AL-TR-1991-0150

AD-A255 768

DEVELOPMENT OF THE EXPERT SYSTEM DOMAIN ADVISOR AND ANALYSIS TOOL

Craig M. Arndt

CREW SYSTEMS DIRECTORATE
HUMAN ENGINEERING DIVISION

SEPTEMBER 1991

FINAL REPORT FOR PERIOD JUNE 1990 TO SEPTEMBER 1991

Approved for public release; distribution is unlimited.

92 9 30 021

92-26206

AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

NOTICES

TECHNICAL REVIEW AND APPROVAL

AL-TR-1991-0150

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

KENNETH R. BOFF, Chief
Human Engineering Division
Armstrong Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
13 Sep 91

3. REPORT TYPE AND DATES COVERED
Final June 1990 to September 1991

4. TITLE AND SUBTITLE
Development of the Expert System Domain Advisor and Analysis Tool

5. FUNDING NUMBERS
PE - 62202F
PR - 7184
TA - 08
WU - 41

6. AUTHOR(S)
Craig M. Arndt

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Engineering Division
Workload and Ergonomics Branch
Wright-Patterson Air Force Base, Ohio 45433-6573

8. PERFORMING ORGANIZATION REPORT NUMBER
AL-TR-1991-0150

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 words)*

This thesis describes the development of an analysis tool for the evaluation of expert systems and their suitability for use in domains of interest. There is clearly a need for quantitative evaluation tools for determining the usability of expert systems for new problem domains. This research and development effort is based on the Structure of Intellect (SOI) theory as a model of human cognition and the Domain Suitability Analysis Tool (DSAT) developed by J. A. Horn as a basic data gathering tool. The objective of this project is to take the basic data gathering tool and the Structure of Intellect theory and construct an analytically correct and useful tool for evaluating domain suitability. The resulting evaluation tool has a three level output. Level one is an answer to the question whether to develop the expert system (the Global Decision Rule). The level two output is an explanation of the potential problems areas in the development of the system. The level three output gives additional information about the domain.

14. SUBJECT TERMS
expert systems
task analysis
neural nets

15. NUMBER OF PAGES
218

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C -	Contract	**PR** -	Project
G -	Grant	**TA** -	Task
PE -	Program Element	**WU** -	Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. ***(If known)***

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

- **DOD** - See DoDD 5230.24, "Distribution Statements on Technical Documents."
- **DOE** - See authorities.
- **NASA** - See Handbook NHB 2200.2.
- **NTIS** - Leave blank.

Block 12b. Distribution Code.

- **DOD** - Leave blank.
- **DOE** - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
- **NASA** - Leave blank.
- **NTIS** - Leave blank

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

1.0 INTRODUCTION

Goal: The goal of this research is to validate that the Structure of Intellect (SOI) model (Guilford, 1985) can be used as a sufficient multi-dimensional domain description for representing and describing both the capabilities of expert systems and candidate application domain features and requirements. This representation will permit the development of an automated domain suitability evaluation tool.

Objective: The objective of this research is to develop and validate an expert system domain suitability evaluation tool. This tool/decision aid will systematically solicit information from domain experts. The tool will then use linear and non-linear multi-dimensional analysis techniques to develop information on the correspondence between the candidate domain and expert systems capabilities as they are represented by the Structure of Intellect model. The results of the analysis should be presented in a format suitable for direct presentation to project managers and expert systems designers.

Problem statement: There are no theoretically based, empirically established methods for analyzing domain suitability for applications of expert systems technology. In many cases, the use of expert systems is characterized by a complex and costly development effort. Because of the lack of a useful domain evaluation tool, systems designers must first construct a system before an evaluation can take place. There is a need within the theory and practice of expert systems implementation to define and verify a theory-based methodology and analytic procedures for analyzing and evaluating the suitability of candidate domains. This research will contribute to answering this need in the following ways. First, this project will serve to verify the usability of the Domain Suitability Analysis Tool (DSAT) as a comprehensive, reliable descriptor of domains. Second, this project will define and validate specific analytic methods which will define the domain suitability in terms of comparisons with expert systems capabilities. Last, a presentation format will be developed that will allow expert systems designers to directly assess their candidate domain and receive a meaningful evaluation which is neither oversimplified nor incomplete.

The project proceeded from the original development of the DSAT model. From this starting point, we defined a problem statement and objectives for the project. Figure 1 shows a flow chart of how the project was performed. As can be seen from the figure, the thrust of the project was in two areas. The first was the development of a capability model of current expert systems. This included a review and summary of current documentation on expert systems and a survey of experts in the area. The second effort was to develop and validate the numerical data analysis methodology.

The development of this new methodology marks a fundamental change in the way domain selection is done. The existing methods for selecting domains and evaluating their suitability consists of doing subjective comparisons of the new domain with past development efforts. This new methodology starts with a compact parametric description of the domain and a comprehensive description of the capabilities of expert systems. From these, the analysis compares requirements and capabilities to determine both the suitability and predict the problem areas in a development effort. The differences between the old and new method for domain description are shown in Figure 2.

There has been work in the last few years to develop methods for evaluating domain suitability. The majority of the efforts have concentrated on developing subjective cost benefit analyses by breaking out and evaluating various aspects of the development of an expert system for a specific domain application. Jay Horn, in his work at Wright State, developed a concept of detailed analysis of candidate domains to determine the practically of the expert system development effort.

The DSAT was developed to address a comprehensive evaluation of candidate domains for expert systems projects in a theoretically based deterministic comparison with capabilities inherent in expert systems. However, his efforts did not include construction of more than a very simple metric of the data analysis.

Typical of the current methods in use at this time is the "tarot metric". This method defines a decision rule whose output is whether to go ahead with an expert system development effort. Evaluation factors for this method are listed below.

Evaluation Factors: Worth

Risk

Employee Acceptance

Solution Availability

Easier Solution

Teachability

These factors are used as part of a weighted decision rule. The system designer makes a subjective evaluation of each factor and then decides whether to go ahead with the development based on the weighted sum of the factors in the decision rule.

When we look at an evaluation of the suitability of a domain for the application of expert systems, it becomes clear that the problem of describing the suitability is a function of the description of the domain itself, as it compares to the capability of expert systems technology. Therefore it is not effective to generate a single value for such a complex multi-dimensional problem.

The purpose of the data analysis is the development of an empirically established algorithm for producing a domain suitability index that represents the capabilities and limitations of expert systems technology and domain characteristics relative to the elements specified in the SOI model (see Figure 3). Figure 3 shows the structure of the Intellect Cube. The cube shows graphically how the three dimensions of the SOI model combine to represent all elements of intelligent tasks. The principal dimensions of the SOI model are contents, operators, and products. Data will be collected for the analysis using the data acquisition tool developed by Jay Horn. He has demonstrated that the DSAT format will consistently gather data regarding candidate domains to support the Guilford Structure of Intellect model. The mapping system of analysis is based on two basic constructs. The first of these is that the Structure of Intellect model of a domain and expert systems capability can be represented as a plot or profile of various attributes defined within the model. The second is that we can compare the individual elements of the SOI model on a one to one basis to determine the overlaps and shortcomings of expert systems technologies in relation to the domain of interest. The first issue has been defined and verified by Jay Horn's research and will be further verified during this project. The latter issue has been verified a number of times in dealing with cognitive abilities in a multi-channel system. Notably in a study by Wickens (1988) in which he predicts system performance based on matching profiles of needed and available attributes for decision making (see Figure 4). In Figure 4, we see how Wickens predicts performance by representing capability in terms of a multi-dimensional plot, and the comparison of the demands of a particular task defined in terms of the same multi-dimensional plot. The SOI model domain will be defined by a set of scaled vectors, each representing a dimension in the model. The set of these vectors will define a N-dimensional vector space into which each domain will define a topology based on the values for each parameter of the domain.

To make the mapping analysis feasible, a map of expert systems attributes in the same format as the domain representations is required. This map will be developed by interviewing various knowledge engineers on the nature and abilities of current expert systems and constructing a model of expert systems capabilities in the same form as the DSAT domain representation. During the interviews with the knowledge engineers, the strengths and weaknesses of expert systems will be determined. In addition to this, we will try to learn something about the flexibility of system implementations and what would be a useful and/or acceptable format to present domain information to the design engineers.

Once the domain of interest and the expert system capabilities are mapped in the same space, we can then make direct comparisons between them. The comparison will be grouped into two categories: 1) the general shape or global analysis of the two maps, and 2) a point-by-point comparison of the maps to determine the dimensions the DSAT model in which the expert systems capabilities may not support the demands of the domain. The mapping comparisons will highlight critical elements which will be studied in the second phase of the analysis. An example of global analysis methods is a comparison of the number of elements of the model which are active in a given domain or how these elements are arranged with regards to one another. An example of the point-by-point comparison is to compare the values of a single element from one domain to another.

Critical Element Analysis

The critical element is a secondary interview to obtain more information about the most important elements of the domain as determined by the mapping of the data collected by the DSAT tool. To determine which elements to examine further, we will develop a threshold function which will be a function of the raw data from the original DSAT data and the mapping analysis. This will allow us to look at the most important elements of each domain independent of predetermined procedures. The threshold function will be developed based on such factors as overall value of the DSAT raw data, differences between the domain and the expert system, and uncommon factors in the data.

In order to create a usable tool for the computer/expert systems industry, the data collection and analysis will be automated and implemented on a personal computer format. An automated software product will evaluate and map a prospective domain onto the expert system capability map, and analyze key elements of the critical attributes of the domain.

When looking at whether the model is comprehensive and valid, we need to look at describing some of the other expert systems evaluation factors in terms of the Structure of Intellect model. The development of the analytic methods will start by using data collected by Jay Horn. Using this data, we will be able to construct mappings based on actual domain representations. Because the critical element analysis can be done after the original DSAT analysis, this analysis can be done on the domains previously documented by Jay Horn. To enrich the overall data base, additional data will also be collected regarding additional domains. In selecting additional domains for data collection, domains were chosen which would increase the coverage of the SOI modeling space and for which some data exists on how well expert systems development efforts have gone in the past. This better enables us to draw conclusions from this data.

Project Flow Chart

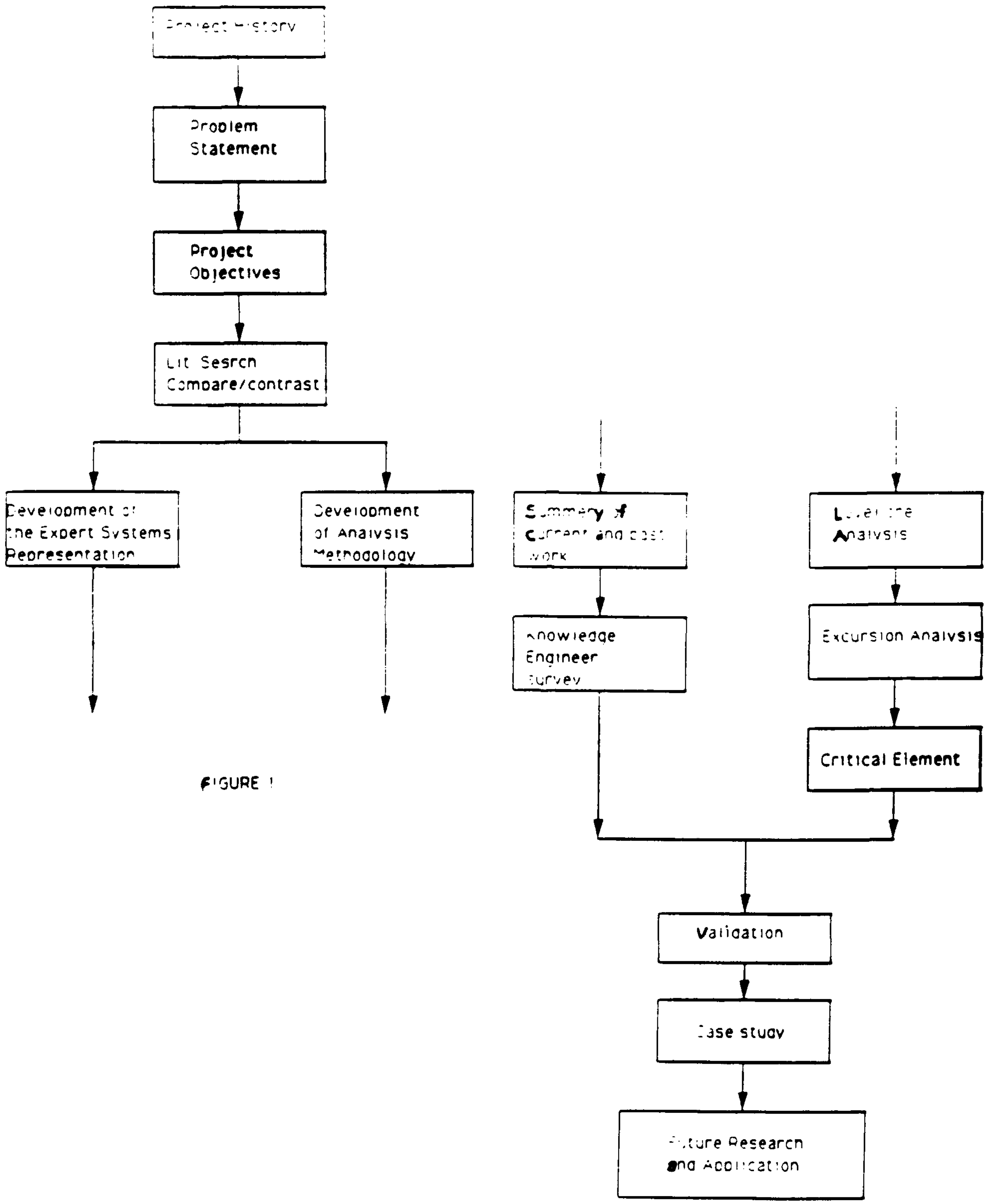
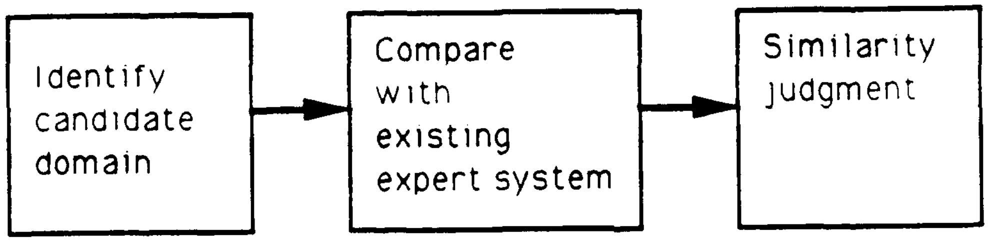


FIGURE 1

HOW TO DO DOMAIN SELECTION

OLD.



NEW

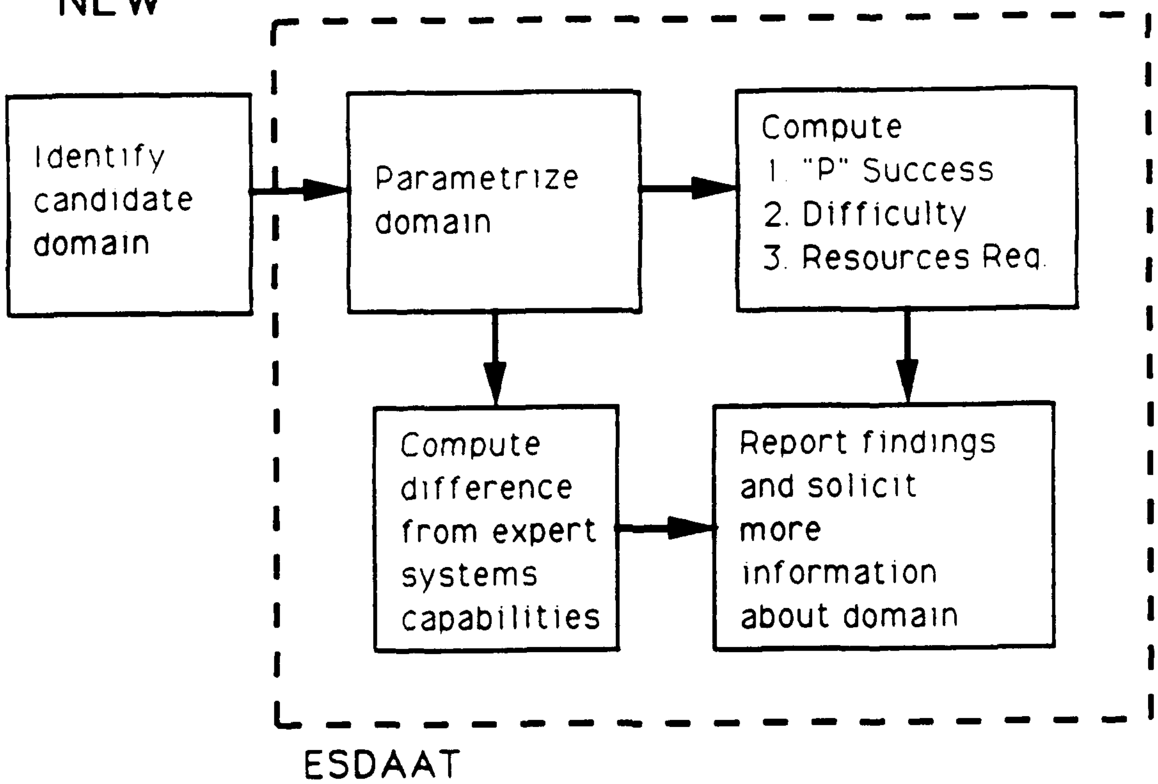
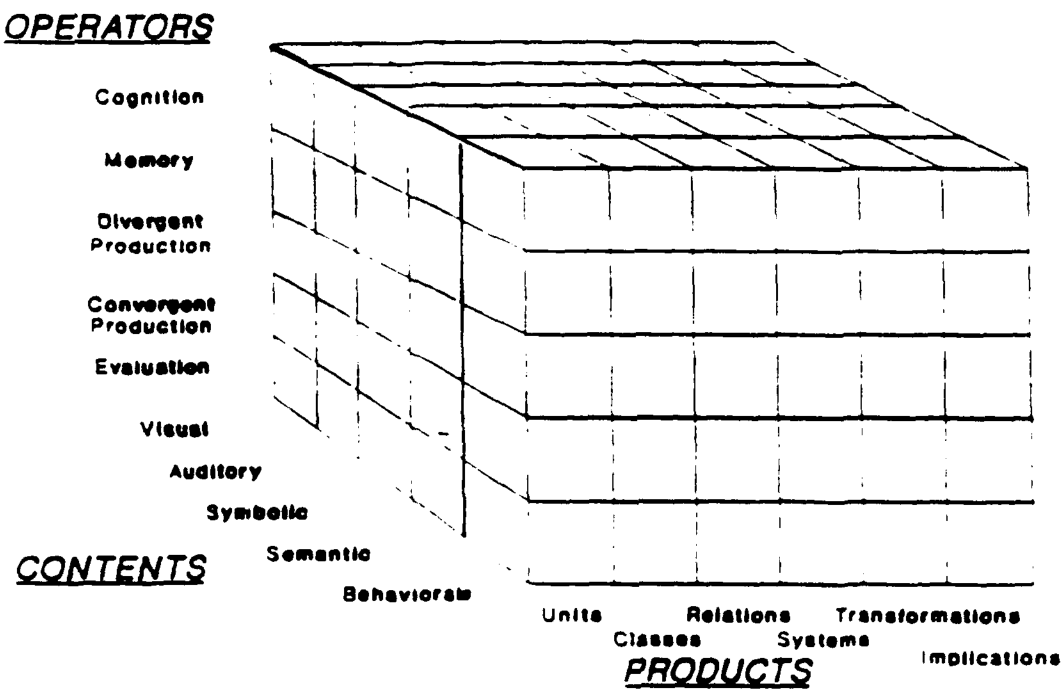
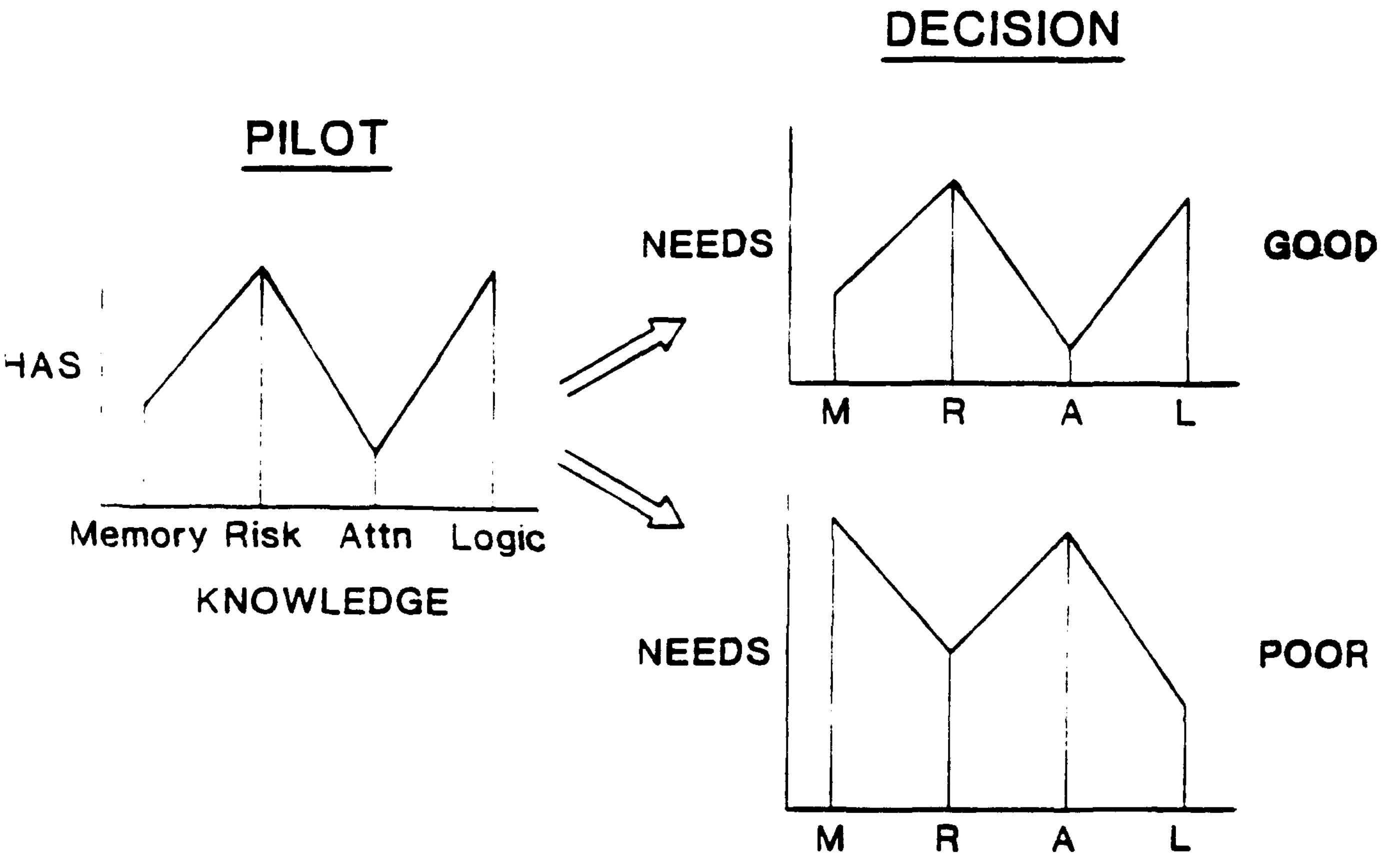


FIGURE 2



The Structure of Intellect Cube (Guilford, 1967; 1985).

FIGURE 3



Profile of pilot's cognitive attributes, along with two representative scenario profiles. To the extent that the demands of the scenario match the pilot's profile, good performance is predicted. To the extent that a mismatch occurs, poorer performance is expected.

FIGURE 4

2.0 THEORY AND BACKGROUND

2.1 THEORETICAL BASIS

2.1.1 MOTIVATION

Jay Horn demonstrated that the DSAT tool can be of considerable use to the research community, as well as to decision makers in the development of practical expert systems. By development of more complete and descriptive analysis procedures the DSAT tool will be able to give the system decision makers and the system design engineers a descriptive view for the domain they will be working with and hopefully some specific information as to the interaction between the domain and the human experts which interact with it. With the development of the critical element analysis procedures, it will be possible to give information to the designers as to the relative importance and/or interaction between the domain elements.

2.1.2 PSYCHOMETRIC THEORIES OF INTELLIGENCE

The psychometric theorists use individual differences data (refined through the use of factor analysis) to separate patterns of reasoning from other abilities and to examine the various reasoning skills exhibited. These various methods have relied on individual difference data for testing and formulating theories (Guilford and Hoepfner, 1971).

Spearman (1904), who refined the factor analysis method, is regarded as one of the first psychometric theorists. He developed a factor theory of intelligence (specifically for intelligence testing) which proposed a single, central element of intelligence, G (Spearman, 1904). The second factor was originally believed to be a factor of intelligence unique to specific tests, and would be indiscernible by any other test.

However, as results of factor analysis mounted, there appeared to be other related factors that inter-correlated more strongly than initially predicted by the theory. Spearman called variables common to a specific group of tests "group factors." He attempted to downplay the importance of these factors, emphasizing the importance of G instead (Guilford and Hoepfner, 1971).

Thurstone (1938), intrigued by the existence of group factors, used over 50 different intelligence tests to uncover a number of intellectual factors in a large group of college subjects. He proposed a theory of primary mental abilities (PMA) composed of seven factors. These were verbal comprehension, numerical facility, spatial ability, perceptual speed, rote memory, induction, and deduction.

The next step in the growth of psychometric theories of intelligence came during World War II. J. P. Guilford, as director of Psychology Unit #3 of the Aviation Psychology Research Program, was asked to determine selection criteria for aircrew personnel in the intellectual area. Examination of the reasons students washed-out of pilot training revealed eight general psychological constructs: judgment, foresight and planning, memory, comprehension, visualization of flight path, spatial orientation, reasoning, and coordination of information. Guilford and Lacey (1947) performed an in-depth factor analysis of these constructs and demonstrated approximately 25 intellectual factors.

After World War II, Guilford continued investigation of these factors of intelligence under the aegis of the Aptitudes Research Project for the Office of Naval Research. The early years of the project demonstrated all of Thurstone's primary mental abilities, as well as finding two aspects of his spatial factor; arrangement of objects in space, and visualizing changes in objects (Guilford, 1985). This brought the list of abilities to near 40.

As the list of factors began to mount, several similarities and differences became apparent. Some factors could be grouped based on the mental processes involved, such as cognition, memory, and evaluation. Others could be segregated based on the information used; symbolic, semantic, or visual, for example. A third dimension involved the form of the information used; units, classes, or relations, for example.

The resulting cubic figure which encompasses these dimensions is the Structure of Intellect (SOI) model (Guilford, 1967; Guilford, 1985). Figure 3 shows the SOI model with its three dimensions: operations, contents and products. This model illustrates the focus of psychometric theories on cataloging and systematically identifying the components of intelligence and cognitive behavior.

2.1.3 STRUCTURE OF INTELLECT MODEL

Guilford's SOI model is the most logical choice as a theoretical basis for examining domain suitability with respect to rule-based expert systems technology. To summarize, reasons for selecting this model over others are: this model has sensitivity to many aspects of a domain and unambiguous representation of those aspects (over 150 attributes can be specified); the specificity of the SOI model will enhance the reliability of the tool; the SOI model has high content validity; and the SOI model 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.

Content Validation

The SOI model meets this criterion since the model examines over 150 facets of a domain. Specification of a particular operator, content, and product specifies the type of process, the type of information used, and the type of information produced during the activity. This model allows sufficient domain coverage to establish a high degree of satisfactory content validity.

Criterion-Related Validity

Both predictive and concurrent validities have been established for the SOI model in many different intelligence and cognition related applications such as intelligence testing, creativity measurement, and job selection (Guilford, 1985; Guilford and Hoepfner, 1971; Meeker, 1969). While the theory does possess satisfactory levels of criterion-related validity, the specific criterion-related validity for this application must be established.

Construct Validity

While the theory has existed for over three decades, it remains a viable tool for understanding the various aspects of human intelligence. Kolodner (1984) posits that the structure of information used in human intellectual problem solving is different in experts than in novices, based on her research. The importance of information structure in the mind of the problem solver (cited by Kolodner) suggests that a structural approach, like the SOI model, is useful in describing application domains. This lends some support to the existence of construct validity in this theory.

Reliability

The layout of the SOI model and the terms used lend themselves to a reliable method of describing application domains and expert systems technology attributes. The development of logical and specific administration procedures will further insure the reliability of the tool. Jay Horn's development demonstrated the reliability of the DSAT instrument.

2.1.4 ANALYSIS METHODS

The DSAT is an inherently multi-dimensional representation of the cognitive and signal processing structure of complex task domains. Therefore, it is reasonable to derive a multi-dimensional model of the domain characteristics which are elicited by the DSAT questionnaire.

The multi-dimensional model will be used to describe the domain as a whole and derive global characteristics for the domain. However, this form of analysis is not well suited to deriving specific relationships between the key factors or elements that make up any given domain. In fact, the basic DSAT questionnaire is not well suited to this analysis. It is known from previous research (Horn, 1988) that human experts can make very fine discriminations between factors if comparing them side by side. We can use this ability to gain a great deal of information about the key factors which contribute most to defining the nature of a given domain of interest. Therefore, the maximum possible information about these domains can be obtained by examining the spanning set of their parameters.

Excursion Analysis

Excursion analysis allows the analysis of the data describing the domain of interest to concentrate on those areas which are not well implemented by expert systems. Wickens, in his studies of workload (1987), used the technique of excursion analysis to describe what tasks a human operator might reasonably be expected to perform based on a description of the task and the difference between task demands and the capabilities of the operator. In excursion analysis, the object is to map the two items of interest (which in this case are expert systems capabilities and domain requirements) in the same coordinate system so that they can be compared on a one to one basis. Therefore, the challenge becomes to develop an equivalent representation for expert systems capabilities and domain requirements.

Critical Incident Analysis

Critical incident or critical element analysis is widely used for identifying key elements in a larger system or representation. There are a number of studies and principles which demonstrate that the majority of problems can be represented by only a few of the most important subgroups (Perado Principle). The excursion analysis allows for a first level filter of the elements of the SOI model that are of the most importance. Additional thresholding algorithms for critical incident analysis, based on difficulty and criticality, are developed in section 4.2.

Neural Net Theory and Explanation Application

Artificial neural net models or simply "neural nets" go by many names such as connectionist models, parallel distributed processing models, and neuromorphic systems. Whatever the name, all of these models attempt to achieve good performance via dense inter-connection of simple computational elements. In this respect, artificial neural net structure is based on our present understanding of biological systems. Computational elements or nodes used in neural net models are nonlinear and are typically analog. The simplest node sums N weighted inputs and passes the results through a nonlinearity. Neural net models are specified by the net topology, node characteristics, and training or learning rules. These rules specify an initial set of weights and indicate how weights should be adapted during use to improve performance.

Traditional neural nets are good as classifiers. Classifiers can perform three different tasks. First, they can identify which class best represents an input pattern. Second, the classifiers can be used as a content-addressable or associative memory, where the class exemplar is desired and the input pattern is used to determine which exemplar to produce. A third task these classifiers can perform is to quantify vectors or cluster the N inputs into M clusters (Lippmann, 1987).

The problem of designing a system tool for domain evaluation is well-suited to the application of neural net classifiers. The domain description from the DSAT tool will serve as the input to the classifier and the desired output of the classifier will be a numeric evaluation of whether or not the domain falls in a class of domains well-suited to an expert systems implementation.

2.2 BACKGROUND

This section reviews the current status of expert systems domain evaluation and selection.

The procedures necessary to perform an accurate evaluation of potential application domains for expert systems technology using the theory-based model have been integrated to create the Domain Suitability Analysis Tool (DSAT). The DSAT has been designed to be both theoretically valid and operationally efficient. Validation of the DSAT was achieved by examining several diverse application domains (to which expert systems suitability had previously been established) and comparing the recommendations of the DSAT against the existing knowledge of the domain's suitability.

The DSAT was designed to describe the domain information elements (based on the SOI model) as revealed by the domain expert and produce a recommendation based on the degree of support provided by expert systems technology for those information elements. While some researchers have attempted (with little success) to map domains in terms of expert systems capabilities, we define expert systems suitability in terms of the domain's information requirements.

Jay Horn's work demonstrates that expert subjects produced very good reliability in inter-subject data convergence both on an absolute basis and relative to novice subjects, expert (0.305) and novice (1.075). Therefore, we chose not to collect data from novice subjects and will concentrate on experts from differing domains, in an effort to increase the convergence and understanding of the performance of the DSAT tool.

2.2.1 PROBLEM STATEMENT

There are no theoretically-based, empirically established methods for determining domain suitability for applying rule-based expert systems technology. While several ad hoc guidelines have been developed and are currently in use, they provide, at best, only general guidelines for determining if a domain can benefit from rule-based implementations of expert systems technology. Hadzikadic, Yun, and Ho (1987) succinctly state the problem:

> "As expert systems technology becomes increasingly popular for (yet) untested applications, a serious gap in knowledge has become increasingly prominent.. ..the appropriateness of the match between a prospective application domain and the tools of ES (expert systems)." (p.64)

Kidd and Sharpe (1988) are also concerned with the lack of theoretically-based research which accounts for human expertise in artificial intelligence. They regard the current generation of expert systems as experiments, which have focused impressive amounts of computational power on specific problems in highly isolated domains, but have yet to achieve sufficient basis in theory to allow growth into diverging domains. They write:

> "Success of the system is directly determined by the appropriate representation and application of specific knowledge from that domain to solve an isolated problem. Despite the vast amount of data now available as a result of these experiments, we are still unable to explain the "why" or "how" of successful systems or to predict for which other domains and tasks the current techniques will work. This is because no theory of tasks or domains currently exists." (p.147).

The taxonomy of the domain information structure that is specified by this research can be useful in identifying critical areas of a domain which deserve additional attention during the expert systems design process. The taxonomy can also be used to estimate the allocation of functions between the operator and the machine, based upon the structure and processing required of specified information elements.

2.2.2 EVALUATION OF THE DSAT AS A DATA ACQUISITION TOOL

The nature of the SOI model lends itself to unambiguous definition of various attributes under consideration in a domain. The vast majority of all attributes composing the SOI model have been operationally defined, significantly reducing the possibility of misidentifying an attribute (Guilford, 1987). This characteristic is also useful in establishing the sensitivity of the theory. The significant number of attributes contributes to the ability to specify differences between domains.

The DSAT questionnaire is structured to collect data about each of the sections of the Guilford Structure of Intellect Cube. For each section of the cube, the questionnaire obtains a rating for Frequency, Difficulty, and Criticality. The DSAT uses a 10-point scale for comparing ratings across dimensions. Jay Horn (1989) reported on the reliability of the DSAT questionnaire (see Jay Horn's thesis). His results suggest that if properly used by a skilled knowledge engineer on highly experienced domain experts, the DSAT questionnaire is both reliable and sensitive in defining the domain representations.

Organization of the DSAT

The DSAT questionnaire involves a series of questions about the domain of interest regarding the various dimensions of the SOI model. The DSAT has two sections: Part I examines the structural components based on the content-product aspects of the domain; Part II examines the operational components which incorporate the domain operators with element frequency, criticality, and difficulty.

The first phase assesses the structural components of the domain. By using the content-product dimension of the SOI, a 30-element psychoepistemology is described which provides a means for determining the basic informational elements evident in the domain. By having the domain expert indicate the presence or absence of each component, the structural information requirements for the domain are established.

The second phase of the DSAT administration involves determining the relevant operators (mental function) required to act upon the information elements defined in the previous step, and to establish the criticality, frequency, and difficulty of the various components to allow comparison with expert systems technology attributes. As an example, assume 10 of the 30 content-product elements are identified as domain-relevant in Part I. In Part II, the domain expert identifies which operators are relevant for each of the 10 elements and the degree of frequency, criticality, and difficulty associated with each.

The evaluation metric which Jay Horn used in his original study of the DSAT tool was a normalized linear weighted combination of the values obtained from the raw survey. The combination algorithm was Capt Horn's best estimation of the relative contributions of the DSAT dimensions to the suitability of the domain to expert systems solution. The algorithm from his thesis is stated again here to form a basis for the reader to consider as we develop the complete model.

OCR = Operator Combined Rating

$$OCR = 0.10\ F + 0.35\ C + 0.50\ D + 0.05\ N$$

F = Frequency rating

C = Criticality rating

D = Difficulty rating

N = Number of information elements

Domain Suitability Index (DSI)

$$DSI = 0.25\ (\ C\ OCR\ ) + 0.05\ (\ M\ OCR\ ) + 0.5\ (\ DP\ OCR\ ) + 0.05\ (\ CP\ OCR\ ) + 0.15\ (\ E\ OCR\ )$$

C = Cognition operator

DP = Divergent Production

E = Evaluation operator

M = Memory

CP = Convergent Production

2.2.3 DOMAIN EVALUATION TOOLS

The early theoretical approaches laid the ground work for the present research. For example, the Additive Rating Model Methodology (ARMM) of Bringelson, De McCray, Thompson, and Salvendy (1987) attempted to define a method of specifying job tasks and skills in terms of expert systems capabilities.

The task list (from Waterman, 1986) defines 11 tasks "involved in knowledge based systems." The 24 skills involved in those tasks are specified from the work of Lenorovitz, Phillips, Ardrey, and Kloster (1984) which examined skills used in human-computer interactions. Table 1 illustrates this matrix.

The product of the matrix evaluation is a numerical rating of the skills encompassed in a task (see Table 1). The scores can range from 0 (no skills are replicable) to 24 (all skills are replicable). Higher scores imply more skills can be replicated by the computer, better defining the task and resulting in better task performance. The scores for each task of a job are then summed and divided by the number of tasks to obtain a composite score. Bringelson, et al. (1987) define scores above 17 (one standard deviation above the mean task score of 11.73) as "good" (expert systems are applicable), scores 12 to 17 as "marginal" (expert systems may be applicable), and scores below 12 as "poor" (expert systems do not apply).

In effect, the tool confirms much of what we already know. Unfortunately, the ambiguous job domains are the most prevalent, and this is where the tool must be accurate. While the overall concept of the Additive Rating Model Methodology (ARMM) is laudable, there are several problems that encourage additional research. The difficulties of achieving a high level of validity and reliability, identifying relevant information types and processes used in the job, and achieving sensitivity among complex domains all point toward the need for a theoretically-based approach that can moderate these deficiencies and provide useful direction for domain assessment.

Guidelines For Domain Selection

While each of the researchers cited by Allen (1986) identifies the selection of a suitable problem domain as an important step in the development process, none go farther than suggesting a few broad guidelines for making this selection. Several ad hoc guidelines for domain selection have been proposed. Table 2 lists several of the observations cited by Prerau (1985) and Dreyfus and Dreyfus (1986) as typical of these guidelines.

The major objection to these guidelines is that they are based on ad hoc observations of past successful cases. Dreyfus (1979) quotes AI researcher Drew McDermott, "... AI (and expert systems) is a field starving for a few carefully documented failures" (p. 46). By only examining the "successes" of any endeavor, useful information and "lessons learned" are lost. The conclusions drawn from this kind of analysis are subject to error and tend to be incomplete.

A second problem with these guidelines is the lack of clear recommendations regarding the utility of expert systems technology for a specific problem. Use of general guidelines places the decision-maker in the position of making potentially cost-intensive decisions based on largely subjective estimates using incomplete criteria.

The current guidelines do not provide specific guidance regarding functional allocation of duties between the user and the system. The theoretically-based methodology proposed here attempts to produce a model of domain and expert system attributes that can be used to examine the relative strengths and weaknesses of each domain as it compares to the capabilities of expert systems.

As problems and domains evolve over time, they change in many ways. The advantage of the ESDAAT is that we capture the fundamental priorities of the domain and not just the parameters of a particular solution to the domain problems. Therefore, the ESDAAT is be much more tolerant to changes in the domain solutions than other evaluation tools. The ESDAAT will differ significantly from other expert system advisors because it performs its analysis based on a concise definition of expert systems capabilities.

TABLE 1

Skills, Tasks, and Scores Used in the Additive Rating Model Methodology

Skills that can be emulated using current expert systems technology (Lenorovitz, Phillips, Ardrey, and Kloster, 1984.)

Detect	Search	Scan	Extract	Cross-Reference
Recognize	Categorize	Calculate	Itemize	Discriminate
Tabulate	Estimate	Translate	Compare	Interpolate
Formulate	Integrate	Evaluate	Select	Extrapolate
Acknowledge/ Respond		Direct/ Inform	Ungroup/ Segregate	Filter

Tasks performed in a job domain (Waterman, 1986), their associated scores of skill components, and qualitative suitability (with appropriate score range) for expert systems applications.

GOOD		MARGINAL		POOR	
(17.00 - 24.00)		(11.73 - 16.99)		(0.00 - 11.72)	
Diagnosis	-23	Instruction	-15	Design	-11
Conflict resolution	-23	Monitoring & gathering	-11	Information	-11
Prediction	-21	Creating	-8		
Planning	-21				
Interpretation	-20				
Delegation	-19				

(Source: Bringelson, Deer, McCray, Thompson, and Salvendy, 1987)

TABLE 2

Guidelines for Selecting an Appropriate Expert Systems Application Domain

---

Dreyfus and Dreyfus (1986).

1. No algorithmic solution to the problem should exist.

2. The problem can be satisfactorily solved by human experts at such a high level that somewhat inferior performance is acceptable.

3. Non-experts have a high probability of making a poor decision.

4. Poor decisions have significant impacts.

5. The problem is stable during the time taken to make a decision.

6. The knowledge domain must be relatively static.

7. An expert must be available to provide the knowledge base.

Prerau (1985). (This list is a sample of his 52 guidelines.)

1. The domain is characterized by the use of expert knowledge.

2. Conventional programming approaches to the task are unsatisfactory.

3. There are recognized experts that solve the problem daily.

4. Experts are probably better than amateurs in performing the task.

5. There is a need to "capture" the expertise for the future.

6. The task is neither too easy nor too difficult for an expert.

7. Domain selected offers the greatest return for the projected risk.

8. The task primarily involves symbolic reasoning.

9. The task requires the use of heuristics and may require the consideration of many alternatives or decisions based on incomplete or uncertain information.

10. The task inputs and outputs are clearly defined at the outset.

3.0 STATEMENT OF OBJECTIVES

3.1 GOAL

The goal of this research is to develop an implementation tool for evaluating domain suitability for expert systems technology applications using multi-dimensional and critical element analysis, and to solicit and present the results in a format suitable for decision makers and expert systems designers.

3.2 RESEARCH OBJECTIVES

There are three objectives in this research project. The first is to demonstrate the validity the Guilford Structure of Intellect model for mapping characteristics of task domains. The second is to develop a representation of the existing capabilities of expert systems in the SOI model. The third is to develop and validate mathematical algorithms for comparing domains against one another and against expert systems capabilities.

3.3 SYSTEM OUTPUT

The output of the domain adviser tool will be in three parts. Each part (level) of the output is designed to provide the user with information about the domain of interest and how well an expert system could be developed for that domain.

LEVEL ONE ANALYSIS

The level one analysis should provide the decision makers with information as to the viability of expert system application.

LEVEL TWO PROBLEM AREA DESCRIPTION / CAPABILITY DIFFERENCE ANALYSIS

The level two analysis should allow the system designer to understand the characteristics of the domain of interest and how these characteristics relate to expert systems capabilities.

LEVEL THREE RECOMMENDATIONS AND COMMENTS

The level three output of the analysis will add additional details to the information presented in the first two levels of analysis.

4.0 METHOD AND PROCEDURE

4.1 DEVELOPMENT OF EXPERT SYSTEMS REPRESENTATION

One of the most important aspects of this research effort is the development of the expert systems capability representation. This representation is important for two reasons. First, the expert systems representation is key to the excursion analysis part of the domain analysis tool. The second reason the expert systems representation is important is that there is currently no closed form analytical representation of expert systems capabilities.

4.1.1 APPROACH

In order to develop the expert systems representation, a two-step procedure was followed. The first step was to review the existing knowledge of expert systems and their capabilities as embodied by the literature on the subject. This review yielded a great deal of important information which was incorporated into the expert systems capability representation. There were, however, a large number of areas which were not covered by this literature survey. The second step in modeling expert systems capabilities was to fill in a complete model of the expert system in terms of the SOI model. To accomplish this, information was solicited from experts in the development of expert systems. To this end, a structured survey questionnaire was developed to solicit expert systems capabilities in the SOI modeling space.

4.1.2 EXISTING EVALUATIONS

For a number of years, there has been a large number of designers and researchers developing expert systems. By doing a well-directed literature search, we hoped to gain an understanding of what these people were able to learn over the last years.

4.1.2.1 EVALUATION OF EXPERT SYSTEMS (SPECIFIC CAPABILITIES)

Expert systems are good at a lot of things. One way of evaluating the current capabilities of expert systems is to evaluate the tasks/ domains that they currently do well. In fact, it is very common in practice today to evaluate a domain based on its similarity to what expert systems do well. Therefore, by evaluating the kinds of tasks expert systems do well in terms of their components in the SOI modeling space, we can learn about expert systems' capabilities.

Expert systems :

- Plan
- Schedule
- Diagnostics
- Configuration
- Modeling and Simulation
- Monitoring and Control

Within these categories there have been a number of successful and unsuccessful expert systems development projects. The results of the evaluations are summarized in terms of the SOI model. Very little was learned about failure of expert systems.

Planning: Devising a method for making or doing something in order to achieve an end. Applications include construction projects, regular delivery routes, and manufacturing schedules (Westinghouse) (Wolfgram et al, 1987). These tasks show that expert systems will perform the convergent production operators and products of relations and systems.

Scheduling: Designing routes and time tables for events. Applications include aircraft scheduling, scheduling of medical treatments and scheduling equipment maintenance (Pham, 1985). An example of this type of system is OPAL, an expert system that schedules cancer patients for chemotherapy. These tasks show that expert systems will perform in the areas of convergent production and memory.

Diagnostics: Identifying causes, given symptoms. Applications include diagnosing infectious diseases, telephone networks, and poisoning (Luger, Stubblefield, 1984). Included in these applications are MYCIN and DENDRAL which are medical diagnosis expert systems. These characteristics indicate that expert systems should perform well in the areas of symbolic and semantic contents as well as memory and evaluation operators.

Configuration: Configuring objects into systems, given constraints. Applications include computer system configuration, layout of computer microchips, and factory floor layouts (Bielawsky, Lewand, 1984). The development systems include XCON, a system developed by DEC for configuring VAX computer systems. This would indicate that expert systems will work well in relations and systems of products.

Modeling and Simulation: Simulation of existing physical relations. Applications include problem solving CAD/CAM systems and simulation of power plants (Woods, Hollnagel, 1988). These examples show that expert systems can perform tasks requiring memory and evaluation, as well as, symbolic and semantic contents.

Monitoring and Control: Comparing observations with established standards and regulating operation. Applications include monitoring power plants, autonomous land vehicle navigation, and manufacturing plants (Costea, 1979). These applications imply that expert systems will perform well in the areas of convergent production and memory.

4.1.2.2 EVALUATION OF EXPERT SYSTEMS (GENERAL CAPABILITIES)

Characteristics of expert systems domains are documented in the literature as rules for selecting expert systems domains. The best and most often used of these rule sets is that written by David Prerau (1989) in "Choosing an Expert System Domain."

In this section we review these rules as they relate to the SOI model of expert systems capabilities. It is important to note that there are a number of methods similar to Prerau's which were studied. Prerau's recommendations are presented because they are so commonly used in design. In "Choosing an Expert System," he states, "To evaluate the potential of a possible application, it has proven very useful to have a set of the desired attributes of a good expert system domain." Prerau goes on to list a number of these attributes, which are listed below and evaluated as to their implications to the SOI model of expert systems capabilities.

"The task primarily requires symbolic reasoning."

This attribute clearly implies that expert systems are capable of performing tasks with symbolic contents.

"The task requires the use of heuristics."

This attribute implies expert systems are capable of performing operations of convergent production.

"The task does not require Knowledge from a very large number of areas and it does not involve common sense reasoning."

This attribute implies that certain behavioral contents and implications are not well suited to expert systems.

"The task is defined as clearly as possible."

This attribute implies that expert systems will generally not perform well in cases of divergent production.

"The expert has built up expertise over a long period of task performance."

This attribute implies that expert systems are well suited to complex memory tasks.

"The task, and preferably every subtask is decomposable."

This attribute implies that an expert system will work well with tasks involving systems and relationships.

There are a large number of other attributes listed by Prerau. Many of the rest, however, deal with issues which are not addressed in this work, such as availability of domain experts and level of management commitment to the project.

4.1.3 EVALUATIONS OF DOMAIN EVALUATION TOOLS

Most notable among evaluation tools is "Methodology for Screening Potential Artificial Intelligence Applications" by Eric Hanson and Stephen Cross (1988). In this methodology, they evaluate a domain of interest based on three overall parts of the design and implementation of the expert system: level of AI risk, systems engineering risk, and potential payoff. There are sub-categories under each of these general parts. The domain is evaluated based on how well it fits these arbitrary implementation parameters. The subclasses of the evaluation are:

--- AI Risk

Type of Application

Nature and Availability of Expertise

Complexity and Difficulty of Task

Role of the System

Size and Complexity of Knowledge Base

Applicability of current AI Tools

Advanced Technology Requirements

--- Systems Engineering Risk

System Complexity

System Scalability

Performance Requirements

Hardware Requirements

Software Requirement

Maintainability

--- Value and Cost

Economic Value

Effectiveness

Generality

Cost

"A mark is made on each major scale that essentially summarizes the specific items under it. Judgment is required to summarize the marks on the detailed scales to come up with an assessment for the major categories." (Hanson and Cross, 1988)

It is important to remember when reviewing evaluation tools that these tools address a number of areas which the ESDAAT does not address. The ESDAAT is principally a tool to evaluate a domain on its technical characteristics as they relate to expert systems capabilities.

Included in Appendix E are two other domain evaluation tools. These two tools are derived from the tool which was just reviewed.

For the purpose of developing the expert system capability representation, these tools are of little or no use except as an example of what is not needed.

Summary

From an analysis of the current literature and existing evaluations, it is clear that expert systems function well in some parts of the SOI model space.

Contents: Symbolic and Semantic

Operators: Memory and Convergent Production

Products: Relations, Systems, and Units

The analysis also shows that expert systems do not function at all well in some other parts of the SOI model space.

Contents: Auditory and Behavioral

Operators: Divergent Production, Cognition, and Evaluation

Products: Transformations and Implication

The information collected in this review is used in conjunction with that obtained in the knowledge engineer survey interviews to create the SOI model of current expert systems capabilities shown in Figure 7.

4.1.4 DERIVED EVALUATION

4.1.4.1 DEVELOPMENT OF THE KNOWLEDGE ENGINEER SURVEY

The purpose of the knowledge engineering survey was to elicit from expert system designers a concise description of expert systems capabilities. In order to obtain the most useful description from the expert systems experts, the survey was constructed to determine a number of separate items.

In Section I of the survey, the administrator explains the nature of the development project and the nature of the SOI model.

In Section II of the survey, the knowledge engineers explain their experience in developing systems. The selection of expert knowledge engineers was done in such a way as to maximize the usefulness of the analysis by including knowledge engineers with the most experience.

In Section III of the survey, the knowledge engineers evaluate some of the expert systems they have worked on in order to give them a chance to think about how to evaluate the nature of expert systems capabilities in terms of the SOI model.

In Section IV, the knowledge engineers are asked to rank in order the elements of the SOI model with respect to the capabilities of expert systems. In this section there are also questions to solicit general comments on which elements are easy or difficult for expert systems to perform.

In Section V, the knowledge engineers are asked to rate the individual elements and combinations of elements of the SOI model as to their criticality to construction of expert systems. In this way, the knowledge engineers relate which of the elements are most important.

In section VI, the knowledge engineers are asked to evaluate the elements and combinations of elements of the SOI model based on the difficulty level at which expert systems can perform these elements and combinations. In this way we get a direct indication of the capabilities of the expert systems to perform in these areas.

In section VII, the knowledge engineers are asked to relate additional information with regards to the possible outputs of the tool which they feel would be most useful to system design in the decision-making process.

The survey is broken into two parts. The first part is for the interviewer and helps him ask the questions, explain the concepts of the project, and direct the interview. The second part is the answer sheet for the knowledge engineer being interviewed. The complete knowledge engineering survey can be found in Appendix A.

4.1.4.2 DEVELOPMENT OF CRITICAL ELEMENT SURVEY

The purpose of the critical element survey is to solicit additional information from the domain experts on the most important aspects of the domain. This survey is given to domain experts after the DSAT survey has been done and the level two analysis has been completed. The level two analysis includes thresholding to determine the most important parts of the domain so that we can solicit more information about these parts of the domain from the domain experts. The results of the critical element survey constitute the level three output from the tool.

The critical element survey is divided into four sections. In the first section, the domain expert is asked to evaluate the influence of the critical element. In the second part of the survey, the domain expert is asked to describe the critical element in terms of its criticality, flexibility, difficulty, and frequency. The third part of the survey asks the domain expert to describe the nature of the expertise in this area. These questions are used to define the requirements for eliciting knowledge about these critical elements within the domain of interest. The last part of the survey asks the domain expert to evaluate the usefulness of an expert system developed without the critical element being examined.

The output from the critical element survey will give systems designers important specific information about those parts of the domain which may cause difficulty in the development of a useful expert system. The complete critical element survey is listed in Appendix B.

4.2 DEVELOPMENT OF ANALYSIS METHODOLOGY

The primary considerations taken into account in the development of the analysis tool were the validity of the analysis and the operational considerations. The development of the analysis tool was also based on the project goals, as stated in Section 3, and on the desired system outputs. The level one output is developed using the neural network. The level two output is based on excursion analysis and parametrizes the differences between expert systems capabilities and the requirements of a given domain. The level three output focuses on providing additional information about the most critical areas of differences between the capabilities of expert systems and the requirements of the domain.

4.2.1 DEVELOPMENT OF THE LEVEL ONE ANALYSIS

Neural Net

There were two considerations in determining the form of the output level one analysis. The first was to provide information that would be of the most use to the system designers and project managers. The second consideration was to present the most information about a domain as is practical in a condensed form.

Based on these criteria and the recommendations of the expert knowledge engineers who were interviewed, the level one analysis presents: Probability of Success, Difficulty, and Resources Required.

The dimensions of the level one analysis are meant to be orthogonal and describe different parts of the design and implementation of an expert system. Probability of success is meant to represent the basic compatibility of the domain with the technology of expert systems. Difficulty is meant to express the complexity of the domain and the amount of difficulty a developer will have in implementing an expert system to perform satisfactorily in this domain. Resources required is a function of number and experience level requirements of the domain experts and systems designer who will implement the expert system. Therefore, this is a multi-dimensional classification problem. While traditional statistical methods might be used for this classification problem, the multi-dimensional character of the problem makes a neural net classifier more desirable.

During the initial development of the level one analysis, consideration was given to the development of a simple decision rule to determine if an expert system is appropriate. It is our opinion, and that of most expert system designers we interviewed, that a go-no go global decision rule would be of very little use to designers. Also, such a "global decision rule" might give the wrong impression to managers that the decision to develop an expert system was a less complex, multi-dimensional question than we know it to be.

4.2.1.1 NET ARCHITECTURE

In developing the neural net we looked at several different architectures and learning methods. When selecting the architecture of the net, we looked at three different input training sets: 1) Inputting all 450 DSAT raw values, 2) Inputting a reduced set of DSAT values, and 3) Inputting a set of summary statistics about the domains.

We started the neural net development with the plan to use the full 450 vector input format of the DSAT survey. This net proved to be unstable and very difficult to train (see Figure 5).

The second possible architecture we studied is based on a reduced set of the DSAT parameters. This is the architecture which was selected because it retained the diverse character of the DSAT and was implementable and stable (See Figure 6). The latter architecture we studied was a net based on summary statistics of the DSAT survey. This architecture is appealing because of its simplicity but it removes too much of the resolution of the domain description.

The summary statistics are a first-level data reduction. To do the data reduction, we go back to the organization of the data collection device (DSAT questionnaire). Based on the first part of the DSAT, we calculate two summary numbers for each of the content-product aspects of the domain. The first summary number is the number of active elements in the block, and the second is the magnitude of the elements in the block. These two numbers f r each content-product aspect of the domain constitute the input vector for the second net architecture.

A three-layer perceptron was chosen to implement the second architecture. A three-layer perceptron such as we are using here can form arbitrarily complex decision regions and can separate meshed classes (Lippmann, 1987). The number of input nodes to the net is 50, two for each combination of operators and contents in the domain description. There are three outputs from the net - Probability of Success, Difficulty, and Resources Required. In selecting the number of nodes in the second and first layers, we again refer to Lippmann. "The number of nodes in the second layer must be greater than one when decision regions are disconnected or meshed and cannot be formed from one convex area. The number of second layer nodes required in the worst case is equal to the number of disconnected regions in input distributions. The number of nodes in the first layer must typically be sufficient to provide three or more edges for each convex area generated by every second-layer node." In the first hidden layer there are six nodes and in the second hidden layer there are also six nodes.

4.2.1.2 NET TRAINING

The decision on a training algorithm was fairly easy. This kind of evaluation/classification problem is very well suited to the use of back-propagation training (McClelland and Rumelhart, 1988). The back-propagation algorithm has been tested with a number of deterministic problems. It has been found to perform well in most cases and to find good solutions to the problems posed. The training values which were used in training the net outputs (probability of success, difficulty, and resources required) were obtained from expert knowledge engineers who estimated the output parameters for the training domains.

4.2.2 EXCURSION ANALYSIS

The critical element (CE) analysis of excursions is similar to critical incident (CI) methods commonly used in behavioral analysis. CI can be most particularly useful as the basis for inferring the qualities or attributes relevant to successful performance. Therefore, we are deriving a similar method which will be suited to analysis of how expert systems interact with the domains for which they are designed.

One of the potential problems with using a CI or CE analysis is that there is very little information about the validity and reliability of the analysis. Many of these concerns are resolved by using the Structure of Intellect model and the DSAT data collection tool. By using this modeling tool to quantify the decision criteria, the ex ursion analysis can be performed on a one-to-one basis within the SOI modeling space.

The excursion analysis is made possible by the development of the expert systems capability representation. The expert systems capability representation defines the level of difficulty or complexity with which an expert system can work within each element of the SOI modeling space. The scale of expert systems capability is in units of difficulty ranging from zero to ten. Once the expert systems capabilities and the domain requirements are represented on the same scale and in the same modeling space, the excursion analysis can be done. The excursion analysis consists of point-by-point subtraction of expert systems capabilities from domain requirements. The remainder is then the level of domain requirements which are not covered by expert systems capabilities.

In evaluating excursions, it is useful to define critical elements of the excursion analysis. Critical elements can be defined in two possible ways: 1) as a point of most excursion from expert systems capabilities , or 2) as a function of the criticality of the element to the successful completion of the domain task.

The critical elements are first defined as all of the excursion points. The excursion points are then examined based on the amount or level of excursion difference between capabilities and requirements. Then the criticality of the elements can be examined. The criticality of each element is assigned based on the data collected from the DSAT domain description. The most important property of a critical element is the level of excursion followed by the criticality of the element. Therefore, the critical element thresholding algorithm first sorts the excursion points by level of excursion and then by criticality of element.

Summary statistics are also calculated for two reasons. The first reason is to provide a quick non-visual means of comparing domain evaluations. The second reason is to provide a measure of how domains relate to one another which is independent of the level one analysis. This will aid in the validation of the methodology. Two summary statistics are calculated for the level two analysis. The first is a count of the number of excursions a domain makes from the expert systems capabilities. In other words, this is a count of the number of elements in which the domain requirements are greater than the expert systems capabilities. The second statistic is a measure of the amount of excursion and criticality of the excursion points. This statistic is called the critical volume. It is calculated by taking the sum of the difficulty difference multiplied by three and the criticality multiplied by two for each excursion point.

By identifying and rank-ordering the criticality of domain requirements which exceed expert systems capabilities (excursion points), an additional opportunity exists to gather valuable information about the domain based on the most critical elements. To this end, the critical element list is used to select elements to study in greater depth.

4.2.2.1 PLOTS OF DOMAIN REQUIREMENTS

The output of the level two analysis consists of two parts. The first part of the output is the chart of the domain requirements which is derived directly from the results of the DSAT description of the domain. The results of the DSAT questionnaire are formatted into the "raw data". The difficulty rating for each element is extracted from the raw data and plotted on the domain requirement chart. In this way the user of the tool can see a complete, concise representation of the domain of interest. This chart is very useful in understanding the general nature of the domain and making certain that everyone agrees on the nature of the domain.

4.2.2.2 PLOTS OF EXCURSIONS

The remainder of the level two output is devoted to representing the excursions. The excursions are first presented in the form of another capability chart. This chart will represent the difference between the level of difficulty which the domain requires and the level of difficulty that an expert system can support. This difference chart presents the excursion points in a concise manner. From this chart the user can see the parts of the domain which cannot be supported by expert systems technology. The last part of the level two output is the listing of critical elements. In this listing, the excursion points are listed in order of their criticality to the domain and the expert system implementation.

4.2.3 CRITICAL ELEMENT

The output of the critical element analysis will be the level three output to the user. The critical element analysis is a questionnaire based on obtaining additional information from the domain experts on the part of the domain with which we can reasonably expect the expert system development project to have difficulty. The questions on the critical element survey were designed to address the key issues that will effect the development and effectiveness of the expert system.

The choice of which elements to input into the critical element survey process is determined from the level two excursion analysis. The elements which differ most from the expert system capabilities are listed, starting with elements with difficulty differences of ten and criticality of ten and continuing through the excursion list as long as there are resources to perform the survey.

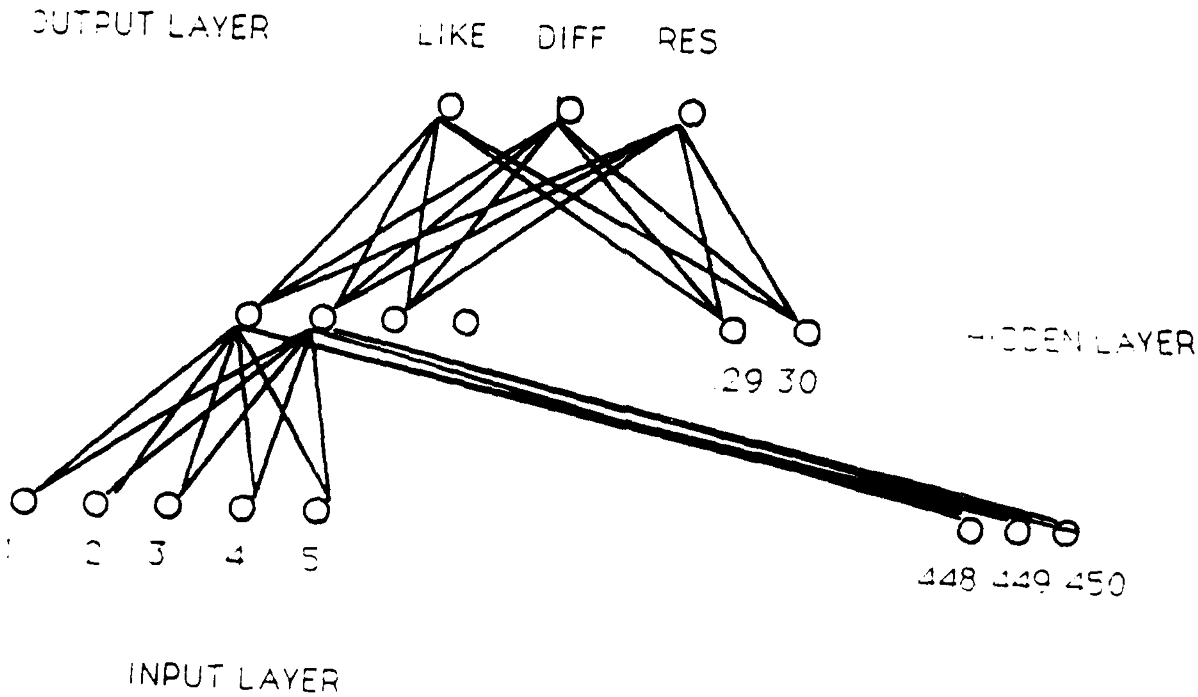
There is no additional analysis done of the critical element survey output data.

Results of the Prototyping

In order to determine the usefulness of the critical element survey, the survey was given to a domain expert in the domain of Mission Planning. The results of the survey for the two most important critical elements are listed in Appendix B.1 and B.2. As can be seen from examining the results of the critical element survey prototyping, a great deal of important information about these critical elements can learned from the critical element survey.

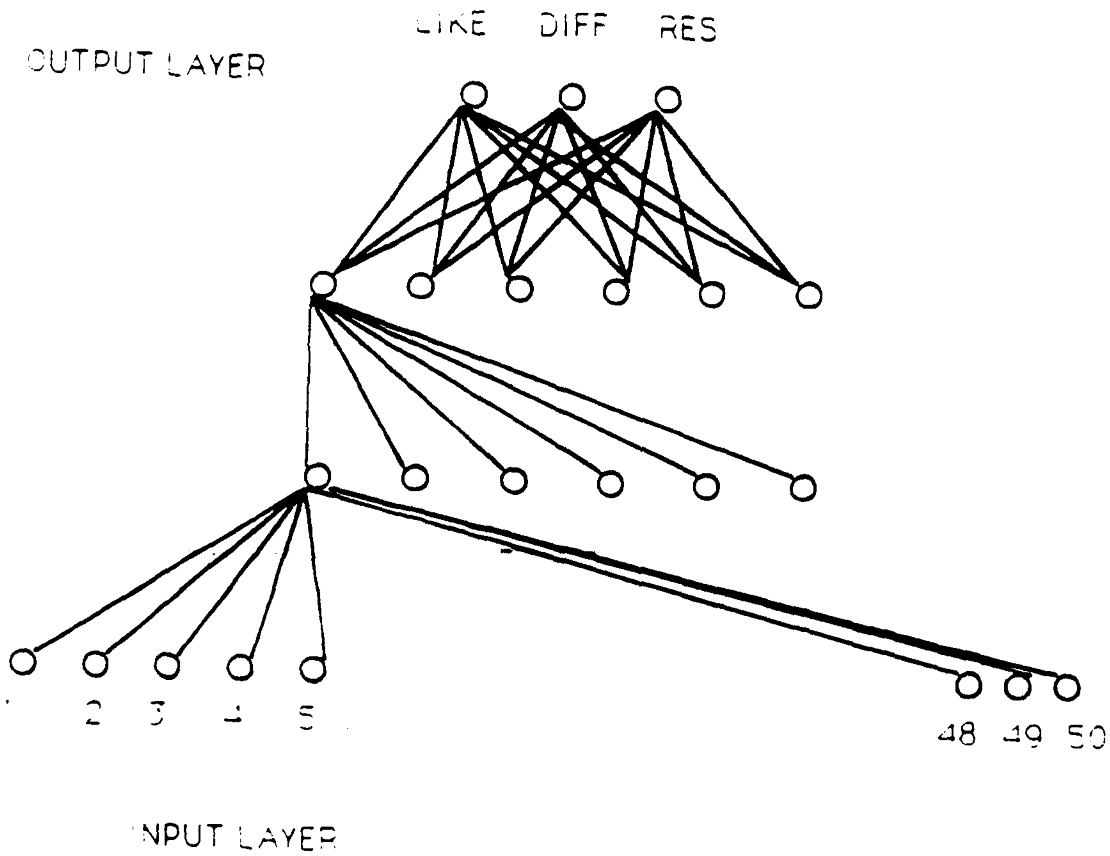
Figure 5

NET A COMPLETE INPUT VECTOR



NET B, REDUCED INPUT VECTOR

Figure 6



4.3 PROCEDURE

The procedures followed in the data collection of this research are presented in this section. The data acquisition devices include: 1) the DSAT survey developed by Jay Horn and 2) the knowledge engineer and critical element surveys developed is in Section 4. The analysis procedures are also described.

4.3.1 KNOWLEDGE ENGINEERS SURVEY

In order to obtain this representation, it was determined that five expert knowledge engineers would be interviewed and their responses summarized to create the capability representation. The expert knowledge engineers were selected based on their level of experience, diversity of experience and availability. The expert knowledge engineers who were selected had experience in the areas of medicine, maintenance, software engineering, systems evaluation, and AI research. Each of the knowledge engineers chosen has extensive experience in AI, computer systems design, and expert system development. Their average amount of experience in expert systems is eight years and four of the five have doctorate degrees. The survey required about two hours to complete.

4.3.2 DOMAIN SURVEY

The domain surveys were administered to domain experts following the procedures listed in Jay Horn's thesis. The DSAT survey was used as the data acquisition device for the domain surveys. There were a total of eight domains for which the DSAT data was collected. These domains and the criteria for their selection are listed in Section 5. The DSAT questionnaire required approximately two to three hours for each of the domain experts to complete. The domain experts were very helpful and cooperative. The domain experts did, however, require a good deal of explanation of the SOI model in order to complete the survey.

4.3.3 ANALYSIS

The analysis of the results of the knowledge engineers survey consists of summarizing the rank ordering and capability evaluations in the survey. The results of this analysis are presented in Section 8. The data analysis of the domain survey data consists of presenting the data to the neural net in order to obtain the global recommendations and to run the level two analysis. The level two analysis or excursion analysis, described in Section 4.2, consists of running the DSAT raw data through a number of FORTRAN and SAS computer programs. The results of the analysis of the domain data are presented in Section 5.

4.3.4 CRITICAL ELEMENTS

After the analysis was completed on all of the data, a domain was selected to use for prototyping of the critical element survey. The domain of mission planning was selected because it is of medium difficulty and because the thresholding showed several interesting elements to prototype. After the mission planning domain was selected, the critical element survey was administered to a domain expert for the top two critical elements. The results of the critical element surveys are discussed in Section 4.2.3 and presented in Appendices B.1 and B.2.

5.0 RESULTS

5.1 DATA COLLECTION

The data collection was conducted in a manner consistent with Section 4.3. The subjects in the data collection were extremely enthusiastic and contributed significantly to this research.

5.1.1 KNOWLEDGE ENGINEERS SURVEY

The knowledge engineers survey was conducted in order to obtain the necessary information to complete the description of expert systems capabilities within the SOI modeling domain. Sections IV, V, and VI of the questionnaire address this description. The results of the knowledge engineers survey is summarized in Appendix A.1. The results of Section IV, which ranks the parameters of three dimensions of the SOI model, are combined with the results of Sections V and VI, which give numerical ratings for the individual SOI elements, to create the capability chart for expert systems (see Figure 7). In Figure 7, there is a histogram of the capabilities of expert systems to perform task elements at certain levels of difficulty of the task element. The scale runs from 0 to 10 for each element consisting of an operator, content, and product. A scale reading of 10 means that expert systems are capable of performing at varying levels of difficulty and complexity to meet demands in this element of the model. A scale reading of 0 means there is little or no capability within expert systems to perform within the model element. Other sections of the survey results are addressed in Sections 4 and 6.

Additional Results

One of the other important problems in developing expert systems is the selection of the software design. There are a number of different approaches to designing a rule-based system, including forward chaining, backward chaining, case-based reasoning, etc. The selection of design is based on the characteristics of the domain. It was noted by several of the knowledge engineering experts that the information obtained in the domain evaluation could be constructively used for recommending a design approach for the expert system implementation (See Section 6.2).

5.1.2 COMPARISON WITH LITERATURE REVIEW

The review of expert systems literature and recommendations provided a great deal of information as to the nature of the capabilities of expert systems (See Section 4.1). This information, however, was incomplete with regards to modeling expert systems capabilities in the SOI modeling space. Therefore, the information from the literature review serves to reinforce the model which was developed based on the knowledge engineers survey (See Figure 7).

5.1.3 DOMAIN DATA COLLECTION

The domain data collection used the DSAT questionnaire to obtain descriptions of various domains of interest. The data collection was conducted as described in Section 4.3. Domain data was collected for six development domains; computer program debugging, gifted child assessment, writing research proposals, mission planning, electrical design, and medical diagnosis. Domain data was also collected for two test domains, musical performance and troubleshooting electrical equipment. The reasons and decision criteria for selecting these domains is described in Section 5.4. The domain characteristics are represented in domain requirement plots, which are contained in Appendix C.1 and make up the first section of the level two analysis.

5.2 NEURAL NET (LEVEL ONE ANALYSIS)

The neural nets were constructed and trained in a manner described in Section 6.1, using net modeling algorithms described by McClelland and Rumelhart (1988).

5.2.1 NET PERFORMANCE IN TRAINING AND CONVERGENCE

The first net we considered was Net A with a complete input vector which included all 450 input values from the DSAT raw data. The training performance of the net is plotted in Figure 8. This net proved to be unstable in training. There was also advice from several neural net experts during this part of the research to the effect that Net A had an inferior design. Net B, which used a reduced input vector, proved to be a very reasonable design and was chosen as the final net for the level one analysis. The training performance for Net B is plotted in Figure 9.

The final net architecture is a 50 input, 3 output back-propagation net with two layers of hidden nodes (see Figure 6). The net converged after 2,138 iterations with a final mean-squared error of 0.023% (See Figure 9). The final output values for the level one analysis are listed in Table 3. The final inter-connection weights for the net are listed in Appendix C.1.

5.2.2 DISCUSSION

After the net/level one analysis was completed, the input data was run in the level one analysis. The results of the analysis are listed in Table 3 and plotted in Figure 13. The results clearly show that some domains are much better suited to an expert system implementation than others. In order to test the sensitivity and usefulness of the level one analysis, two test domains were also run through the level one analysis. The results are plotted along side the other domains in Figure 14.

5.2.3 INTERPRETING RESULTS

The meaning of the scales for the level one analysis are based on useful interpretation of the scale parameters as they relate to the design and implementation of expert systems.

Probability of Success

A score of 0 in probability of success indicates that building an expert system for this domain would be practically impossible. A score of 100 on probability of success indicates a domain which is ideally suited to an expert system solution.

Difficulty

A score of 0 on difficulty indicates that the design of an expert system in this domain would be very easy and require very little expertise in expert systems. A score of 100 on difficulty indicates that the difficulty of the domain will make it almost impossible to develop an expert system.

Resources Required

A score of 0 on resources required indicates that the resources required will be minimal; only an novice in the field will be required and only the simplest of designs will be required (a toy problem). A score of 100 on resources required indicates that resources required to implement an expert system in this domain tends towards infinity. The practicality of designing and implementing an expert system in this domain is eliminated by the overwhelming resources required to do the design task (in terms of domain experts and design complexity).

Generalizability

It has been shown that a multi-layer perceptron trained by a back-propagation algorithm is mathematically equivalent to an optimum Bayesian estimator. It has also been shown that the neural network will perform as an optimum estimator on any arbitrary general input vector provided that the training set constitutes a spanning set of the region in which the classification takes place. Therefore, if the training set of domains can be said to span the region of the domains of interest, then the network will be guaranteed to give an optimum estimation of the mapping.

5.3 EXCURSION ANALYSIS

5.3.1 DATA

A level two data analysis was performed on the raw data collected for all of the domains. This data and the expert systems capability representation make the excursion analysis possible. The input data for each domain can be shown on a domain requirements chart such as the one for the domain of writing research proposals which is shown in Figure 10. The remainder of the capability charts are listed in Appendix C.1.

Capability requirements charts such as the one shown in Figure 10 are laid out in the same manner as the expert system requirement chart shown in Figure 7. In the capability requirements charts, however, the entries represent the level of difficulty that a given domain requires for a complex, sufficient solution. By designing these representations in this way, we can compare numerically the requirements of a domain against the capabilities of expert systems to meet these requirements.

5.3.2 PLOTS AND CRITICAL ELEMENTS

The level two output for the domains for which we collected data includes the domain capability charts, the difference charts, the listings of the critical elements, and the level two summary statistics. The summary statistics for the level two analysis are listed in Table 3. An example of the difference chart and the critical element listing are shown in Figures 11 and 12. The remainder of these charts and tables are listed in the appendix.

The difference charts, like the one shown in Figure 11, represent the difficulty difference for each element of the SOI model between the requirement of the domain and the capability of expert systems. What is plotted, therefore, is the level of difficulty which the domain requires above and beyond what an expert system can perform.

The critical element listing is a listing of all the elements of the model which appear on the difference chart. The elements where domain requirements are greater than expert system capabilities are sorted by difficulty difference and then by criticality of the element. In this way, the system evaluator can review the most critical elements which exceed the capability of expert systems.

5.3.3 DISCUSSION

The level two analysis was designed with the expert system designer in mind as opposed to the level one analysis which addresses managers. In the difference charts, there is a great deal of important information which the system designer can use in developing an approach to implementing or abandoning an expert system project. An example of this is the research proposal domain. By looking at the difference chart, we can see that the domain requires more in the area of semantic contents than expert systems are typically capable of. A design would have to find a method of either altering the domain characteristics or making a breakthrough in expert systems design to develop this solution. As can be seen from the difference charts and critical element listings, there are considerable differences between the different domains. The population of difference charts, however, gives a clear indication of how well an expert system will suit the domain.

5.4 VALIDATION OF ESDAAT

5.4.1 DOMAIN SELECTION

The original three domains for which Jay Horn collected raw data provide the base cases for the validation of the level one analysis and the excursion analysis. The analysis of these domains is shown along with the other domains in Section 5.2.

After the expert systems capability model was developed, it was determined that the original three domains (computer program debugging, writing research proposals, and gifted child assessment) do not sufficiently cover all the elements of the Structure of Intellect model and expert systems capabilities. The original three domains do not have any coverage at all of visual divergent production and behavioral convergent production and have only very sparse coverage of visual and auditory memory, behavioral evaluation, and divergent production. This lack of coverage of the model space limits the theoretical generalizability of the analysis. The lack of coverage of the model space shows that there are additional classes of domains not represented by the original three domains. Therefore, the face validity of the analysis is also reduced.

To meet the need for a greater coverage of the Structure of Intellect model space, we chose to gather DSAT data on three additional domains. The selection of additional domains was made on the basis of three criteria.

(1) That the additional domains complete the coverage of the modeling space.

(2) That the additional domains be significantly different from the original domains in order to increase the coverage of domains in general

(3) That the additional domains be of significant interest to potential expert systems application.

Based on these criteria, we selected the following domains.

a. Medical Diagnosis

b. Mission Planning

c. Electrical Design

The addition of these domains has significantly increased the portion of the Structure of Intellect model which is covered. With these six development domains, we have coverage of all of the SOI modeling space. Complete coverage of the model space assures a level of generalizability of the analysis tool. Also, by including six widely diverse domains in the validation of the analysis tools, we greatly increase the face validity of the tool in general.

For the capability analysis of expert systems as shown in Section 4.1, all of the aspects of expert systems capabilities are covered or exceeded by one or more of the development domains.

Two test domain were selected for two reasons, first to provide an unambiguous test of the level one analysis and, second, to provide a wide range of axis anchors. Therefore, the test domains should be domains where expert systems clearly are or clearly are not good choices for a solution in the domain. We also wish the test cases to be real domains in which significant expert systems development has taken place or been attempted. Based on these criteria, we selected the domains of electrical equipment troubleshooting and musical performance. The results of the level one analysis are indicated by arrows on the plot of the development/verification domains (See Figure 14). As can be seen in the figure, the test cases form a very useful anchor for comparison of other domains on the scale of probability of success. On the scales of difficulty and resources required, the test cases are considerably less useful as scale anchors. This is to be expected, as the test domains are less complex than the more interesting development domains.

5.4.2 EXCURSION ANALYSIS AND NET VERIFICATION

When evaluating the reliability of the analysis technique, the level one analysis outputs and the level two analysis summary statistics can all be compared based on a go/no go binary decision basis using the Wilcoxon Two Sample Rank-Sum test by comparing the orderings of the domains (Lapin, 1973) and by comparing the consistency between the analysis methods.

For the purpose of verification, summary parameters were calculated on the level two analysis. These parameters are, first, the number of excursion with greater than 3.3 difference in the domain requirements and greater than level four criticality. And second, a critical volume parameter, calculated by three times the difficulty difference plus two times the criticality. These parameters are listed side-by-side with the output of the level one analysis in Table 3.

The two samples are grouped by scale of the probability of success parameter of the net output.

Group 1 > 50% probability of success

Group 2 < 50% probability of success

As can be seen from the Rank-Sum test (Table 4), there is considerable agreement between all of the analysis methods.

TABLE 3

LEVEL ONE ANALYSIS

DOMAINS	PROBILITY OF SUCCESS	DIFFICULTY	RESOURCES REQUIRED	NUM.EXC	CRIT. VOLUME
1 Computer Program Debugging	78	31	38	4	79
2. Gifted Child Assessment	40	63	80	30	882
3 Writing Research Proposals	20	88	62	31	1031
4 Mission Planning	60	57	71	28	484
5 Electrical Design	85	35	55	16	504
6 Medical Diagnoses	11	82	99	88	2546
7 Musical Performance	8	98	76	67	2700
8 Troubleshooting Electrical Equipment	95	30	20	13	351

TABLE 4

WILCOXON TWO-SAMPLE
RANK-SUM TEST

DOMAINS	PROBILITY OF SUCCESS	RANK
Troubleshooting Electrical Equipment	95	1
Electrical Design	85	2
Computer Program Debugging	78	3
Mission Planning	60	4
Gifted Child Assessment	40	5
Writing Research Proposals	20	6
Medical Diagnoses	11	7
Musical Performance	8	8

$W1 = 1+2+3+4 = 10$

$W2 = 5+6+7+8 = 26$

TABLE 4

WILCOXON TWO-SAMPLE RANK-SUM TEST

DOMAINS	RESOURCES REQUIRED	RANK
Troubleshooting Electrical Equipment	20	1
Electrical Design	55	3
Computer Program Debugging	38	2
Mission Planning	71	5
Gifted Child Assessment	80	6
Writing Research Proposals	62	4
Medical Diagnoses	99	8
Musical Performance	76	7

$$W1 = 1+3+2+5 = 11$$

$$W2 = 6+4+8+7 = 25$$

TABLE 4

WILCOXON TWO-SAMPLE RANK-SUM TEST

DOMAINS	DIFFICULTY	RANK
Troubleshooting Electrical Equipment	30	1
Electrical Design	35	3
Computer Program Debugging	31	2
Mission Planning	57	4
Gifted Child Assessment	63	5
Writing Research Proposals	88	7
Medical Diagnoses	82	6
Musical Performance	98	8

$$W1 = 1+3+2+4 = 10$$

$$W2 = 5+7+6+8 = 26$$

TABLE 4

WILCOXON TWO-SAMPLE
RANK-SUM TEST

DOMAINS	NUM OF EXCURSION	RANK
Troubleshooting Electrical Equipment	13	2
Electrical Design	16	3
Computer Program Debugging	4	1
Mission Planning	28	4
Gifted Child Assessment	30	5
Writing Research Proposals	31	6
Medical Diagnoses	88	8
Musical Performance	67	7

$$W1 = 2+3+1+4 = 10$$

$$W2 = 5+6+8+7 = 26$$

TABLE 4

WILCOXON TWO-SAMPLE RANK-SUM TEST

DOMAINS	CRITICAL VOLUME	RANK
Troubleshooting Electrical Equipment	351	2
Electrical Design	504	4
Computer Program Debugging	79	1
Mission Planning	484	3
Gifted Child Assessment	884	5
Writing Research Proposals	1031	6
Medical Diagnoses	2546	7
Musical Performance	2700	8

$W1 = 2+4+1+3 = 10$

$W2 = 5+6+7+8 = 26$

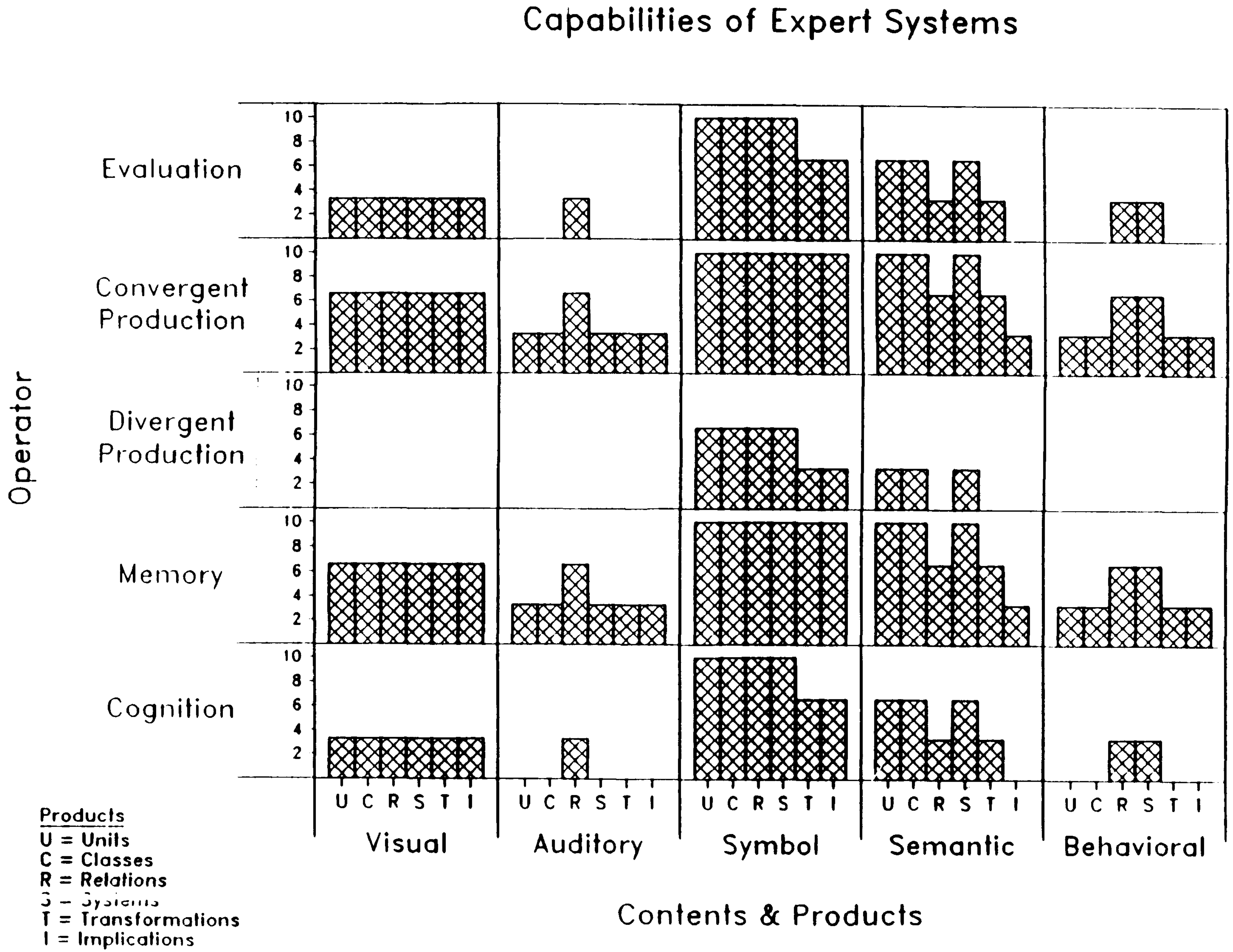

Capabilities of Expert Systems
Operator
Evaluation
Convergent Production
Divergent Production
Memory
Cognition
10
8
6
4
2
U C R S T I
Visual
Auditory
Symbol
Semantic
Behavioral
Contents & Products
Products
U = Units
C = Classes
R = Relations
T = Transformations
I = Implications

FIGURE 7

NET A CONVERGES PLOT

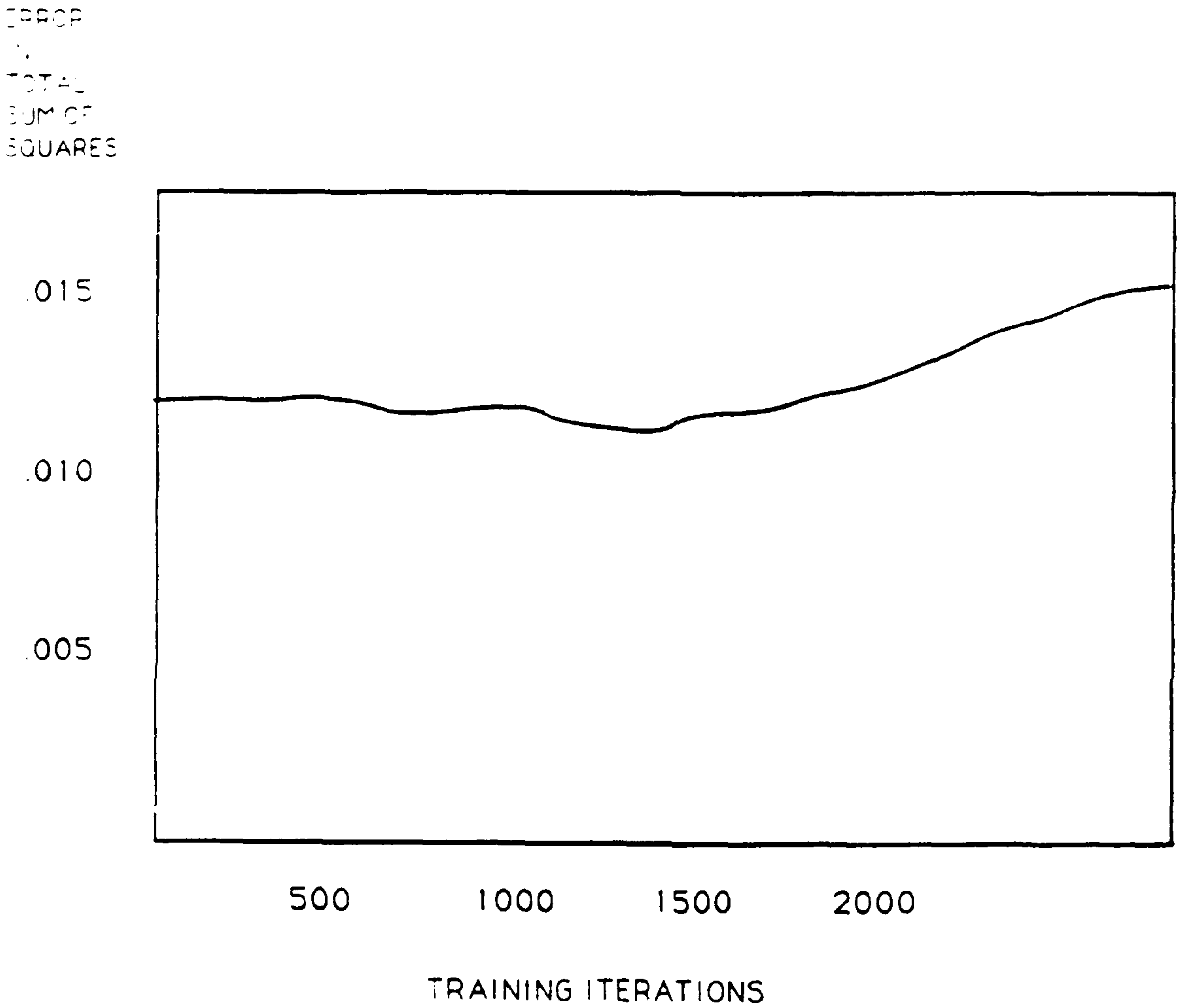


FIGURE 8

NET B CONVERGES PLOT

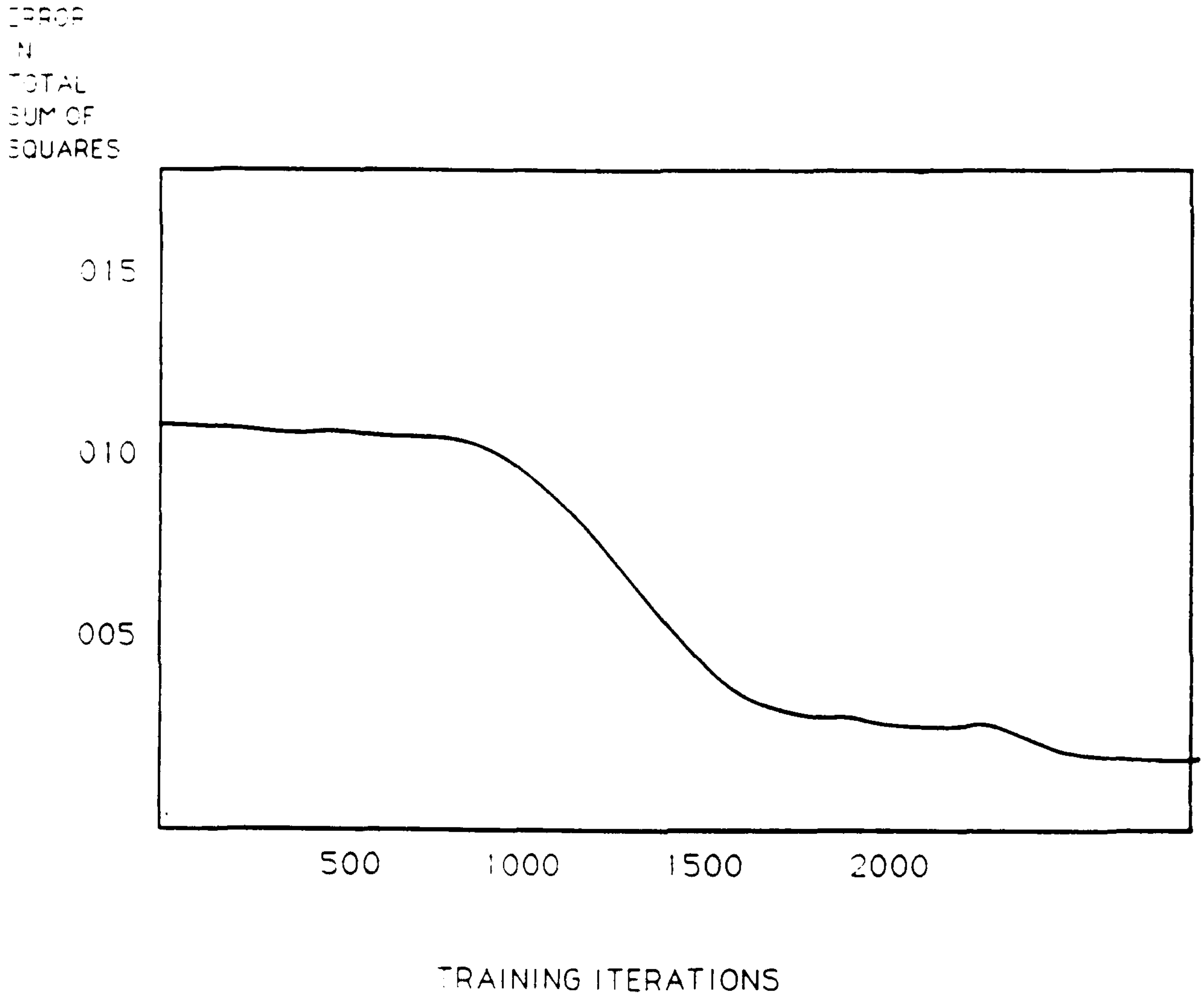


FIGURE 9

Capability Requirements for Research Proposal

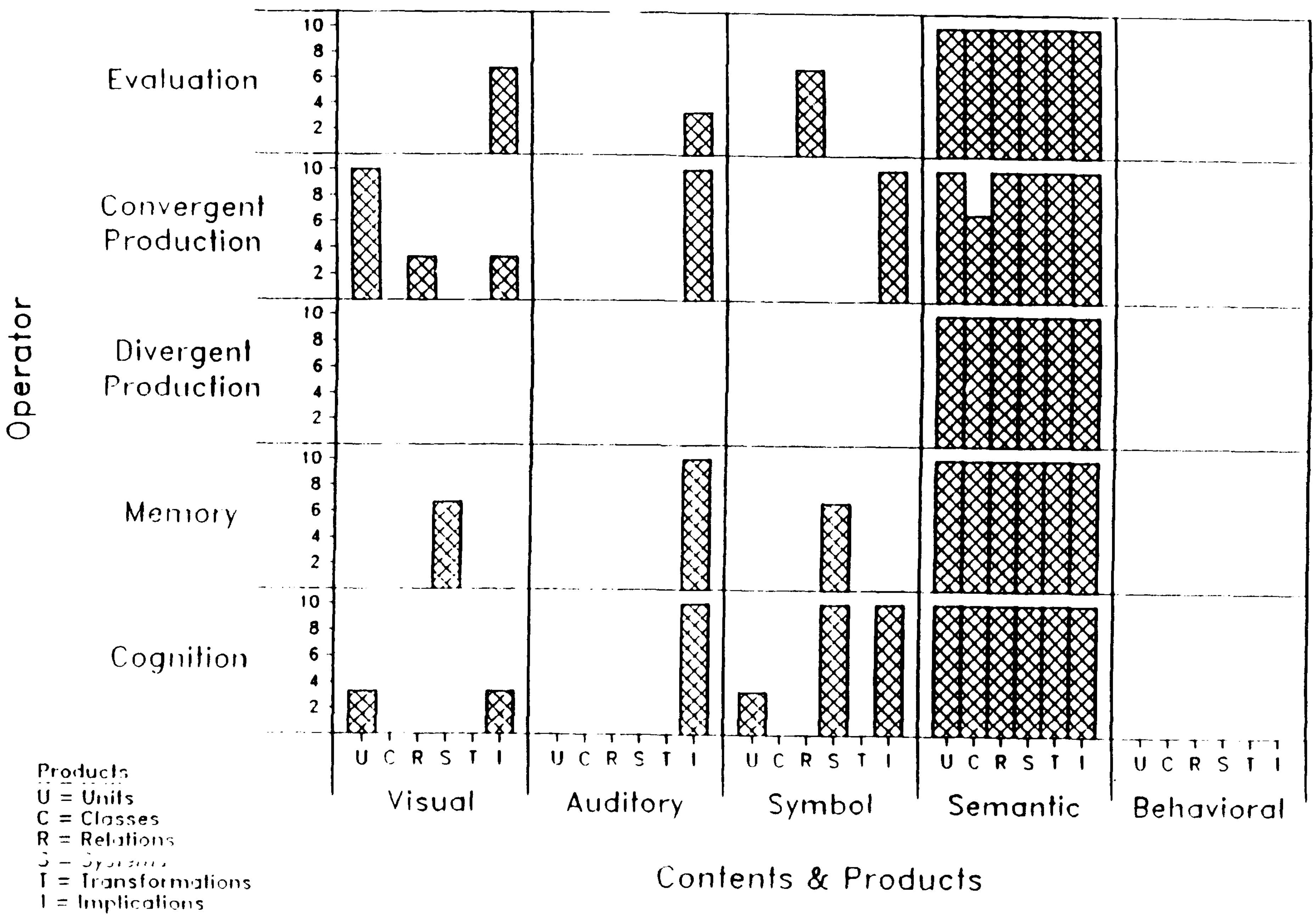
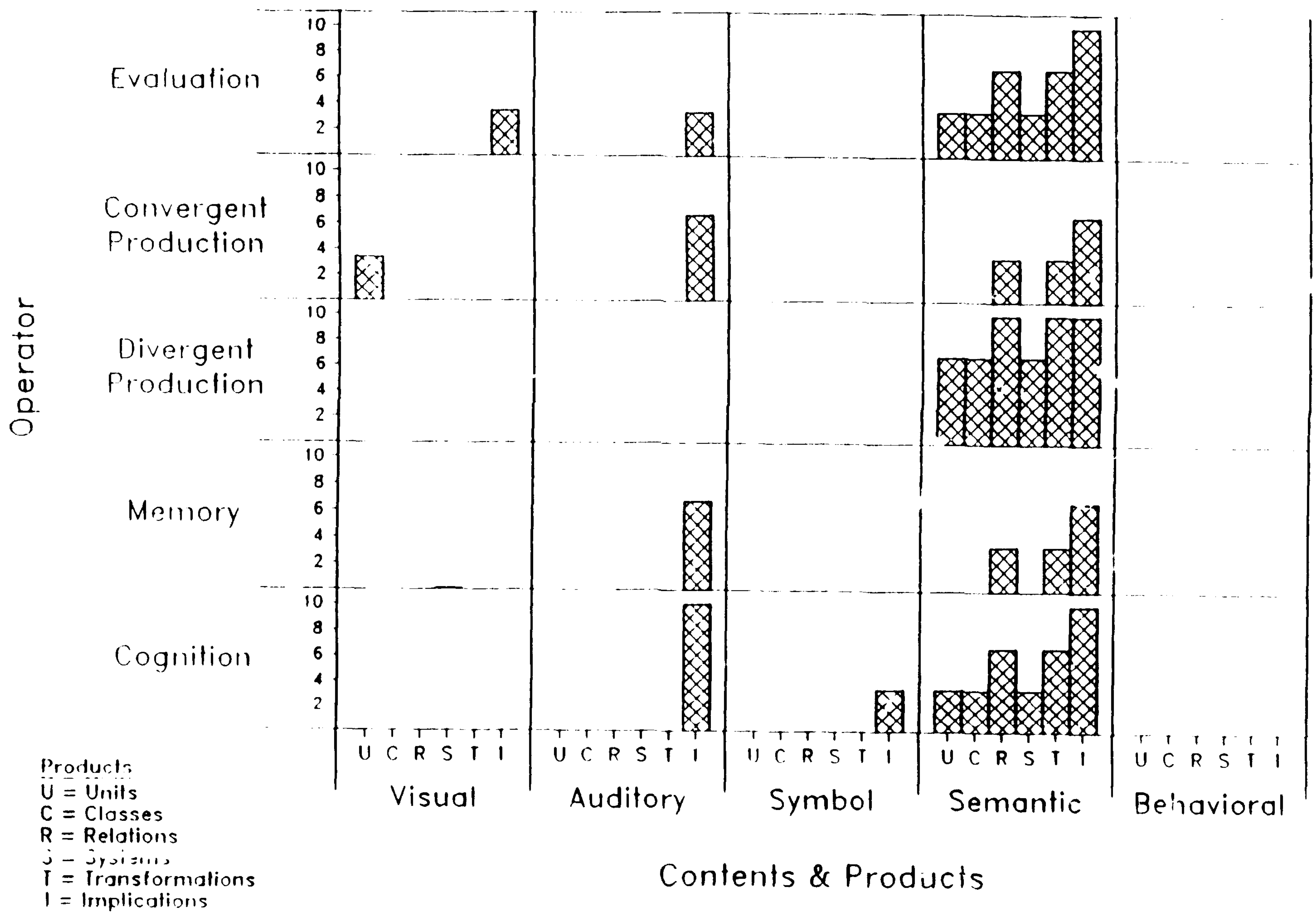


FIGURE 10

Diff. (Reseach Domain–Expert Systems)



FIGURE

THIS

PAGE

IS

MISSING

IN

ORIGINAL

DOCUMENT

73-74

TEST CASES

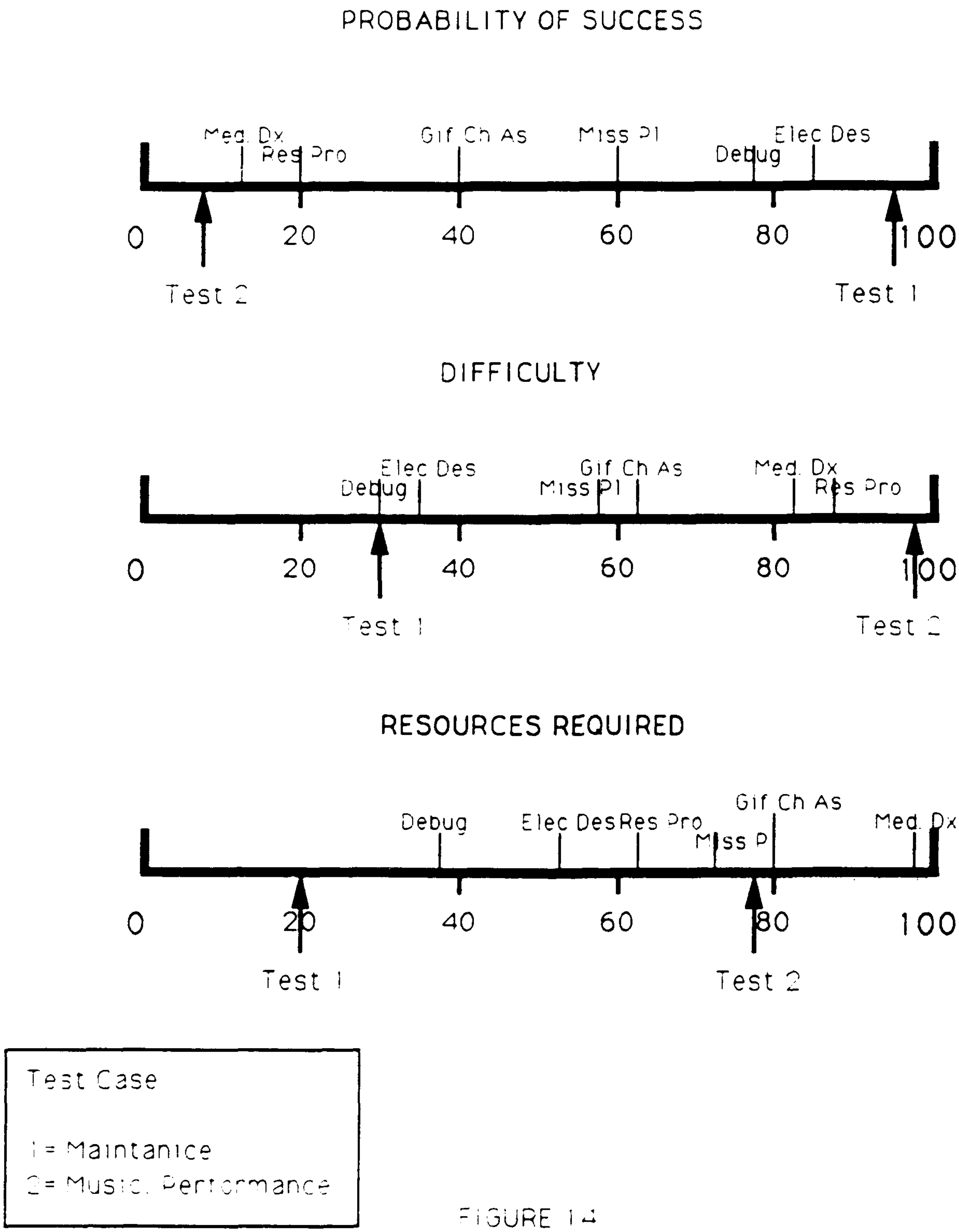


FIGURE 14

5.5 CASE STUDY

In order to demonstrate the use of the ESDAAT, a case study was performed on a domain of interest which had as yet not been studied for possible implementation of an expert system. The domain which was selected was the identification of points on computerized topographies of human heads. This task is presently performed by technicians who work at the Air Force Aeromedical Research Laboratory.

5.5.1 MANAGEMENT

The management of the Aeromedical Laboratory was very receptive to using the ESDAAT to evaluate the suitability of developing an expert system to automate the identification of points within their data. At the time of the case study, the management was considering a number of AI and other computer analysis techniques to automate this task. There was some reluctance to commit the time of the domain experts to the evaluation project. However, the domain experts were very cooperative.

5.5.2 DOMAIN EXPERTS

Two domain experts filled out the DSAT questionnaire for the domain of point by picking landmarks from the computer topography. The results of the DSAT questionnaire were averaged to provide the raw data which was fed into the ESDAAT analysis. The domain experts were very enthusiastic about the project. It is clear from this case study that knowledge engineers and evaluators will need to spend a good deal of time familiarizing themselves with the DSAT survey and the SOI model before they can effectively administer the survey to domain experts.

5.5.3 ANALYSIS OF DATA

The averaged DSAT inputs were run in the level one and level two analysis programs. The results of the level one analysis are as follows:

Probability of Success	60%
Difficulty	56%
Resources Required	67%

The results of level one analysis indicate that there is good reason to believe that an expert system could be developed for this domain with at least some level of success if enough resources are allocated to the project.

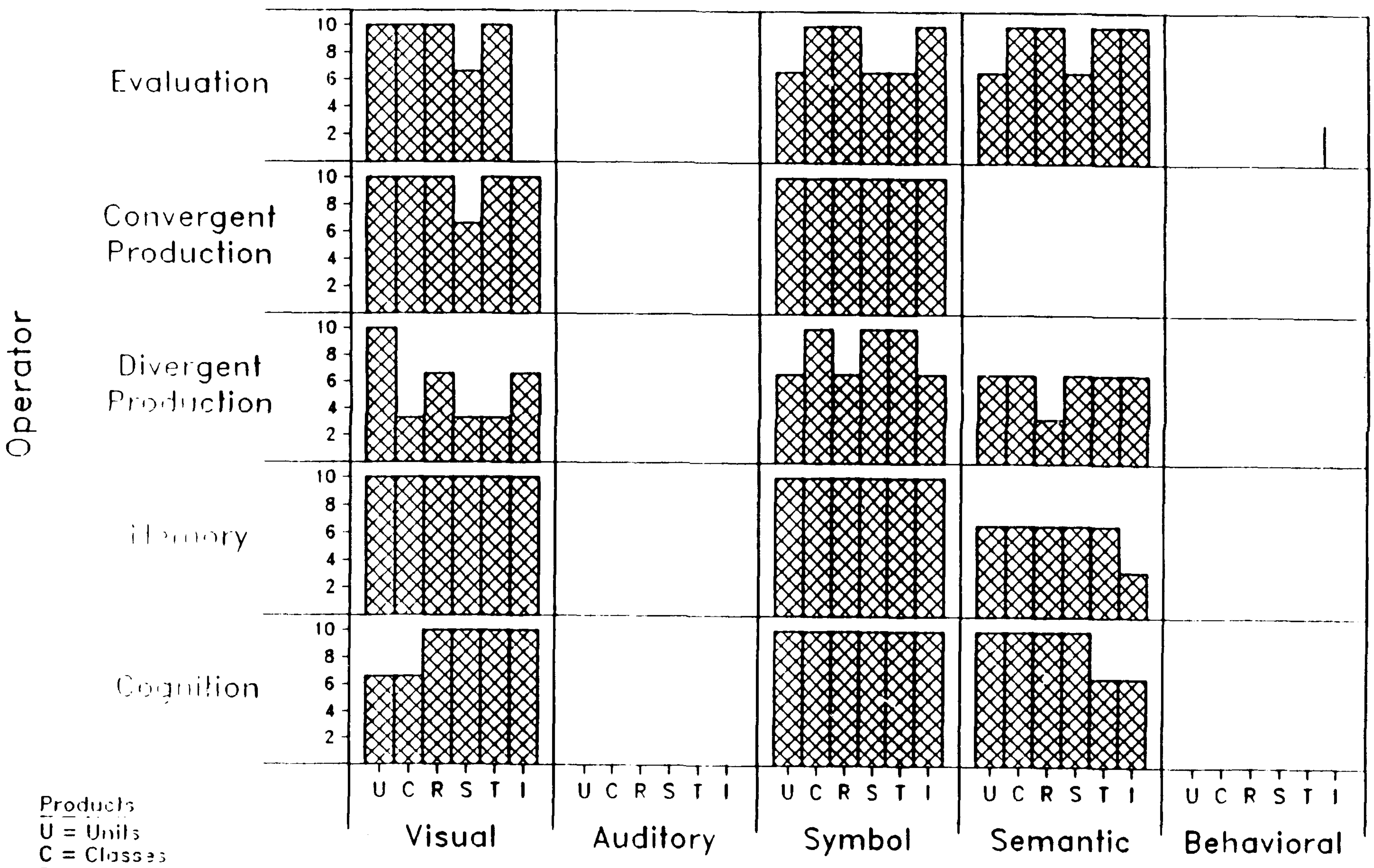
The results of the level two analysis are shown in Figure 15, the requirements chart; Figure 16, the difference chart; and Figure 17, the listing of critical elements of concern in the dom- '.. As can be seen in these figures, there are a number of elements within the requirements of the domain which are not covered by expert systems capabilities. Therefore, these elements of the domain should be of first concern when attempting to develop an actual expert system in the domain.

5.5.4 RECOMMENDATIONS AND ACCEPTANCE

The results of the analysis indicate that this is not an ideal domain for an expert system solution. However, with sufficient resources, it should be possible to develop an expert system to automate some part of the domain. The results of the level one analysis were accepted by the lab management with little need of additional explanation. The level two output data required some explanation, both to the lab management and to the designers of the potential expert system who were unfamiliar with the SOI model. As a result of the

ESDAAT recommendation, the lab is proceeding with the development of an expert system to help automate the point picking.

Requirments Point Picking Domain



Products
U = Units
C = Classes
R = Relations
S = Systems
T = Transformations
I = Implications

FIGURE 15

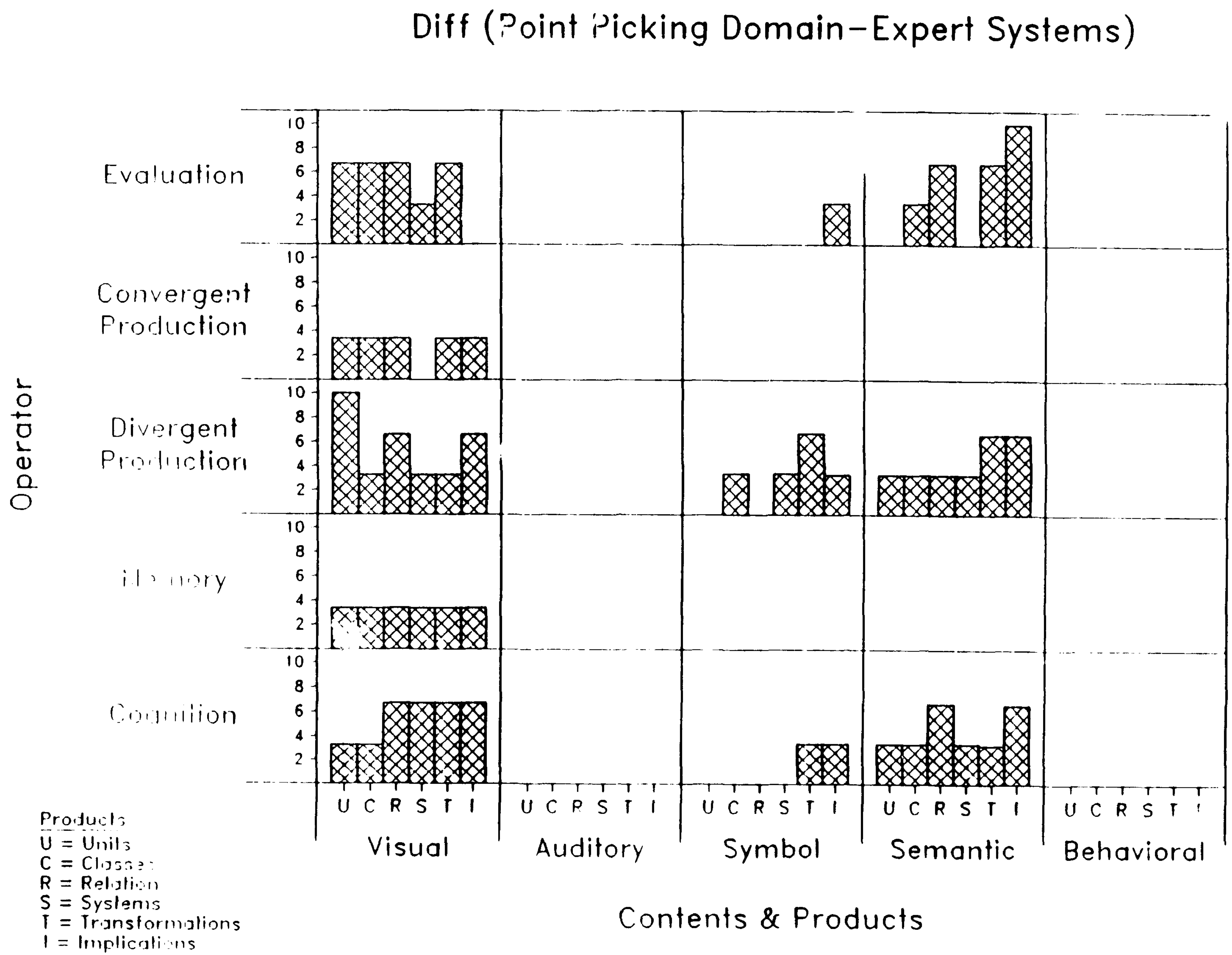

Diff (Point Picking Domain–Expert Systems)
Operator
Evaluation
Convergent Production
Divergent Production
Memory
Cognition
10
8
6
4
2
U C R S T I
Visual
Auditory
Symbol
Semantic
Behavioral
Contents & Products
Products
U = Units
C = Classes
R = Relation
S = Systems
T = Transformations
I = Implications

FIGURE 16

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=3.3

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
1	6	2	COGNITION	SEMANTIC	TRANSFORMATIONS
2	6	6	DIVERGENT PRODUCTION	SEMANTIC	CLASSES
3	6	4	DIVERGENT PRODUCTION	SEMANTIC	SYSTEMS
4	8	6	DIVERGENT PRODUCTION	SEMANTIC	UNITS
5	8	6	DIVERGENT PRODUCTION	SEMANTIC	RELATIONS
6	10	8	COGNITION	VISUAL	UNITS
7	10	6	COGNITION	VISUAL	CLASSES
8	10	4	DIVERGENT PRODUCTION	VISUAL	CLASSES
9	10	4	DIVERGENT PRODUCTION	VISUAL	SYSTEMS
10	10	6	DIVERGENT PRODUCTION	VISUAL	TRANSFORMATIONS
11	10	6	DIVERGENT PRODUCTION	SYSMBOLIC	IMPLICATIONS
12	10	10	EVALUATION	VISUAL	SYSTEMS

DIFF=3.4

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
13	6	8	COGNITION	SEMANTIC	CLASSES
14	6	4	COGNITION	SEMANTIC	SYSTEMS
15	6	4	DIVERGENT PRODUCTION	SYSMBOLIC	CLASSES
16	6	6	EVALUATION	SEMANTIC	CLASSES
17	8	8	COGNITION	SEMANTIC	UNITS
18	8	4	DIVERGENT PRODUCTION	SYSMBOLIC	SYSTEMS
19	10	6	COGNITION	SYSMBOLIC	TRANSFORMATIONS
20	10	8	COGNITION	SYSMBOLIC	IMPLICATIONS
21	10	10	MEMORY	VISUAL	UNITS
22	10	10	MEMORY	VISUAL	CLASSES
23	10	10	MEMORY	VISUAL	RELATIONS
24	10	10	MEMORY	VISUAL	SYSTEMS
25	10	10	MEMORY	VISUAL	TRANSFORMATIONS
26	10	10	MEMORY	VISUAL	IMPLICATIONS
27	10	10	CONVERGENT PRODUCTION	VISUAL	UNITS
28	10	10	CONVERGENT PRODUCTION	VISUAL	CLASSES
29	10	10	CONVERGENT PRODUCTION	VISUAL	RELATIONS
30	10	10	CONVERGENT PRODUCTION	VISUAL	TRANSFORMATIONS
31	10	10	CONVERGENT PRODUCTION	VISUAL	IMPLICATIONS
32	10	8	EVALUATION	SYSMBOLIC	IMPLICATIONS

DIFF=6.6

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
33	6	4	COGNITION	SEMANTIC	IMPLICATIONS
34	6	4	DIVERGENT PRODUCTION	SEMANTIC	TRANSFORMATIONS
35	6	6	DIVERGENT PRODUCTION	SEMANTIC	IMPLICATIONS
36	10	4	DIVERGENT PRODUCTION	VISUAL	RELATIONS
37	10	6	DIVERGENT PRODUCTION	VISUAL	IMPLICATIONS

FIGURE 17

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=6.7

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
38	6	6	COGNITION	SEMANTIC	RELATIONS
39	6	4	DIVERGENT PRODUCTION	SYSMBOLIC	TRANSFORMATIONS
40	6	8	EVALUATION	SEMANTIC	RELATIONS
41	6	6	EVALUATION	SEMANTIC	TRANSFORMATIONS
42	10	10	COGNITION	VISUAL	RELATIONS
43	10	8	COGNITION	VISUAL	SYSTEMS
44	10	8	COGNITION	VISUAL	TRANSFORMATIONS
45	10	8	COGNITION	VISUAL	IMPLICATIONS
46	10	10	EVALUATION	VISUAL	UNITS
47	10	10	EVALUATION	VISUAL	CLASSES
48	10	10	EVALUATION	VISUAL	RELATIONS
49	10	10	EVALUATION	VISUAL	TRANSFORMATIONS

DIFF=10

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
50	4	4	EVALUATION	SEMANTIC	IMPLICATIONS
51	10	6	DIVERGENT PRODUCTION	VISUAL	UNITS

6.0 DISCUSSION AND CONCLUSIONS

6.1 EMPIRICAL OBSERVATIONS

6.1.1 USE AND USEFULNESS OF THE TOOL

Results indicate that the ESDAAT can give decision makers and system designers a great deal of information about the domain in which they are interested. It is not, however, a panacea. The ESDAAT is not designed to address issues other than the suitability of the domain for an expert system solution. The ESDAAT will not design a system for an application or allocate the required resources. The ESDAAT will, however, give a great deal of information that can guide the system designer and knowledge engineer to appropriate domains for building useful, powerful expert systems.

The stated objectives of this project as listed in Section 4 of this paper were, first, to demonstrate the validity of the Guilford Structure of Intellect model for mapping characteristics of task domains. Second, to develop a representation of the existing capabilities of expert systems in the SOI model. And third, to develop and validate mathematical algorithms for comparing domains against one another and against expert systems capabilities.

This project has met all of these research objectives. In Section 5.4, the validation of the model, we discuss how domain systems were selected and then tested in order to demonstrate that the SOI model can accurately and completely represent widely varying domains in a numerically sensitive manner. We successfully derived a model of existing expert system capabilities which is presented in Section 5.1 and used in subsequent analysis.

We have also developed and presented in this paper valid, useful computer algorithms for domain selection and evaluation for expert systems.

6.1.2 PATTERNS IN THE LEVEL TWO ANALYSIS

The number of high criticality elements in a domain has a significant effect on the difficulty of system implementation. Domains in which there are an extreme number of critical elements are domains of high complexity. These domains generally cannot be implemented as expert systems. However, they can be candidates for expert systems which address some subset of this domain. Domains in which there are large numbers of difficult, but not critical, elements are generally domains with greater flexibility in the way that they may be performed and/or implemented as an expert system. In general, domains which have fewer elements and elements with lower degrees of difficulty are easy to implement. Usually, domains of interest will tend more to complex domains with moderate to high difficulty. During the course of this research, it has become apparent that the domain analysis can also give hints and direction on how to design and implement an expert system.

6.1.3 DOMAINS, COMPLEXITY, AND EVALUATION

One of the most interesting things we learned in this research is that domains vary in complexity in ways similar to the way we describe levels of experts. This form of describing domains is key to being able to determine whether expert systems can or cannot be designed for dealing with an entire domain or whether the best we can do is develop a solution for a small part of the domain. (Typically an expert system domain application is for the whole domain.)

Just as there are different levels of experts (Novice, Expert, Super Expert), there are different levels of domain size, complexity, and character.

Size:	Resources needed to implement the expert system	
Character:	SOI DSAT modeling	
Complexity:	Toy Domains	/ Level 0
	Sparse Domains	/ Level 1
	Complex Domains	/ Level 2
	Super Domains	/ Level 3

In the case of level 2 domains (i.e. complex domains), the difficulty levels increase with the complexity and the domain will most likely require super experts to describe it. Also, in level 2 domains, it is likely that an expert system will not be able to solve the complete domain task, i.e., a part domain implementation will be more successful. There has been very little description to date of level three domains. Super domains are characterized by being so complex that humans either relegate the performance of the domain to a highly elite subgroup of the population or require more then one super expert to completely perform the domain. In such super domains, the best we can hope is for an expert system to be implemented for some small subset of the super domain. An example of a super domain is the domain of medical diagnoses. For years this domain has required many super experts, each specializing in sub-domains and devoting many years of preparation and study.

The medical domain has produced a number of good expert systems. These have been successful primarily because their domain has been limited to a small sub-set of the overall super domain.

Once a level 2 or 3 domain has been identified as a domain of interest for an expert system implementation, the description of expert systems capabilities found in this research can serve as a guide to selecting a suitable subset of the domain for which to implement the expert system.

6.1.4 METHODOLOGICAL PROBLEMS

During the development and use of the analysis methods for the ESDAAT, several methodological problems were noted which are important in using the tool or reproducing the results reported here. The first thing that is important to note is that the administration of the DSAT and ESDAAT questionnaires requires a high degree of training and expertise with the structure of intellect model.

The next most important aspect of the methodology and procedure is that in order to do an accurate, orderly analysis, the domain experts must have a clear, well-defined idea of the domain they are describing and that all domain experts agree exactly as to the nature of the task. If these constraints on the data gathering are observed, the data analysis will yield a reliable result.

6.2 FUTURE RESEARCH AND DEVELOPMENT

6.2.1 SUMMARY

The development of the ESDAAT has demonstrated the practicality of theory-based domain suitability analysis. However, there are a number of issues which have arisen during this research which require additional research and ongoing study. In this section we briefly address a number of these issues.

6.2.2 CHANGES IN EXPERT SYSTEMS CAPABILITIES

During the history of computer science, in general, and expert systems in particular, there have been changes and advancements in the understanding of the capabilities of the implementation of computer algorithms to solve problems. As computer hardware and software design continues to develop, these capabilities will also continue to increase. The model of expert system capabilities presented here should not change significantly. This conclusion needs to be researched and confirmed over the course of further expert systems development.

The reason we believe that our model is fundamentally complete is twofold: (1) the fundamental structure of expert systems implementation is fully defined and implemented into our current model, and (2) there was considerable agreement among all of the expert knowledge engineers as to the capabilities of expert systems.

6.2.3 ISSUE OF DIFFICULTY IN TASKS

One of the areas of interest in evaluating domain suitability must be the problem of trying to determine the level of difficulty in a particular task or subtask for which an expert system can be designed to perform at an acceptable level.

What are the consequences of the level of difficulty in a particular area to the design and implementation of the design and implementation of the expert system?

6.2.4 AUTOMATION OF THE ANALYSIS

The usability and full-scale validation and evaluation of this design resource tool will require the development of an automated version of the DSAT data acquisition tool and an automation of this analysis.

6.2.5 ISSUE OF KNOWLEDGE ACQUISITION

The ESDAAT deals primarily with matching the characteristics of the domain with the capabilities of expert systems.

However, this analysis does not consider in large part one of the most important practical issues in expert systems development, that of knowledge acquisition from the experts.

6.2.6 TAILORING EXPERT SYSTEMS DESIGN BASED ON ESDAAT DESCRIPTIONS

During the course of this research, a number of both domain experts and system developers requested that the output of the ESDAAT include information about what approach to take in the development of an expert system in the domain of interest. The basic goals and theoretical construction of the ESDAAT do not allow these kinds of recommendations to be made directly. However, there are indications from some patterns in the level two analysis that this information may be available in some form. In the next iteration of the ESDAAT project, this issue will be investigated further.

6.3 CONCLUSIONS

There are several important general conclusion to be drawn from this research. First, the field of expert systems can benefit from the inclusion of basic principles of human cognition in the selection of potential application domains. Second, if properly solicited, domain experts can and will provide comprehensive and detailed information regarding the nature and characteristics of the domain which can be used to determine the domain's compatibility with expert systems. Third, theories of human intelligence form a reasonable and comprehensive modeling space in which to describe the nature and characteristics of domains and expert systems technologies. Fourth, an analysis tool of the characteristics and mappings of domains will provide decision-makers with a useful knowledge of the domain suitability for an expert systems technology solution.

There are also several important specific conclusions to be drawn from this research. The results described in Section 5 suggest that the Domain Suitability Analysis Tool is ready to be implemented as a system analysis tool for describing domains and their relative suitability to expert systems technology solutions.

The representation of expert systems capabilities presented in this research is an important step forward in understanding the nature of expert systems in a global sense.

BIBLIOGRAPHY

Allen, M. (1986). *The Development of an Artificial Intelligence System for Inventory Management Using Multiple Experts.* Oakbrook, Illinois: Council of Logistics Management.

Barr, A. and Feigenbaum, E. A. (1987). "Volume 2: The Handbook of Artificial Intelligence"

Bell, M. Z., (1985). Why expert systems fail, Journal of the Operational Research Society, 36(7), 613-619.

Bielawski, L. and Lewand, R. (1984) "Expert Systems Development", Wellesley, Massachusetts: QED Information Sciences, Inc.

Bringelson, L., Deer, L., McCray, G., Thompson, S., and Salvendy, G. (1987). The development of a methodology for assessing applications for expert systems. School of Industrial Engineering, Purdue University.

Computer Science Corporation, "Expert system development methodology standard under contract from NASA Goddard Space Flight Center"

Costea, Ilenna, "Artificial Intelligence: Expert Systems in Design and Manufacturing"

Dreyfus, H. (1979). *What Computers Can't Do.* New York: Harper & Row, Publishers.

Dreyfus, H. and Dreyfus, S. (1986). *Mind Over Machine.* New York: The Free Press.

Guilford, J. (1967). *The Nature of Human Intelligence.* New York: McGraw-Hill.

Guilford, J. (1985). The structure-of-intellect model. In B. Wolman, (Ed.), *Handbook of Intelligence.* New York: John Wiley & Sons, 225-266.

Guilford, J., and Hoepfner, R. (1971). *The Analysis of Intelligence.* New York: McGraw-Hill.

Guilford, J., and Lacey, J., (Eds.) (1947). Printed classification tests. Army Air Forces Aviation Psychology Research Program Reports. Washington, D.C.: Government Printing Office, Number 5.

Hadzikadic, M., Yun, D., and Ho, W. (1987). A model-based framework for characterization of application domains for the expert system technology. In Z. Ras and M. Zemankova (Eds.), *Methodologies for Intelligent Systems*. New York: North-Holland, 64-72.

Hanson, E. N., and Cross, S. E. (1988). Methodology for Screening Potential Artificial Intelligence Applications, Proceedings of Westex-88 Conference on Expert Systems, Anaheim, CA.

Horn, J. A. (1989). A theory-based methodology for analyzing domain suitability for expert systems technology applications. Masters thesis, Wright State University.

Kidd, A. and Sharpe, W. (1988). Goals for expert systems research: Analysis of tasks and domains. In D. Moralee (Ed.), *Research and Development in Expert Systems IV*. Cambridge: Cambridge University Press, 146-152.

Kolodner, J. (1984). Towards an understanding of the role of experience in the evolution from novice to expert. In M. Coombs, (Ed.), *Developments in Expert Systems*. London: Academic Press, 95-116.

Lapin, L. L. (1973). *Statistics for Modern Business Decisions*. New York: Harcourt Brace Jovanovich, Inc.

Lenorovitz, D.R., Phillips, M.D., Ardrey, R.S. and Kloster, G.V. (1984). Taxonomic approch to characterizing human-computer interfaces, Human Factors Society, Proceedings of the First U.S.A-Japan Conference on Human-Computer Interaction.

Lippmann, R. P. (1987). An introduction to computing with neural nets. IEEE ASSP, April 1987, 4-22.

Lodge, M. (1984). *Magnitude Scaling Quantitative Measurements of Opinions*. New York: Sage Publications.

Luger, G. F. and Stubblefield, W. A. (1987). *Artificial Intelligence and the Design of Expert Systems*. Tokyo: Benjamin/Cummings Publishing.

McClelland, J. L. and Rumelhart, D. E. (1988). *Explorations in Parallel Distributed Processing*. Cambridge, Massachusetts: MIT Press.

Meeker, M. (1969). *The Structure of Intellect: Its Interpretation and Uses*. Columbus, OH: Charles E. Merrill Publishing Company.

Pham, D. T. (1985). *Expert Systems in Engineering*. New York: IFS Publications.

Prerau, D. (1985). Selection of an appropriate domain for an expert system. The AI Magazine, Summer, 26-30.

Prerau, D. (1989). Choosing Expert System Domains. In G. Guida and C. Tasso (Eds.), *Topics in Expert System Design*. North-Holland: Elsevier Science Publishers, B.V., 27-43.

Schaefer, H. H. (1966). *Topological Vector Spaces.* New York: MacMillan Company.

Spearman, C. (1904). "General Intelligence," objectiveley determined and measured. American Journal of Psychology, 15, 201-293.

Thurstone, L. (1938). Primary mental abilities. Psychometric Monographs, 1.

Waterman, D. (1986). *A Guide to Expert Systems.* Reading, Massachusetts: Addison-Wesley Publishing Company, Inc.

Wickens, C. D. (1988). Componential analysis of pilot decision making. Technical Report AAMRL-TR-88-017, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson AFB OH.

Wolfgram, D. D., Dear, T. J., Galbraith, C. S. (1987). *Expert Systems for the Technical Professional.* New York: John Wiley and Sons.

Woods, D. D. and Hollnagel, E. (1988). *Mapping Cognitive Demands in Complex Problem Solving Worlds, Knowledge-Based System, Vol. 1.* London: Academic Press.

APPENDICES

A. STRUCTURED INTERVIEW WITH KNOWLEDGE ENGINEERS

STRUCTURED SURVEY FOR KNOWLEDGE ENGINEERS

Interviewer's Question sheet

I. INTRODUCTION

Explain to the KE the general purpose of this project.

There are no theoretically based, empirically established methods for determining suitability for applying rule-based expert systems technology. While several ad hoc guidelines have been proposed, at best, they provide only general guidelines for determining if a domain can benefit from rule-based implementations of expert systems technology.

The goal of this project is to develop A methodology which allows the knowledge engineer (or program manager) to accurately determine the degree of success achievable by pursuing an expert systems technology solution in a particular problem domain.

Review some definition of the terms that we will be using (domain,evaluation tool,ect.)

Make note of the recording device(taping the interview so as to better retain the additional comments.)

Explain the DSAT model and Jay thesis project.

The procedures necessary to perform an accurate evaluation of potential application domains for expert systems technology using the theory-based model have been integrated to create the Domain Suitability Analysis Tool (DSAT) The DSAT has been designed to be both theoretically valid and operationally efficient. The DSAT is designed to describe the domain information elements (based on the SOI model) as revealed by the domain expert and then produce a recommendation on the support provided by expert systems technology for those information elements.

Explanation of the Guilford, Structure of Intellect (SOI) model.

Show the Guilford Cube (figure 1)

This model attempts to define human cognition and intelligence. It falls under the category of a Psychometric theory of intelligence. Psychometric theory is based on separating human cognition and intelligence into different factors or elements.

As the list of factors began to mount, several similarities and differences became apparent. Some factors could be grouped based on the mental processes involved, such as cognition, memory, and evaluation. Others could be segregated based on the information used; symbolic, semantic, or visual, for example. A third dimension involved the form of the information used; units, classes, or relations, for example.

The resulting cubic figure that encompasses these dimensions is the Structure-of-Intellect (SOI) model (Guilford,1967,1985). The figure shows the SOI model with its three dimensions : operation, contents, and products. This model illustrates the focus of psychometric theories on cataloging and systematically identifying the components of intelligence and cognitive behavior.

II. EXPERIENCE OF THE KNOWLEDGE ENGINEER

A. Domains

1. What domains (i.e. what kinds of problems/fields) are you familar with working with in the development of expert systems?

2. What similarities do you see in problems which can be addressed by expert systems?

3. What aspects of the problem domains would you say are the most important to address in order to assure that the expert system is workable.

B. Expert systems

1. What expert systems have you worked on?

   Please list the system by name and give a short description of the system and how well it performs. Include systems which did not work out as well as successful systems.

2. What, if any, evaluation tools were used to make decisions about whether or not to undertake the expert systems.

C. Areas of resonsibility

Which of these areas have you participated in when developing experts systems.

(Please note the area and give a short explanation.)

1. Systems feasibility evaluation

2. Knowledge elicitation

3. System development / implementation

D. Success / Failure

1) From your experience what about a problem domain would tend to indicate to you that an expert system can be developed in that domain.

2) From your experience what about a problem domain would tend to indicate to you that an expert system can not be developed in that domain.

E. General

1. Years of experience total in technical field.

2. Years of experience in working with expert systems.

3. Educational background

a. General

b. Expert Systems

III. Description of some expert systems worked on.

(For each of the Expert Systems discussed.)

1. Described the results of the development effort in terms of:

a. Likelihood of completion/success

b. Difficulty

c. Resources

1) K. E. 's
2) Domain Experts
3) System programmer

2. Describe or relate any key or unique lessons learned in the development of these expert systems.

3. Describe as best as you can the problem (domain) for which this expert system was designed in terms of the Structure of Intellect model.

4. What element elements within the model would require the greatest expenditure of resources in implementing.

5. Knowledge availability is very important to the development of expert systems. What elements or patterns would show you, as a knowledge engineer, that you would be able to get the important information from the domain experts?

End of the First day..

A)

1. Review the purpose of the project.

2. Review the Structure of intellect model.

3. Go over the contents of the second part of the survey.

B)

In the next section of the document you have an explanation of the contents and products of the Structure of Intellect model. Please look over this explanation and think about how expert systems capabililes could best be described in the context of the Structure of Intellect model.

IV. Description of Expert systems characteristics in terms of the Structure of intellect model.

(Define Buildability as: The function relating the domain problem to the current ability of expert systems to perform these tasks)

1. In order of importance rank the Operators in influence over the buildability of an expert system.

2. In order of importance rank the Contents influence over the buildability of an expert system.

3. In order of importance rank the Products influence over the buildability of an expert system.

4. In order of importance rank the Dimension elements influence over the buildability of an expert system.

5. How would you describe the attributes of an expert system which allow it to solve a problem in a given domain space?

6. What factors would you say are the most deterministic to the development of an expert systems, in terms of the Structure of Intellect model?

7. What factors would you say are most important to determining the difficulty of developing a system?

8. What factors would you say are most important to determining the level of resources needed in the development of an expert system?

V. Analysis of the Structure of Intellect elements in the developing an Expert System (Influence of Individual elements)

Going down the list of individual elements of the SOI model evaluate each element on a scale from 1-7 as to the element's importance to the difficulty of implementing an expert system.

Note; 7 being the most important , 1 having no influence on the problem or system.

(see answer sheet)

VI. Analysis of the ability of an expert system to perform tasks from the SOI model

Going down the list of individual elements of the SOI model, evaluate each element on a scale from 1 to 7 as to whether an expert system could easily perform this kind of task.

Note; 7 being difficult to perform
1 being very easy to perform

(see answer sheet)

VII. Other Issues

1. Desired output

a. What information would be of most use to you in evaluating a domain or problem for an expert system development?

b. In what format would you prefer to see this information presented?

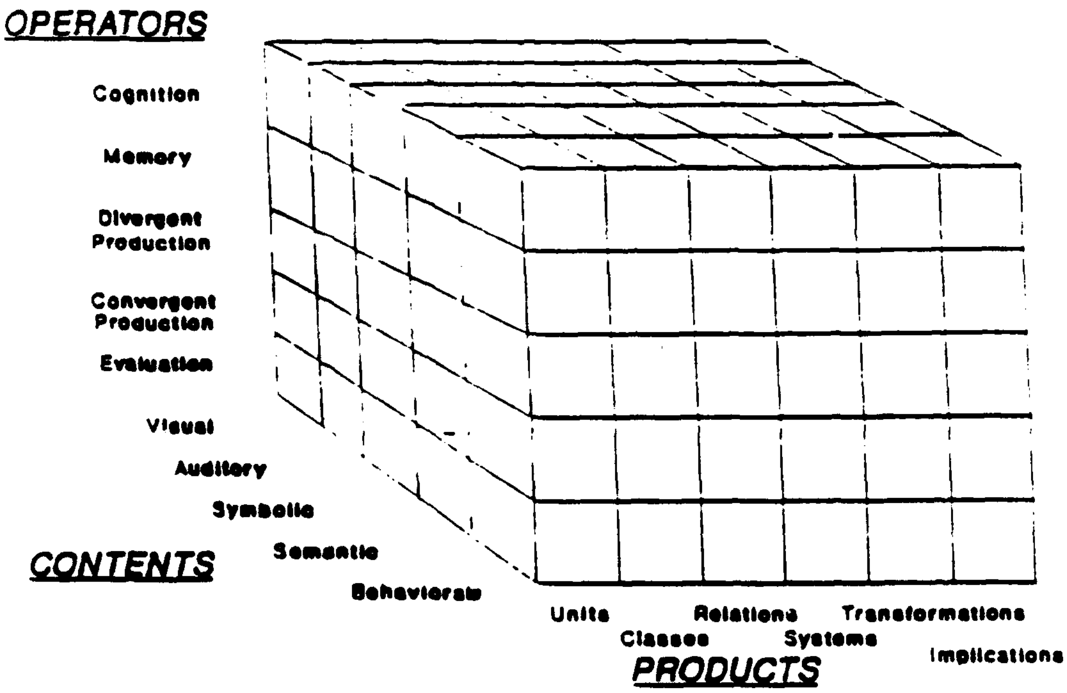
2. Critical Element Analysis

3. Flexibility

4. Additional Comments on Expert Systems:

5. Additional Comments on this project:

6. Additional Comments on this survey:



The Structure of Intellect Cube (Guilford, 1967; 1985).

Figure 1

KNOWLEDGE ENGINEER SURVEY

SECTION I INTRODUCTION

In this survey you will be asked to evaluate the capabilities of Expert systems to solve problems.

The way in which you will evaluate these capabilities is to evaluate the ability of expert systems to perform given kinds of tasks.

These tasks are defined by Guilford in his Structure of Intellect model. This model is used to describe elements of operator task domains.

See Figure 1 The Structure of Intellect Cube

SECTION II EXPERIENCE OF THE KNOWLEDGE ENGINEER

A. Domains

1. ________________________________

2. Similarities ____________________

3. Aspects ________________________

B. Expert Systems

1.

2.

C. Areas of Responsiblilty

1.

2.

3.

D. Successes / Failure

1.

2.

E. General

1.

2.

3a.

3b.

SECTION III DESCRIPTION OF SOME EXPERT SYSTEMS WORKED

1a.

1b.

1c.

1)

2)

3)

2.

3.

4.

Explanation / Examples to describe the elements of the SOI model.

In the following sections there is an explanation of the contents and products of the Structure of Intellect model. As you read over these examples and explanations, try to think about how these elements relate to the ability of an expert system to solve problems in a specific domain which includes the sections of the SOI model which is being explained.

Please feel free to make notations in your sheets that might help you answer questions later.

SECTION IV. DESCRIPTION OF EXPERT SYSTEMS CHARACTERISTICS IN TERMS OF THE STRUCTURE OF INTELLECT MODEL

STRUCTURE OF INTELLECT DOMAIN

1) Operators

a. Cognition 1 ____

b. Memory 2 ____

c. Divergent Production 3 ____

d. Convergent Production 4 ____

e. Evaluation 5 ____

2) Contents

a. Visual 1 ____

b. Auditory 2 ____

c. Symbolic 3 ____

d. Semantic 4 ____

e. Behavioral 5 ____

3) Products

a. Units 1 ____

b. Classes 2 ____

c. Relations 3 ____

d. Systems 4 ____

e. Transformations 5 ____

f. Implications 6 ____

4) Dimensions

a. Frequency — 1 ______

b. Criticality — 2 ______

c. Difficulty — 3 ______

d. Flexibility — 4 ______

5.

6.

7.

8.

SECTION V. ANALYSIS OF THE STRUCTURE OF STRUCTURE ELEMENTS IN DEVELOPING AN EXPERT SYSTEM (INFLUENCE IF INDIVIDUAL ELEMENTS)

Elements	Importance
VISUAL CONTENTS	______
Visual Units	______
Visual Classes	______
Visual Relations	______
Visual Systems	______
Visual Transformations	______
Visual Implications	______
AUDITORY CONTENTS	______
Auditory Units	______
Auditory Classes	______
Auditory Relations	______
Auditory Systems	______
Auditory Transformations	______
Auditory Implications	______
SYMBOLIC CONTENTS	______

Symbolic Units ______

Symbolic Classes ______

Symbolic Relations ______

Symbolic Systems ______

Symbolic Transformations ______

Symbolic Implication ______

SEMANTIC CONTENTS ______

Semantic Units ______

Semantic Classes ______

Semantic Relations ______

Semantic Systems ______

Semantic Transformations ______

Semantic Implications ______

BEHAVIORAL CONTENTS ______

Behavioral Units ______

Behavioral Classes ______

Behavioral Relations ______

Behavioral Systems ______

Behavioral Transformations ______

Behavioral Implications ______

SECTION VI. ANALYSIS OF ABILITY OF EXPERT SYSTEMS TO PERFORM TASKS FORM THE SOI MODEL

Elements	Difficulty
VISUAL CONTENTS	________
Visual Units	________
Visual Classes	________
Visual Relations	________
Visual Systems	________
Visual Transformations	________
Visual Implications	________
AUDITORY CONTENTS	________
Auditory Units	________
Auditory Classes	________
Auditory Relations	________
Auditory Systems	________
Auditory Transformations	________
Auditory Implications	________
SYMBOLIC CONTENTS	________
Symbolic Units	________
Symbolic Classes	________
Symbolic Relations	________
Symbolic Systems	________
Symbolic Transformations	________
Symbolic Implication	________
SEMANTIC CONTENTS	________
Semantic Units	________
Semantic Classes	________
Semantic Relations	________
Semantic Systems	________
Semantic Transformations	________

Semantic Implications ________

BEHAVIORAL CONTENTS ________

Behavioral Units ________

Behavioral Classes ________

Behavioral Relations ________

Behavioral Systems ________

Behavioral Transformations ________

Behavioral Implications ________

SECTION VII. OTHER ISSUES

1a.

1b.

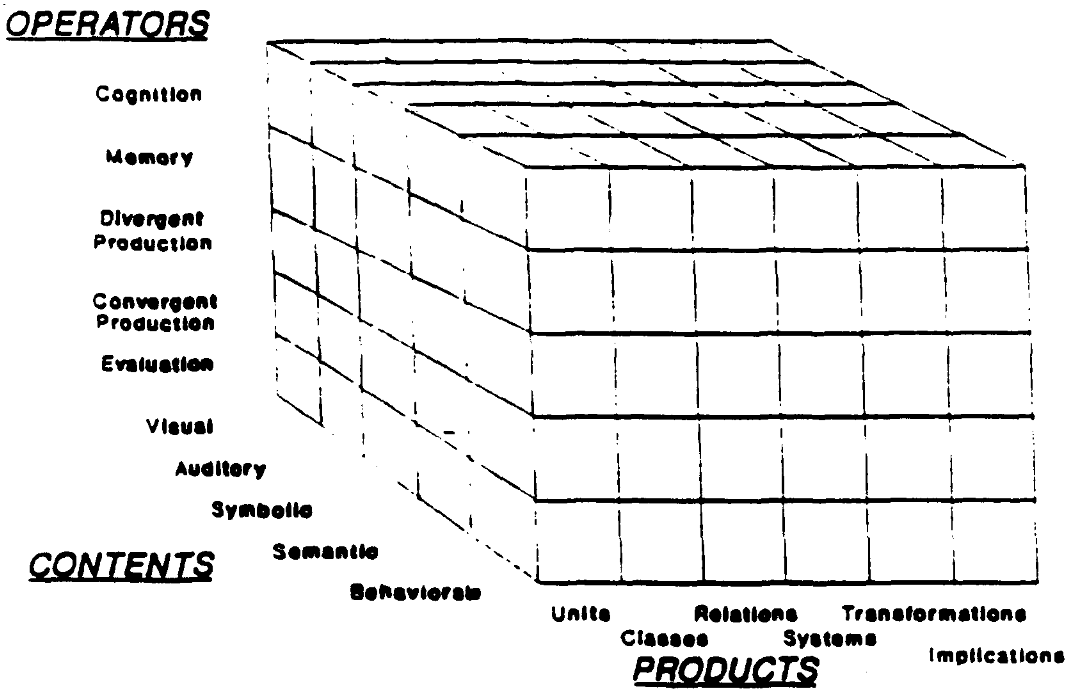
2.

3.

4. Comments:

5. Comments:

6. Comments:



The Structure of Intellect Cube (Guilford, 1967; 1985).

Figure 1

A.1 RESULTS OF KNOWLEDGE ENGINEER SURVEY

SECTION IV. DESCRIPTION OF EXPERT SYSTEMS CHARACTERISTICS IN TERMS OF THE STRUCTURE OF INTELLECT MODEL

STRUCTURE OF INTELLECT DOMAIN

1) Operators

a.	Cognition	1 __d___
b.	Memory	2 __b___
c.	Divergent Production	3 __a___
d.	Convergent Production	4 __e___
e.	Evaluation	5 __c___

2) Contents

a.	Visual	1 __c___
b.	Auditory	2 __d___
c.	Symbolic	3 __e___
d.	Semantic	4 __a___
e.	Behavioral	5 __b___

3) Products

a.	Units	1 __b___
b.	Classes	2 __a___
c.	Relations	3 __d___
d.	Systems	4 __c___
e.	Transformations	5 __e___
f.	Implications	6 __f___

4) Dimensions

a.	Frequency	1 __a___
b.	Criticality	2 __d___
c.	Difficulty	3 __c___
d.	Flexibility	4 __b___

SECTION V. ANALYSIS OF THE STRUCTURE OF STRUCTURE ELEMENTS IN DEVELOPING AN EXPERT SYSTEM (INFLUENCE IF INDIVIDUAL ELEMENTS)

Elements	Importance
VISUAL CONTENTS	1
Visual Units	1
Visual Classes	1
Visual Relations	1
Visual Systems	1
Visual Transformations	1
Visual Implications	1
AUDITORY CONTENTS	2
Auditory Units	1
Auditory Classes	2
Auditory Relations	1
Auditory Systems	1
Auditory Transformations	2
Auditory Implications	2
SYMBOLIC CONTENTS	6

Symbolic Units	6
Symbolic Classes	6
Symbolic Relations	7
Symbolic Systems	6
Symbolic Transformations	5
Symbolic Implication	6
SEMANTIC CONTENTS	6
Semantic Units	4
Semantic Classes	3
Semantic Relations	5
Semantic Systems	6
Semantic Transformations	7
Semantic Implications	7
BEHAVIORAL CONTENTS	2
Behavioral Units	1
Behavioral Classes	2
Behavioral Relations	2
Behavioral Systems	1
Behavioral Transformations	2
Behavioral Implications	1

SECTION VI. ANALYSIS OF ABILITY OF EXPERT SYSTEMS TO PERFORM TASKS FORM THE SOI MODEL

Elements	Difficulty
VISUAL CONTENTS	6
Visual Units	5
Visual Classes	7
Visual Relations	6
Visual Systems	7
Visual Transformations	7
Visual Implications	6
AUDITORY CONTENTS	7
Auditory Units	7
Auditory Classes	7
Auditory Relations	6
Auditory Systems	7
Auditory Transformations	7
Auditory Implications	6
SYMBOLIC CONTENTS	1
Symbolic Units	1
Symbolic Classes	1
Symbolic Relations	1
Symbolic Systems	1
Symbolic Transformations	2
Symbolic Implication	1
SEMANTIC CONTENTS	6
Semantic Units	4
Semantic Classes	5
Semantic Relations	4
Semantic Systems	7
Semantic Transformations	7

Semantic Implications	7
BEHAVIORAL CONTENTS	7
Behavioral Units	7
Behavioral Classes	7
Behavioral Relations	6
Behavioral Systems	6
Behavioral Transformations	7
Behavioral Implications	7

B. CRITICAL ELEMENT SURVEY

CRITICAL ELEMENT SURVAY

The purpose of this questionnaire is to obtain additional information about some key parts of the model of the domain which we are studying.

For each of the Critical Elements identified by the excursion analysis algorithm please answer the following questions.

When answering these questions please try to limit your responses to the one part of the model that we are investigating at that time.

What about this part of the overall domain task makes it important in successfully completing the domain task?

A.1 What is the influence of this part of the domain over the systems solution in terms of likelyhood of success?

A.2 What is the influence of this part of the domain over the systems solution in terms of the difficulty of the domain?

A.3 What is the influence of this part of the domain over the systems solution in terms of the resources required?

B.1 How critical is this part of the domain to the overall success of the project is this part of the task?

B.2 Flexibility: can this part of the domain be implemented or performed in some other way? If it can please describe in what other part of the model the task could be preformed?

B.3 How difficult is this part of the domain to preform?

B.4 How frequently is this part of the domain performed in the overall task?

C.1 Is there some agreement on how to do this task?

C.2 Is there some level of agreement on what is a good solution to the domain problems?

C.3 What level of expertise is required to be a ture expert or master in this domain?

C.4 What effect does this part of the overall domain task have on the ability of the systems designers to obtain information about the domain?

C.5 What effect does this part of the over all domain task have on the complexity of modeling or describing the over all task?

C.6 Is this part of the domain well defined?

D.1 Assuming That This part of the domain is difficult for an expert system to perform how difficult is this part of the domain for the human expert to perform?

D.2 If an expert system where to be developed with this part of the domain not addressed would it still be useful to a domain expert in performing in this domain?

D.3 If an expert system where to be developed with this part of the domain not addressed would it still be useful to a domain Novice?

D.4 Do you think you would have more confidence in the usability/performance of an expert system of this part of the domain was addressed by the expert system? Why.

B.1 FIRST PROTOTYPE

Results of the First prototype of the Critical Element Survey
Domain is Mission Planning
Element is Cognition of Behavioral Units

CRITICAL ELEMENT SURVEY

The purpose of this questionnaire is to obtain additional information about some key parts of the model of the domain which we are studying.

For each of the Critical Elements identified by the excursion analysis algorithm please answer the following questions.

When answering these questions please try to limit your responses to the one part of the model that we are investigating at that time.

What about this part of the overall domain task makes it important in successfully completing the domain task?

Ans. Subject would miss or unintentionally read an observed expression and misinterpret the data. This could drive the domain expert to include or exclucle pertinent or questionable data thereby skewing the outcome.

A.1 What is the influence of this part of the domain over the systems solution in terms of likelyhood of success?

Ans. If recognized, this error can be corrected.

A.2 What is the influence of this part of the domain over the systems solution in terms of the difficulty of the domain?

Ans. Can influence systems solutions on rare occasions

A.3 What is the influence of this part of the domain over the systems solution in terms of the resources required?

Ans. Can influence the whole span of the solution.

B.1 How critical is this part of the domain to the overall success of the project is this part of the task?

Ans. Possibility exists, that if (1) unrecognized and given a high probability of happening against a critical event, Then the outcome (2) could be critical. Otherwise, as an exact opposite to this case.

B.2 Flexibility: can this part of the domain be implemented or performed in some other way? If it can please describe in what other part of the model the task could be preformed?

Ans. Yes, verbally

B.3 How difficult is this part of the domain to preform?

Ans. Easy

B.4 How frequently is this part of the domain performed in the overall task?

Ans. Infrequently

C.1 Is there some agreement on how to do this task?

Ans. Yes

C.2 Is there some level of agreement on what is a good solution to the domain problems?

Ans. No

C.3 What level of expertise is required to be a true expert or master in this domain?

Ans. Moderate

C.4 What effect does this part of the overall domain task have on the ability of the systems designers to obtain information about the domain?

Ans. Minimal

C.5 What effect does this part of the over all domain task have on the complexity of modeling or describing the over all task?

Ans. Possibly no effect

C.6 Is this part of the domain well defined?

Ans. No

D.1 Assuming That This part of the domain is difficult for an expert system to perform how difficult is this part of the domain for the human expert to perform?

Ans. Easy to perform, yet easy to misinterpret.

D.2 If an expert system where to be developed with this part of the domain not addressed would it still be useful to a domain expert in performing in this domain?

Ans. Yes

D.3 If an expert system where to be developed with this part of the domain not addressed would it still be useful to a domain Novice?

Ans. Yes

D.4 Do you think you would have more confidence in the usability/performance of an expert system if this part of the domain was addressed by the expert system? Why.

Ans. No, machines don't smile or frown.

B.2 SECOND PROTOTYPE

Results of the Second prototype of the Critical Element Survey
Domain is Mission Planning
Element is Cognition of Semantic Implications

CRITICAL ELEMENT SURVEY

The purpose of this questionnaire is to obtain additional information about some key parts of the model of the domain which we are studying.

For each of the Critical Elements identified by the excursion analysis algorithm please answer the following questions.

When answering these questions please try to limit your responses to the one part of the model that we are investigating at that time.

What about this part of the overall domain task makes it important in successfully completing the domain task?

Ans. Symbology plays a major role in this task since recognizing, interpreting and using symbols is a basic skill required to perform this task.

A.1 What is the influence of this part of the domain over the systems solution in terms of likelyhood of success?

Ans. Fairly Significant

A.2 What is the influence of this part of the domain over the systems solution in terms of the difficulty of the domain?

Ans. Fairly significant

A.3 What is the influence of this part of the domain over the systems solution in terms of the resources required?

Ans. Little influence

B.1 How critical is this part of the domain to the overall success of the project is this part of the task?

Ans. Fairly significant

B.2 Flexibility: can this part of the domain be implemented or performed in some other way? If it can please describe in what other part of the model the task could be preformed?

Ans. Inflexible

B.3 How difficult is this part of the domain to preform?

Ans. Fairly simple

B.4 How frequently is this part of the domain performed in the overall task?

Ans. Infrequently

C.1 Is there some agreement on how to do this task?

Ans. Well defined

C.2 Is there some level of agreement on what is a good solution to the domain problems?

Ans. Yes

C.3 What level of expertise is required to be a ture expert or master in this domain?

Ans. Beginner to moderate

C.4 What effect does this part of the overall domain task have on the ability of the systems designers to obtain information about the domain?

Ans. Minimal

C.5 What effect does this part of the over all domain task have on the complexity of modeling or describing the over all task?

Ans. My guess is minimal although I unsure of a systems ability to perform this task.

C.6 Is this part of the domain well defined?

Ans. Yes

D.1 Assuming That This part of the domain is difficult for an expert system to perform how difficult is this part of the domain for the human expert to perform?

Ans. Fairly simple

D.2 If an expert system where to be developed with this part of the domain not addressed would it still be useful to a domain expert in performing in this domain?

Ans. Possibly, Domain expert would need to use work around procedures to modify ir correct errors made by expert system.

D.3 If an expert system where to be developed with this part of the domain not addressed would it still be useful to a domain Novice?

Ans. Yes, same reason as D.2

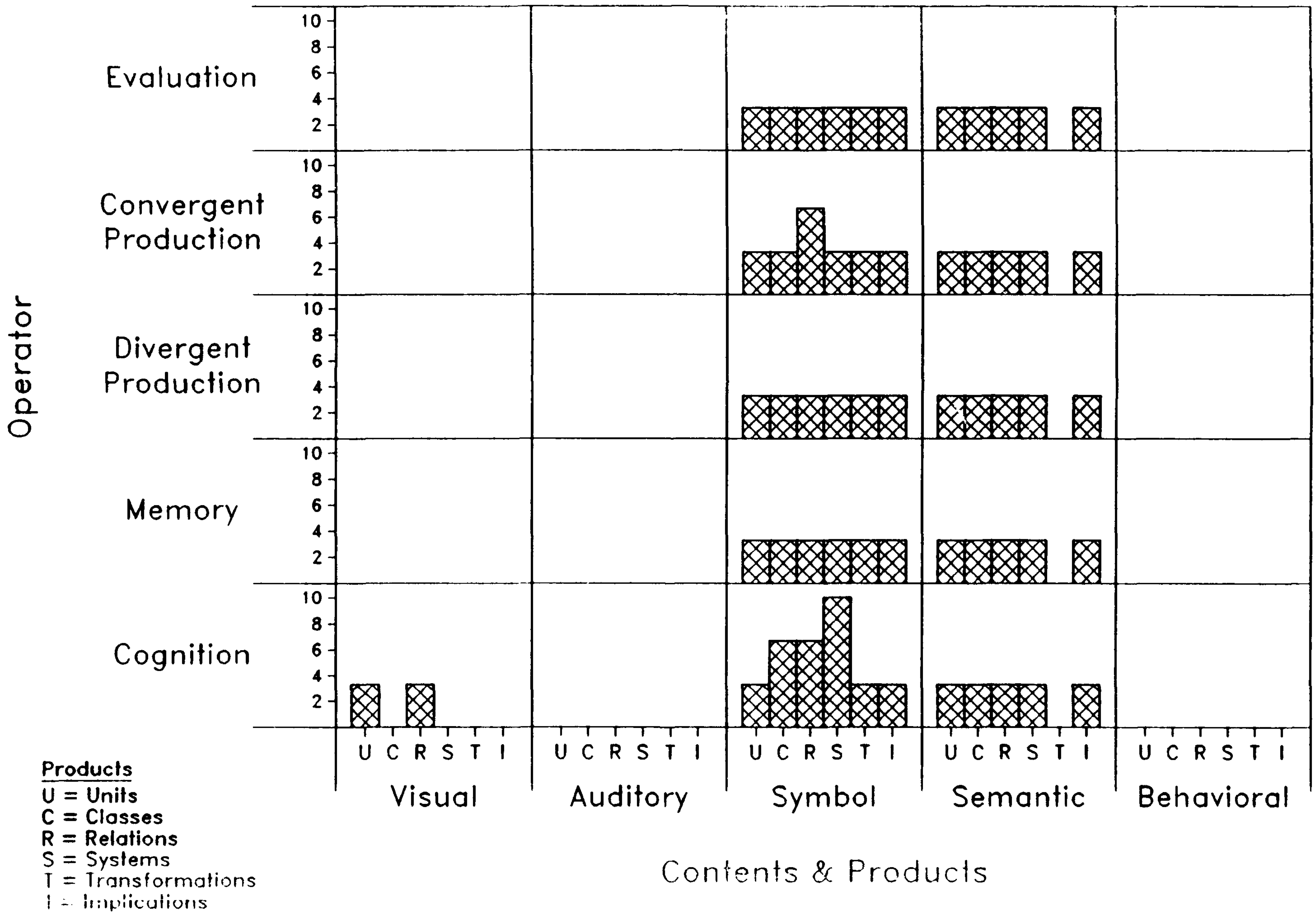
D.4 Do you think you would have more confidence in the usability/performance of an expert system of this part of the domain was addressed by the expert system? Why.

Ans. Yes, Successful recognition and implementation of this part of the domain is critical to the overall success of this portion of the task.

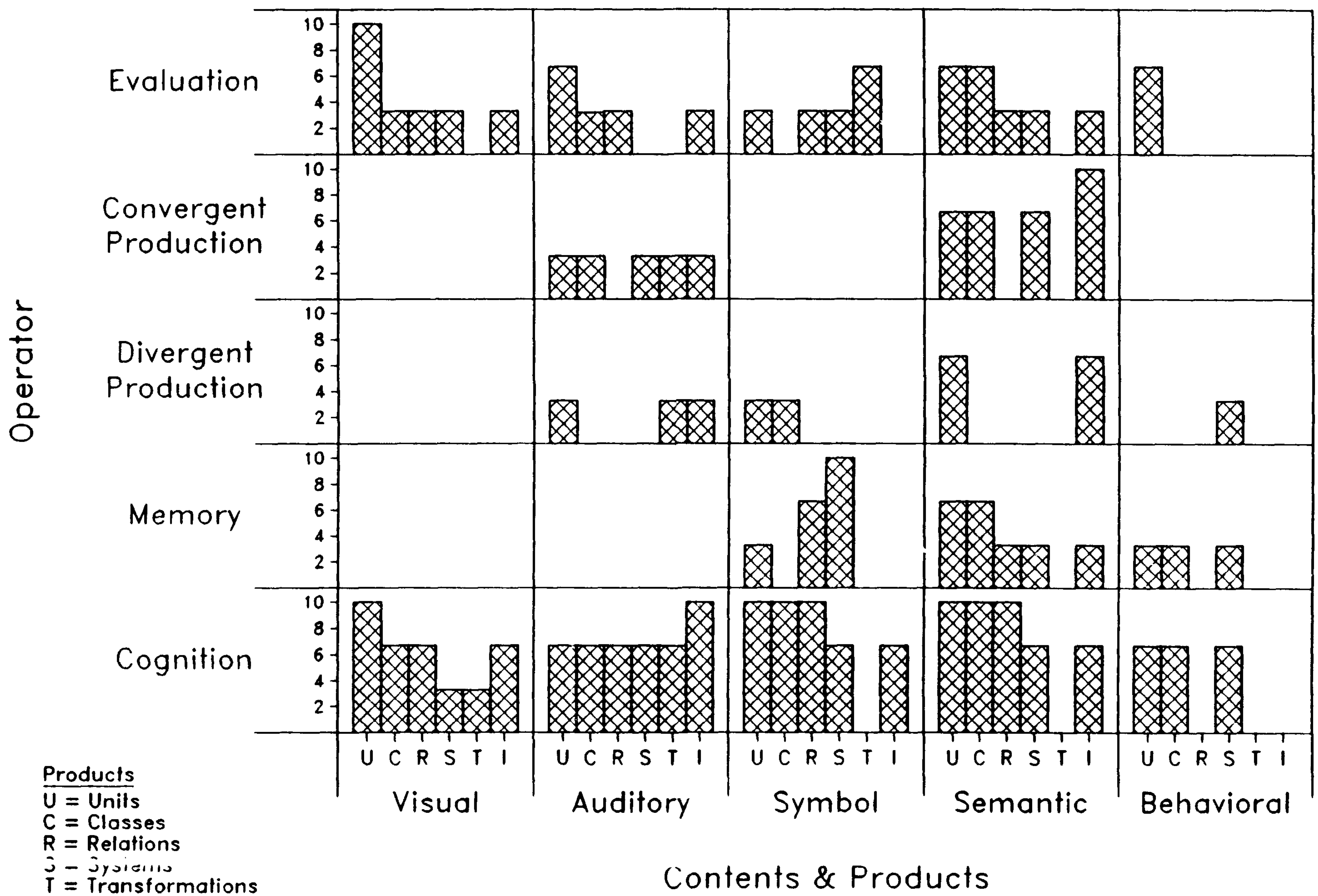
C. DATA ANALYSIS

C.1 REQUIREMENT CHARTS

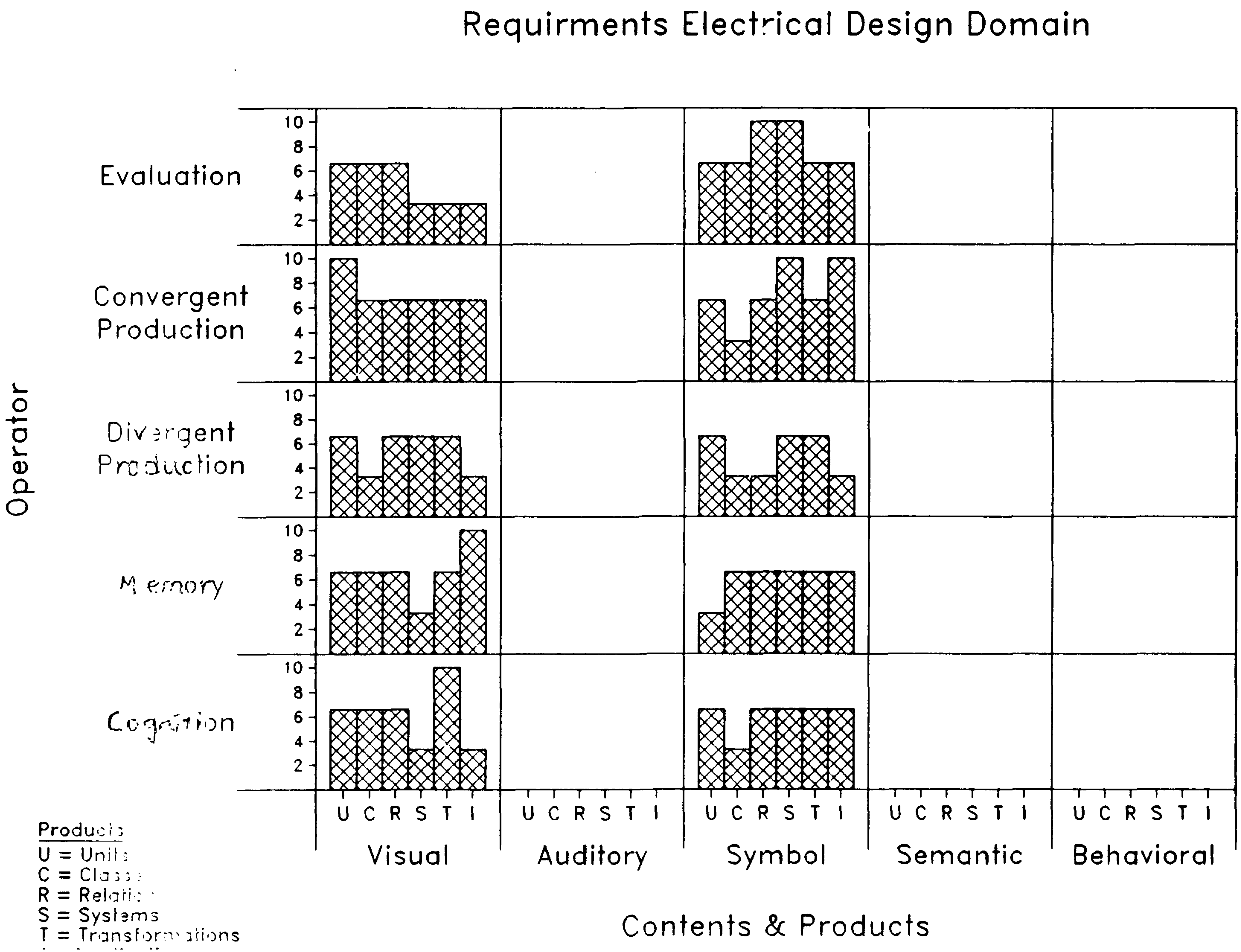
Capability Requirements for Debuging Domain

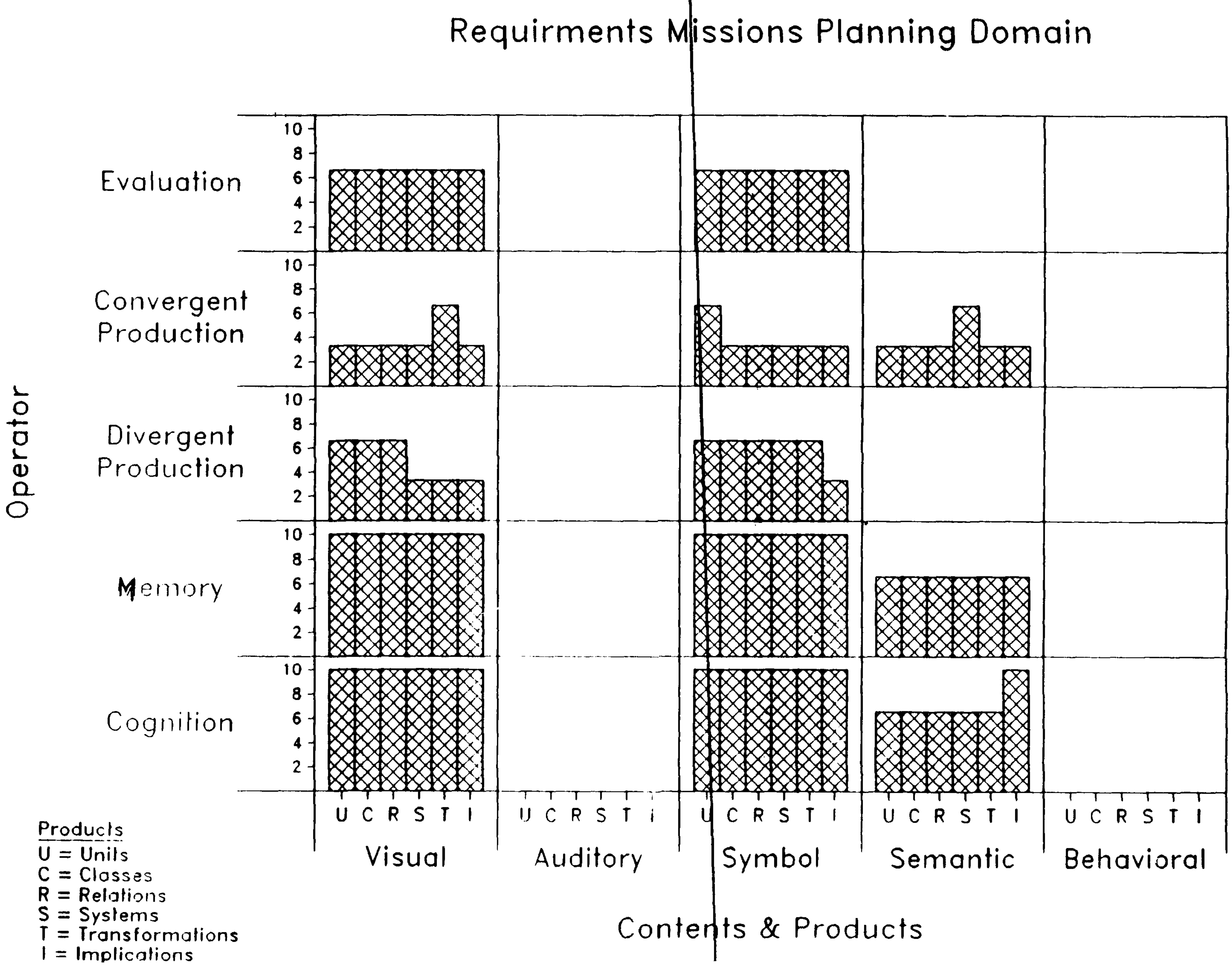


Capability Requirements for Gifted Child Assessmen



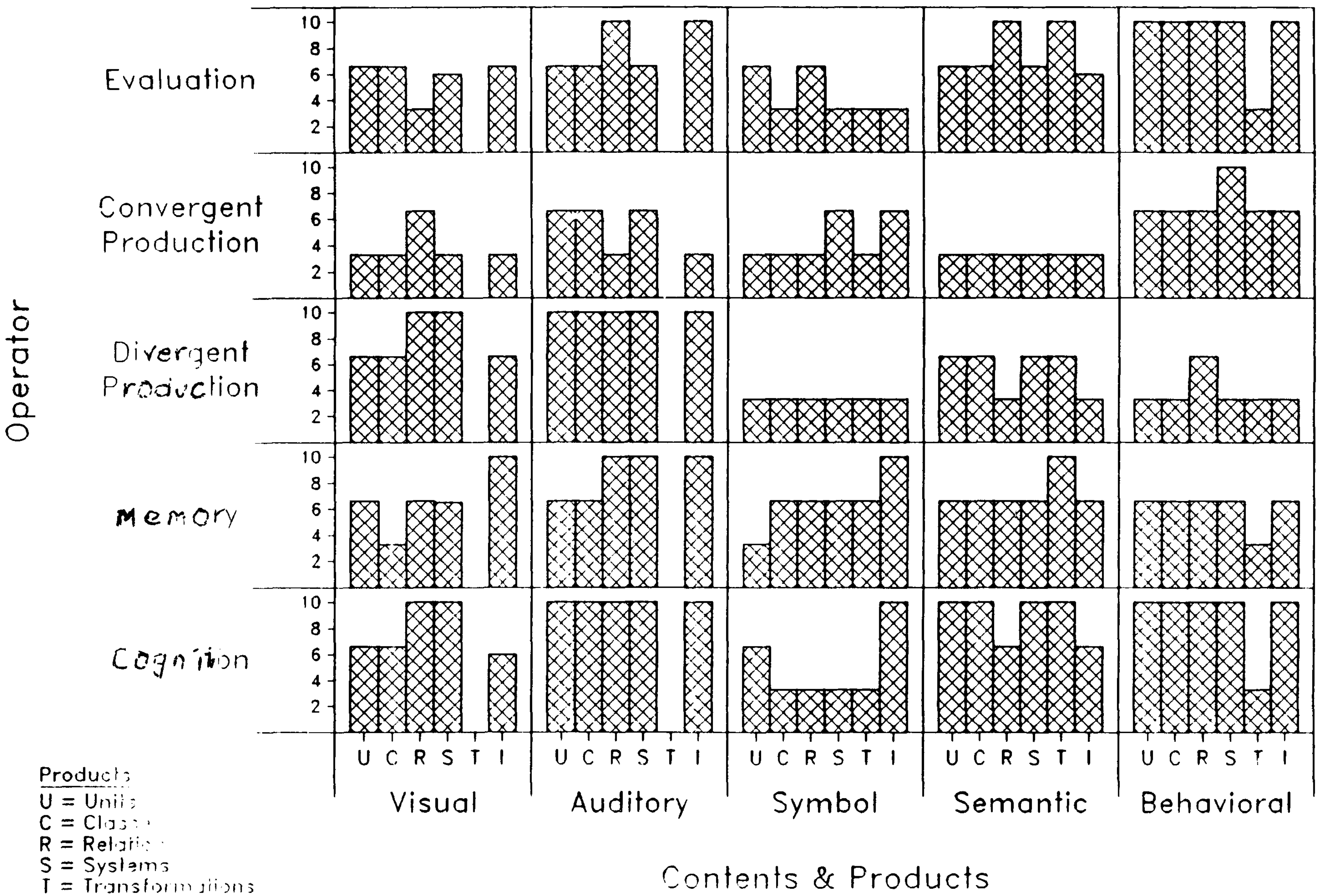
Products
U = Units
C = Classes
R = Relations
S = Systems
T = Transformations
I = Implications

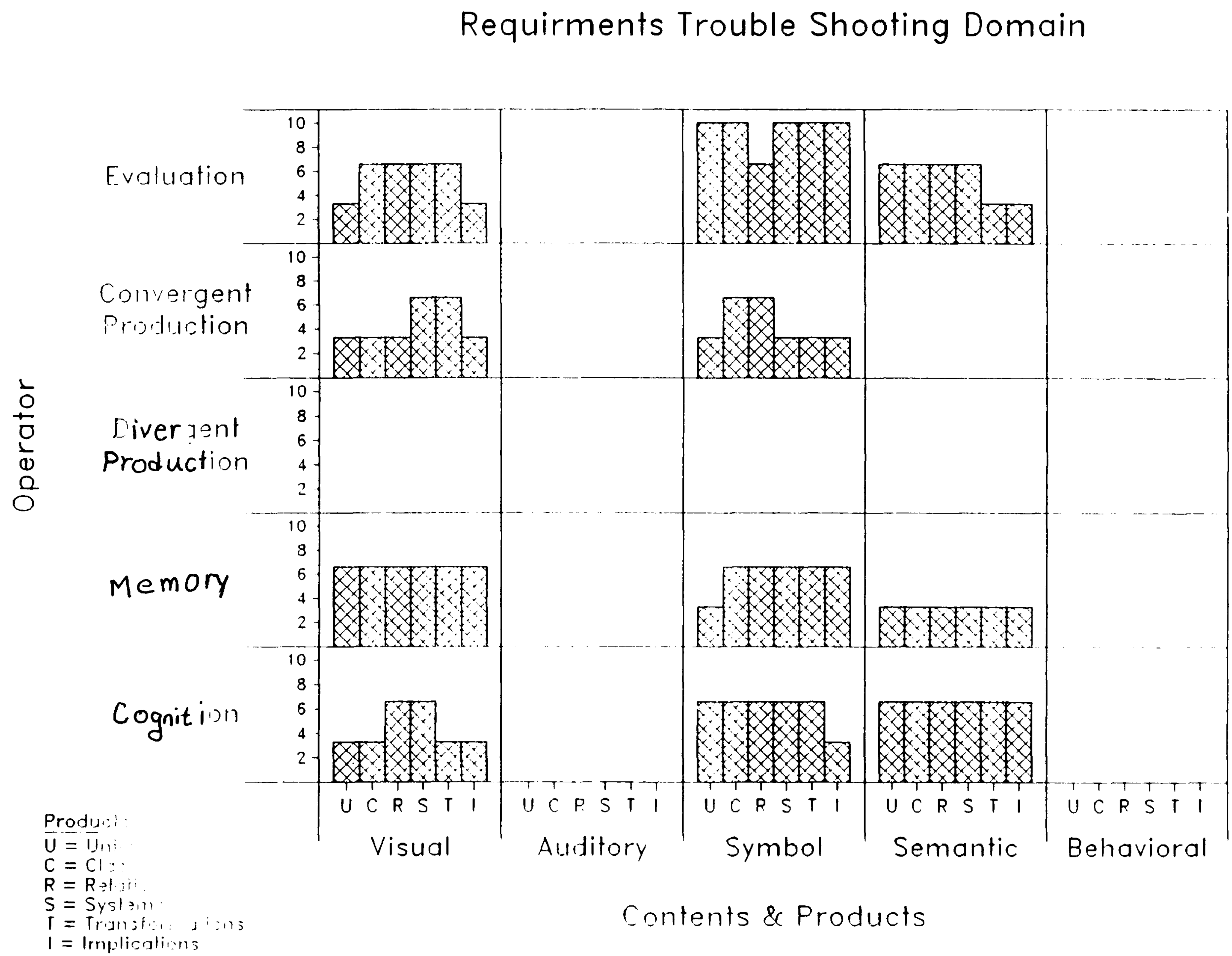

Requirments Electrical Design Domain
Operator
Evaluation
Convergent Production
Divergent Production
Memory
Cognition
10
8
6
4
2
U C R S T I
Visual
Auditory
Symbol
Semantic
Behavioral
Contents & Products
Products
U = Units
C = Class
R = Relatio
S = Systems
T = Transformations



Requirments Missions Planning Domain
Operator
Evaluation
Convergent Production
Divergent Production
Memory
Cognition
10
8
6
4
2
U C R S T I
Visual
Auditory
Symbol
Semantic
Behavioral
Contents & Products
Products
U = Units
C = Classes
R = Relations
S = Systems
T = Transformations
I = Implications

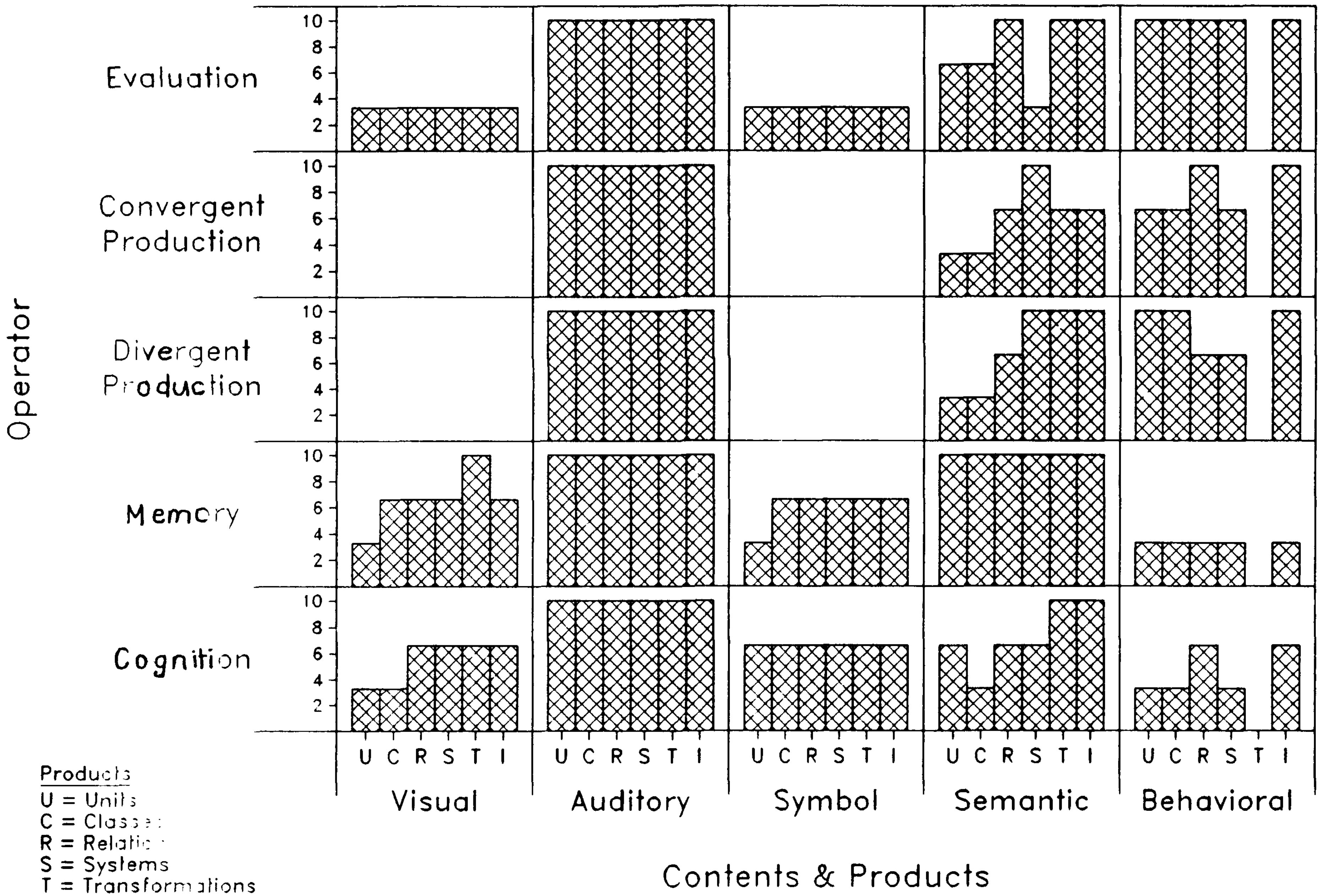
Requirments Medical Dx. Domain

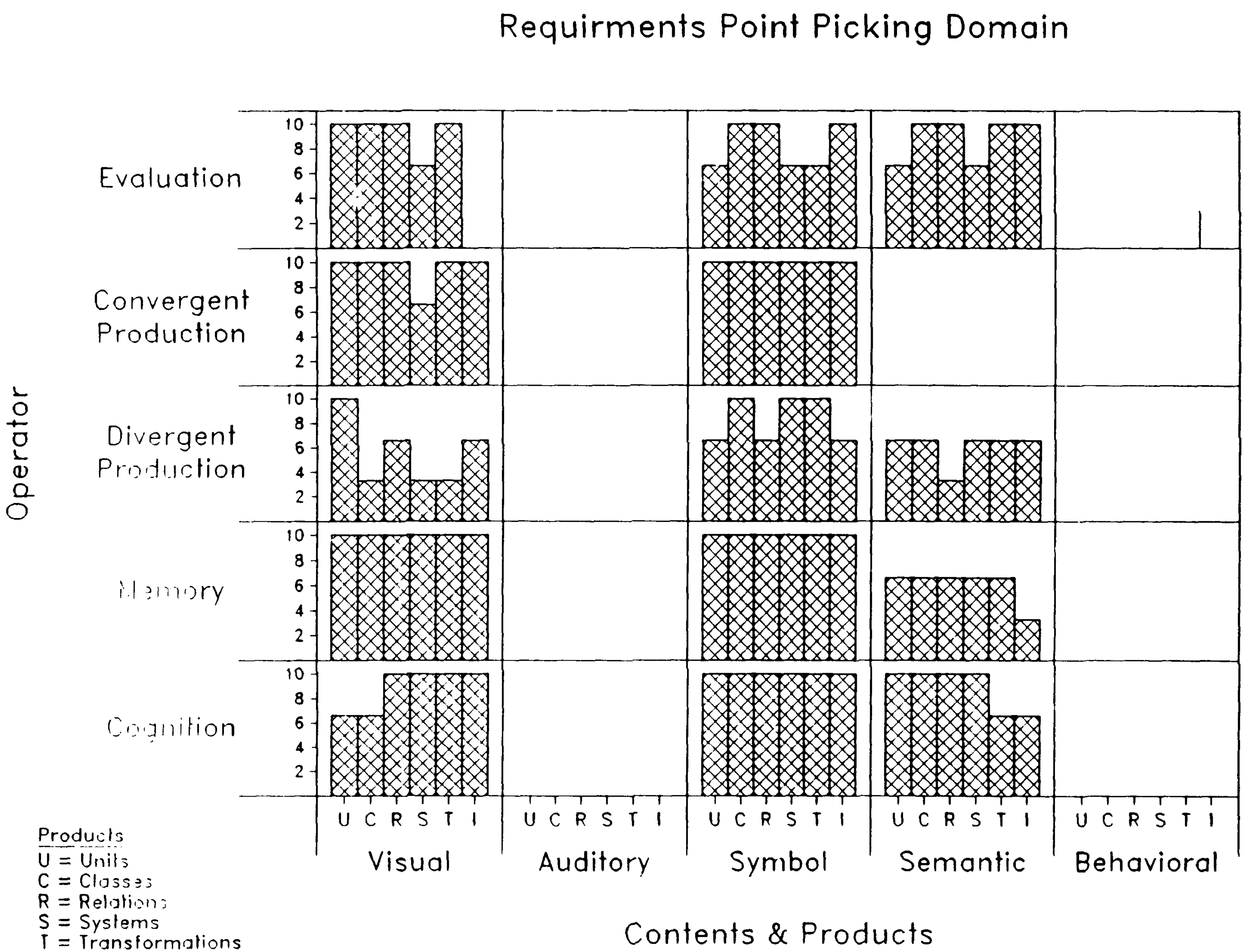




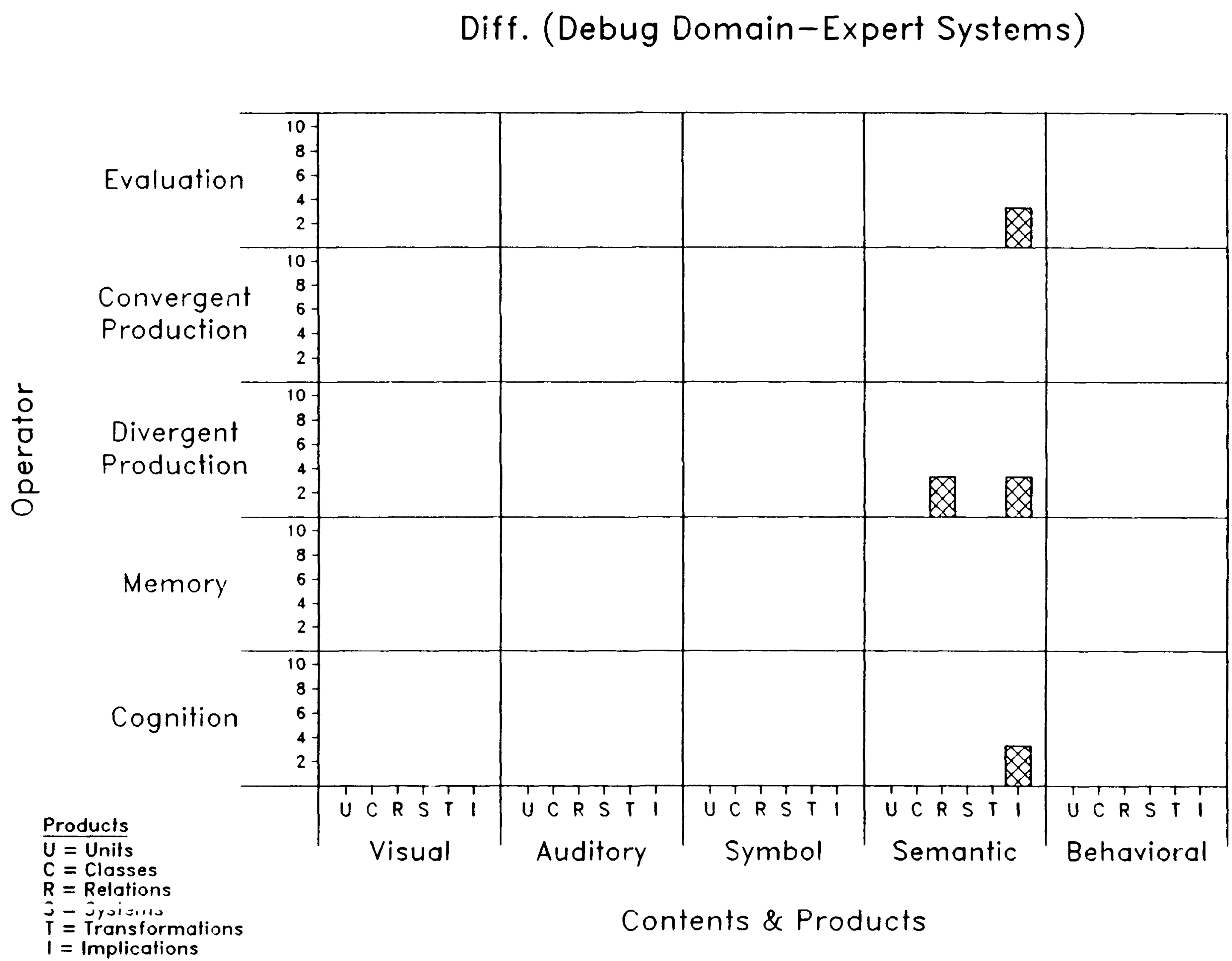
Requirments Trouble Shooting Domain
Evaluation
Convergent Production
Divergent Production
Memory
Cognition
Operator
10
8
6
4
2
U C R S T I
Visual
Auditory
Symbol
Semantic
Behavioral
Contents & Products
Products
U = Units
C = Classes
R = Relations
S = Systems
T = Transformations
I = Implications

Requirments Musical Performance Domain

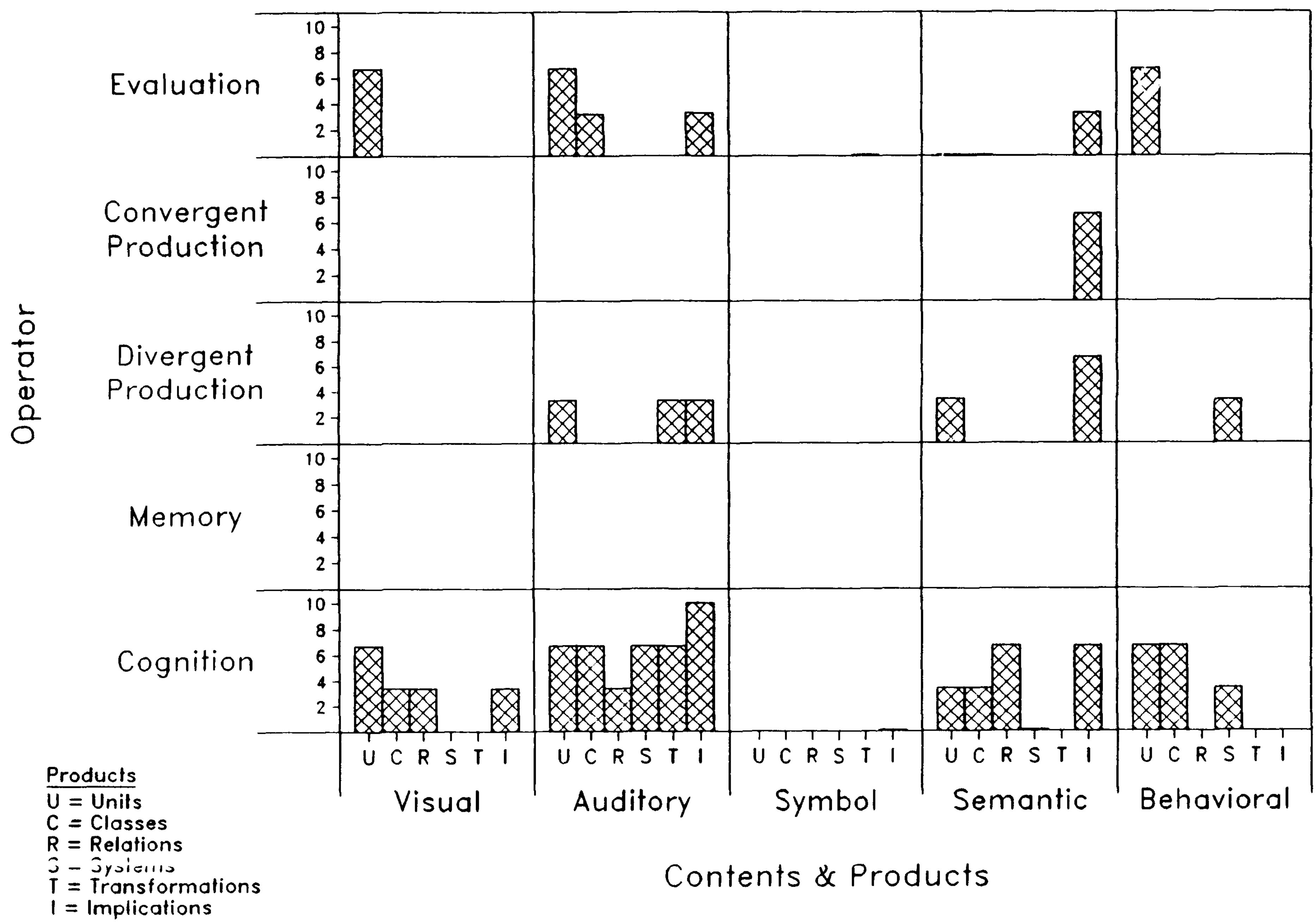


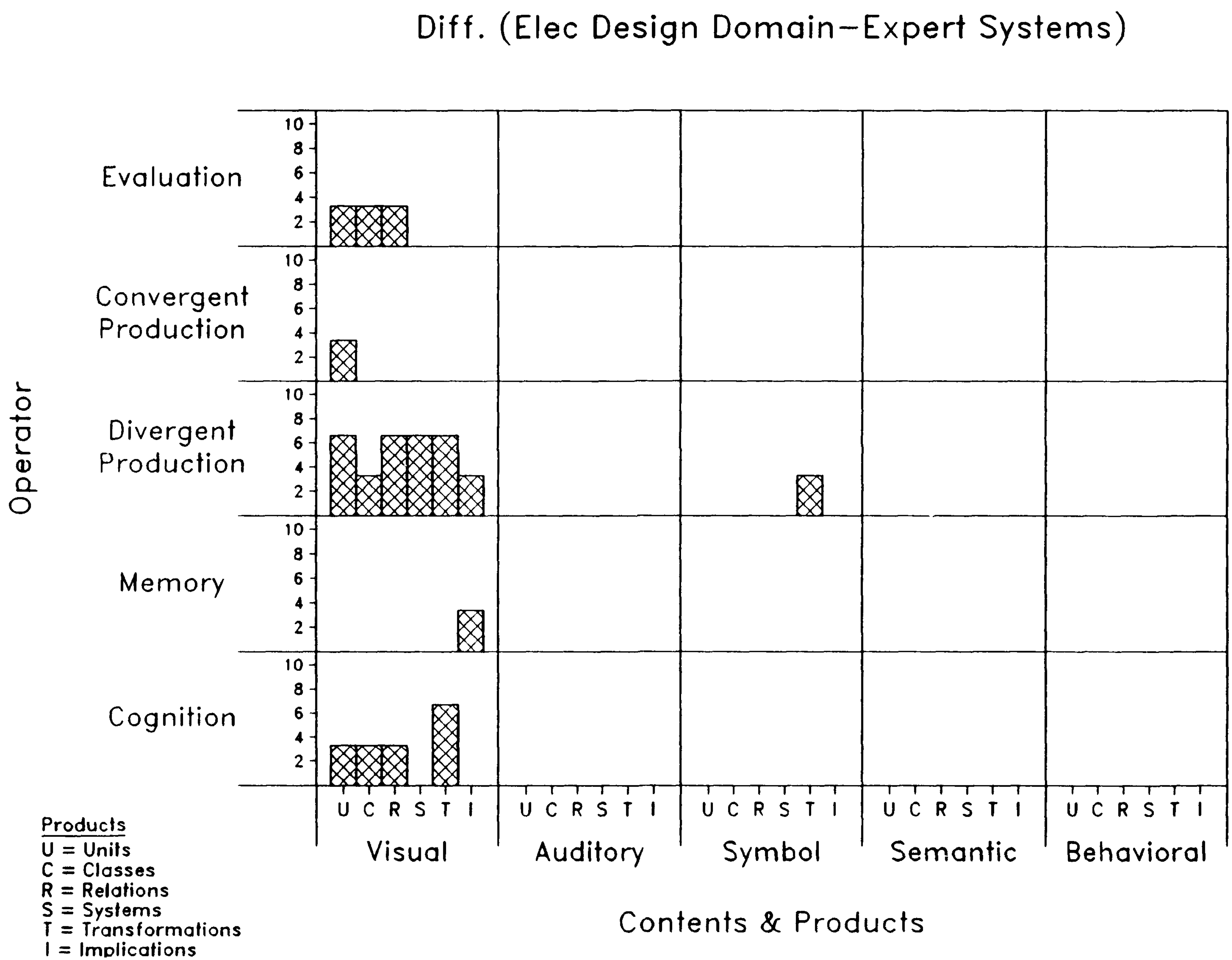

Requirments Point Picking Domain
Operator
Evaluation
Convergent Production
Divergent Production
Memory
Cognition
10
8
6
4
2
U C R S T I
Visual
Auditory
Symbol
Semantic
Behavioral
Contents & Products
Products
U = Units
C = Classes
R = Relations
S = Systems
T = Transformations

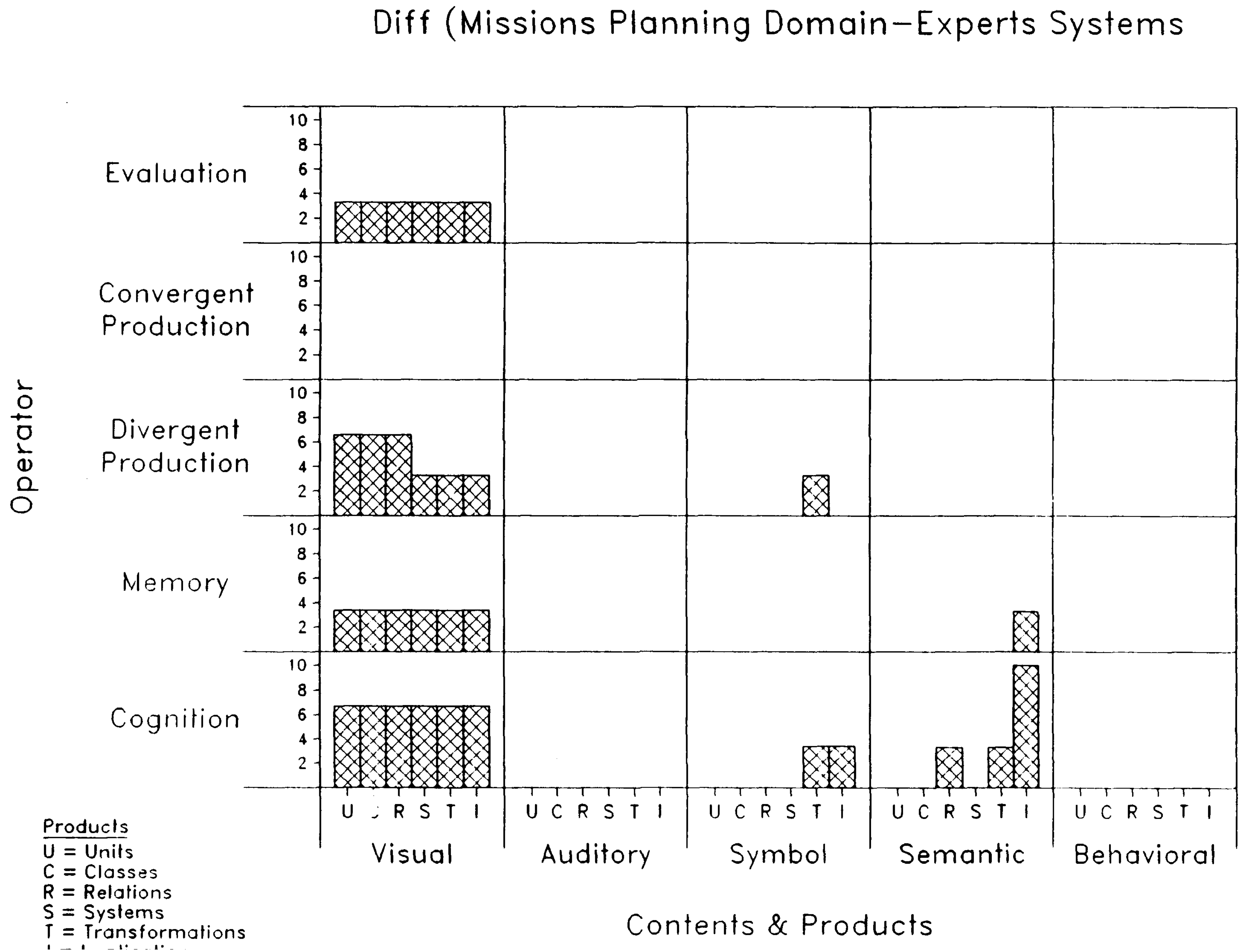
C.2 DIFFERENCE CHARTS


Diff. (Debug Domain–Expert Systems)
Operator
Evaluation
Convergent Production
Divergent Production
Memory
Cognition
10 8 6 4 2
U C R S T I
Visual
Auditory
Symbol
Semantic
Behavioral
Contents & Products
Products
U = Units
C = Classes
R = Relations
T = Transformations
I = Implications

Diff. (Child Assec. Domain–Expert Systems)

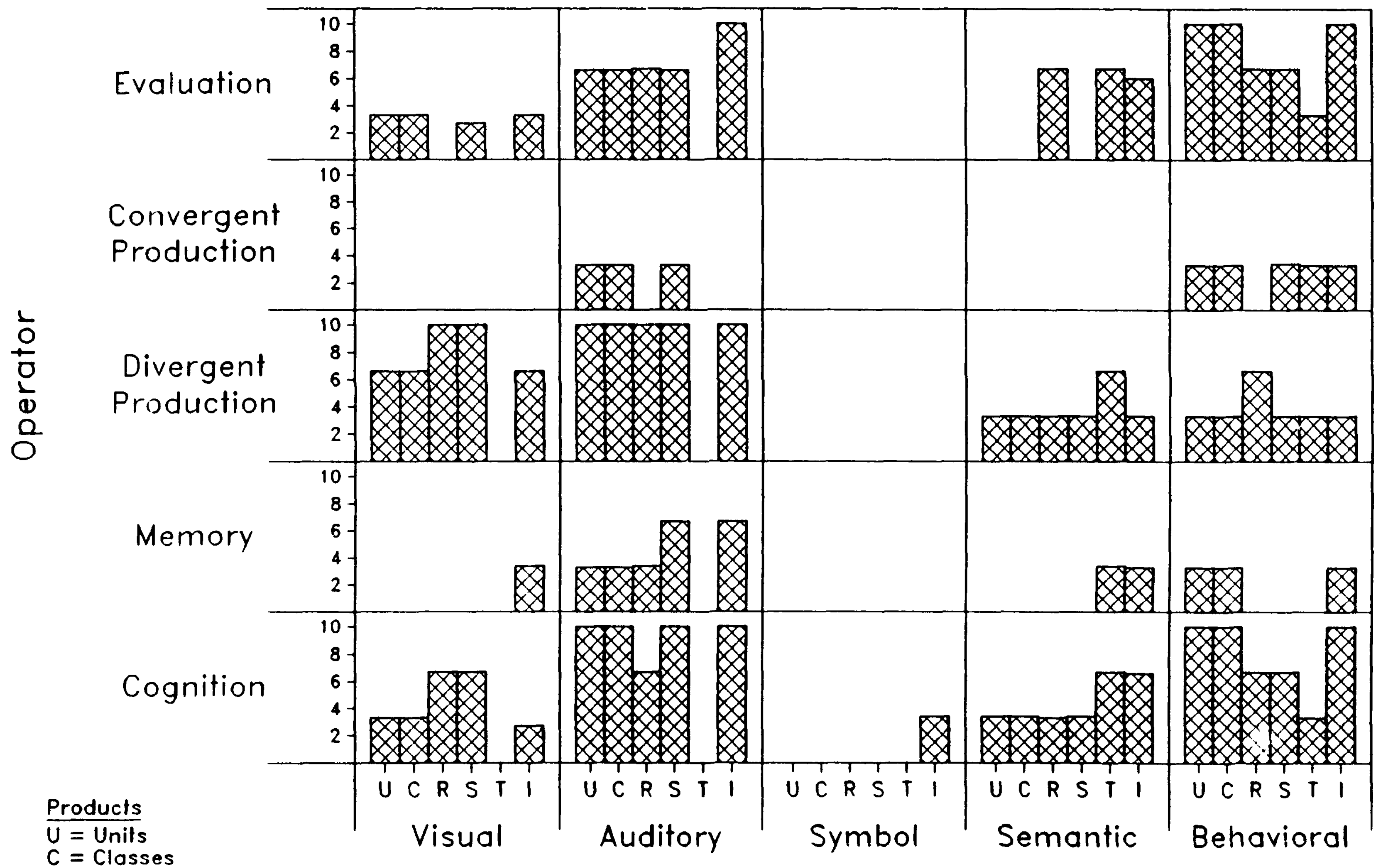



Diff. (Elec Design Domain–Expert Systems)
Operator
Evaluation
Convergent Production
Divergent Production
Memory
Cognition
10
8
6
4
2
U C R S T I
Visual
Auditory
Symbol
Semantic
Behavioral
Contents & Products
Products
U = Units
C = Classes
R = Relations
S = Systems
T = Transformations
I = Implications



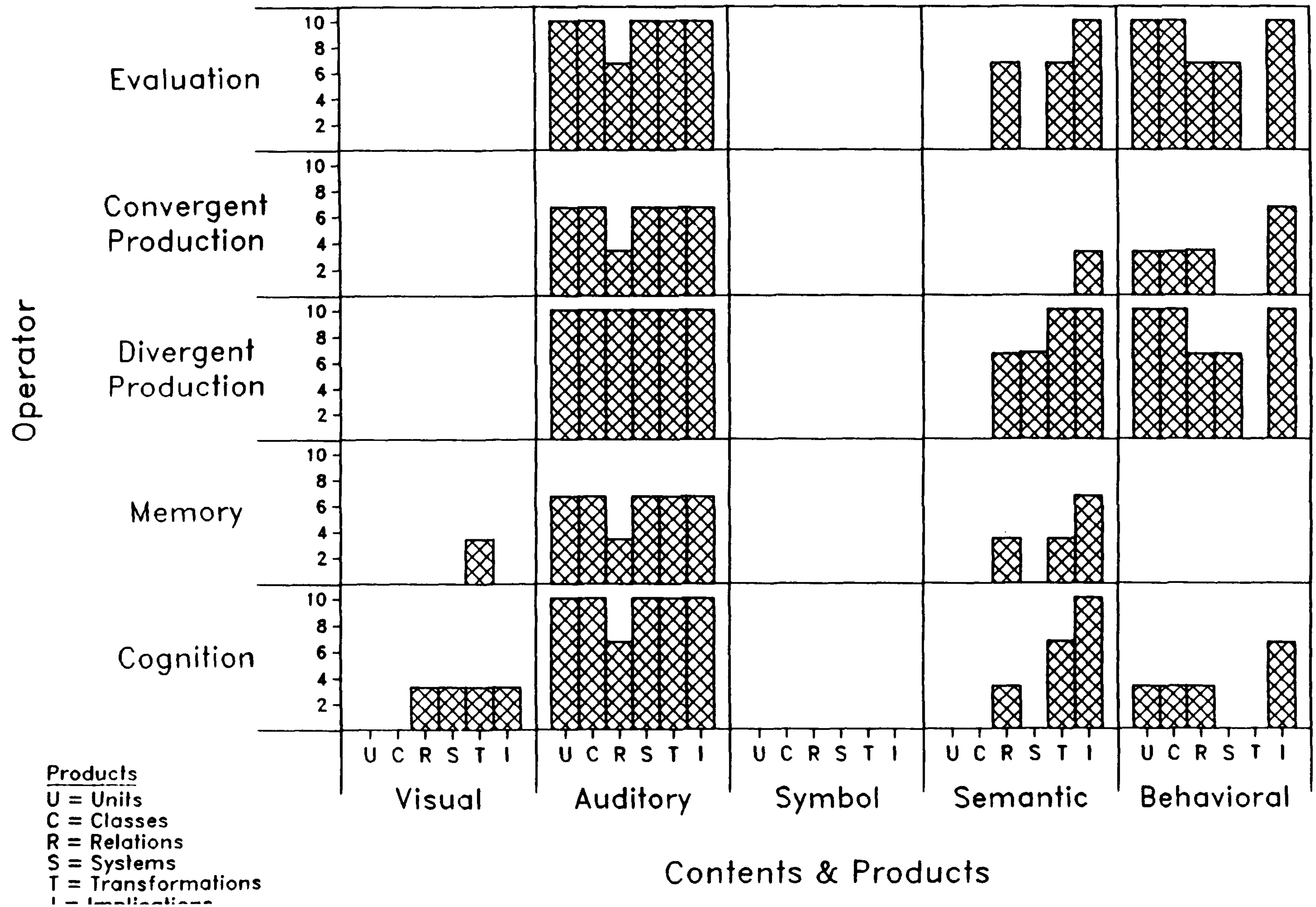
Diff (Missions Planning Domain–Experts Systems
Operator
Evaluation
Convergent Production
Divergent Production
Memory
Cognition
10
8
6
4
2
U C R S T I
Visual
Auditory
Symbol
Semantic
Behavioral
Contents & Products
Products
U = Units
C = Classes
R = Relations
S = Systems
T = Transformations

Diff. (Medical Dx. Domain–Expert Systems)

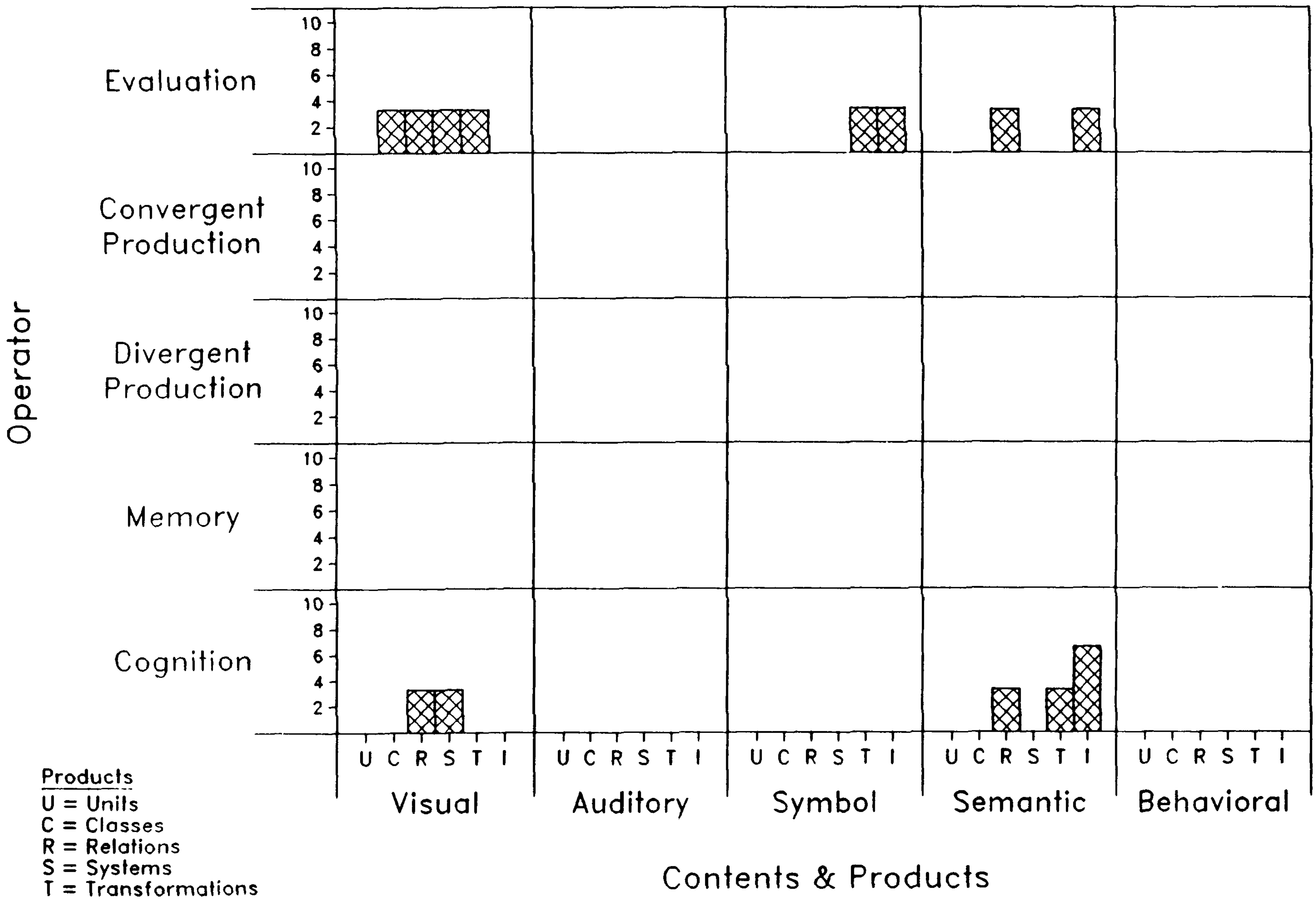


Products
U = Units
C = Classes
R = Relations
S = Systems
T = Transformations

Diff. (Musical Performance Domain–Expert Systems)

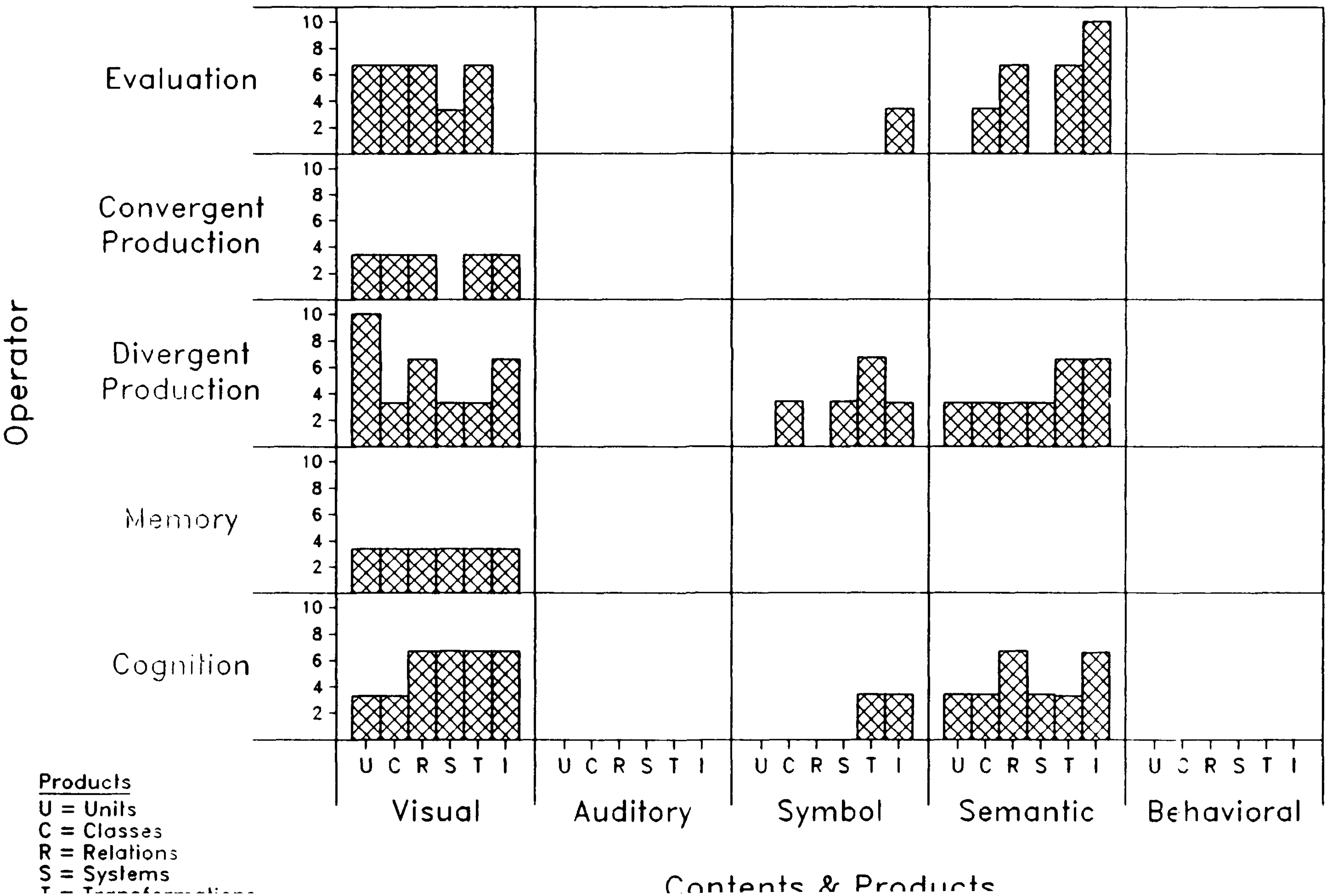


Diff. (Troublshooting Domain–Expert Systems)



Products
U = Units
C = Classes
R = Relations
S = Systems
T = Transformations

Diff (Point Picking Domain–Expert Systems)



C.3 CRITICAL ELEMENT LISTING

Listing of Elements where Domain Req. are greater then E. S. Capabilities

------------------------------------ DIFF=3.3 ------------------------------------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
1	2	4	DIVERGENT PRODUCTION	SEMANTIC	RELATIONS
2	4	4	COGNITION	SEMANTIC	IMPLICATIONS
3	4	4	EVALUATION	SEMANTIC	IMPLICATIONS
4	10	10	DIVERGENT PRODUCTION	SEMANTIC	IMPLICATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=3.2

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
1	4	2	EVALUATION	AUDITORY	CLASSES

DIFF=3.3

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
2	2	2	DIVERGENT PRODUCTION	BEHAVIORAL	SYSTEMS
3	4	2	DIVERGENT PRODUCTION	AUDITORY	TRANSFORMATIONS
4	4	2	DIVERGENT PRODUCTION	AUDITORY	IMPLICATIONS
5	6	2	DIVERGENT PRODUCTION	AUDITORY	UNITS
6	6	4	EVALUATION	SEMANTIC	IMPLICATIONS
7	8	6	EVALUATION	AUDITORY	IMPLICATIONS

DIFF=3.4

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
8	6	6	COGNITION	VISUAL	RELATIONS
9	6	6	DIVERGENT PRODUCTION	SEMANTIC	UNITS
10	8	4	COGNITION	VISUAL	CLASSES
11	8	4	COGNITION	SEMANTIC	CLASSES
12	8	6	COGNITION	AUDITORY	RELATIONS
13	8	8	COGNITION	BEHAVIORAL	SYSTEMS
14	8	4	COGNITION	VISUAL	IMPLICATIONS
15	10	6	COGNITION	SEMANTIC	UNITS

DIFF=6.7

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
16	4	2	COGNITION	SEMANTIC	IMPLICATIONS
17	6	4	COGNITION	AUDITORY	SYSTEMS
18	6	6	COGNITION	AUDITORY	TRANSFORMATIONS
19	6	4	DIVERGENT PRODUCTION	SEMANTIC	IMPLICATIONS
20	8	6	COGNITION	VISUAL	UNITS
21	8	8	COGNITION	AUDITORY	UNITS
22	8	8	COGNITION	BEHAVIORAL	UNITS
23	8	6	COGNITION	AUDITORY	CLASSES
24	8	8	COGNITION	BEHAVIORAL	CLASSES
25	8	2	COGNITION	SEMANTIC	RELATIONS
26	8	8	EVALUATION	AUDITORY	UNITS
27	8	4	EVALUATION	BEHAVIORAL	UNITS
28	10	6	CONVERGENT PRODUCTION	SEMANTIC	IMPLICATIONS
29	10	6	EVALUATION	VISUAL	UNITS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

------------------------------------ DIFF=10 ------------------------------------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
30	8	8	COGNITION	AUDITORY	IMPLICATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=3.3

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
1	8	6	MEMORY	SEMANTIC	IMPLICATIONS
2	8	2	DIVERGENT PRODUCTION	VISUAL	SYSTEMS
3	8	2	DIVERGENT PRODUCTION	VISUAL	TRANSFORMATIONS
4	8	4	DIVERGENT PRODUCTION	SYSMBOLIC	TRANSFORMATIONS
5	8	2	DIVERGENT PRODUCTION	VISUAL	IMPLICATIONS
6	8	6	EVALUATION	VISUAL	UNITS
7	8	6	EVALUATION	VISUAL	CLASSES
8	8	4	EVALUATION	VISUAL	RELATIONS
9	8	4	EVALUATION	VISUAL	SYSTEMS
10	8	2	EVALUATION	VISUAL	TRANSFORMATIONS
11	8	4	EVALUATION	VISUAL	IMPLICATIONS
12	10	6	COGNITION	SEMANTIC	RELATIONS
13	10	6	COGNITION	SEMANTIC	TRANSFORMATIONS

DIFF=3.4

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
14	10	8	COGNITION	SYSMBOLIC	TRANSFORMATIONS
15	10	8	COGNITION	SYSMBOLIC	IMPLICATIONS
16	10	8	MEMORY	VISUAL	UNITS
17	10	8	MEMORY	VISUAL	CLASSES
18	10	8	MEMORY	VISUAL	RELATIONS
19	10	8	MEMORY	VISUAL	SYSTEMS
20	10	8	MEMORY	VISUAL	TRANSFORMATIONS
21	10	8	MEMORY	VISUAL	IMPLICATIONS

DIFF=6.6

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
22	8	4	DIVERGENT PRODUCTION	VISUAL	UNITS
23	8	4	DIVERGENT PRODUCTION	VISUAL	CLASSES
24	8	4	DIVERGENT PRODUCTION	VISUAL	RELATIONS

DIFF=6.7

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
25	10	6	COGNITION	VISUAL	UNITS
26	10	6	COGNITION	VISUAL	CLASSES
27	10	6	COGNITION	VISUAL	RELATIONS
28	10	6	COGNITION	VISUAL	SYSTEMS
29	10	6	COGNITION	VISUAL	TRANSFORMATIONS
30	10	6	COGNITION	VISUAL	IMPLICATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

-- DIFF=10 --

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
31	10	8	COGNITION	SEMANTIC	IMPLICATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=3.3

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
1	8	6	COGNITION	VISUAL	CLASSES
2	10	8	COGNITION	VISUAL	UNITS
3	10	10	COGNITION	VISUAL	RELATIONS
4	10	10	DIVERGENT PRODUCTION	VISUAL	CLASSES
5	10	10	DIVERGENT PRODUCTION	SYSMBOLIC	TRANSFORMATIONS
6	10	10	DIVERGENT PRODUCTION	VISUAL	IMPLICATIONS
7	10	10	EVALUATION	VISUAL	UNITS
8	10	10	EVALUATION	VISUAL	CLASSES
9	10	8	EVALUATION	VISUAL	RELATIONS

DIFF=3.4

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
10	8	6	MEMORY	VISUAL	IMPLICATIONS
11	10	10	CONVERGENT PRODUCTION	VISUAL	UNITS

DIFF=6.6

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
12	6	8	DIVERGENT PRODUCTION	VISUAL	TRANSFORMATIONS
13	8	10	DIVERGENT PRODUCTION	VISUAL	SYSTEMS
14	10	10	DIVERGENT PRODUCTION	VISUAL	UNITS
15	10	10	DIVERGENT PRODUCTION	VISUAL	RELATIONS

DIFF=6.7

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
16	8	6	COGNITION	VISUAL	TRANSFORMATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=3.3

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
1	2	2	COGNITION	BEHAVIORAL	TRANSFORMATIONS
2	2	4	DIVERGENT PRODUCTION	BEHAVIORAL	TRANSFORMATIONS
3	4	8	COGNITION	VISUAL	UNITS
4	4	8	CONVERGENT PRODUCTION	AUDITORY	SYSTEMS
5	4	8	CONVERGENT PRODUCTION	BEHAVIORAL	TRANSFORMATIONS
6	6	6	COGNITION	VISUAL	CLASSES
7	6	6	COGNITION	SEMANTIC	RELATIONS
8	6	8	MEMORY	SEMANTIC	IMPLICATIONS
9	6	8	DIVERGENT PRODUCTION	BEHAVIORAL	UNITS
10	6	6	DIVERGENT PRODUCTION	SEMANTIC	RELATIONS
11	6	8	DIVERGENT PRODUCTION	SEMANTIC	SYSTEMS
12	6	8	DIVERGENT PRODUCTION	SEMANTIC	IMPLICATIONS
13	6	6	DIVERGENT PRODUCTION	BEHAVIORAL	IMPLICATIONS
14	6	6	CONVERGENT PRODUCTION	AUDITORY	CLASSES
15	6	4	EVALUATION	BEHAVIORAL	TRANSFORMATIONS
16	8	6	MEMORY	AUDITORY	UNITS
17	8	8	MEMORY	BEHAVIORAL	UNITS
18	8	4	MEMORY	AUDITORY	CLASSES
19	8	8	MEMORY	BEHAVIORAL	CLASSES
20	8	8	MEMORY	BEHAVIORAL	IMPLICATIONS
21	8	8	DIVERGENT PRODUCTION	SEMANTIC	UNITS
22	8	6	DIVERGENT PRODUCTION	SEMANTIC	CLASSES
23	8	8	DIVERGENT PRODUCTION	BEHAVIORAL	CLASSES
24	8	6	CONVERGENT PRODUCTION	AUDITORY	UNITS
25	8	8	CONVERGENT PRODUCTION	BEHAVIORAL	UNITS
26	8	10	CONVERGENT PRODUCTION	BEHAVIORAL	CLASSES
27	8	6	CONVERGENT PRODUCTION	BEHAVIORAL	IMPLICATIONS
28	8	6	EVALUATION	VISUAL	UNITS
29	8	8	EVALUATION	VISUAL	CLASSES
30	8	6	EVALUATION	VISUAL	IMPLICATIONS
31	10	8	DIVERGENT PRODUCTION	BEHAVIORAL	SYSTEMS

DIFF=3.4

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
32	6	6	COGNITION	SEMANTIC	CLASSES
33	6	4	MEMORY	VISUAL	IMPLICATIONS
34	8	8	COGNITION	SEMANTIC	UNITS
35	10	10	COGNITION	SEMANTIC	SYSTEMS
36	10	10	COGNITION	SYSMBOLIC	IMPLICATIONS
37	10	8	MEMORY	AUDITORY	RELATIONS
38	10	8	MEMORY	SEMANTIC	TRANSFORMATIONS
39	10	6	CONVERGENT PRODUCTION	BEHAVIORAL	SYSTEMS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

---------- DIFF=6 ----------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
40	8	6	EVALUATION	SEMANTIC	IMPLICATIONS

---------- DIFF=6.6 ----------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
41	4	4	DIVERGENT PRODUCTION	VISUAL	CLASSES
42	6	6	COGNITION	SEMANTIC	IMPLICATIONS
43	6	10	DIVERGENT PRODUCTION	SEMANTIC	TRANSFORMATIONS
44	6	8	EVALUATION	AUDITORY	SYSTEMS
45	8	6	DIVERGENT PRODUCTION	VISUAL	UNITS
46	8	6	DIVERGENT PRODUCTION	BEHAVIORAL	RELATIONS
47	8	4	DIVERGENT PRODUCTION	VISUAL	IMPLICATIONS
48	8	6	EVALUATION	AUDITORY	UNITS
49	10	4	EVALUATION	AUDITORY	CLASSES

---------- DIFF=6.7 ----------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
50	6	6.0	COGNITION	VISUAL	RELATIONS
51	6	6.0	COGNITION	BEHAVIORAL	RELATIONS
52	6	6.0	MEMORY	AUDITORY	IMPLICATIONS
53	8	6.0	COGNITION	AUDITORY	RELATIONS
54	8	4.0	MEMORY	AUDITORY	SYSTEMS
55	8	6.0	EVALUATION	AUDITORY	RELATIONS
56	8	6.0	EVALUATION	SEMANTIC	RELATIONS
57	8	6.0	EVALUATION	BEHAVIORAL	RELATIONS
58	10	6.6	COGNITION	VISUAL	SYSTEMS
59	10	10.0	COGNITION	BEHAVIORAL	SYSTEMS
60	10	10.0	COGNITION	SEMANTIC	TRANSFORMATIONS
61	10	6.0	EVALUATION	BEHAVIORAL	SYSTEMS
62	10	8.0	EVALUATION	SEMANTIC	TRANSFORMATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=10

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
63	2	6	DIVERGENT PRODUCTION	AUDITORY	UNITS
64	4	8	DIVERGENT PRODUCTION	AUDITORY	CLASSES
65	6	6	COGNITION	AUDITORY	SYSTEMS
66	6	6	COGNITION	AUDITORY	IMPLICATIONS
67	6	4	DIVERGENT PRODUCTION	VISUAL	RELATIONS
68	6	6	DIVERGENT PRODUCTION	AUDITORY	RELATIONS
69	6	6	DIVERGENT PRODUCTION	VISUAL	SYSTEMS
70	6	6	DIVERGENT PRODUCTION	AUDITORY	SYSTEMS
71	6	6	DIVERGENT PRODUCTION	AUDITORY	IMPLICATIONS
72	6	6	EVALUATION	AUDITORY	IMPLICATIONS
73	8	10	COGNITION	AUDITORY	UNITS
74	8	8	COGNITION	BEHAVIORAL	UNITS
75	8	8	COGNITION	BEHAVIORAL	CLASSES
76	8	8	COGNITION	BEHAVIORAL	IMPLICATIONS
77	8	8	EVALUATION	BEHAVIORAL	UNITS
78	10	8	COGNITION	AUDITORY	CLASSES
79	10	8	EVALUATION	BEHAVIORAL	CLASSES
80	10	8	EVALUATION	BEHAVIORAL	IMPLICATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=3.3

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
1	6	6	COGNITION	SEMANTIC	RELATIONS
2	8	6	CONVERGENT PRODUCTION	BEHAVIORAL	UNITS
3	8	6	CONVERGENT PRODUCTION	BEHAVIORAL	CLASSES
4	10	6	COGNITION	BEHAVIORAL	UNITS
5	10	6	COGNITION	BEHAVIORAL	CLASSES
6	10	8	COGNITION	VISUAL	RELATIONS
7	10	6	COGNITION	BEHAVIORAL	RELATIONS
8	10	8	COGNITION	VISUAL	SYSTEMS
9	10	6	COGNITION	VISUAL	TRANSFORMATIONS
10	10	6	COGNITION	VISUAL	IMPLICATIONS
11	10	6	CONVERGENT PRODUCTION	SEMANTIC	IMPLICATIONS

DIFF=3.4

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
12	8	6	MEMORY	SEMANTIC	RELATIONS
13	8	6	MEMORY	SEMANTIC	TRANSFORMATIONS
14	8	4	CONVERGENT PRODUCTION	BEHAVIORAL	RELATIONS
15	10	10	MEMORY	AUDITORY	RELATIONS
16	10	10	MEMORY	VISUAL	TRANSFORMATIONS
17	10	10	CONVERGENT PRODUCTION	AUDITORY	RELATIONS

DIFF=6.6

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
18	10	6	COGNITION	BEHAVIORAL	IMPLICATIONS
19	10	8	DIVERGENT PRODUCTION	SEMANTIC	RELATIONS
20	10	2	DIVERGENT PRODUCTION	BEHAVIORAL	RELATIONS
21	10	4	DIVERGENT PRODUCTION	BEHAVIORAL	SYSTEMS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

------------------------------ DIFF=6.7 ------------------------------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
22	8	6	COGNITION	SEMANTIC	TRANSFORMATIONS
23	8	6	MEMORY	SEMANTIC	IMPLICATIONS
24	8	4	CONVERGENT PRODUCTION	BEHAVIORAL	IMPLICATIONS
25	8	6	EVALUATION	SEMANTIC	RELATIONS
26	8	8	EVALUATION	SEMANTIC	TRANSFORMATIONS
27	10	10	COGNITION	AUDITORY	RELATIONS
28	10	10	MEMORY	AUDITORY	UNITS
29	10	10	MEMORY	AUDITORY	CLASSES
30	10	10	MEMORY	AUDITORY	SYSTEMS
31	10	10	MEMORY	AUDITORY	TRANSFORMATIONS
32	10	10	MEMORY	AUDITORY	IMPLICATIONS
33	10	6	DIVERGENT PRODUCTION	SEMANTIC	SYSTEMS
34	10	10	CONVERGENT PRODUCTION	AUDITORY	UNITS
35	10	10	CONVERGENT PRODUCTION	AUDITORY	CLASSES
36	10	10	CONVERGENT PRODUCTION	AUDITORY	SYSTEMS
37	10	10	CONVERGENT PRODUCTION	AUDITORY	TRANSFORMATIONS
38	10	10	CONVERGENT PRODUCTION	AUDITORY	IMPLICATIONS
39	10	10	EVALUATION	AUDITORY	RELATIONS
40	10	4	EVALUATION	BEHAVIORAL	RELATIONS
41	10	8	EVALUATION	BEHAVIORAL	SYSTEMS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

-------------------- DIFF=10 --------------------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
42	8	8	COGNITION	SEMANTIC	IMPLICATIONS
43	8	6	EVALUATION	SEMANTIC	IMPLICATIONS
44	10	10	COGNITION	AUDITORY	UNITS
45	10	10	COGNITION	AUDITORY	CLASSES
46	10	10	COGNITION	AUDITORY	SYSTEMS
47	10	10	COGNITION	AUDITORY	TRANSFORMATIONS
48	10	10	COGNITION	AUDITORY	IMPLICATIONS
49	10	10	DIVERGENT PRODUCTION	AUDITORY	UNITS
50	10	4	DIVERGENT PRODUCTION	BEHAVIORAL	UNITS
51	10	10	DIVERGENT PRODUCTION	AUDITORY	CLASSES
52	10	4	DIVERGENT PRODUCTION	BEHAVIORAL	CLASSES
53	10	10	DIVERGENT PRODUCTION	AUDITORY	RELATIONS
54	10	10	DIVERGENT PRODUCTION	AUDITORY	SYSTEMS
55	10	10	DIVERGENT PRODUCTION	AUDITORY	TRANSFORMATIONS
56	10	6	DIVERGENT PRODUCTION	SEMANTIC	TRANSFORMATIONS
57	10	10	DIVERGENT PRODUCTION	AUDITORY	IMPLICATIONS
58	10	6	DIVERGENT PRODUCTION	SEMANTIC	IMPLICATIONS
59	10	4	DIVERGENT PRODUCTION	BEHAVIORAL	IMPLICATIONS
60	10	10	EVALUATION	AUDITORY	UNITS
61	10	6	EVALUATION	BEHAVIORAL	UNITS
62	10	10	EVALUATION	AUDITORY	CLASSES
63	10	6	EVALUATION	BEHAVIORAL	CLASSES
64	10	10	EVALUATION	AUDITORY	SYSTEMS
65	10	10	EVALUATION	AUDITORY	TRANSFORMATIONS
66	10	10	EVALUATION	AUDITORY	IMPLICATIONS
67	10	4	EVALUATION	BEHAVIORAL	IMPLICATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

---------------- DIFF=3.3 ----------------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
1	4	2	EVALUATION	SEMANTIC	IMPLICATIONS
2	6	4	COGNITION	SEMANTIC	RELATIONS
3	6	2	COGNITION	SEMANTIC	TRANSFORMATIONS
4	6	4	EVALUATION	SEMANTIC	RELATIONS
5	8	6	COGNITION	VISUAL	SYSTEMS
6	10	6	COGNITION	VISUAL	RELATIONS
7	10	8	EVALUATION	VISUAL	CLASSES
8	10	8	EVALUATION	VISUAL	RELATIONS
9	10	8	EVALUATION	VISUAL	SYSTEMS
10	10	6	EVALUATION	VISUAL	TRANSFORMATIONS

---------------- DIFF=3.4 ----------------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
11	10	6	EVALUATION	SYSMBOLIC	TRANSFORMATIONS
12	10	6	EVALUATION	SYSMBOLIC	IMPLICATIONS

---------------- DIFF=6.6 ----------------

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
13	6	2	COGNITION	SEMANTIC	IMPLICATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=3.3

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
1	6	2	COGNITION	SEMANTIC	TRANSFORMATIONS
2	6	6	DIVERGENT PRODUCTION	SEMANTIC	CLASSES
3	6	4	DIVERGENT PRODUCTION	SEMANTIC	SYSTEMS
4	8	6	DIVERGENT PRODUCTION	SEMANTIC	UNITS
5	8	6	DIVERGENT PRODUCTION	SEMANTIC	RELATIONS
6	10	8	COGNITION	VISUAL	UNITS
7	10	6	COGNITION	VISUAL	CLASSES
8	10	4	DIVERGENT PRODUCTION	VISUAL	CLASSES
9	10	4	DIVERGENT PRODUCTION	VISUAL	SYSTEMS
10	10	6	DIVERGENT PRODUCTION	VISUAL	TRANSFORMATIONS
11	10	6	DIVERGENT PRODUCTION	SYSMBOLIC	IMPLICATIONS
12	10	10	EVALUATION	VISUAL	SYSTEMS

DIFF=3.4

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
13	6	8	COGNITION	SEMANTIC	CLASSES
14	6	4	COGNITION	SEMANTIC	SYSTEMS
15	6	4	DIVERGENT PRODUCTION	SYSMBOLIC	CLASSES
16	6	6	EVALUATION	SEMANTIC	CLASSES
17	8	8	COGNITION	SEMANTIC	UNITS
18	8	4	DIVERGENT PRODUCTION	SYSMBOLIC	SYSTEMS
19	10	6	COGNITION	SYSMBOLIC	TRANSFORMATIONS
20	10	8	COGNITION	SYSMBOLIC	IMPLICATIONS
21	10	10	MEMORY	VISUAL	UNITS
22	10	10	MEMORY	VISUAL	CLASSES
23	10	10	MEMORY	VISUAL	RELATIONS
24	10	10	MEMORY	VISUAL	SYSTEMS
25	10	10	MEMORY	VISUAL	TRANSFORMATIONS
26	10	10	MEMORY	VISUAL	IMPLICATIONS
27	10	10	CONVERGENT PRODUCTION	VISUAL	UNITS
28	10	10	CONVERGENT PRODUCTION	VISUAL	CLASSES
29	10	10	CONVERGENT PRODUCTION	VISUAL	RELATIONS
30	10	10	CONVERGENT PRODUCTION	VISUAL	TRANSFORMATIONS
31	10	10	CONVERGENT PRODUCTION	VISUAL	IMPLICATIONS
32	10	8	EVALUATION	SYSMBOLIC	IMPLICATIONS

DIFF=6.6

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
33	6	4	COGNITION	SEMANTIC	IMPLICATIONS
34	6	4	DIVERGENT PRODUCTION	SEMANTIC	TRANSFORMATIONS
35	6	6	DIVERGENT PRODUCTION	SEMANTIC	IMPLICATIONS
36	10	4	DIVERGENT PRODUCTION	VISUAL	RELATIONS
37	10	6	DIVERGENT PRODUCTION	VISUAL	IMPLICATIONS

Listing of Elements where Domain Req. are greater then E. S. Capabilities

DIFF=6.7

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
38	6	6	COGNITION	SEMANTIC	RELATIONS
39	6	4	DIVERGENT PRODUCTION	SYSMBOLIC	TRANSFORMATIONS
40	6	8	EVALUATION	SEMANTIC	RELATIONS
41	6	6	EVALUATION	SEMANTIC	TRANSFORMATIONS
42	10	10	COGNITION	VISUAL	RELATIONS
43	10	8	COGNITION	VISUAL	SYSTEMS
44	10	8	COGNITION	VISUAL	TRANSFORMATIONS
45	10	8	COGNITION	VISUAL	IMPLICATIONS
46	10	10	EVALUATION	VISUAL	UNITS
47	10	10	EVALUATION	VISUAL	CLASSES
48	10	10	EVALUATION	VISUAL	RELATIONS
49	10	10	EVALUATION	VISUAL	TRANSFORMATIONS

DIFF=10

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
50	4	4	EVALUATION	SEMANTIC	IMPLICATIONS
51	10	6	DIVERGENT PRODUCTION	VISUAL	UNITS

DIFF=96.7

OBS	CRITIAL	FREQU	OPERATOR	CONTENTS	PRODUCTS
52	10	10	EVALUATION	VISUAL	IMPLICATIONS

D. CURRENT DOMAIN EVALUATION TOOLS

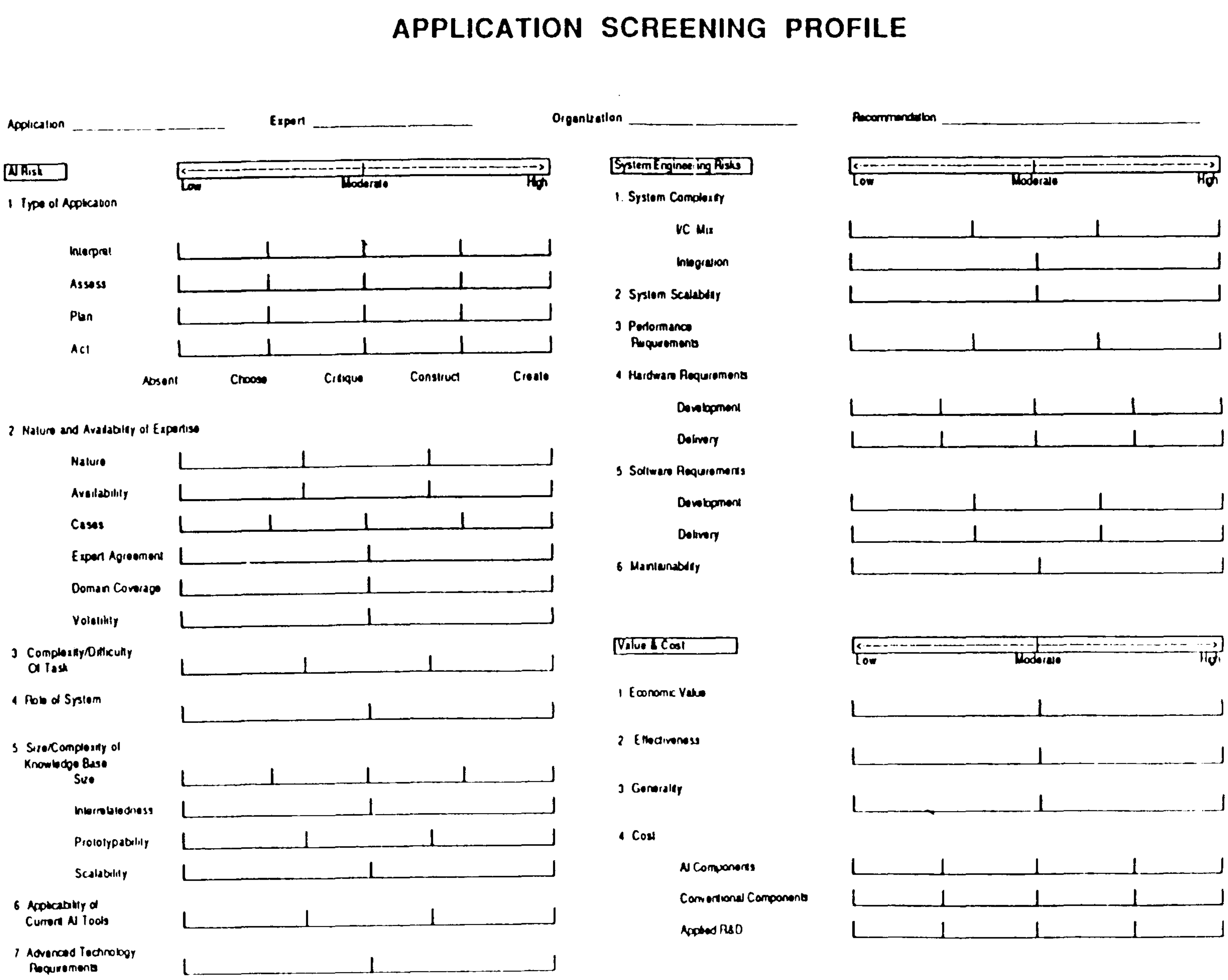


Figure 2-1: The Application Screening Profile.

RISK ASSESSMENT

Project Title: ______________________________

User Organization: ______________________________

User POC(s): ______________________________

The objective here is to measure the amount of risk associated with the successful development and implementation of an Expert System for use by a requesting user organization.

A minimum of   point (out of the maximum   ) can be generally considered sufficiently risk free for development within the AI office. Some of the risks can be diminished through discussion with user management or the purchase of other hardware/software. Other risks can not be overcome.

Each category has a maximum score associated with it. Within each category (or sub-category) questions have a maximum score associated with them. These are guideline only. The maximum points for a group of questions can be redistributed among those questions as may be required under some circumstances. Likewise, the maximum points for a group of categories may be redistributed. Care and forethought should be given to the redistribution of any points.

TOTAL POINTS (out of   ): _______

RISK (high, medium, low): _______

MANAGEMENT RISK

Solution Awareness

If management is not aware of the solution means and the capabilities / limitations of that solution means, they may be unwilling to support it in the future.

A. Does the user organization already own hardware and/or software for Expert System technology? ____

0 — 2 — 4

No — Some — Yes

B. Does the user organization have realistic expectations of Artificial Intelligence and Expert System technology? ____

0 — 3 — 6

No — Some — Yes

C. Is the user management aware of the solution being considered? ____

0 — 2 — 4

No — Some — Yes

D. Is the user management skeptical of Artificial Intelligence or Expert System technology? ____

0 — 3 — 6

Yes — Some — No

Total ____

MANAGEMENT RISK (cont)

Cost Awareness

If user management is not aware of, and willing to support the cost of development, they may be unwilling to fund those costs in the future.

A. Are the project assumptions, costs, and constraints understood and accepted by the user management? ____

0	10	20
No	Some	Yes

B. Has the organization ever developed any AI system? ____

0	5	10
No	Some	Yes

C. Is it expensive or time consuming to train others to solve the problem? ____

0	5	10
No	Somewhat	Yes

Total ____

MANAGEMENT RISK (cont)

Value Awareness

If user management is not aware of the potential benefits available to them, they may be unwilling to support the effort now or in the future.

A. Is improved understanding of the current problem-solving process viewed as valuable to your organization? ____

0 — 1 — 2

No — Some — Yes

B. Is solving this problem a priority issue for the user organization? ____

0 — 3 — 6

No — Somewhat — Yes

C. Is the expert required to spend excessive amounts of time helping others? ____

0 — 2 — 4

No — Some — Yes

D. Are excessive amounts of some resources needed that could be used more effectively or used elsewhere if this problem did not exist? ____

0 — 2 — 4

No — Somewhat — Yes

Total ____

MANAGEMENT RISK (cont)

Overall Management Support

This is just an overall, across-the-board assessment of support.

A. Is user management committed to solving the problem with Expert System technology? ____

0	5	10
Not committed	Somewhat committed	Yes committed

B. Do several layers of user management support this development effort? ____

0	5	10
No	Some	Yes

Total ____

USER AWARENESS / APPROVAL / SUPPORT

If the user will not support or use the system, it will be a failure no matter how wonderful the system may be.

A. Do the users view the solution with a <u>non</u>-hostile attitude? ____

0	7 1/2	15
Yes hostility exists	Some hostility exists	No doesn't exists

B. Will the users <u>actually</u> use the proposed system? ____

0	10	20
No	Some	Yes

C. Are there <u>realistic</u> expectations of the proposed system? ____

0	2 1/2	5
No	Some	Yes

D. Do the users perceive any problems with ES approach? ____

0	5	10
Many problems	Some problems	No problems

E. Do the users fear or hate the proposed system? ____

0	5	10
Yes	Some	No

<u>Total</u> ____

TECHNOLOGY RISK

Appropriate To ES

The solution must be "do-able" efficiently and effectively with Expert System technology.

A. Are heuristics, techniques, or methods involved in solving the problem? ____

0	15	30
No	Some	Many

B. Would an algorithm or a conventional programming solution be too difficult or time consuming to attempt? ____

0	7 1/2	15
Not	Somewhat	Yes

C. Does the solution involve a relatively constrained solution space? ____

0	15	30
No	Somewhat	Yes

D. Have conventional solutions been ruled out? ____

0	7 1/2	15
No	Somewhat	Yes

Total ____

TECHNOLOGY RISK (cont)

Possible With ES

Not all systems will be possible to develop with Expert System technology.

A. Is the problem solution generally accepted/agreed upon? ____

0	9	18
Not agreed upon	Somewhat agreed upon	Yes agreed upon

B. Is the problem area basically simple or can it be broken into simple independent sub-problems? ____

0	9	18
Complex	Average	Simple

C. Does the problem solution depend upon a narrowly defined body of knowledge excluding common sense. ____

0	9	18
No	Somewhat	Yes

D. Is there a recognized source of available and reliable knowledge? ____

0	9	18
No	Some	Yes

E. Can the expert articulate the problem solving process? ____

0	7 1/2	15
No	Somewhat	Yes

F. Has the expert ever trained someone else to solve this problem? ____

0	7 1/2	15
No	Some	Yes

G. Is the expert willing to commit to the development effort? ____

0	7 1/2	15

No	Some	Yes

<u>Total</u> ____

TECHNOLOGY RISK (cont)

Justification Of ES

There must be a real value associated with and sufficient to justify resource expenditures to develop a system. If there is not sufficient justification, development support will be weak.

A. Is there a need for consistent application of policy and procedures that are not achieved today or are achieved only at great cost? ____

0 3 6

No Some Yes

B. Is there a possibility of losing the knowledge? ____

0 3 6

No Some Yes

C. Is there a need to distribute this knowledge to others? ____

0 3 6

No Some Yes

D. Does the problem solution require scarce resources or knowledge? ____

0 3 6

No Some Yes

E. Is an expert repeatedly required to help others solve this problem? ____

0 3 6

No Sometimes Yes

Total ____

PERFORMANCE RISK

Accuracy / Uncertainty

Can the accuracy required be provided by Expert System technology.

A. Does the problem involve uncertainty? ____

0	4 1/2	9
Yes, uncertainty exists	Some uncertainty exists	No uncertainty exists

B. If uncertainty is involved, can less than complete accuracy be tolerated? ____

0	4 1/2	9
No	Somewhat	Yes

Total ____

Speed

Is it possible to reach the response time required; real time.

A. What are the required response times/rates? ____

0	1	2	3
Millisecond	Second	Minutes	No requirement

Note: Response time/rate requirements can limit processing ability.

C. Can the hardware / software / communication requirements and costs be met or procured to meet the response time? ____

0	1	3
No	Somewhat	Yes

Total ____

PERFORMANCE RISK (cont)

Interfacing

If the required interface can not be done, the information will have to be retrieved and entered manually. This will lower speed and efficiency as well as increasing the chances for error. As this becomes more of a problem, the likelihood of system usage diminishes.

A. Is there frequent interaction among system modules(Files)? ____

0	1	2
High interaction among modules	Moderate Interaction among modules	Low interaction among modules

B. Are the interfacing systems classified? ____

0	5
Yes	No

C. Is the hardware and software platform of the ES compatible with interfacing hardware and software? ____

1	2	5
No	Somewhat	Yes

Total ____

KNOWLEDGE ENGINEERING RISK

A. Can the expert express the knowledge (solution method) verbally? (telephone test)

1	2	3	5
Extremely difficult to verbalize; performance based expression.	Partially expressible verbally; requires some performance.	Difficult to express verbally.	Easy to express verbally.

B. Is the domain expertise available.

-200	1	2	4
No expertise available.	Only analytical expertise.	Some operational expertise.	Significant operational expertise.

C. Are there representative cases/scenarios of the problem available?

1	3	4
Pseudo case/scenarios are difficult to make.	Pseudo case/scenarios can be easily made.	Adequate representative coverage.

D. Does the solution have a high degree of agreement among the experts?

0	3	5
Little agreement.	Moderate agreement.	Highly agreed upon.

E. How many experts are needed to adequately cover the domain?

0	1	2
Domain can not be adequately covered.	Experts specialize but do not know about the entire domain.	Experts specialize but some know about the entire domain

F. How often does the knowledge and/or the process to solve the problem change?

-20	0	1	2
More than once a month. (System maintenance will exceed system development effort)	Once a month.	Once a year. (System will require moderate maintenance)	Little if ever. (Once built, system will require little maintenance)

KNOWLEDGE ENGINEERING RISK (cont)

G. Is the knowledge straightforward (can it be represented)? ____

0	1	2
NO Very difficult.	Some Moderately difficult; convoluted.	Yes Not Difficult.

H. How large do you estimate the final knowledge base(s) to be? ____

-50	0	3	4
More than 1300 elements/objects.	700 - 1300 elements/objects.	200 - 700 elements/objects.	Less than 200 elements/objects.

I. Can a prototype be accomplished over a subset of the problem domain to adequately prove the worth of such a system? ____

0	2	3
A meaningful prototype can not be built.	A very large prototype would have to be built.	Meaningful prototype can be done.

J. Are there commercially available tools that can be used to develop this system? ____

-100	1	3
Tools are not available; tools must be developed.	Tools are at the tail end of research.	Tools are available commercially.

K. Is the required technology mature enough to rely on? ____

-40	0	4
No	Somewhat	Yes

Total ____

SYSTEM ENGINEERING RISK

A. Based on the number of separate modules, how complex is the system? ____

1	3	5
Several expert systems and conventional modules.	Single expert system module and one or more conventional modules.	Single expert system module.

B. Is there a high degree of interaction between modules? ____

1	4	7
High interaction.	Moderate interaction.	Low interaction.

C. What response time is required? ____

1	3	4	5
Milliseconds.	A few seconds.	A few minutes.	No requirement.

D. Would the requirements on hardware(both development & delivery) be readily available? ____

0	2	4
No (Very restricted)	Somewhat	Yes (Unrestricted)

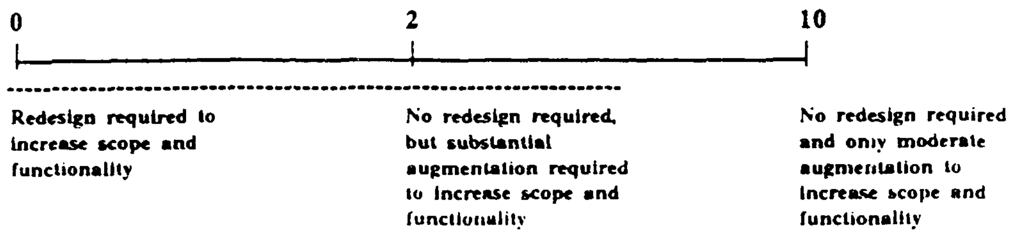
E. Does the delivery environmental ready exist in the field, and is it a standard configuration? ____

0	2 1/2	5
No	Somewhat	Yes

F. Are there any restrictions on what software(both development & delivery) choice can be made? ____

0	2 1/2	5
Yes (Very restricted; few tools available)	Some (Somewhat restricted; some tools excluded)	No (Unrestricted)

G. Will the prototype system scale to a full system without major redesign? ____


0
2
10
Redesign required to increase scope and functionality
No redesign required, but substantial augmentation required to increase scope and functionality
No redesign required and only moderate augmentation to increase scope and functionality

SYSTEM ENGINEERING RISK (cont)

H. How quickly does the solution and/or the problem domain change; can we expect it to change during the development period? ___

0	2 1/2	5
Changes frequently	Likely to change during development	Not often

I. Can the prototype knowledge base be used in full scale development or will the knowledge have to be recoded/designed/structured? ___

0	2	4
Must be re-design/ re-structure/re-code	Will have to be recoded	Used with little Modification

J. How changeable will the data, models, and modules comprising the system be over time? ___

0	5	20
System maintenance will exceed system development effort	Moderate maintenance	Little maintenance after built

Total ___

ECONOMICAL RISK

A. Does the life cycle cost of the system exceed the payoff? ___

0	5	20
Payoff much less than life cycle cost of the system	Moderate payoff	Payoff much greater than life cycle cost of the system

B. Could the basic structure/framework/knowledge of the system be applied to other applications within the organization? ___

0	5	20
Low generally; useful for this application only	Moderate generally	High generally; adaptable to many high payoff applications

C. What is the estimated investment in time, money, equipment, etc. to design, build, test and field the system? ___

0	5	15	40
Large	Moderate	Little	None

PRELIMINARY

CSC/TM-88/6147

Expert System Development Methodology Standard

Revision 1

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

Under

Contract NAS 5-31500
Task Assignment 29 104

August 1989

APPENDIX B - TAROT METRIC

B.1 INTRODUCTION

The system chart of ESDM, Figure 1, shows the following three risk-based decision points:

1. At project initiation. - the KE must make a determination, first, on the suitability of ES technology for the project, and, second, on the risk of developing and using the automated system.
2. At the completion of each stage of work. - the KE must estimate the reduction in risk achieved in the stage.
3. After stopping stage work. - the KE must assess the risk in moving the project to the conventional development methodology.

To assist in the evaluation of a project for ES suitability and in estimating risk, the factors listed in Table B-1 should be used. The table uses levels of indention to indicate factors that roll into less indented factors above them. The overall score for suitability is the TAROT metric value: it depends on the values of all of the factors in the table. It is not assigned independently; instead, it is determined by the the values of all the other factors.

Projects vary widely in their characteristics, and not all the factors listed in Table B-1 are necessarily relevant for a given project. Also, other factors may be added to the list for other projects. This metric is primarily geared towards larger sized projects and should be adapted for projects smaller in size. Also, even though a project has been assigned as an ES project, a suitability analysis should still be performed to insure that nothing was missed when making the initial assessment, and that this is a suitable candidate for an ES implementation base on the information available.

The factors in the table can be viewed simply as a checklist of items that should be reviewed before making any decision or can be viewed in a more technical sense as the factors in a decision rule. When viewed as a set of factors with a set of rules for combining the factors in an automated rules-based decision system, they form part of an ES. The use of an ES to evaluate the suitability of a project for using ES technology is not recommended because the wide variation in projects would require developing a new rules base for each possible application.

The factors can be used more directly as part of a weighted decision rule. This approach to decision-making is more flexible than the rules-based approach and has often been used for choosing among possible hardware suites and for "make or buy" decisions.

Table B-1. Evaluation Factors for ES Development

FACTORS	POSSIBLE VALUE RATINGS
TAROT metric (overall suitability)	Poor, Fair, Good
Worth	Negative, Low, Moderate, High
Payoff/Cost	< 1, 1 - 1.5, 1.5 - 3, > 3
Target Functionality	< 50%, 50%-75%, 75%-90%, > 90%
Priority	Demo, Useful, Necessary, Crucial
Expertise Needed in:	
Many Locations	No, Yes
Hostile Environment	No, Yes
Location Difficult to Access	No, Yes
Expertise Skills:	
Being Lost	No, Yes
Scarce	No, Yes
Risk	Low, Moderate, High
Complexity	Low, Moderate, High
Intuition/Common Sense	< 10%, 10% - 50%, > 50%
Technology	Build, Enhance, Modify, Exists
Decision Definition	Fuzz., OK, Well-Defined
Knowledge Domain	Eclectic, OK, Narrow
Experts	Available, OK, Unavailable
Control	Tight, OK, Loose
Size	Small, Medium, Large, Very Large
Autonomy	Advisor, Aide, Assistant, Agent, Administrator (Supervisor)
% Conventional	> 50%, 10% - 50%, < 10%
Interface Requirements	User, File, Comm, PLI, Message
Employee Acceptance	Negative, Neutral, High
Solution Available	Adequate, Partial, None
Easier Solution	Complete, Partial, None
Teachability	Difficult, Possible, High

B.2 USE OF FACTORS IN A DECISION RULE

To use the factors in a decision rule, numerical values should be assigned to each of the possible values for each independent factor; the independent factors are those that do not have an indented set of subfactors. For example, the values of the Solution Available factor may be assigned as follows:

- o Adequate: 1
- o Partial: 5
- o None: 10

To aid in interpreting the factors, Table B-2 lists them by origin.

Next, the actual values for the proposed project must be evaluated. As an example, it may be known that there is no solution available to the problem for which the system is intended to solve, so the contribution of this factor would be 10 for the proposed project.

Next, assign a weighting for the importance of each factor. For example, on a project of high priority, the possible acceptance of the intended system by employees (the Employee Acceptance factor) may be considered to be of little importance and, thus, be assigned a low weight.

A linear decision function can be constructed by forming a weighted sum of factor numerical values. The decision is then made to proceed if the weighted sum is above a certain threshold, and not to proceed if the decision is below the threshold. The value of the threshold is not set arbitrarily; it is evaluated by assuming extreme cases for the set of relevant factors and then judging what would be a prudent value.

Use of the table yields values for three key factors: suitability (the value for the TAROT metric), risk, and worth. The numerical values for risk and worth (the assignment of numbers to the ratings of poor, fair, and good) are a spinoff from the computation of suitability. Breakpoints are set for these subsidiary factors in the same way as for suitability.

There are two principal criteria for linear decision functions: they must be robust and they should exhibit sensitivity to critical variables. Robustness implies that small changes in the input variables should not cause wide swings in the dependent variables or cause the decision to go the other way. Sensitivity implies that a shift in a key variable should cause the decision to shift. These two criteria are to some extent conflicting, and experimentation with weights may be needed to find the decision function most suitable for a given project.

Table B-2. Factors in ES Development by Origin

FACTORS	VALUES
Problem Factors:	
Solution Available	Adequate, Partial, None
Easier Solution	None, Partial, Complete
Complexity	Low, Moderate, High
Intuition/Common Sense	< 10%, 10% - 50%, > 50%
Technology	Build, Enhance, Modify, Exists
Decision Definition	Fuzzy, OK, Well-Defined
Knowledge Domain	Eclectic, OK, Narrow
Object System Factors:	
Size	Small, Medium, Large, Very Large
No. Rules	< 50, 50-200, 200-500, 500-1000, > 1000
Type of Inference	Production, Resolution, Analogy, Generate and Test, Statistical
NLI	No, Yes
KA Module	No, Yes
Autonomy	Advisor, Aide, Assistant, Agent, Administrator
Interface Requirements	User, File, Comm, PLI, Message, Multiple
% Conventional	> 50%, 10% - 50%, < 10%
Expertise Needed in:	
Many Locations	No, Yes
Hostile Environment	No, Yes
Location Difficult to Access	No, Yes
Development System Factors:	
Host Computer	Limited, OK, Powerful
Development Environment	Poor, OK, Rich
Languages, Shells, and Tools	Few, OK, Many
Environmental Factors:	
Expertise Skills:	
Being Lost	No, Yes
Scarce	No, Yes
Employee Acceptance	Negative, Neutral, High
Teachability	Difficult, Possible, High
Level of Staff Skill	0-1 year, 1-3 years, 3-5 years, > 5 years
Experts	Unavailable, OK, Available
No. of Experts	0, 1 - 3, > 3
Expert Availability	< 50%, 50%-75%, 75%-90%, > 90%
Turnover	Low, Moderate, High
Expert Attitude	Hostile, Inarticulate, Uninterested, Willing
Control	Loose, OK, Tight
Data Control	Low, Moderate, High
Procedure Control	Low, Moderate, High
Performance Metric	Low, Moderate, High

B.3 DISCUSSION OF FACTORS

The key factors in a decision rule are described below.

Suitability. This factor provides a measure of the overall suitability of a project for possible implementation as an ES. It is a dependent factor which must be found by evaluating the independent factors and then combining them in weighted fashion.

Risk. This dependent factor is evaluated before, during, and after the project. It provides an index for monitoring progress and contributing to the initial estimate of suitability.

Worth. This factor is concerned with the potential benefit that might be derived from a successful system development. It is primarily evaluated only at the start of ESDM, but it might be reevaluated if knowledge acquired during the project refines estimates of the factors contributing to worth.

Employee Acceptance. In general, if the user base intended for a system is opposed to using it (conventional or expert), then the chances are high that the system may not be used or may not be used to its capacity. A low employee acceptance for an ES has a negative impact on the suitability for that system.

Solution Available. If an automated solution already exists for a given problem, then the possible gains to be had from developing a new one, based on the use of ESs, may be small. Indirectly, this affects both Suitability and Worth.

Easier Solution. If a solution not only already exists, but is easier to implement than an ES, then the use of an ES approach to the problem must be strongly questioned.

Teachability. If a manual system exists to accomplish a certain task, and if the system is easily taught to operators, then the likelihood is increased that an ES can easily be developed to accomplish the task. However, if use of the manual system is not easily taught, then it is less likely that a satisfactory ES can be developed to perform the task.

Payoff/Cost. This factor is the key factor in the evaluation of worth. The cost/benefit analysis is so well known and widely used for systems of all types that it needs no explanation here. However, it should be noted that the payoff/cost factor is only one of five factors that should be considered in evaluating the worth of a possible project.

Target Functionality. If the target functionality for a proposed system does not now exist or cannot be accomplished in any other way, the possible importance of this factor may be sufficiently high that it could outweigh other factors.

Priority. The priority of a proposed system has an obvious bearing on the worth of the project.

Expertise Needed. If expertise of a special nature is needed in many locations, in a hostile environment or in locations that are difficult to access, the potential worth of an ES could be increased.

Expertise Skills. If the skills of experts are being lost due to attrition of personnel, or if they are scarce, then the possible worth of a proposed ES to duplicate these functions may outweigh other factors, including a high-risk factor. ESs have been proposed for many applications simply because there is a desire to capture the expertise of humans, and the ES is a very effective tool for this purpose.

Complexity. In general, the higher the complexity of a manual system, the less chance that it can be duplicated by an ES (i.e., the greater the risk of development for the project). This factor is related to the teachability of manual systems, but can be evaluated independently when there is no data on the teachability of the system.

Experts. At present, there is a high demand for human experts from whom the expertise for a given task can be extracted. The presence of a sizable group of experts to serve as part of the team for the proposed project reduces the risk of development. The further development of automated tools for knowledge acquisition may reduce the importance of this factor in the future.

Control. The term control refers here to that which is exerted in the manual system to be duplicated by machine. In general, a manual system that is well controlled (even though complex) is easier to duplicate than one that is poorly controlled. This factor has a direct bearing on risk.

Size. The rule of thumb in ESs is as follows: there is no task too small for an ES. In general, the larger the size of the expected system, the greater the risk of attempting to develop an ES to duplicate the function.

Autonomy. If a proposed system is required to function with a high degree of autonomy (e.g., working for long periods of time without human supervision or making critical decisions), the risk of development for that system is high. The additional testing and special techniques that must be employed to ensure robustness for an autonomous system can add significantly to the cost of the system and to the risk in undertaking development.

Percent Conventional. In general, a system with a high percentage of conventional software components and only a small percentage of rules-based or other ES elements is less risky than one that has a high percentage of ES elements. However, this factor must be tempered by the total size of the ES component required.

Interface Requirements. An ES that interfaces only with a human being, providing advice in response to a dialogue by the user is generally a lower risk system than one that must interface with other systems in addition to the user.

☆U.S. Government Printing Office: 1992 – 648-069/60218