TASK ALLOCATION AND AUTOMATION IN DESIGN AND OPERATION OF MAN-MACHINE SYSTEMS

Craig M. Arndt
Armstrong Laboratory
U.S. Air Force

ABSTRACT

Cockpit automation is a subject that evokes considerable controversy among users, manufactures, and regulatory agencies. As more and more complex computer technologies become available for use in cockpits and air traffic control application, it becomes more and more important to make the right decisions in implementing automated systems and also to use the most appropriate technology for that automation. The effect of task automation is sometimes to create additional new tasks. These new tasks are typically monitoring, fault detection or management tasks which human operators are not well suited to perform. These "automation residual tasks" or complementary tasks lead to situations where automation invites new forms of human error in their operation, often leading to gross blunders rather than the relatively minor errors which characterize traditional systems.

In order to meet the challenges that face the aviation industry in the design and operation of intelligent human centered flight decks, it is increasingly important to have analytic methods for evaluating new technologies for automation. The Structure of Intellect Capability-Requirement (SOI C-R) method will provide a tool to make these decisions in a well defined analytic manner.

1 INTRODUCTION

This task allocation methodology was originally developed as part of a research project to develop a domain suitability measure for expert systems technology applications. This project was very successful and is documented in an Air Force tec report(Arndt 1991). The method is based on a mapping analysis based on two constructs. The first of these is that the structure of intellect model of a task or technology's capability can be represented as a plot or profile of various attributes defined within the model. The second is that we can predict system performance based on matching the profiles of the task, and the technology(Wickens 1988). The SOI models domain is then defined by a set of scaled vectors representing the dimensions of the model. During the course of the expert system project, it was found that this method also has the general capability to represent tasks and operators.

2 MOTIVATION AND USE

The FAA National Human Factors plan and a number of DoD and USAF efforts are under way to examine, evaluate, and improve the use of automation in the aerospace industry. This intense concern and effort is entirely justified by safety and performance requirements and the availability of increasingly complex and exotic computer software.

The continued use of current and advanced technology in automation of tasks in the areas of flight deck operation and Air Traffic Control(ATC) requires new methods for the development of automation conceptual guidelines and task allocation. Particularly important are the development methods to evaluate new technologies such as AI and expert systems and their adaptation to new domains. The SOI Capability-Requirements method is well suited to the evaluation of automation philosophies and new technologies.

3 APPROACH

The SOI C-R methods approach to function allocation and automation implementation is to fully describe the requirements of a task in a numeric representation and to represent the capabilities of task performance operators within the same numeric modeling space. The specific task requirements and capabilities of possible task operators can be compared

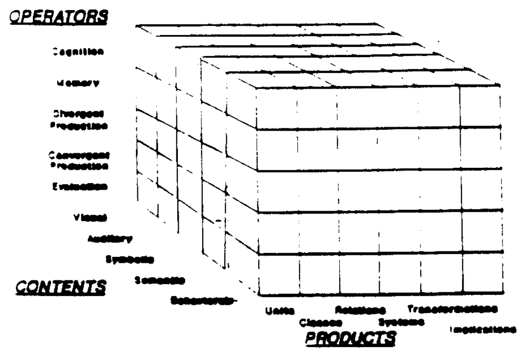

Figure 1: The Structure of Intellect Cube (Guilford, 1967,1985)

numerically and an objective determination, as to the best solution can be made. The modeling space used in the SOI C-R method is the Guilford Structure of Intellect (Guilford 1985) model. The SOI model is a multi-dimensional model of the elements of tasks. This model is illustrated by the Guilford Cube (see figure 1). Modeling the task requirements and the technology capabilities in the same space permits us to do direct numeric analysis to determine which tasks are most appropriate for which technologies. The structure of intellect model illustrates the focus of psychometric theories on cataloging and systematically identifying the components of intelligence and cognitive behavior. The Guilford model is the most logical choice as a theoretical modeling space for mapping task-operator characteristics. This model has sensitivity to many aspects of a domain and presents an unambiguous representation of the domain or task. The specificity of the SOI model will enhance the reliability of the tool. The SOI model has high content validity, and has been developed over the past 40 years, resulting in several refinements and an "accumulation" of empirical evidence suggesting its construct validity for this approach.

In the development of the SOI R-C methods there are two parts of the method each with their own complexities. The first part is the development of the tools to represent generic tasks and operators within the SOI modeling space. Before the development of the SOI R-C method, there were limits to our ability to parameterize the characteristics of task requirements and operator capabilities. The SOI R-C model solves this problem by systematically eliciting independent descriptions of each task and operator in each area of the modeling space, allowing a complex and numeric representation of both tasks and operators never before possible. The second part of the SOI R-C method is the analysis of the requirements and capability models. To define the interactions between the requirements model and the capability model, the analysis is done in three steps. The first step is to compare the capabilities and requirements on a one for one basis across the elements for the modeling spaces. The areas where the requirements exceed the capabilities are then highlighted. Second we study the criticality of the highlighted areas of the domain. From this information we can understand the nature of the relationship between the task requirements and operator capabilities. The last part of the analysis involves using neural networks to summarize the overall analysis and to make decisions about task allocation.

3.1 Advantages over Current Methods

The SOI C-R model offers us many advantages over current automation philosophies and task allocation methods. Current allocation of functions is done by heuristic rules. Generally, after the task allocation is done by rules, the system is prototype or simulated and then evaluated. The problem with the current method is that it is very difficult to understand the meaning of the evaluations. Using the SOI C-R methodology, we first describe the task, then the task operator and then compare the descriptions. The ability to do these paramateriztions and comparisons allows us to predict performance before prototyping and evaluation, and gives us a means to better understand the subsequent evaluating. By having a tool of this kind we can evaluate the performance and compatibility of systems in a off-line numeric manner not previously possible. By using this method we can add an important tool for design and evaluation of automated systems.

3.2 Results of the first research project

The first application of the SOI C-R method was the development of a domain suitability analysis tool for expert systems. This tool is the first comprehensive evaluation tool for determining whether a task should be allocated to expert systems. Figure 2 shows the capability plot for Expert systems. The scale of the capability plot shows the level of difficulty that a generic

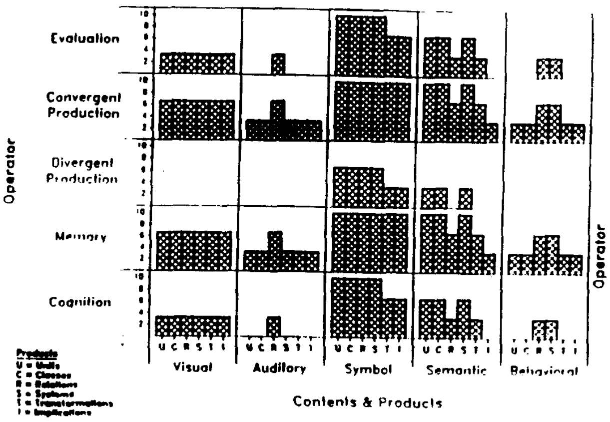

Figure 2: Capability Plot, Expert Systems

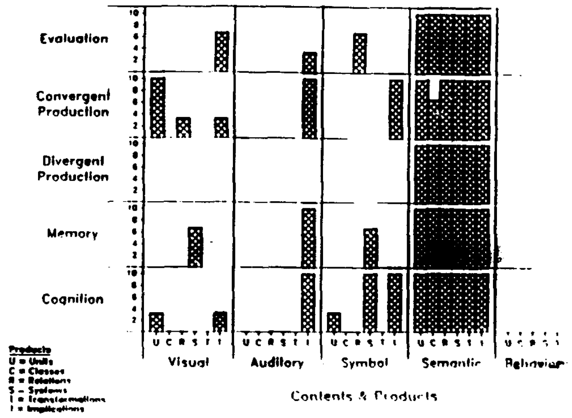

Figure 3: Requirement Plot, Research Proposal

expert system can perform an element of a task, ranging from no capability (0) to a capability to perform at a very high level (10). The parameterization of the task is represented by a task requirements plot (see figure 3). In this example, the task of interest was writing research proposals. As can be seen in figure 3, the task requires significant capabilities in the area of semantic contents. Figure 4 shows a plot of the task requirement that exceeded the capabilities of the proposed technology, in this case expert systems. By examining the differences between the capabilities and requirements, we can predict the performance and potential problems with implementing a given solution to a automation issue. The results of the expert system project were extremely good. The method was able to evaluate a number of human tasks for possible automation by expert systems. The method proved to be sensitive to differences and complexities in tasks not apparent to human experts. These results demonstrate the power of the method. The results of the expert system work will be published in the journal of applied ergonomics.

Methodology for Human centered Automation concepts and tools (FAA Project 1.1)

The SOI C-R method could be used to evaluate the suitability of a particular new software technology such as expert systems for implementation within an automated cockpit. The SOI C-R method can also be used to evaluate and categorize technologies and tasks within a complex environment, such as a flight deck or ATC center. By parameterizing the task and task operators in a complex environment we can allocate tasks based on the ability of the operator to

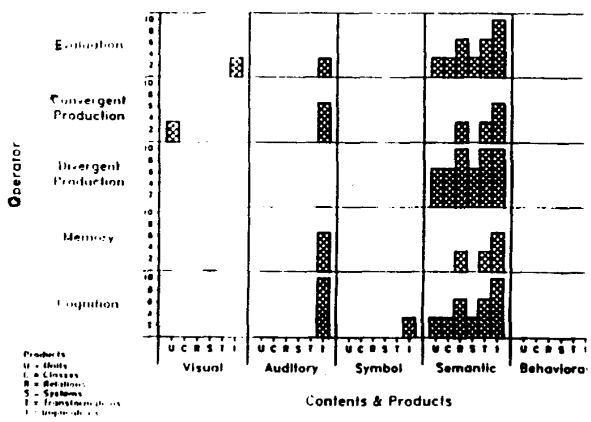

Figure 4: Capability-Requirements, Difference Plot

perform the task, regardless of whether the operator is an expert human operator or a computer system.

One of the key factors of the SOI C-R method is that by comparing task requirements with operator capabilities, the method allows a numeric comparison of different operator technologies.

4 RECOMMENDATIONS

I recommend that the FAA and the Air Force fund the continuing research and development of the structure of intellect capability requirement methodology in an effort to increase the understanding, usability, and safety of advanced computer algorithms in automated systems.

4.1 Future Research

Future research in the development of the SOI C-R method will include integration of the method with existing task decomposition methods, and the development of more fully integrated software tools to develop the Capability and Requirement models. Currently the methodology uses manually administrated surveys and a number of different computer analysis programs. With the implementation of online development tools, additional researchers and systems designers will be able to make use of the methodology. The integration of task decomposition tools will improve the usability of the methodology for more complex systems and task environments.

4.2 General use of the Method

Although this methodology was originally designed to do domain suitability analysis for expert systems, the SOI C-R method will prove a useful tool in the evaluation and definition of any task allocation decision process. Currently the FAA and the Air Force are considering the use of this method for analysis of system automation projects. The Nuclear Regulatory Commission is also reviewing the method for implementation. I and my colleagues feel that the SOI C-R methodology represents a step forward in the development of analytic task allocation.

REFERENCES

1. Arndt C. M., Air Force Technical Report AL-TR-1991-0150, U.S.Air Force Wright-Patterson AFB 1991

2. Guilford, J.,(1985). The Structure-of-Intellect model. in B. Wolman (ed.), Handbook of Intelligence. New York: John Wiley and Sons,225-266

3. Wickens, C. D. (1988). Componential analysis of pilot decision making. Technical Report AAMRL-TR 88-017 Wright-Patterson AFB