines *function* in the

² Some projects do not need development of all 5 levels, but levels not developed are implied.

³ The argument regarding number of levels continues even among practitioners of Cognitive Work Analysis.

manner in which he intends it to be used in Cognitive Work Analysis and while he does not specifically define *process*, his definition of *product model* indicates what he means by *process* (Box 1).

Box 1: Function & Process (Vicente, 1999)

Function - An Affordance relevant to the purposes for which the work domain was designed (p 6)

Product Model - a black-box model describing the behavior of a system, but not the process or mechanism by which that behavior is generated (i.e., *what*, but not *how*) (p 7)

Comment: By these definitions, function is a structural property whereas process is an action property.

There is also confusion about the distinction between *purpose* and *goal* but again Vicente defines the manner in which they can be distinguished (Box 2). Nevertheless, there are many examples in the literature of Work Domain Analysis completed since the publication of Vicente's book in which *process* is equated to *function* and *goal* is substituted for *purpose*.

Box 2: Purpose & Goal (Vicente, 1999)

Purposes - the overarching intentions the work domain was designed to achieve. Note that purposes are properties of domains, not actors, and that they are relatively permanent (p 8)

Goal -- a state to be achieved, or maintained, by an actor at a particular time. Note that goals are attributes of actors, not domains, and that they are dynamic (p 6)

This lack of discipline in use of words is particularly troublesome for the practice of Work Domain Analysis because this method generates so much controversy. Our continuing lack of discipline in this area can only serve to confuse those we are trying to inform and leave us open to the sort of criticism that Lind has leveled.

On the other hand, many of the conceptual issues Lind identifies do not emanate from unclear and inconsistent use of terminology and I respond to those issues below in the same manner I responded to the methodological issues.

Issue: A means-ends relation has causal properties but Work Domain Analysis does not deal with causes.

Response: Vicente (1999, p 7) is unambiguous. He refers to the structural means available for achieving the ends (Box 3). This is consistent with the common language interpretation of the means test (Houghton Mifflin, 2000), which essentially asks whether you have the resources that will permit you to live without additional resources. Vicente's treatment of means-ends excludes consideration of causality, which is not to claim causality is irrelevant but rather that it should be considered elsewhere.

Box 3: Means-Ends Relation (Vicente, 1999)

Means-Ends Relation - the relationship between adjacent levels in a means-ends hierarchy. The level below a given level describes the structural means that are available for achieving the level above. The level above a given level describes the ends (or functions) that can be achieved by the level below (p 7).

Issue: The combination of means-end(s) and causality concepts is inconsistent with the intrinsic logic of many-to-one mappings.

Response: A key benefit of the Abstraction-Decomposition space is that it reveals complex mappings (many-to-one, many-to-many, one-to-many). The standard Systems Engineering strategy of assigning Integrated Product Teams to different functional areas prevents mapping of subtle and unexpected interdependencies between functional areas. To my knowledge, the Abstraction-Decomposition space is the only representation available today that reveals these interdependencies and it does so by allowing complex mappings. As noted above, means-ends relations are not causal. The incompatibility of causal concepts with complex mappings is one reason that practitioners of Cognitive Work Analysis do not enter them into their Abstraction-Decomposition spaces.

Issue: It is important to distinguish between different types of means-ends relations.

Response: Again, Vicente (1999, p 7) is unambiguous. There is one type of means-ends relation. Would others be useful and could they be incorporated into Work Domain Analysis? Resolution of that question would require extensive exploration but I doubt it would be a productive exercise. Multilevel Flow Modeling (Lind, 1999) uses diverse types of means-end relations, which are presumably useful for the form of technical analysis he undertakes, but those distinctions have no obvious implications for the design of Human-Systems Interaction.

Issue: The semantics of the means-end(s) and causal relations in the Abstraction-Decomposition space allows circular plant descriptions

Response: The circular description problem is one reason the Functional Abstraction Network of Applied Cognitive Work Analysis as an alternative to the Abstraction-Decomposition space (Elm, 2002). It is possibly no accident that the Functional Abstraction Network has some of the characteristics of a Multilevel Flow Model, including references to causality (Elm, 2002). However, circular descriptions are not valid in an Abstraction-Decomposition space and those who note it as a problem do so because they do not understand the nature of means-ends relations as defined by Vicente and do not recognize the significance of complex mappings. Neither Multilevel Flow Modeling nor a Functional Abstraction Network depicts functional interdependencies. That does not invalidate their use as tools for design of human systems but those tools do not substitute for an Abstraction-Decomposition space.

Issue: The inclusion of actions on the level of physical function in the Abstraction Hierarchy (Rasmussen, Petjersen & Goodstein, 1994) is problematic. Most people would regard actions as genuine means (consider e.g. the following sentence "*the turning of the valve by 30 degrees is a means to increase the flow of water*") but actions does not fit naturally in the same category as material objects like pumps and valves.

Response, Part a: I could not find that quote in Rasmussen et al (1994) and remain uncertain whether Lind meant to attribute it to them. Vicente (1999) is clear; an Abstraction-Decomposition space does not have action statements. Many follow that guidance rigorously.

Response, Part b: Vicente's recommendation is consistent with the exposition of Rasmussen et al, (1994). One unfortunate characteristic of the English language is that certain words signify either functions or actions (e.g. landing as relevant to aircraft) and I sometimes notice words that have this characteristic in Rasmussen's and Vicente's treatments of Work Domain Analysis. I have not found Rasmussen to be as unambiguously explicit as Vicente but neither do I find noteworthy conceptual incompatibilities between them. Lind's claim that actions do not to fit into the same category as material objects is, I believe, consistent with both Vicente's and Rasmussen's expositions.

Response, Part c: The search for conceptual incompatibilities between Rasmussen and Vicente is an unfortunate exercise. Cognitive Work Analysis continues to evolve. I doubt that anyone, including either Rasmussen or Vicente, believe the earlier treatments are flawless. From that perspective, we would hope that more recent expositions refine issues and correct inconsistencies.

SUMMARY

On several occasions, while reviewing Lind's papers, I puzzled over the origin of certain statements and have come to believe that they emerge from a techno-centric view and a focus on automated control systems. Rasmussen typically takes a global perspective on cognitive systems (e.g., Rasmussen, et al, 1994). That, however, does not make Lind wrong; the substantive content of his claims need to be assessed as I have sought to do here.

The single dimension of his critique that I can accept is in relation to confusing semantics. However, he takes the view that this confusion results from attempts to generalize to a number of work domains while I continue to believe that the potential to generalize across work domains is a major strength of Work Domain Analysis. Lind also takes the view that clarification of the semantics will restrict the range of domains to which Work Domain Analysis is applicable while I take the view that clarification of the semantics will extend the range and value of application. These are unsupported claims but we should note that no research endeavor could progress without a number of strategic commitments of faith.

Much of Lind's critique is premature but at some stage it is essential that Work Domain Analysis be shown to contribute to the design of cognitive systems. Some examples in that direction have been noted earlier in this paper. Work is ongoing and we will be able to update our ideas about this form of analysis as that is reported. However, I remain unaware of any competing analysis devoted exclusively to mapping out functional structure. Part of the disagreement may be about whether it is useful to map functional structure, which is a potential topic for future discussion. Suffice to say at this stage that those who undertake Cognitive Work Analysis believe it important.

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