CFM: A SOFTWARE TOOL TO SUPPORT COGNITIVE FUNCTION MODELING IN SYSTEM DESIGN

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ABSTRACT

We are engaged in a Navy sponsored innovative research effort to synthesize techniques of Cognitive Task Analysis (CTA) with Operator Function Modeling (OFM) and provide a new methodology, termed Cognitive Function Modeling (CFM), to capture the humans' cognitive requirements within the context of operator functioning in a complex system. The OFM contributes a mathematical, dynamic, and graphical systems engineering perspective of the operator component in the system. The CTA provides in-depth textual descriptions of cognitive challenges imposed by the decision making requirements. Together these provide a powerful potential for understanding and addressing the larger human-system design issues we face today. The purpose of the software-based CFM project is not solely the development of a *hybrid methodology*. Our system under development will provide system engineers and human engineers/analysts a set of methods supported by customized *instructional and model building software tools* for taking the human cognitive requirements and operations context into account in their design of large-scale, complex, and highly automated systems. The CFM system will enable a *human engineering specialist* to create operations models, assess the cognitive challenges of various system components, and conduct cognitive analysis of the highly complex pieces of the system. It will enable a *system engineer* to review and revise previously built models (i.e., CFM representations) to gain an understanding of the human role and cognitive challenges associated with the system early on in the system design. Finally, CFM models and data will provide a common frame of reference for people of various backgrounds (human factors analysts, system engineers, end users, etc.) to work together more effectively within a multidisciplinary system design team.

Keywords: cognitive complexity, operator function model, cognitive task analysis, system design

INTRODUCTION

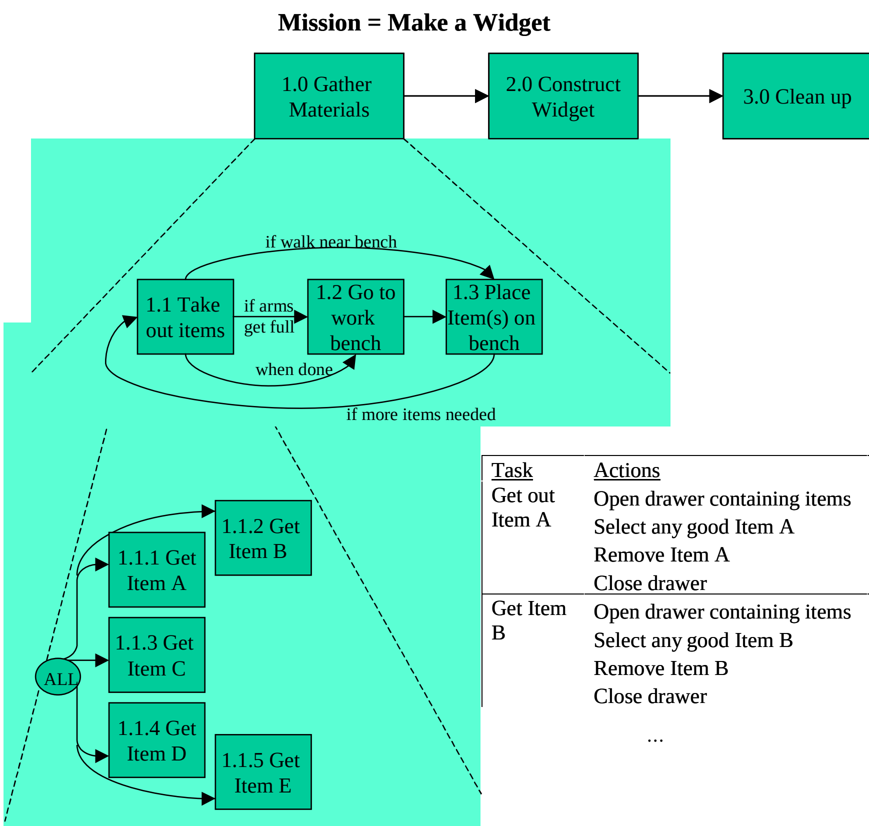
This paper will describe the development of the cognitive function model/methodology and the implementation of the method into a software system – a system that provides both instruction on how to create cognitive function models and software applications to build actual models of a system in design.

There are three major components to the cognitive function model. The first is the **Operator Function Model** (OFM), a human-system engineering model that is used as a means to represent the human role within a system context, in terms of hierarchical functions/tasks and dynamic triggering events (Mitchell, 1987). The second major component of the CFM system enables engineers to identify the challenging aspects of those tasks to further focus design efforts. This piece, which Klein Associates Inc. has termed the **Cognimeter**, will highlight the tasks or functions within the OFM that are cognitively challenging and that require further cognitive analysis. **Cognitive Task Analysis** (CTA), the third component of CFM, is a means for those involved in system design to understand the human-system integration (HSI) design issues.

The initial phase of the project (a six month effort) focused on determining the feasibility of merging OFM and CTA techniques and developing the Cognimeter as the link between the two. We are currently well into the two year follow-on phase, refining and operationalizing the Cognimeter concept and developing software that supports and integrates each of the three CFM components: OFM, Cognimeter, and CTA.

OPERATOR FUNCTION MODEL

An Operator Function Model (OFM) is a method of task analysis used in the design of automated supervisory control systems (Jones and Mitchell, 1995) that documents the role of the human in the system, with respect to a specific mission or goal. See Figure 1. It defines the important triggering events, flow/sequence of tasks comprising the mission, and the actions and information needed to perform the mission tasks.



Task	Actions	Information
Get out Item A	Open drawer containing items Select any good Item A Remove Item A Close drawer	Drawer location = third column, first row Good = not chipped
Get Item B	Open drawer containing items Select any good Item B Remove Item B Close drawer	Drawer location = fifth column, third row Good = not bent
	…	

Figure 1. Three levels of OFM diagram hierarchy with a task element table.

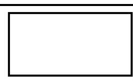
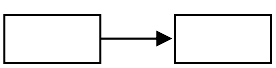
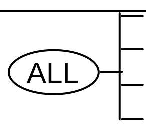
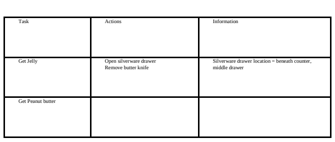
Jones, Chu, and Mitchell (1995) outline an iterative knowledge engineering process to gather the data required to build an Operator Function Model representation:

- *collect* existing system design and operations documentation, including the concept of operations, standard operating procedures, user manuals containing the layouts and meanings of display pages, any required reporting or other paperwork that operators fill out, and existing training and certification materials.
- *observe* operators' on-the-job activities and interactions over the course of several weeks including during mission operations. If possible ask operators to explain what they are doing and why while they work. Otherwise, pose questions as soon as possible after the fact.
- *interview* operators and supervisors about their knowledge of the system including their overall view of the mission and operations, their specific duties and interactions, and historical insights.
- *validate* the data and later the graphical representation of the data by presenting these to Subject Matter Experts revising as necessary until they agree that essential system operations are adequately represented.

In addition to representing the current tasking requirements that propagate into the design of a new or modernized system, the OFM model must incorporate "to be" (future) tasking/responsibilities. Possible sources for infusing this information include future system requirements, concept of operations documentation, operator insight, and interaction with top level designers and decision makers.

Building the OFM graphical representation uses knowledge acquisition data in two steps. First, identify the major operator activities and how they are the carried out, as well as what kind of problems and challenges the operators face and how they solve them (Jones, Chu, and Mitchell, 1995). Second, translate that data into the OFM framework of hierarchical-heterarchic nodes. Figure 1 shows a generic OFM for a "build a widget" mission and shows three levels of hierarchy. At each hierarchical level, trigger events, represented as arcs between nodes, are defined (see Figure 1). The shapes representing OFM model elements are shown in Table 1.

Table 1: Elements of the operator function model with definitions

Element/Shape	Definition
	Rectangles with square corners – task without an associated lower level decomposition
	Rectangles with rounded corners – task with an associated lower level decomposition
	Rectangles with square corners and shadow = Lowest level (action) node
	Horizontal arrows – indicate triggering events. Unlabeled arrows indicates completion of the previous activity and transition to the next; labeled arrows indicate a specific state or triggering condition has initiated the event.
	Label top part of branch with: ALL, ANY, ONE, PAR (in parallel) to indicate any dependencies/relationships between branches.
	Task elements table– indicate specific physical (e.g. executing a command) and cognitive actions (e.g., monitoring, assessing data), and data items (e.g., azimuth) needed to complete the task at hand

COGNIMETER

Cognitively challenging tasks are defined for our purposes as those that require people to make decisions; make subtle judgments, perceive subtle cues, and patterns of cues; integrate many data into a meaningful understanding of a situation and its implications and anticipate the consequences of these data; manage ambiguous, missing, unreliable, and complex information; develop plans in the face of uncertainty and anticipate the consequences of actions; and so forth.

These types of tasks require thinking skills and are the targets for further analysis via CTA techniques. CTA (discussed in the next section) uncovers the information, cues, and strategies of expert decision makers, and helps the designer of systems understand why these cognitive tasks are difficult and thus how to support these tasks through systems design, function allocation and interface design.

The Cognimeter tool is used in a two stage process. The first stage identifies initial candidates for CTA by assessing whether an OFM node under consideration is procedural and whether it is mission critical. The mission critical and non-procedural nodes are of highest interest for further CTA. The second stage assesses a node on five broad areas of cognition, or thinking skills:

1) Situation Awareness
2) Course of Action Development and Evaluation
3) Course of Action Execution Monitoring
4) Teamwork and Coordination
5) Information and Attention Management

Each dimension is operationalized for CFM implementation in the Cognimeter scan capability. For Situation Awareness, for example, CFM model builder is queried along the follow lines. Is a difficult aspect of this task developing and/or revising a situation awareness, including the anticipation of how the situation might evolve and detecting problem situations? This might be difficult, for example, in dealing with uncertainty (ambiguous information, unreliable information, missing information, complex information); seeing subtle signs or seeing meaningful patterns of information; judging when a situation has changed; detecting problem situations or anomalous situations; and judging that you need to reinterpret. All these contributors may make this task cognitively challenging along this first dimension.

Any task could conceivably have any combination of these five complexity dimensions hold true; thus with the simplest scoring method of 0 or 1 for each dimension there are 32 possible task profiles. For example, a profile of 01100 (indicating elements of Course of Action Development and Evaluation, Course of Action Execution Monitoring) may indicate a heavy planning aspect to the task. A link from each profile to the CTA method(s) most appropriate is currently under development. Using the example task profile 01100, the Critical Decision Method (CDM) (Klein, Calderwood, and MacGregor, 1989) might be the most appropriate to start the CTA.

COGNITIVE TASK ANALYSIS

Cognitive aspects of a task are often overlooked in the design process because it is often difficult to elicit such information and the associated impact on system performance may be hard to understand. The Cognimeter screening tool (described in the previous section) is intended to help human factors analysts and design engineers identify tasks and functions that are cognitively challenging and thus focus a Cognitive Task Analysis (CTA) appropriately within the constraints of the project (e.g., funding and time). The Cognimeter will highlight the cognitively challenging aspects of existing task environments as well as envisioned task environments, and CTA will reveal those challenges. This will allow designers to address design implications by developing function allocation strategies, HCI recommendations, or other human-system integration solutions.

For the CTA portion of the CFM we are reviewing products and representations from the Klein Associates' archives (an experience base of over 100 CTA projects in over 30 domains for a period of over 20 years) from projects relating to system design or more specifically interface design (Klinger et al., 1993), decision support systems (Miller and Lim, 1993), and organizational design and redesign (Klein et al., 1996; Klinger and Klein, 1999).

The current implementation of the CTA component of the system is a listing of some methods/ analyses that are appropriate for nodes in the system, based on the cognitive challenges identified by the Cognimeter. As the CFM project progresses, we will develop on-line tutorials and other supporting software for CTA knowledge elicitation and representation methods or approaches.

COGNITIVE FUNCTION MODEL IMPLEMENTATION

The Cognitive Function Model is being developed in three iterative builds to get the tool into the hands of potential end-users at early stages of CFM concept definition and system development.

Build 0 – Storyboard of CFM Concept – In Build 0 (completed) we built upon commercial software (SPSS allCLEAR 5.0; OLE; Visual Basic) to demonstrate the CFM application shell, a capability to launch tutorials, and a partially user-interactive OFM diagramming and Cognimeter scanning capability (Aptima and Klein, 2000). The purpose of Build 0 was to demonstrate to potential end-users the *end-to-end concept* (Build 0 demonstrates what capabilities the CFM system will provide). Figure 2 provides a snapshot of the now completed Build 0 concept.

Build 1 – In this build (in progress) we are using the *actual system development environment* including any COTS software (Aptima and Klein, 2000). Build 1 will consist of the Build 0 prototype implemented in the actual development/COTS environment. The goal of Build 1 is to develop the individual system components (Build 1 demonstrates each capability separately).

Build 2 – In the final build, all Build1 components of CFM shall be *integrated* into a running system and we will demonstrate some level of data share with other engineering design tools.

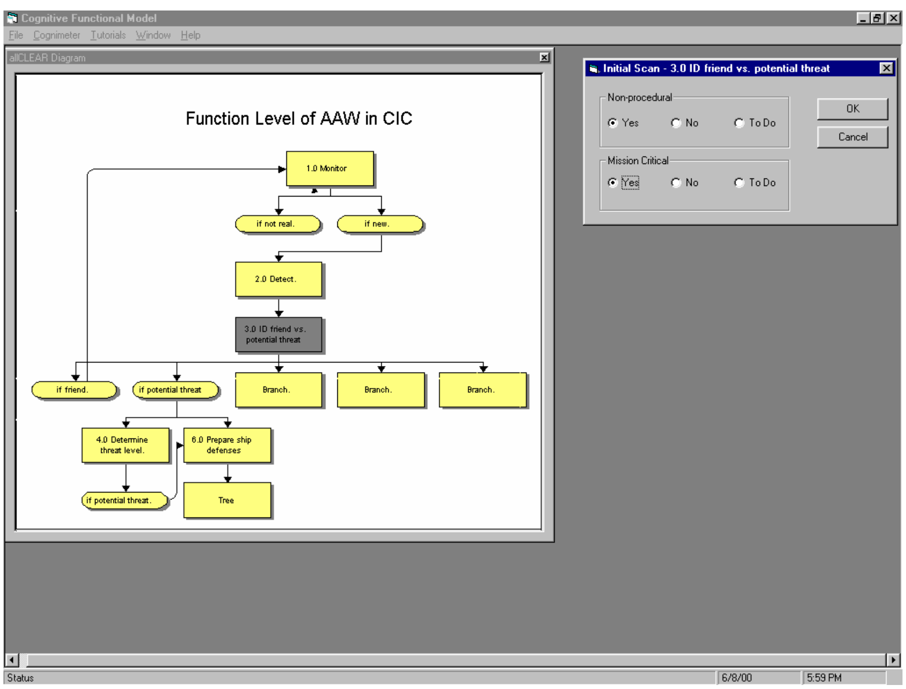


Figure 2. A Build 0 screen snapshot with OFM diagram and initial Cognimeter scan

Shown in Figure 2 is the CFM application shell, a view of one level of OFM decomposition with a node selected, and the top level cognimether scan on the node. Build 0 is currently in the hands of representative user groups and we are awaiting feedback, which we plan to apply to our Build 1 design.

CONCLUSION

A Cognitive Function Modeling tool helps design teams break missions down into their meaningful functions and tasks and informs the team of which tasks are likely to be cognitively challenging for the human. The tool directs designers toward appropriate CTA methods to use for further analysis of those areas of the system. This type of software support will allow design teams to develop more robust designs – designs that have considered the human from the beginning of the development process.

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