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THE DEVELOPMENT OF AN ARTIFICIAL
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USING MULTIPLE EXPERTS

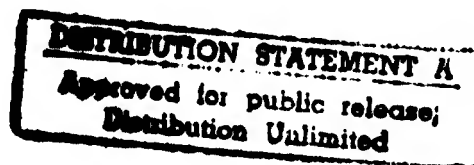
DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate School of
The Ohio State University

By

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The Ohio State University
1986



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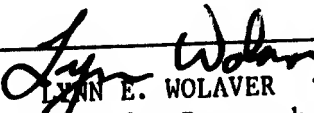
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→ A fourteen-step approach to the development and testing of expert systems which incorporates many of the lessons learned from past developmental efforts was used. The approach included the use of the Delphi Technique for task and expert selection, the use of multiple experts as a group, and use of the Nominal Group Technique to achieve consensus. Seven experts worked as a group with the researcher to determine the decision heuristics. The expert system which was developed, the Inventory Management Assistant (IMA), contained 441 rules and recommended advice to the user on ten separate elements. The expert system was then tested to determine the effect of the expert system on decision effectiveness and efficiency.

Inventory managers who were assisted by the expert system exhibited significant performance improvements on a complex problem. Improvements of 15.1 to 17.73 percent were demonstrated. In addition, during a single pretest a \$600,000 error was found in one item by using the expert system. The potential for efficiency improvements was also demonstrated.

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For my husband

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CHAPTER I

INTRODUCTION

The artificial intelligence subdiscipline of expert systems appears to hold great promise of improved productivity and better decision-making. Certainly, the technology has attracted widespread interest. As Harmon and King note in their 1985 book Expert Systems: Artificial Intelligence in Business:

"...the United States, Japan, England, and the European Economic Community are all in the process of launching major research programs to develop and implement expert systems in the near future. Many Fortune 500 corporations are assembling AI departments, venture capitalists are rushing to invest in entrepreneurial expert systems companies, and expert systems technology is well on its way to commercial success [Harmon:1]."

Similarly, Mishkoff, in his 1985 book Understanding Artificial Intelligence, states:

"Since the expert systems field promises a great deal of practical application and commercial potential in the near future, it has begun to attract an enormous amount of attention. Expert systems technology is poised to become the first AI technology to have a widespread impact on business and industry [Mishkoff:16]."

Already, expert systems have been developed to assist managers in solving a number of different problems. For example, expert systems exist which

"...diagnose diseases, locate mineral deposits, configure complex computer hardware, and aid mechanics in troubleshooting locomotive problems [Harmon:1]."

However, no expert systems have been documented in the public domain which make inventory management decisions.¹

The objective of this research is to determine if expert systems can improve the effectiveness and efficiency of inventory management decision-making. A discussion of the problem, specific objectives of the research, research hypotheses, and research methodology follow later in Chapter I. First, however, background information on artificial intelligence and expert systems is provided, such that the reader may better understand the proposed research.

Artificial Intelligence

Artificial intelligence is the subfield of computer science that concerns itself with "making machines do things that would require intelligence if done by humans [Systems Manufacturing Technology Group:1]." In order to understand this technology, then, it is necessary to examine the concept of intelligence or intelligent behavior.

"Intelligence is the ability to learn or understand from experience, and the ability to acquire and retain knowledge. To be considered intelligent one must have the ability to respond quickly and adapt fully to a new situation. Also, the facility of reason must be applied to improve one's level of performance based on one's

¹A review of the artificial intelligence literature was conducted.

past experience in solving problems [Systems Manufacturing Technology Group:1]."

Intelligence can be

"viewed in terms of the ability of any decision-making entity to achieve a degree of success in seeking a wide variety of goals under a wide variety of environments [Fogel:119]."

"It appears that the clue to intelligent behavior, whether of men or machines, is highly selective search, the drastic pruning of the tree of possibilities explored [Feigenbaum and Feldman:6]."

Intelligence, then, is not a dichotomous construct; but rather, a continuum of values of human capacity or ability. However, recent advances in the field of study known as "artificial intelligence" provide a challenge to the consideration of intelligence as a strictly human characteristic.

But, can computers really be made to think, to reason, to learn? Again, this is a question of degree. Michie, for example, has argued against the potential to impart true intelligence to a computer; noting that two of the most important aspects of human intellect -- originality and the ability to learn -- could never be imparted to a computer program [Michie:6].

Feigenbaum and Feldman have an opposing view. They have suggested that computer programs behave intelligently when they "search problem mazes in a highly selective way, exploring paths relatively fertile with solutions and ignoring paths relatively sterile [Feigenbaum and Feldman:6]." Rich concurs and expands this thought of selective search in her definition of artificial intelligence as

"...the study of techniques for solving exponentially hard problems in polynomial time by exploiting knowledge about the problem domain [Rich:37]."

Research in AI has been so intense that the topic could be viewed as a discipline in its own right. For example, Rich refers to AI as "a relatively new discipline [Rich:xii]." Indeed, several subfields of study in AI have already developed and are being actively pursued. These subfields include: problem solving, more popularly known as expert system or knowledge representation; natural language, the ability to convert English into computer language; sensing, vision and speech understanding for robotics; manipulators, hand and arm movements; and search techniques [Systems Manufacturing Technology Group:2]. Although all these subfield areas of study will likely be beneficial contributors to future logistics applications, this research will focus on the first subdiscipline, expert systems.

Brief History of AI and Expert Systems

Although artificial intelligence seems to be enjoying a recent surge of interest and popularity, the study is not new. AI has been pursued for more than thirty years. However, most of the original research was in the area of cognitive psychology, rather than computer science [Systems Manufacturing Technology Group:1]. AI research began in the mid 1950's, spurred in part by scientists' preoccupation with the now famous Turing Imitation Game [Feigenbaum

and Feldman:12]. The Turing Game was a test to determine whether or not a machine could fool a human in an interrogation game. The machine was considered to possess intelligence if the person performing the interrogation was unable to distinguish the machine's responses from another human's.

The first formal meeting "to confer about the possibilities of producing computer programs that could behave or think intelligently [Gardner:138]" was held in the summer of 1956 at Dartmouth College in Hanover, New Hampshire. Ten scholars attended the summer conference. The scholars exchanged views and made plans to collaborate on future research. Allen Newell and Herbert Simon from the Rand Corporation were two of the attendees at the summer conference. Newell and Simon, together with Cliff Shaw, a colleague at Rand, developed the first artificial intelligence program called Logic Theorist in 1956 [Klahr:1].

Rudimentary AI programs capable of playing chess, proving mathematical theorems, answering questions, recognizing patterns, and even balancing an assembly line were soon developed [Feigenbaum and Feldman]. Indeed, Marvin Minsky developed an AI program capable of performing Euclidean geometry which produced an "original" proof [Michie:5].

As early as 1963, list processing languages such as Information Processing Language V (IPL-V), FORTRAN List Processing Language (FLPL), COMIT, and LISP were in use. These languages were crucial

to the feasibility of expert systems. For the first time, via these languages, the computer was provided with the capability to manipulate symbols and reason about symbols. In 1965, DENDRAL -- an expert system capable of inferring chemical structures -- was created. DENDRAL was a key turning point towards other knowledge-based AI programs [Feigenbaum and McCorduck]. In developing DENDRAL, Feigenbaum "pioneered the rule-based approach that is currently popular in the development of expert systems [Mishkoff:38]." Expert systems really began to flourish in the mid 1970's as "...AI research centers were formed at increasing numbers of educational institutions [Mishkoff:37]."

The decade of the 1980's saw the first introduction of expert systems for daily use in business and industry. The first system XCON, short for expert configurer, was introduced at Digital Equipment Corporation in 1980. XCON is used to assist Digital personnel in the task of configuring orders for VAX computers [Digital:17]. The trend of the 1980's towards increased use of expert systems to address "the large volume of nontechnical problems involving decisions or assessments" is projected to accelerate [Hart:98].

What is an Expert System?

"An expert system is a computer program that mimics a human expert; using the methods and information acquired and developed by a human expert, an expert system can solve problems, make predictions, suggest possible

treatments, and offer advice with a degree of accuracy equal to that of its human counterpart [Ham:34]."

According to Shurkin, Dr. Davis at MIT defines human experts in terms of seven attributes: ability to solve problems, to explain results, to learn by experience, to restructure their knowledge, to break rules when necessary, to determine relevance, and to exhibit graceful degradation of performance. In 1983, Shurkin commented that to date, "expert systems exhibit only the first three properties in any depth [Shurkin:75]."

Expert systems have also been distinguished as "intelligent assistants" that

"permit their bosses to work more effectively and creatively. The key difference between them and human experts is that computers have special-purpose intelligence, designed to perform a limited task and perform it superbly, whereas we are general purpose beings able to perform a wide variety of tasks reasonably well and a few tasks brilliantly [Systems Manufacturing Technology Group:2]."

Since expert systems, by definition, mimic human experts, an understanding of how people solve problems is necessary. Research has shown that experts do not consider all possibilities and their expected outcomes in making decisions; rather, experts "simply apply an enormous store of textbook knowledge and experiential knowledge" switching between these two as necessary [Systems Manufacturing Technology Group:3].

Expert systems emulate our reasoning processes by employing search heuristics. A heuristic is any "rule of thumb, strategy,

trick, simplification or any other kind of device which drastically limits search for solutions in large problem spaces [Feigenbaum and Feldman:6]." Boose notes that human experts use heuristics "to make educated guesses when necessary, to recognize promising approaches to problems, and to deal effectively with incomplete or inconsistent data [Boose:27]."

Sell notes that expert systems possess both

"essential and desirable characteristics: essential ones, without which they could not be called expert systems and desirable ones without which, in most cases, they would not be usable [Sell:13]."

Essential characteristics are the knowledge in the system which correctly captures the expert's thought processes and the significance of the problem which the system is designed to solve. Desirable characteristics include an ability to "perform well on difficult problems," to "converse in terms the user can understand," "to explain how it reached its conclusions from the facts," and to "work at the speed that the situation demands" [Sell:16-17].

Classification of Expert Systems

Stefic et al. note three orthogonal dimensions along which expert systems can be classified: a roles dimension, a techniques dimension, and a task dimension [Stefic:163]. Minsky addresses a fourth dimension: the sophistication of the expert system. Each of these dimensions will be addressed in turn below.

Roles

Basden notes four key roles which an expert system can fulfill: a "consultancy role," a "checklist" role, a "training role," and a "refining expertise" role.

"In a consultancy role an expert system is used by a non-specialist to obtain specialist advice or other forms of help in accomplishing some task [Basden:64]."

Such a system can alleviate the number of calls on the specialist. The expert system also serves to make the specialist's expertise more accessible. A consultancy system would be used by a "practitioner," a person who has "some experience in a domain" but does "not have a deep specialist understanding [Basden:63]."

In the checklist role, the expert system serves to remind:

"the user of all the factors to take into account, even if no other benefits accrue. An advantage over checklists on paper is that these inevitably include questions that do not really matter in a given case but do in others, while expert systems can intelligently select or order the questions [Basden:66]."

Expert systems show tremendous potential in a training role.

Such systems would:

"lead the trainee through a set of exercises, determine his/her specific areas of weakness and tailor the exercises to suit [Basden:66]."

Two training systems which have been developed are SOPHIE which teaches electronic troubleshooting and GUIDON which teaches diagnostic problem solving. SOPHIE was developed at Bolt, Beranek and Newman to teach students how to troubleshoot electrical circuits. SOPHIE requires that the student select a fault in a

simulated circuit and then find the fault by proceeding through a step by step analysis. At each step SOPHIE asks the student to predict whether the measured voltage of the test instrument will be correct, too high, or too low. If the student makes a mistake in predicting the voltage, SOPHIE displays the correct measurement and explains why this measurement resulted [Waterman:258]. GUIDON, developed at Stanford University, teaches students the proper selection of antimicrobial therapy for hospital patients with bacterial infections. GUIDON selects a patient's medical record, presents the medical record to the student, and analyzes the student's questions and responses during the student's consultation with GUIDON. GUIDON then uses this analysis to guide the tutoring provided to the student as a result of the consultation [Waterman:278-279].

The role of refining expertise in a given domain is perhaps most applicable to the research reported herein.

"Most specialists will freely admit to having gaps in their knowledge, and it is likely that expert systems can help to identify where these lie [Basden:66]."

Basden also notes that an expert system used in this capacity can

"be of significant benefit as a guide to research, by highlighting weaknesses in current understanding [Basden:67]."

Techniques

In terms of techniques Ham notes that most "expert systems fall into one of three categories: rule-based systems, frame-based systems, and blackboard systems [Ham:36]. Each of these categories will be addressed in turn.

Rule-Based Systems

Rule-based systems, also known as "production systems," are the most popular in current use. Winston states that "most successful" expert "systems embody the rule-based problem-solving paradigm [Winston:172]." Sell adds that "of the various representation schemes, production rules are not only the most used, but also the best tried and tested [Sell:38]."

The rules are of the form: If A, then B. Note that both A and B can be either a single fact or a series of related facts. Such a representation

"can directly accommodate the knowledge of the domain experts in the form they most often communicate it -- for example, 'In this situation I suspect this problem and perform these tests.' [Barr:83]."

Feigenbaum notes that the rule-based representation also permits both "ease of modification of the knowledge" and "ease of explanation" [Feigenbaum (1977):5].

One of two reasoning mechanisms or a mixture of the two is commonly used in rule-based systems. In "data driven" or "forward chaining," the system attempts to reason forward from the facts to a

solution. In "backward" or "goal-driven" chaining, the system works backwards from the desired solution to find facts which support the solution [Kinnucan:34]. The reasoning is called "chaining" as the expert system links together or chains several knowledge base rules [Van Horn:108].

An example of forward chaining is provided by Winston. See Figure 1. In forward chaining, then,

"the interpreter evaluates the conditions with reference to the database of facts and, if successful in fulfilling the condition, performs the action. As the interpreter does this repeatedly, its action is referred to as the 'recognise-act cycle' [Sell:34]."

Figure 2 depicts when forward and backward chaining are used. Each box in the figure represents an if/then rule. The bold arrow depicts how the rules are chained together as well as the direction of chaining. The reasoning process should start where there is the smallest number of factors to consider initially, either with the initial facts and conditions (forward chaining) or with the number of possible solutions (backward chaining).

Frame-Based Systems

Frame-based systems store factual knowledge in frames, where frames resemble miniature data bases which are hierarchically ordered.

Here is the procedure for forward chaining:

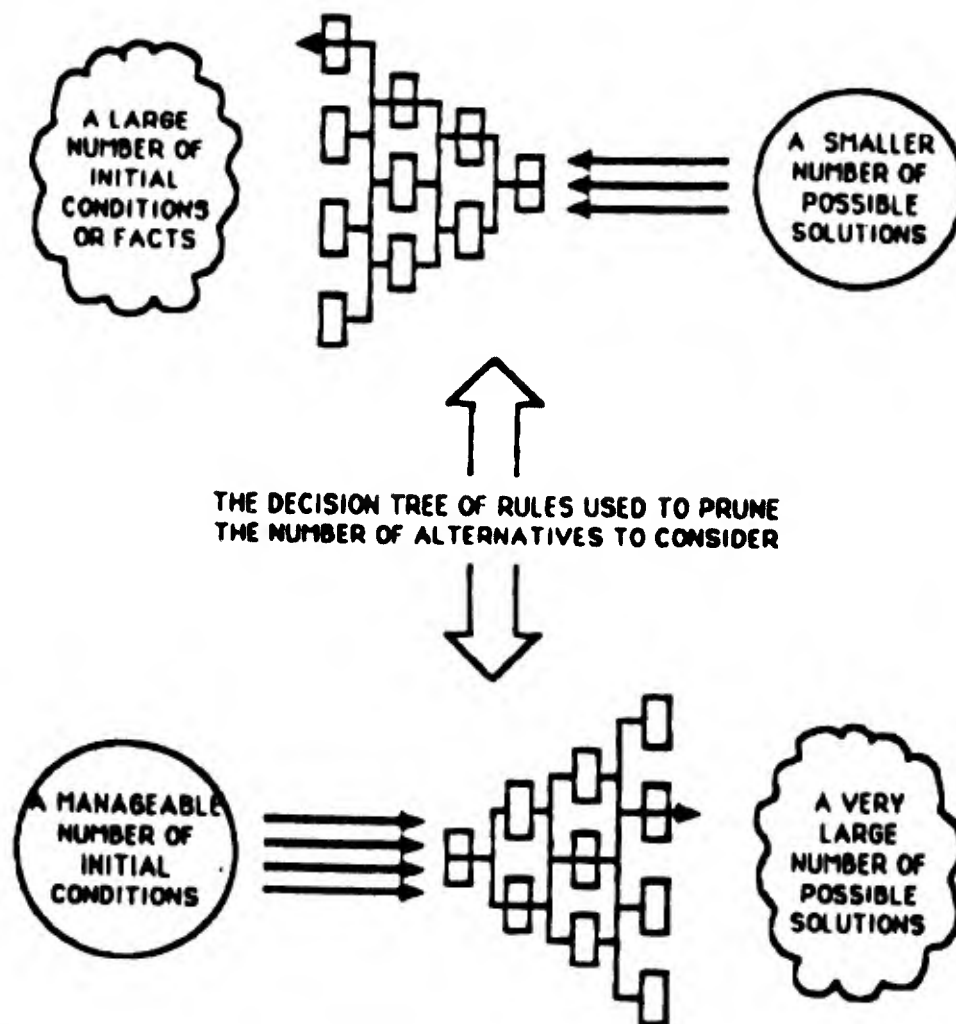
To forward chain using if-then rules:

1. Until a problem is solved or no rule's if parts are satisfied by the current situation:
 - 1.1 Collect rules whose if parts are satisfied. If more than one rule's if parts are satisfied, use a conflict-resolution strategy to eliminate all but one.
 - 1.2 Do what the rule's then parts say to do.

Source: Patrick Henry Winston, Artificial Intelligence (Reading, Massachusetts: Addison-Wesley Publishing Company, 1984), p. 172.

Figure 1

Forward Chaining



Source: Mike Van Horn, Understanding Expert Systems. (New York: Bantam Books, 1986), p. 109.

Figure 2

Determining When To Use Forward and Backward Chaining

Figure 3 depicts knowledge about a 16x1 switch card represented as a frame. A separate frame would exist for each of the components or subcomponents of a system or organization. Each frame has "slots," each of which is assigned a particular "value."

Frame-based systems use production rules to control the system. These rules are frequently of the form when/then. The when part of a rule is true when a frame's slot is equal to the value given in the rule [Laffey:16].

Blackboard Systems

A blackboard system

"takes its knowledge from several knowledge sources embodied as separate data bases and calls in the information it needs with appropriate subroutines. Each knowledge system acts like a separate system and conclusions are sent to a shared data base (the blackboard) that can be viewed and accessed by any data base [Ham:37]."

The separate knowledge sources may be either rule-based or frame-based. The advantage of such blackboard-style expert systems is that one knowledge source can use the conclusions drawn by other knowledge sources.

Tasks

Another way to classify expert systems is by the tasks that they perform. Stefic et al. offer six generic tasks which experts may perform [Stefic:136-140]. "Interpretation" is the "analysis of

Category: CARD	
Slot	Value
NAME	'16x1 switch'
TYPE OF	'16x1 card'
LOCATION	'cabinet 302 A1 A4 A20'
FAULTY LIKELIHOOD	'0.1'
SIGNAL PASSING	'TRUE'
ELECTRICALLY CONNECTED INPUT	'CARD (NAME = 1x16
buffer)'	
ELECTRICALLY CONNECTED OUTPUT	'CARD (NAME = 8x1 second
level)'	
ELECTRICALLY SUPPORTED BY	'CARD (NAME = 16x16
matrix)'	
ELECTRICALLY SUPPORTS	"
HAS FAULT LIGHT	'TRUE'
TESTABLE INPUT POINT	'FALSE'
TESTABLE OUTPUT POINT	'TRUE'
GIVES ALARM	'FALSE'
FAULTY	"
INPUT SIGNAL PRESENCE	"
OUTPUT SIGNAL PRESENCE	"

Source: Thomas J. Laffey, Walton A. Perkins, and Tin A. Nguyen. "Reasoning About Fault Diagnostics with LES," IEEE Expert, Spring, 1986, p. 15.

Figure 3

Frame Representation of a 16x1 Switch Card

data to determine their meaning [Stefic:137]." "Diagnosis" is the determination of "reasons for or sources of disparity between expected and actual states or operations of a system [Sell:19]." "Monitoring" is the act of "continuously interpreting signals and setting off alarms when intervention is required [Stefic:137]." "Prediction" is forecasting the next state or action of a system on the basis of data from its current state or a model of its past. "Planning" constitutes preparing a "program of actions that can be carried out to achieve goals [Stefic:138]." Finally, "design" is the "making of specifications to create objects that satisfy particular requirements [Stefic:139]." Waterman adds three additional tasks: repair, instruction, and control [Waterman:33]. See Table 1. An expert system can be designed to perform one or more of these tasks.

Sophistication

Minsky presents a classification of the sophistication of expert systems based upon the level of programming used in the systems. "Do now programming" is the most primitive of these and forces "you to imagine everything your program will do from one minute to the next." "Do-if-needed programming" is a slightly more advanced structure wherein systems "automatically apply rules whenever they're needed." Finally, "do something sensible programming" is the most progressive form. These programs "match patterns in memory to decide what to do next [Minsky:66-67]."

Table 1
Generic Categories of Expert
System Applications

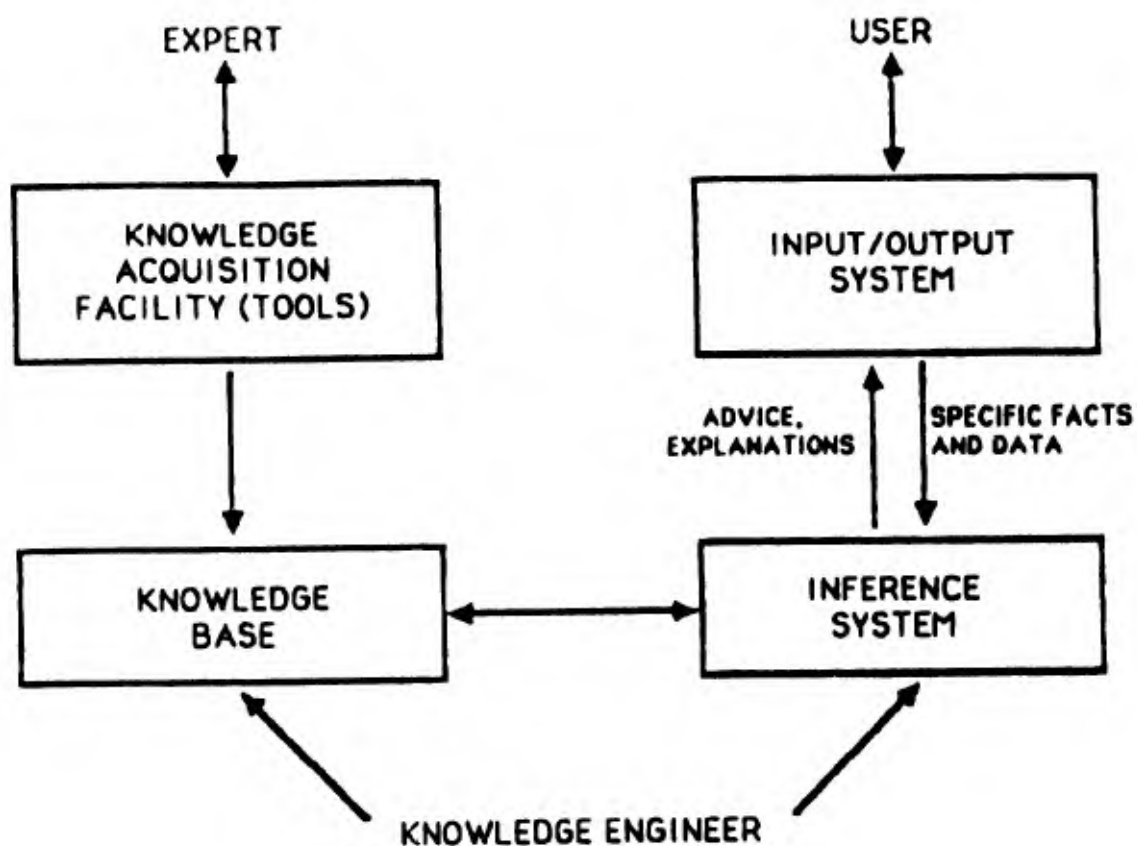
Category	Problem Addressed
Interpretation	Inferring situation descriptions from sensor data
Prediction	Inferring likely consequences of given situations
Diagnosis	Inferring system malfunctions from observables
Design	Configuring objects under constraints
Planning	Designing actions
Monitoring	Comparing observations to expected outcomes
Debugging	Prescribing remedies for malfunctions
Repair	Executing plans to administer prescribed remedies
Instruction	Diagnosing, debugging, and repairing student behavior
Control	Governing overall system behavior.

Source: Donald A. Waterman, A Guide to Expert Systems (Reading, Massachusetts: Addison-Wesley Publishing Company, 1985), p. 33.

Dillard et al. discuss still a different taxonomy of design concerning "the level and sophistication of the 'intelligence' which can be implemented in the system [Dillard:7]." An "intelligent manual," the most rudimentary application, is basically an on-line reference manual or computer-aided tutorial system, with no analytical capability. A "deductive system" would contain some reasoning capabilities which would allow it to make simple deductions on its own. Finally, a "data rich system" would be the most advanced, having the capability to read, understand, and formulate positions [Dillard:7-9].

Structure of an Expert System

The basic structure of an expert system is shown in Figure 4. The knowledge base of this system contains the basic information gleaned from the human expert. Two types of knowledge are typically included within this knowledge base: basic facts and heuristic knowledge or good judgement. The inference system, frequently termed the inference engine, provides overall control of the system. The inference engine establishes the method of reasoning used to match rules to data and to determine which rule should be applied next. In addition, the inference engine adds the conclusion drawn from this process to the problem data base [Why Can't A Computer:76]. This inference system may provide advice or explanations to the user or may query the user for additional facts



Source: Edward A. Feigenbaum and Pamela McCorduck, The Fifth Generation (Reading, Massachusetts: Addison-Wesley Publishing Company, 1983), p. 76

Figure 4

Basic Structure of an Expert System [Why Can't A Computer:76]

and data to add to the existing data base. Ham notes a distinct design objective relative to the ability of the inference system to return explanations to the user, which Ham terms an "explanation facility." This facility enables the expert system to explain how it arrived at its present conclusion or why it is pursuing a certain line of reasoning [Ham:37]. Such a capability is critical to validating and debugging the expert system, and can serve as an excellent training tool as well.

The expert plays a particularly crucial role in the development of an expert system. Peltu notes that the real starting point of an expert system is an expert -- called a "domain specialist" [Peltu:71]. The expertise of this specialist must then be captured in the rules and knowledge base of the program. This function is called "knowledge engineering" and the individual who performs this task is referred to as a "knowledge engineer." This task appears to be particularly difficult. Waterman states that people simply do not know exactly how they make decisions or perform tasks [Waterman:153]. The knowledge engineer's job is to draw the information out. Special cases, in particular, can present problems. "Human experts are not very good at remembering special cases until they are confronted with a concrete example" [Why Can't A Computer:79]. The knowledge engineering and knowledge acquisition portions of Figure 4 will be addressed in detail in Chapter II.

Advantages of Expert Systems

"Expert-systems research promises to lead to AI applications of great economic and social impact [Barr:79]."

Numerous advantages of expert systems have been cited. First, an expert system serves to make the knowledge of a domain explicit. Hence, a written record of the knowledge of a domain is frequently made available for the first time.

"Having a knowledge system available is like having ready access to a storehouse of experience and hindsight. It is a 'tool' to help the end-users do their jobs. Knowledge systems are a new resource you may consult for assistance in making a decision, just like other reference materials. Better yet, this reference system asks for the information it needs, explains how it reasons when asked, and gives consistent advice with infinite patience [Teknowledge-Building: 2-11]."

A second advantage, then, is the greater consistency of expert systems over human decision-makers. As Basden points out,

"humans can forget relevant factors, especially if under stress or in a situation where time is critical [Basden:64]."

Sell adds that an expert system will "give the same answer to beggars and kings [Sell:15]." Therefore, poor decisions are not made due to favoritism or politics. Such systems also do not "suffer from Monday morning blues or Friday afternoon impatience [Sell:16]."

Still another advantage is the greater accessibility to expertise which expert systems permit. Expert systems are available twenty-four hours a day. Expert systems do not get tired or go on holidays.

Further, this expertise is more readily duplicated. Copies can be made of the expert system instead of placing many individuals into lengthy training or apprenticeship programs.

Basden also notes that expert systems provide for

"...increased consistency in the relative importance given to different factors and in dealing with probabilities [Basden:64]."

At the same time, expert systems provide for more "human-like processing."

"Compared with conventional computer programs, an expert system operates at a level and in terms and concepts with which the user can feel affinity [Basden:62]."

Because of this, such systems

"are much more easily understood by practitioners in the domain who might not be very computer-literate [Basden:62]."

Further, since "uncertainty, and even contradictory evidence, are handled in a natural way" expert systems "can be used in areas of incomplete knowledge and where judgement is needed [Basden:63]." Expert systems can, therefore, more easily tackle real-world problems.

Expert systems also offer the potential to reduce the workload on many problems which, although trivial to the human expert, are nevertheless critical to the successful operation of a firm. Such problems are frequently difficult for the novice to handle. The real expert is then freed to pursue more challenging tasks. Indeed, Harmon and King predict

"as expert systems are built, experts will be freed to focus on the more difficult aspects of their specialty. This, in turn, will result in solutions to new problems, and the range of problems that experts can solve will widen [Harmon:2]."

Feigenbaum and McCorduck in their book, The Fifth Generation, provide a brief description of forty-nine current expert systems in various fields such as bio-engineering, computer systems, education, law, manufacturing, and medicine. However, no expert systems are listed for inventory management functions [Feigenbaum and McCorduck:244-250]. The Systems Manufacturing Technology Group Working Paper also lists numerous examples of current expert systems [Systems Manufacturing Technology Group:9-13]. Again, no inventory management applications are noted. Finally, Waterman provides one of the most current and detailed descriptions of existing expert systems. One hundred and seventy-eight expert systems are briefly described. Still, there are no systems for inventory management [Waterman:244-299]. Further, the only current applications of expert systems in any logistics subtask are those systems which perform maintenance troubleshooting or diagnostic functions.

Statement of the Problem

The current applications of expert systems have demonstrated quite successful results in terms of better and more efficient decision-making which translates directly to dollars saved and more effective management. However, the logistics discipline has not yet

harnessed this technology in the public domain. Expert systems technology has emerged from the research laboratories as a powerful practical tool [Harmon:1]. Logistics should also be able to reap the benefits of this new technology. Therefore, research was conducted to investigate the applicability of expert systems to logistics, specifically to inventory management. The following questions were addressed:

1. Do inventory managers use heuristic decision rules?
2. Can these rules be captured and programmed as an expert system?
3. Can expert systems for inventory management provide effective decisions?
4. Can expert systems for inventory management suggest solutions as quickly as human experts?

Inventory as a Potential Application

Inventory offers a pervasive and potentially quite lucrative area in which to apply expert systems. Materials management and inventory problems are common to all business organizations -- retailers, wholesalers, distributorships, and manufacturers.

Further, inventory is big business. As Ballou notes the figures for the United States alone are "substantial":

"It has been estimated that over the decade of 1970-79 the average annual investment in business inventories was \$305 billion, or about 18 percent of the gross national product. The cost of carrying these inventories in the business sector has been estimated at between 30 and 40 percent of inventory value before taxes. This was an annual cost to the nation of between \$128 and \$170 billion in 1979.

Among individual firms, inventory carrying costs can represent 10 to 40 percent of total logistics costs depending on whether the firm is a manufacturing, merchandising, consumer, or an industrial goods-oriented company. Costs of this magnitude suggest that inventory is an asset that should be carefully managed [Ballou (1984):356-357]."

The National Council of Physical Distribution Management (NCPDM) study, Measuring and Improving Productivity in Physical Distribution 1984, reported similar figures. The estimated U.S. logistics expenditures for inventory carrying cost for 1982 were listed as \$130 billion [NCPDM:19]. Silver and Peterson also quote impressive statistics:

"According to Statistics Canada the total inventories owned by Canadian manufacturers are in the neighborhood of \$30 billion. Furthermore, on average, 34 percent of the current assets and 90 percent of the working capital of a typical company in the United States are invested in inventories. In addition, considerable labor costs (clerical and managerial) are incurred in the control of inventories...Thus, we see that even a small percentage reduction in costs will be transformed into huge absolute savings, when viewed from a national or international perspective [Silver:2]."

Poor inventory management wastes resources. Further, Mather suggests that inventory mismanagement may be a major cause of "economic disruption:"

"Anyone who has been in business more than just a few years knows about the business cycle. It's a fact of life, repeating almost exactly every 4 years. Check the statistics if you don't believe me. One of the real contributors to this cycle is mismanaged inventories. All economists talk about inventories and suggest they amplify the boom -- and bust cycle, but don't explain why. Some even look to inventory growth to pull us out of recessions; why can't they see inventory growth as the seed of the "next" recession? Inventories are just

like other natural phenomena: what goes up must come down. So if inventories can pull us out of recession by going up, they can plunge us deeper into recession by going down. Why can't they be stabilized? Why can't they operate against the cycle, growing when business drops off and dropping when business picks up? That way they would become a real dampener on the business cycle instead of an amplifier. But to do this means getting them under control. And under control they're not [Mather:xvi]."

The issue then becomes how to do a better job of managing inventory such that control can be regained. This issue strikes at the very essence of inventory management, which has primarily been treated as "scientific" or the application of mathematical techniques. However, according to Tersine

"mathematical techniques are only aids to management decision-making. They cannot replace the judgement and intellect of the manager, who must modify and improvise to deal with the unexpected [Tersine:xii]."

Silver and Peterson note that although inventory management has "been studied in considerable depth from a theoretical perspective," it is surprising "to find how limited, and ad hoc, many of the existing decision systems actually are [Silver:ix]." Perhaps, this is because the theoretical models do not perform so well in the multiechelon inventory arena and the simulations frequently require an "extensive amount of data to be collected" and "long computer running times [Ballou (1985):400]."

Silver and Peterson state that

"one must accept the fact that existing theory is, and will be, for some time to come, insufficient to do the whole job. There will always be room for personalized, tested-in-practice, approaches to fill the gaps in theory [Silver:57]."

Further, Silver and Peterson "advocate the development and use of so-called heuristic decision rules [Silver:71]" for help in dealing with complex inventory situations. New techniques and new knowledge appear wanting.

Objectives of the Research

A primary objective of this research was to identify the basic rules and heuristics for a particular inventory management problem which experts in the field have gained from years of experience and textbook knowledge. However, the discovery that such heuristics do in fact exist would not in itself demonstrate the applicability of the expert systems technology to inventory management. Therefore, a secondary objective was to incorporate these heuristics into an actual expert system and measure the performance level of this expert system, both in terms of the effectiveness and efficiency of the decisions which resulted.

Scope of the Research

A comprehensive approach to this study might be to look at inventory management in a number of different companies and types of firms, and even across product types, to discover some new base of knowledge which would significantly advance the art of inventory management. However, such a broad scope would raise many other issues such as the ability to generalize inventory heuristics across

product groups and types of firm, and stage of product life cycle issues. A realistic test situation was required. Therefore, the first decision was to focus on only one organization or firm, and, the United States Air Force was chosen.

Selection of that organization was based primarily on the complexity of the task environment, so that any resultant findings would not be trivial. The ability to obtain the required cooperation and commitment of individuals and the necessary data, and the lack of any proprietary restrictions on the research results, were also important considerations. The Air Force met all of these requirements. The Air Force provides an excellent test environment for such a study due to the complexity and worldwide scale of the task environment.² Further, the United States Air Force ensured the cooperation and availability of personnel and any required data and documentation. All findings are free of proprietary restriction.

If the Air Force were an actual corporation, it would be one of the largest corporations in the United States [Hiatt:1]. Further reduction in scope was required. Within the Air Force there are five different Air Logistics Centers (ALCs), each of which provides

²The United States Air Force Logistics Command currently supports 19,000 aircraft in operation around the world. These planes require 916,000 types of spare parts and twenty million pages of technical manuals [Hiatt:1].

wholesale support for a different group of products or systems. The ALCs are similar to major divisions of any large corporation. The Air Force suggested that Sacramento Air Logistics Center (Sacramento, California) be the particular ALC where the study would be conducted. The Ogden Air Logistics Center (Ogden, Utah) was used as an additional test site.

Two major classes of items are managed at each of the Air Logistics Centers. These are expendable items and recoverable items. Expendable items are items such as nuts and bolts, capacitors and resistors, which are consumed in use or discarded when no longer serviceable. Recoverable or repairable items are high cost items which are recovered after use, repaired as necessary, and returned to stock for reuse. Pumps, hydraulic actuators, electronic circuitry, and motors are examples of recoverable assemblies.

Silver and Peterson state:

"The analysis of a repairable item situation is considerably more complicated than that of a consumable item. Normally, in a repair situation the number of units demanded is not balanced completely by the return of repairable units. Thus, in addition to repairs, one must also purchase some new units from time to time. Consequently, even at a single location, there are five decision variables: (1) how often to review the stock status, (2) when to repair returned units (3) how many to repair at a time, (4) when to order new units, and (5) how many to order [Silver:487-488]."

Given that the recoverable situation is so much more complex and given the high relative cost of recoverable items to expendable items, it was believed that the strongest contribution could be made by studying recoverable item management.

Still, the scope was unmanageable. There are too many aspects of recoverable item management: requirements issues, distribution issues, allocation issues, exception management issues, etc. Therefore, it was decided to let the item managers³ at Sacramento Air Logistics Center nominate and select the particular problem to be addressed by the expert system. The rationale for letting the item managers select the task will be discussed in detail in Chapter II.

In addition, only a prototype expert system was developed for the selected aspect of the task, not a fully validated operational system. Boose notes: "The time required to build an expert level prototype is typically six to twenty-four months [Boose:27]." Therefore, the prototype developed as part of this research could address only a narrow problem. These stages of development will be more closely examined in Chapter II.

Finally, since the purpose of this research was to demonstrate the feasibility of applying the existing technology of expert systems, no attempt was made to create new knowledge representations or develop a better inference engine. The production rule formalism was used to represent the knowledge, given its proven record of

³Item managers are the individuals who perform inventory management functions at the Air Logistics Centers.

success. Also an expert system development tool or "shell"⁴ was used which required that only the knowledge base of the system be created and programmed by the researcher. Such shells provide a useful method of speeding the development of a prototype expert system. M.1, a product of Teknowledge [Williamson:60], is the shell which was used in this effort.

Hypotheses of the Research

The following research hypotheses were investigated:

1. Expert inventory managers use key knowledge and heuristics in decision-making.
2. This knowledge and these heuristics can be captured and programmed as an "expert system."
3. Expert systems can significantly improve the performance of inventory managers.
4. Use of expert systems will allow inventory managers to solve complex or difficult problems more efficiently.

The Research Methodology

This research was composed of three key phases. Phase I was the Problem Selection phase. Phase II was the Knowledge Engineering phase. Finally, Phase III involved Performance Measurement. Each phase will be discussed in turn.

⁴A shell is a computer software package that helps to simplify the effort involved in building an expert system. Most shells contain an inference engine and various user interface facilities such as an explanation capability and lack the knowledge base. The Williamson reference describes twenty-six different shells.

Phase I: Problem Selection

Problem Selection involved gaining a better understanding of the overall domain of item management, flowcharting the decision process, conducting workshops at Sacramento ALC with all the item managers to prepare them to recommend candidate problems, having the item managers select the preferred problem from the nominated candidates, and finally, having the item managers self-elect the ten best experts at Sacramento ALC from whom to obtain the knowledge. A combination of protocol analysis and the Delphi Technique were used as basic tools for Phase I of the research.

Phase II: Knowledge Engineering

During the second phase of the research the actual scope of the expert system and its objectives were determined.

Once the scope of the expert system had been defined, the actual heuristics and facts to be included in the knowledge base were determined and encoded. The knowledge base was then exercised on a series of case studies to validate its rules, correct any errors, and add any previously omitted information. Phase II of the research employed the Nominal Group Technique combined with case analysis.

Phase III: Performance Measurement

Once the expert system had been validated against the development case studies, experiments were conducted using case

studies preselected to cover both routine and nonstandard aspects of the problem. The test cases were different from those case studies used for development purposes. These experiments determined the degree of performance improvement achieved with the use of the expert system. Further, an attempt was made to gauge how quickly the expert system was able to make decisions compared to its human counterparts. These phases and the operationalization of these measures are discussed in depth in Chapter III.

Limitations of the Research

There are four principal limitations of this research. The first concerns the preselection of an expert system shell with which to develop an expert system for a new domain. M.1, like any shell, has predefined characteristics of knowledge representation formalism and reasoning mechanism. These predefined attributes are, respectively, production rules and backward chaining. This technology, however, may not be the most efficient means of representing or reasoning about the knowledge of inventory management. It is possible that the nature of the domain might be much more efficiently handled with frames or forward chaining.

A second limitation concerns the bias which may have been introduced by the item managers at the Sacramento Air Logistics Center in selecting the actual problem to be addressed by the expert system developed as part of this research effort. Due to management

emphasis, past audit reports, or other reasons, certain problems may have been perceived to be more important at Sacramento than at the other Air Logistics Centers. Other centers may have provided a much different list and/or ranking of the problems which the expert system was designed to address.

A third limitation concerns the possibility that item managers at Sacramento Air Logistics Center may have a unique "culture" which would bias the heuristics obtained to solve the problem which was selected. Such heuristics then might not be directly applicable to a different Air Logistics Center or a different company involved with the management of the same products or types of products, but possessing a totally different organizational culture.

Finally, the attempt to measure how quickly subjects assisted by the expert system make decisions can not properly be measured without allowing test subjects adequate time to gain familiarity with the expert system. Subjects were only given one brief practice session prior to measuring their actual performance and time to completion. The results of such an experiment will most likely result in longer times than would actually be experienced by subjects who use the system on a daily basis.

Contributions of the Research

The contributions of this research are theoretical, methodological, and managerial.

Theoretical Contribution

The current theory of inventory management is basically mathematical in nature. However, a large part of inventory management appears to involve judgment and decision. The exploratory nature of this research contributed to the more qualitative aspects of the theory of inventory management. The primary contribution was an elucidation of how inventory cost and leadtime decisions are actually made, the key decision variables which are examined in this process, and an explanation of the decision process itself.

"The methodology we use gives a way of bringing heuristic knowledge to the surface and making it concrete, so that it can be discussed and consensus can be achieved. If consensus is not achieved, at least the alternatives to the consensus are available for examination. In the end it may be irrelevant that a computer program is available to be an intelligent assistant! The gain to human knowledge by making explicit the heuristic rules of a discipline will perhaps be the most important contribution of the knowledge-based systems approach [Feigenbaum (1983):49-50]."

Indeed, Ballou has stated that in attempts to apply this technology to logistics, the "weak link" will be encountered.

"The weak link is in relationships that convert observations into possible courses of action. These relationships embody our understanding of physical distribution management. It is all of the rules of thumb, principles, and concepts that we practice, teach and write about [Ballou (1984):511]."

Strengthening this "weak link" provides a significant theoretical contribution.

Methodological Contribution

Mittal and Dym have challenged that much AI research

"...needs to be done to resolve issues such as identifying different aspects of a problem and corresponding experts, integrating knowledge from various experts, resolving conflicts, and assimilating competing strategies [Mittal:36]."

Further, Van Horn notes:

"When the knowledge of several experts must be combined into one expert system, the problem of reconciling their diverse approaches has been a major hurdle for knowledge engineers. It's no surprise to learn that leading experts often disagree about tough problems in their profession. To build expert systems in some areas will require knowledge engineers to learn how to resolve disagreements among the needed experts [Van Horn:219]."

The execution of the methodology detailed in Chapter III made a contribution to these needs in several ways.

First, this methodology entailed the use of multiple experts from whom to collect the domain knowledge. To date the majority of expert systems have utilized only a single expert as the source of their domain knowledge. In most cases where more than one expert was used, a single expert was still selected to work directly with the knowledge engineer as a liaison to, and final decision authority for, the other experts. No documentation of an attempt to use a consensus driving technique was found in any expert system project. This methodology used the Nominal Group Technique in an attempt to drive consensus.

Next, the methodology introduced the Delphi Technique as a vehicle for both selecting the particular project or problem to be

addressed and for identifying the experts to be used for system development. Finally, the methodology clearly documents an in-depth, step-by-step approach to expert system development which can be replicated.

Managerial Contribution

The ability to better manage inventory, which should derive from applications of expert systems to inventory management problems, could potentially save billions of dollars annually in inventory carrying costs alone. If a 10 percent productivity gain is realized, this equates to \$30.5 billion less inventory each year and a savings in inventory carrying costs of \$9-13 billion per year in the United States alone. The research addressed herein has demonstrated the feasibility of applying the expert system technology to the inventory area. Hopefully, such cost reductions will eventually be realized.

A second pragmatic gain relates to manpower. Expert systems appear to offer a unique opportunity to alleviate some of the critical manpower shortages of trained technicians and to magnify the abilities of our best managers and extend their expertise to others.

Inventory decision-making could become both more effective and more efficient. In just a few minutes the computer may be able to match hundreds of pieces of signal data to derive an appropriate decision.

These systems can also serve as a training tool. The novice can work with the system and have it explain its process of arriving at a decision via the explanation facility. Frequently, human experts are so busy and so in demand that they do not have the time required to properly train a novice. Further, as mentioned earlier, because no one has collected their decision rules and processes, it is difficult for experts to explain exactly what they do and why.

Organization of the Research Report

This chapter has provided background information on expert systems, stated the problem, research objectives, scope, limitations, and contributions. The research methodology was also summarized. Chapter II reviews the literature on the development of expert systems for guidance on how to proceed. Chapter III discusses the methodology followed in the conduct of this research. Chapter IV presents the findings. Chapter V offers the conclusions and provides recommendations for further research. Interview guides, protocols, Delphi questionnaires, a sample case study, a sample consultation, and test directions and questionnaires are presented in appendices.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The purpose of this chapter is to provide an understanding from the AI literature of the steps in the development of an expert system and some of the lessons which have been learned from past developmental efforts. As mentioned earlier, over 178 expert systems have been previously developed. This review demonstrates how those developments proceeded. This information determined the methodology for the current research. Lessons learned from these previous developmental efforts were sought and incorporated into the present methodology. As Table 2 indicates, the statements of the individuals referenced and quoted in this chapter, for the most part, are rooted in actual expert system development efforts.

This chapter is organized into four major sections. The first section discusses the sequence of steps which various authors recommend for the development of an expert system. The second section reviews the stages of expert system evolution, as a second way to view progress on an expert system developmental effort. The third section takes an indepth chronological look at each of the aspects of an expert system, beginning with design considerations and proceeding to testing considerations. Finally, the fourth

Table 2

Experts Quoted in This Chapter
And the Systems Each Developed

Developer	Expert System or Tool
Feigenbaum	DENDRAL - infers the molecular structure of unknown chemical compounds from mass spectral and nuclear magnetic response data.
Freiling, et al.	DETEKTR - a system-building aid that helps domain experts construct troubleshooting expert systems.
Hayes-Roth	ROSIE - a knowledge engineering language for rule-based systems.
Lenat	EURISKO - invents designs for new kinds of three-dimensional micro-electronic devices.
McDermott	R1 (or XCON) - configures VAX 11/780 computer systems. Decides based upon a customer's order what components must be added to produce a complete operational system.
	XSEL - helps a salesperson select components for a VAX 11/780 computer and assists in designing the floor layout for the computer.
Mittal and Dym	PRIDE - expert system which aids in the design of copier sub-systems.
Polit	R1 (see above)
Smith	DIPMETER ADVISOR - infers subsurface geological structure by interpreting dipmeter logs.
Teknowledge	DRILLING ADVISOR - assists an oil-rig supervisor in resolving problems related to the drilling mechanism sticking within the borehole during drilling.
Waterman	LDS - assists legal experts in settling product liability cases.

Source: Donald A. Waterman, A Guide to Expert Systems (Reading, Massachusetts: Addison-Wesley Publishing Company, 1985), pp. 244-365.

section provides a summary that relates the research reported in the literature to the objectives and methodology of this research effort.

Steps in the Development of an Expert System

Several authors offer a sequence of steps to be followed in the development of an expert system. As Freiling et al. note:

"...one major advantage of a methodological approach to knowledge engineering is that it provides a basis for communicating about the progress of a knowledge engineering project. All too often, knowledge engineering projects become a black hole, and managers have difficulty perceiving signs of progress [Freiling:158]."

However, by providing a sequence of steps required in the building of an expert system, the developmental process is more clearly elucidated and management can more readily assess progress on the project to date. As is typical of most software system developmental efforts, the steps do not always follow directly in sequence. Frequent reiteration is required, particularly in the earliest phases of the project.

Polit

Polit suggests the following sequence of steps:

"Step 1: problem recognition,
Step 2: task definition,
Step 3: initial design,
Step 4: knowledge acquisition, and
Step 5: system maintenance [Polit:76]."

During Step 1, potential problems are identified and an assessment is made as to the appropriateness of using artificial intelligence

techniques to solve them. Polit notes that one criterion for the identification of a problem where expert systems technology may be applicable is a situation where a bottleneck exists in the organization due to a "scarcity of trained personnel [Polit:76]."

During Step 2, the problem to be addressed must be clearly specified. Polit states:

"these two steps may be the most difficult ones, because researchers must have a comprehensive understanding of all available AI tools and techniques as well as of the problem itself [Polit:76]."

Step 3 entails the initial design of the expert system. Here, choices are made regarding the manner in which knowledge is to be represented, e.g., production rules or frames. Also, the choice of inferencing is determined, e.g., backward or forward chaining.

Step 4 is the knowledge acquisition phase. During this step an attempt is made to uncover the facts and heuristics that the experts actually use in solving problems. Then, during Step 5, updates are made to the expert system as required to add, modify, or delete entries in the knowledge base.

These steps, however, do not occur as discrete, independent events; there is an interaction between the steps, which is especially true for Steps 2, 3, and 4. As Polit explains,

"During the knowledge acquisition phase, a greater understanding of the problem is obtained. The design of the system may be changed because unexpected difficulties are recognized, or the task may be redefined because perception of the problem has changed [Polit:77]."

Freiling et al.

Freiling, et al. offer another two-phase methodology, consisting of "The Knowledge Definition Phase" and "The Prototype Implementation Phase." The first phase of knowledge definition

"is a phase of analysis and definition of the knowledge structure that precedes actual acquisition of knowledge and implementation of a prototype. The emphasis at this stage is to make progress on decomposing a large and complex problem, while not getting bogged down in the specifics of the problem [Freiling:156]."

Three steps comprise this first phase. During Step 1, "Familiarization," the scope and complexity of the selected task are explored.

"Experienced knowledge engineers often know how to initiate this process by a combination of relatively unstructured interviews and observation sessions. A record of the sessions are made by taping them or by taking notes. After the session is over, the tape and the notes should be combed to produce a 'paper knowledge base' consisting of English sentences that are representative expressions of the facts and rules the expert has given you. They do not, of course, need to be direct quotes from the expert. But they do need to be sentences that the expert can recognize as clear and unambiguous descriptions of relevant knowledge [Freiling:156]."

This "paper knowledge base" is then reviewed with the expert and modified as required.

Step 2 of Phase One entails "Organizing Knowledge." Freiling et al. recommend that a "semantic grammar" be established "to express the facts and rules in the paper knowledge base [Freiling:157]." Such a grammar might be comprised of rules and observations, where rules and observations have the following structure:

```

" rule  :: = IF  observation
           THEN conclusion "
" observation :: = signal
           HAS  property
           OF  value "

```

During Step 3, "Representing Knowledge," decisions regarding the actual representation schema of the knowledge in the prototype expert system are made.

With Step 4, "Acquiring Knowledge," the process transitions to Phase Two, "The Prototype Implementation Phase." During this phase, a prototype expert system is actually constructed.

"The implementation process consists of acquiring the knowledge base, building an inference engine, and building an appropriate interface [Freiling:157]."

The actual steps are:

- Step 4: Acquiring Knowledge,
- Step 5: Inference Strategy Design, and
- Step 6: Interface Design.

The user interface plays a key role in the user's willingness to use the expert system as well as the user's ability to correctly solve problems when assisted by an expert system. According to the authors, this step should be highlighted in the development process. The Freiling, et al. development schema is the only one which emphasizes the user interface.

Waterman

Waterman provides still another sequence of phases.

"Expert system development can be viewed as five highly interdependent and overlapping phases: identification, conceptualization, formalization, implementation, and testing [Waterman:136]."

Figure 5 illustrates the interaction of these phases. As the figure indicates and as Waterman clarifies:

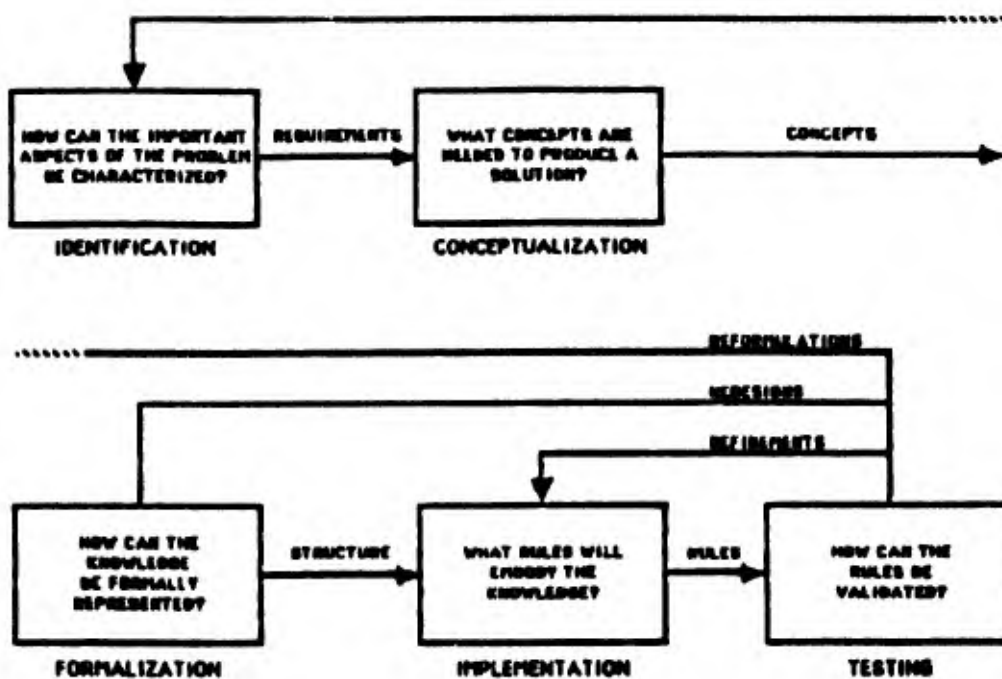
"Although we distinguish between these phases of expert system building, there is no simple way to describe the order in which they take place. Identification does happen first and testing last, but at any time during system development the knowledge engineer may engage in any of the processes [Waterman:136]."

During the identification phase the important features of the problem are determined.

"This includes identifying the problem itself (e.g., type and scope), the participants in the development process (e.g., additional experts), the required resources (e.g., time and computing facilities), and the goals or objectives of building the expert system (e.g., improve performance or distribute scarce expertise) [Waterman:136]."

Identification of the problem and the determination of the scope of the problem to be addressed by the expert system are claimed to be the most difficult of these activities.

The conceptualization phase entails working with the expert to "make explicit the key concepts and relations needed to solve problems in the domain [Waterman:164]." An attempt is made to determine the terms and concepts used by the expert and to clearly define these. Waterman suggests that presenting sample cases to an



Source: Donald A. Waterman, A Guide to Expert Systems (Reading, Massachusetts: Addison-Wesley Publishing Company, 1985), p. 37.

Figure 5

Waterman's Development Phases for an Expert System

expert and observing how the expert analyzes them is a good technique for this purpose.

"Subtasks, strategies, and constraints related to the problem-solving activity are also explored [Waterman:137]."

An important issue, to be addressed within the conceptualization phase, is that of "granularity." This requires determining the level of detail required to represent the knowledge. For example, at a low level of granularity the user might be asked the date of the first significant delivery.¹ At a higher level of granularity, the user would be asked very specific questions such as the total contract quantity, dates of any deliveries, and the delivery quantities. The system could then internally check to determine the date of the first significant delivery.

Actual knowledge representation, however, is a function of the formalization phase.

"'Formalization' involves expressing the key concepts and relations in some formal way, usually within a framework suggested by an expert system building language [Waterman:137]."

This phase, then, is similar to the "Organizing Knowledge" step of the Freiling et al. methodology, where a semantic grammar is recommended for this purpose.

¹First significant delivery is a term used in the Air Force to indicate that at least 10 percent of the contract quantity has been delivered.

"During 'implementation,' the knowledge engineer turns the formalized knowledge into a working computer program [Waterman:138]."

Waterman cautions that knowledge engineers should not wait too long before beginning program implementation. Frequently, the tendency is to thoroughly analyze the problem before beginning coding.

Waterman states, however, that much can be learned

"...from the first implementation that will shape and direct the conceptualization process [Waterman:137]."

"Finally, 'testing' involves evaluating the performance and utility of the prototype program and revising it as necessary [Waterman:138]."

Waterman recommends that testing begin as soon as "the prototype runs on a few examples [Waterman:138]."

Hayes-Roth et al.

In Building Expert Systems, Hayes-Roth et al. list these same five steps of identification, conceptualization, formalization, implementation, and testing as the five "major stages of knowledge acquisition [Hayes-Roth:140]." However, the authors stress:

"These stages are simply a rough characterization of the complex and ill-structured activity that takes place during knowledge acquisition. They will vary from one individual situation to another, and the acquisition process is not understood well enough to outline a standard sequence of steps that will optimize the expert-system-building process [Hayes-Roth:140]."

Further, Hayes-Roth et al. provide the following questions which they suggest need to be answered during the identification stage:

- "- What types of data are available?
 - What is given and what is inferred?
 - Do the subtasks have names?
 - Do the strategies have names?
 - Are there identifiable partial hypotheses that are commonly used? What are they?
 - How are the objects in the domain related?
 - Can you diagram a hierarchy and label causal relations, set inclusion, part-whole relations, etc.? What does it look like?
 - What processes are involved in problem solution?
 - What are the constraints on these processes?
 - What is the information flow?
 - Can you identify and separate the knowledge needed for solving a problem from the knowledge used to justify a solution? [Hayes-Roth:143-144]."

Systems Manufacturing Technology Group

The Systems Manufacturing Technology Group discuss seven steps in the development of an expert system, noting that total development is never achieved; since knowledge and rules must be continuously added, modified, or deleted to reflect business changes. The first step is "system design." During this phase the expert and knowledge engineer spend time together talking about the knowledge which the expert uses. Phase Two involves "prototype development." Here, the knowledge engineer attempts to create the actual rules to be used by the expert system. Phase Three can be called "making the prototype an expert." Phase Three is in essence,

knowledge debugging. A large number of sample problems are presented to the expert system, and any unsatisfactory performance is corrected as required. Phase Four concerns "evaluation and acceptance." This involves any required modifications to the actual computer code. Note that Phase Three involves only changes to the rules of the system, not the code. Phase Five involves "extended use in a prototype environment." This phase involves field testing and usually results in new rules and knowledge being added to the system. Each time new information is added, however, the prototype must be revalidated to insure that no rule discrepancies are created. Phase Six entails the "development of maintenance plans." Finally, Phase Seven is the "system release" [Systems Manufacturing Technology Group:6].

Comparison of the Developmental Approaches

Table 3 summarizes the development approaches of these authors. All of these approaches begin with some form of problem definition, where the problem to be addressed by the expert system is more clearly defined and delimited. Polit refers to this problem definition step as "Task Definition." Freiling, et al. refer to this step as "Familiarization." Waterman and Hayes-Roth, et al. refer to this step as "Identification." The Systems Manufacturing Technology Group call this step "System Design."

Table 3

Summarization by Author of the Steps
in the Development of an Expert System

Step	Politt	Freiling, et al.		Waterman		Hayes-Roth, et al.	Systems Manufacturing Technology Group
		Phase One: Knowledge Definition	Step 1: Familiarization	5 overlapping phases: Identification Conceptualization Formalization Implementation Testing	5 steps: Identification (emphasized) Conceptualization Formalization Implementation Testing		
Step 1:	Problem Recognition						Phase One: System Design
Step 2:	Task Definition						Phase Two: Prototype Development
Step 3:	Initial Design						Phase Three: Making the Prototype an Expert
Step 4:	Knowledge Acquisition						Phase Four: Evaluation and Acceptance
Step 5:	System Maintenance						Phase Five: Extended Use in a Prototype Environment
							Phase Six: Development of Maintenance Plans
							Phase Seven: System Release

All of the authors also include a knowledge acquisition step where the knowledge engineer works with the expert to uncover the key knowledge and concepts which the expert possesses. Polit calls this step "Knowledge Acquisition." Freiling, et al. refer to the knowledge acquisition step as "Knowledge Organization." Waterman and Hayes-Roth, et al. refer to this step as "Conceptualization." Finally, the Systems Manufacturing Technology Group include the activity of knowledge acquisition in the "Prototype Development" step.

The development or coding of the prototype expert system is another activity which all of the authors have included. Polit includes this activity under "Knowledge Acquisition." Freiling, et al. refer to this step as "Prototype Implementation." Steps 4, 5, and 6 of the Freiling, et al. methodology all entail coding of the prototype expert system. Waterman and Hayes-Roth, et al. refer to the development of a computer program or the expert system code as "Implementation." The Systems Manufacturing Technology Group call this step "Prototype Development."

As can be seen from Table 3, however, no author appears to have included all of the steps required for the life cycle of the expert system from first conceptualization to operational use. Only Polit emphasizes the "Problem Recognition" step. This step serves to identify various problems with which an organization is faced and to assess the use of AI as a technique with which to solve these problems.

Only Waterman, Hayes-Roth, et al., and the Systems Manufacturing Technology Group address formal evaluation of the expert system. Waterman and Hayes-Roth, et al. refer to this step as "Testing." The Systems Manufacturing Technology Group refer to this step as "Evaluation and Acceptance."

Further, while Polit addresses "System Maintenance," where required updates are made to the operational expert system, only the Systems Manufacturing Technology Group addresses detailed steps required to field an operational expert system. These fielding steps include: "Extended Use in a Prototype Environment," "Development of Maintenance Plans," and "System Release." The evolution of the expert system prototype to an operational expert system will now be discussed.

Stages of Prototype Evolution

In addition to the actual steps in building an expert system, several authors chart progress in the developmental effort in terms of the evolution of the expert system prototype. The first prototype constructed in the development of an expert system is frequently referred to as the "Mark-I system" [Smith:69]. Smith offers the following guidance on when such a system should be coded:

"It is generally accepted that construction of the Mark-I system should be commenced as soon as one example of the intended behavior is understood [Smith:69]."

Further, Smith warns that by waiting too long to construct the Mark-I system, the overall rate of progress on the knowledge engineering project is frequently slowed.

Waterman provides a categorization of five stages in the evolution of the prototype from the initial Mark-I system to its use as a "commerical system." These stages and their corresponding descriptions are provided in Table 4.

The "demonstration prototype" most closely describes the scope of this research effort. Waterman states:

"Most expert systems begin as a demonstration prototype, that is, a small, demonstration program that handles a portion of the problem that will be eventually addressed. This type of program is often used in two ways: first, to convince potential sources of funding that AI and expert systems technology can effectively be applied to the problem in question; and second, to test ideas about problem definition, scoping and representation for the domain. A typical rule-based demonstration prototype might contain 50 to 100 rules, perform adequately on one or two test cases, and take one to three months to develop [Waterman:139]."

Taylor also recommends the early development of a prototype expert system. Results of prototype testing are then used to specify a "system for field use" [Taylor:62]. However, specification and design issues should be considered from the very beginning of an expert system development effort.

Expert System Design Considerations

Three key design considerations are the users of the system, the goals of the system, and the measures of system success. Hayes-

Table 4
Evolution of Expert Systems

Development Stage	Description
Demonstration Prototype	The system solves a portion of the problem undertaken, suggesting that the approach is viable and system development is achievable.
Research prototype	The system displays credible performance on the entire problem but may be fragile due to incomplete testing and revision.
Field prototype	The system displays good performance with adequate reliability and has been revised based on extensive testing in the user environment.
Production model	The system exhibits high quality, reliable, fast, and efficient performance in the user environment.
Commercial system	The system is a production model being used on a regular commercial basis.

Source: Donald A. Waterman, A Guide to Expert Systems (Reading, Massachusetts: Addison-Wesley Publishing Company, 1985), p. 40.

Roth et al. strongly recommend involving the users of the expert system early in the design process.

"The key question 'Will the system be used?' should motivate the system-building process. This question should not be withheld until the evaluation stage; it should dominate every stage of system specification, design, and implementation. The expert system must render a service for which a need really exists. It will not be sufficient for the system to produce good answers; the system must also be usable and useful. To create a system that will be acceptable to users, knowledge engineers must acquaint themselves with the users' needs and desires and become familiar with the users' terminology, daily routines, and main headaches or worries. To introduce a system successfully into routine production use, they must strive to make it match closely the users' current needs and habits. The new tool must be as nondisruptive as possible, imposing few (if any) new requirements and demanding little training in its use and interpretation [Hayes-Roth:278]."

Another key design consideration regarding users is the specific makeup of the target user population. Basden notes that while theoretically expert systems could be designed for a novice with no understanding whatsoever of the task domain, such a design would

"not be as easy, nor as useful, as was first thought. On the one hand, in any specialist field not only are there phrases and jargon words of specialized meaning, but apparently ordinary words might have special meanings of which the novice might be dangerously unaware. On the other, there are a large number of factors which practitioners in the domain take for granted but which would have to be posed to the novice explicitly [Basden:64]."

A second design consideration is the intended purpose or goal of the expert system. The purpose should be determined and

explicitly stated early on in the development process. Hayes-Roth et al. offer the following as some possible goals of an expert system:

"formalizing an otherwise informal set of practices, distributing scarce expertise, helping experts solve problems better, and automating routine aspects of the expert's job [Hayes-Roth:143]."

Note that an expert system can apparently have more than one of these statements as its goal.

In addition to explicitly stating the goal of the expert system, Hayes-Roth et al. also discuss the importance of providing

"explicit statements of what the measures of the program's success will be and how that failure or success will be evaluated [Hayes-Roth:258]."

Such decisions should be made far in advance of the actual "testing" stage of development. Given the above considerations, actual approaches to problem identification will now be reviewed.

Approaches to Problem Identification and Assessment

Unfortunately, as Mittal and Dym note:

"One of the areas of expert systems activity least touched upon in literature is the early part of a project when issues about the suitability of a problem and identification of experts are decided [Mittal:35]."

However, the identification phase is crucial to the success of the overall knowledge engineering effort. Teknowledge suggests that this initial problem assessment consists of the following activities:

- "- Identify problem domain and task
 - Judge appropriateness
 - Consider economic justifications
 - Identify experts and the nature of their advice
 - Identify the users of advice
 - Identify sample cases [Teknowledge, Course]."

Relative to actual problem identification, Taylor offers the following advice:

"In the process of building our knowledge engineering capabilities, we have learned lessons not found in the expert system literature. The most important lesson is that expert systems are best conceived of by the experts themselves. The idea of a team of knowledge engineers who identify human tasks that can be profitably automated did not work here. (We think mastery of the domain knowledge is required to make good decisions about building expert systems, and the mastering of significant domain knowledge takes years.) What did work was company-wide briefings that spelled out what might be done with this new technology, and that challenged experts in the company to propose and participate in the development of useful expert systems. Our successful expert systems were conceived of by people who had never written a line of LISP [Taylor:62]."

Prerau reports on a similar approach to problem identification undertaken "as part of a major expert system development project at GTE Laboratories." An extensive list of criteria, to be discussed in the next section, was used to focus a series of interviews with "over 50 corporate managers and 'experts'." Prerau notes that during the interviews, a discussion of the criteria

"...was an excellent way to give our interviewees, who usually knew nothing about artificial intelligence or

expert systems, some quick idea of the sort of application area for which we were looking. As each potential application surfaced, a brief check through the desired attribute list enabled us to identify possible problems related to the candidate area, and then to focus our further questions. When the set of major possibilities was determined, we were easily able to highlight the good and bad points of each potential application. Finally, when the actual application area was decided upon, we used the attribute list to justify the decision. One further point: at each step, the list proved very useful to justify the dropping of politically favored candidate areas [Prerau:27]."

Prerau reports that over 30 diverse potential application areas were suggested as a result of the series of interviews. Of the thirty, eight were considered as

"...major possibilities, and these were further analyzed and ranked. Two primary candidate areas were studied in great detail. Finally, one application area was chosen, and our system development was begun [Prerau:27]."

A key question that arises as part of problem identification concerns the level of detail and permanence of the task or "application area" definitions. That is, how can a good definition of the task be provided before beginning the actual knowledge engineering; and, is it appropriate to begin developing a system whose scope is not clearly delineated? Smith suggests that although "traditional wisdom" would require that the task "be very carefully defined before the system is designed, our experience has been that this process is quite difficult [Smith:69].". Rather, a "contingent definition -- one that is clear for a time, but can be easily changed [Smith:69]" is recommended. Likewise, Hayes-Roth et al. state that:

"Several iterations of problem definition may be necessary since the knowledge engineer or domain expert may find that the initial problem considered is too large or unwieldy for the resources available [Hayes-Roth:141]."

McDermott presents an account of the approach used to help arrive at a contingent definition and determine the scope of the task for the R1 development effort. R1 is an expert system which is used today by Digital Equipment Corporation to help configure large computer systems. McDermott states that "a great deal of work" was done early in the project "to uncover the structure of the task." Specifically, the task was broken up "into a number of smaller subtasks," and, within each of these subtasks, a description "of the kinds of actions called for [McDermott:22]" was generated.

Teknowledge recommends that one way to focus the task definition early on is to write a proposal for the planned system.

"This document should contain:

- a description of the domain,
- a profile of the intended user of the system,
- a description of the advice the system will give,
- the scope of the knowledge of the system,
- expected difficulties and uncertainties,
- a sample typescript that shows how the system is intended to operate, and
- a design of the proposed system that includes the principal classes and their relationships, the outline of the problem solving, and an outline of the main control blocks used to structure the system [Teknowledge, Temperature:54]."

Hayes-Roth et al. provide guidance on problem identification that raises a much more basic issue than just scope or focus of the particular problem. Until now, it has been implicitly assumed that

first the problem would be identified and then the particular experts knowledgeable in this area would be identified. However, Hayes-Roth et al. state:

"Before the knowledge-acquisition process can begin, the participants must be selected and their roles defined. Once the participants are chosen the knowledge engineer and domain expert can proceed toward identifying the problem under consideration [Hayes-Roth:141]."

A choice, then, would appear to be required as to whether the problem will drive the selection of the expert or experts or whether the expert or experts will select the problem. The question is whether to give precedence to problem selection or expert selection.

Specific criteria for the problem selection process will now be considered. Next, criteria for expert selection will be addressed.

Problem Selection Criteria

The most basic criterion for the development of an expert system is the availability of a human expert. Although this may appear obvious, given the nature of expert systems, attempts have been made to apply the technology to hard problems for which no known solution exists. However, Sell cautions about such attempts to apply expert systems to "new problems":

"If there is no expert in the field in which we wish to use the system, our chances of success are negligible [Sell:92]."

A common adage in the literature is that a knowledge engineer steals the knowledge, rather than inventing it. Obviously, a human

expert must be available from whom to steal the knowledge. Smith adds that the expert must be committed, as well as available. He suggests, "One way to ensure this commitment is to work on problems that the experts actually want solved! [Smith:69]"

In addition to an available, committed expert, Freiling et al. suggest that the existence of "pockets of knowledge" or "knowledge bottlenecks" creates a fitting requirement for the development of an expert system.

"Pockets of knowledge occur when knowledge crucial to the success of an organization is possessed by only one or a few individuals. Knowledge bottlenecks are pockets of knowledge that impede an organization's progress because the knowledge needs to be more widely distributed [Freiling:150]."

Further, pockets of knowledge

"can quickly become serious bottlenecks if the individuals retire or decide to leave the organization [Freiling:150]."

Teknowledge stresses that, "Good domains and tasks are knowledge-intensive. Unless knowledge and expertise have a sizeable effect on the solution, there is little leverage to be found in a knowledge engineering approach [Teknowledge, Building:2-5]."

Knowledge-intensive problems are contrasted with "data-intensive problems" such as "drawing inferences from a statistical database." Teknowledge argues that expert systems should not be applied to data-intensive problems, but only to knowledge-intensive problems. Tasks can be described as knowledge-intensive

"when there is a substantial variability in people's ability to perform them. If novices gain competence with experience, then you probably have a knowledge-intensive task [Teknowledge, Building:2-6]."

Mittal and Dym specify "separability of task knowledge" as a further criterion. The following questions are posed:

"Is the given problem a viable one, i.e., can it be reasonably separated from the other activities of the experts, or is it intricately tied to other kinds of knowledge and problem solving? Can you identify the kinds of problem-dependent knowledge and strategies the experts are using or do they seem to rely upon common sense approaches and generic knowledge? [Mittal:35]."

This issue of separability of task knowledge is central to the feasibility of an expert system. The history of artificial intelligence is replete with examples of systems which attempted general purpose or common sense tasks and failed [Sell:2].

A test to see if the task or problem under consideration meets the criterion of being knowledge-based is the "telephone test." The telephone test simply requires that a "competent performer" could, over the telephone, help the intended user of the expert system by posing questions to the user and offering advice.

"This means that a verbal dialog is sufficiently rich to capture the important facets of the problem. If perception plays an important role in problem solving, then the task will fail the telephone test [Teknowledge, Building:2-8]."

Waterman suggests criteria for selecting an appropriate problem which fall along three dimensions:

"Consider expert systems only if expert system development is possible, justified, and appropriate [Waterman:127]."

Figure 6 depicts those criteria which, when satisfied, result in expert system development being possible.

Waterman states that,

"Expert systems are justified when significant expertise is being lost to an organization through personnel changes. Retirement, job transfer, and military duty reassignment often cause disruption and even havoc because of the vital expertise that experienced personnel take with them when they leave. The institutional memory aspect of an expert system can minimize or even eliminate this problem [Waterman:131]."

Other criteria which, according to Waterman, justify the development of an expert system are shown in Figure 7.

In terms of appropriateness, Waterman notes,

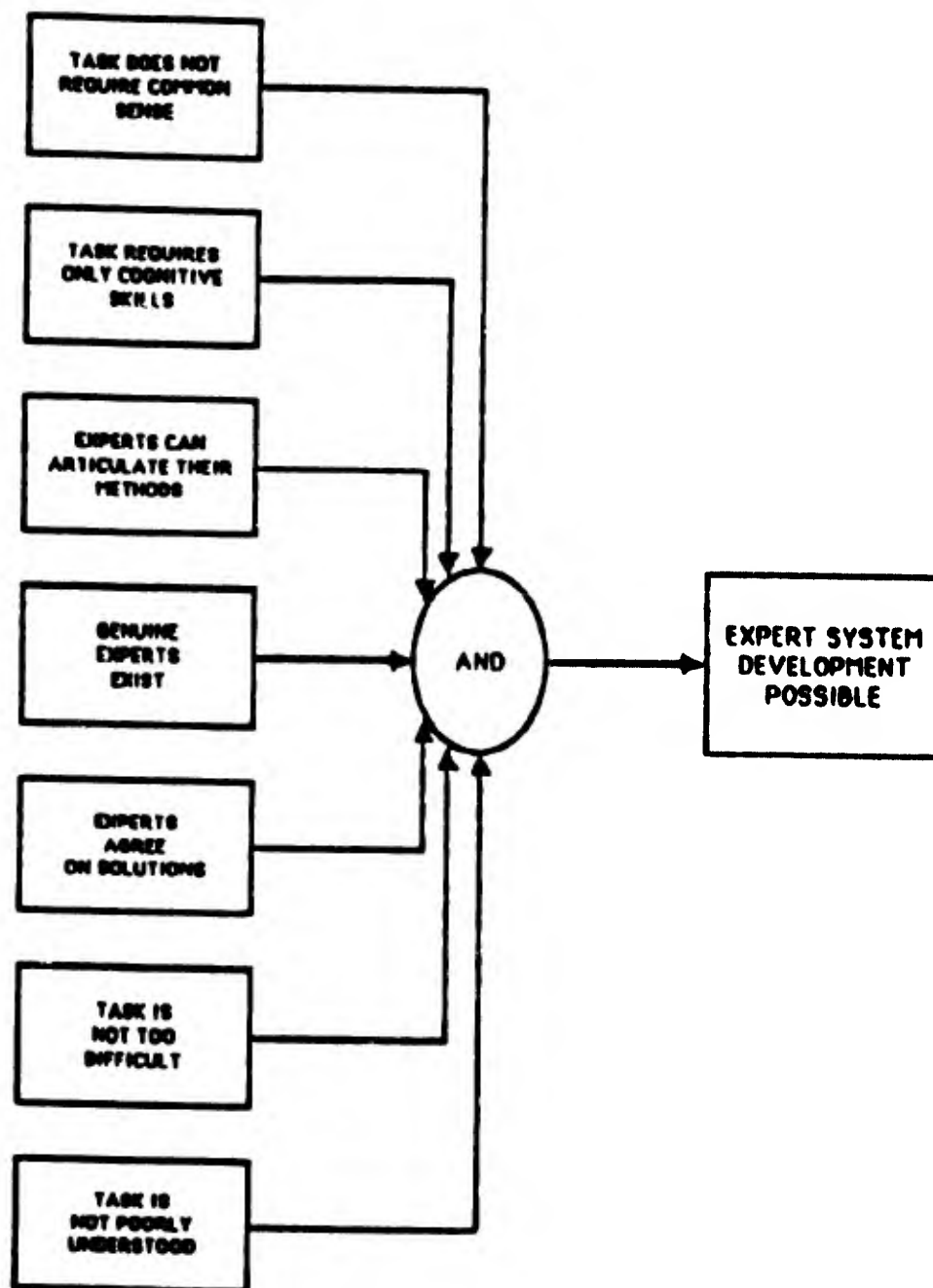
"The key factors in determining when it is appropriate to develop an expert system are the nature, complexity, and scope of the problem to be solved [Waterman:131]."

Figure 8 depicts criteria for each of these factors of the appropriateness dimension.

In terms of scope, Waterman emphasizes,

"...the problem should have the proper scope. It should be sufficiently broad to ensure that the problem has some practical interest. Unfortunately, the definitions of 'manageable' and 'practical' depend on the particular problem domain. And to make matters worse, choosing the proper scope is crucial to the success of the expert system endeavor. Indeed, one of the most dangerous pitfalls in expert system building is choosing a problem that is too broad or general to be handled adequately [Waterman:133]."

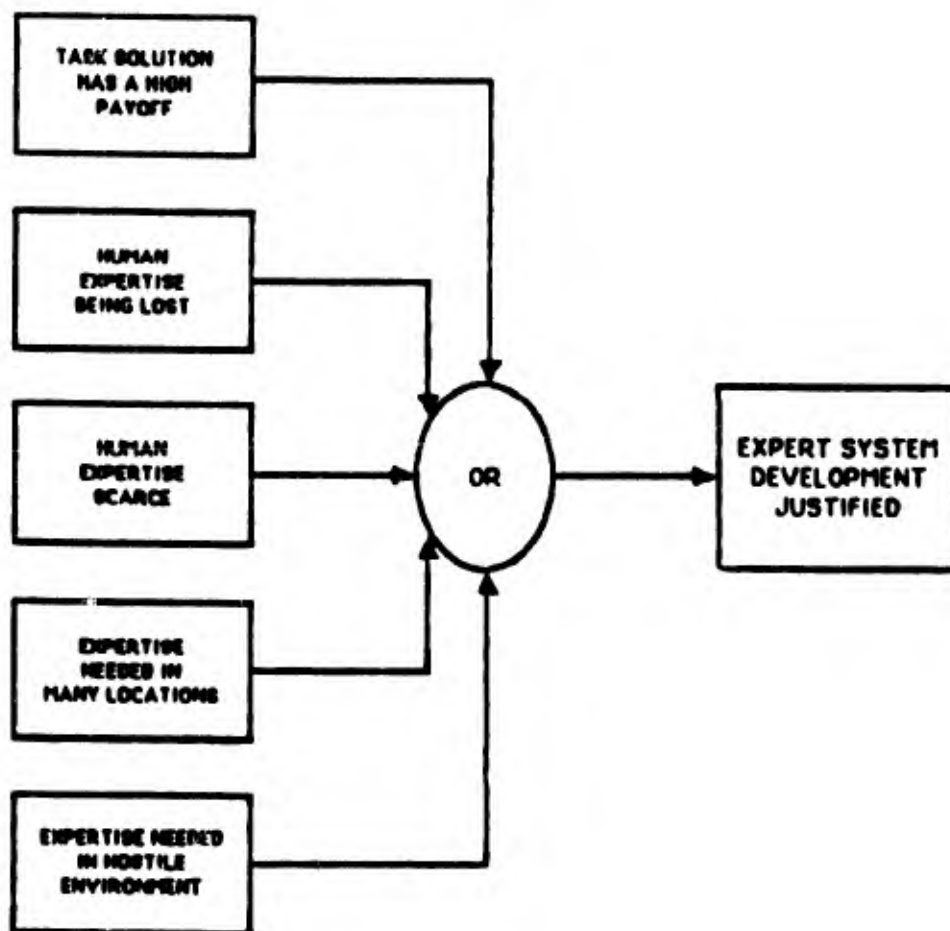
Waterman states that there is no methodology per se for determining this appropriate scope. However, the recommendation is offered that breaking the task down into its subcategories and then making a



Source: Donald A. Waterman, A Guide to Expert Systems (Reading, Massachusetts: Addison-Wesley Publishing Company, 1985), p. 129.

Figure 6

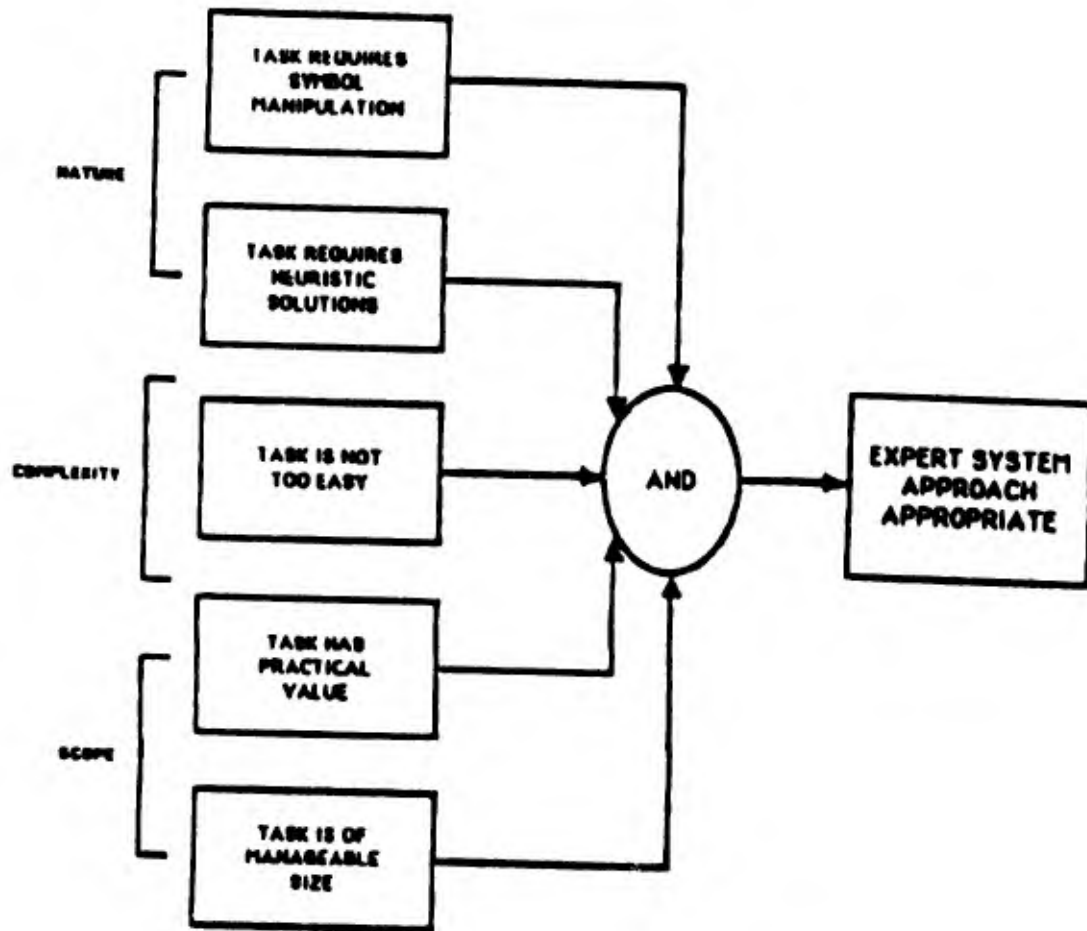
Necessary Requirements for Expert System Development



Source: Donald A. Waterman, A Guide to Expert Systems (Reading, Massachusetts: Addison-Wesley Publishing Company, 1985), p. 129.

Figure 7

Justification for Expert System Development



Source: Donald A. Waterman, A Guide to Expert Systems (Reading, Massachusetts: Addison-Wesley Publishing Company, 1985), p. 132.

Figure 8

Characteristics That Make The Use Of Expert Systems Appropriate

judgment as to whether these are "too broad" or "too narrow" is an appropriate starting point.

Digital Equipment Corporation's Systems Manufacturing Technology Group provides three specific criteria for determining the relevancy of expert systems:

- "1. There must be at least one accessible human expert acknowledged to perform the task well.
2. The primary source of the expert's exceptional performance must be specialized knowledge, judgment, and experience.
3. The task must be a well-bounded domain of application. You want narrow areas of specialization because it is easier to assemble this knowledge than the vast amount of knowledge that humans bring to bear on everyday problems [Systems Manufacturing Technology Group:4]."

The Digital Group argues that expert systems are not applicable to all disciplines. Rather both expert systems and conventional data base systems will be developed, with each exploiting its own area of advantage. Myers discusses the desirability of linking expert systems and traditional data base systems.

"At present, most expert systems depend upon a specialized knowledge base. They will become more usable with existing data processing systems when they become able to draw upon general databases, either in the immediate computer system or on a network [Myers:100]."

Lippiatt and Waterman note that a data-oriented expert system would

"use procedures that are invoked when data are changed or read. These procedures monitor the values of variables in a program [Lippiatt:31]."

Feigenbaum and McCorduck note that expert systems lend themselves especially well to two generic types of problems. These are combinatorial problems where the number of possible alternatives is unmanageable, such as, for example, chess. The second group of problems particularly suited for expert systems are those where large amounts of distinguishing or signal data must be interpreted [Feigenbaum and McCorduck:67-68]. Medical diagnosis is an example of this type of problem.

Prerau provides the best and most extensive listing of criteria categorized according to "basic requirements," "type of problem," "the expert," "problem bounds," "domain area personnel," and "other desirable features." Appendix A lists these criteria as presented by Prerau.

Prerau accepts, however, that

"Very few of these desired attributes are absolute, and it is unlikely that any domain will meet all of them completely [Prerau:27]."

Further, the criteria may be weighted differently in different situations.

Basden lists the required accuracy of the system's performance as an interesting criterion. Basden notes that when an expert system is first introduced to the organization, its accuracy may not be very high. Therefore,

"It is important that its initial uses and roles are those where this will not prevent it giving tangible benefits, otherwise it may be rejected by its users and never achieve its full potential [Basden:65]."

Problems apparently should be sought which require satisfactory versus optimal solutions.

Expert Selection

Peltu notes that the real starting point of an expert system is an expert, called a "domain specialist" [Peltu:71]. Teknowledge suggests that "a good expert" is:

- " - Articulate, Introspective
- Honest
- A teacher, able to explain
- Committed to the project [Teknowledge, Course]."

Mittal and Dym recommend that the peer group can provide the best information as to who are the real experts or "valuable sources of knowledge [Mittal:35]." Waterman provides similar guidance,

"Be sure to pick an expert highly skilled in the target domain. Rely on the opinions of the expert's peers and other knowledgeable people [Waterman:192]."

Waterman states, however, that

"Competency in the relevant area is the most important criterion for selecting a domain expert [Waterman:192]."

Mittal and Dym also stress competency and recommend that the experts be "practicing experts in the selected task [Mittal:33]."

Accessibility and availability are two other important criteria for expert selection. Waterman offers the following guidelines regarding the experts' time commitment to the project:

"The experts must be nearby and be able to devote up to three quarters of their time to the effort during the first six months and up to half of their time thereafter [Waterman:185]."

The most controversial issue regarding expert selection, however, appears to be the question of using single versus multiple experts. Almost all knowledge engineering projects to date have relied upon a single expert. As Smith notes in his report on the Dipmeter Advisor system, "A single expert was studied in detail, again adhering to standard practice [Smith:66]." However, Smith challenges this practice.

"One piece of traditional wisdom might be questioned. It is common to deal with a single expert during the development of an expert system. The perceived danger is that it is difficult enough to capture the perspective of a single expert, let alone those of a number of experts. In the particular context of dipmeter interpretation, however, it might have been useful to involve a number of experts with differing backgrounds from the outset [Smith:70]."

Mittal and Dym argue for the use of multiple experts especially for purposes of problem specification. Using a single expert "leads to difficulties in judging the suitability of the chosen task and in acquiring the detailed knowledge required to carry out the task [Mittal:32]." Mittal and Dym note that particularly

"In complex and varied domains such as medicine or engineering, any given expert is often very knowledgeable about only a small subset of the tasks in the domain [Mittal:32]."

Such a situation, they argue, can lead to a single expert recommending a task for an expert system which may not be appropriate. Thus, especially "for the task selection process," multiple experts are preferred.

In the PRIDE expert system which Mittal and Dym developed, the specific task was selected by "systematically interviewing as large and diverse a group of experts as possible [Mittal:34]." PRIDE is an expert system which aids in the design of copier sub-systems. Mittal and Dym used a combination of a systematic interview and protocol analysis of the experts' problem-solving activity in the tentative problem area to focus the actual task of the expert system. By employing multiple experts, Mittal and Dym found that many more of the problem dimensions were enumerated. "Having different people work on the same problem helped to fill in many holes in the specifications [Mittal:35]."

Waterman also argues for multiple experts; however, here the suggestion is that using multiple experts helps to alleviate "evaluation problems in those domains where experts often disagree [Waterman:183]." Still, Waterman acknowledges that use of more than one expert can increase "the chances of introducing inconsistencies into the knowledge base [Waterman:182]."

Hall suggests that decision-making groups can frequently outperform even their own best individual resource [Hall:53]. The idea is stressed that the group needs to reach consensus on the underlying assumptions of the decision process. Such agreement is what makes groups effective decision-makers. Despite this guidance from the psychology literature, no reference could be found in the expert systems literature of an attempt to use a consensus-driving

technique for either task selection or knowledge engineering.

Indeed, in those few projects where more than one expert has been used as the source of the knowledge, the approach has been to choose one primary expert and use this individual's rules or heuristics in the event of a disagreement among the experts. Knowledge engineering will now be examined in more depth.

Knowledge Engineering

Sell states,

"The greatest difficulty when collecting data in these fields is that the expert may not be able to verbalize the knowledge that he uses. This is what makes knowledge acquisition often a difficult and frustrating task for both the expert and the knowledge engineer [Sell:28]."

This section will briefly examine the nature of expert knowledge and then review methods and techniques for acquiring this knowledge.

The Knowledge of an Expert System

Winston suggests four questions which must be answered regarding the knowledge of an expert system: What kind of knowledge is required, general or specific? How should the knowledge be represented? How much knowledge is required? What exactly is the knowledge needed? Winston notes that there is a general tendency to grossly overestimate the amount of knowledge required [Winston:41]. However, Sell cautions that

"at the moment the knowledge of even such a narrow domain requires a lot of effort to get hold of, to get into a working state, and to get right [Sell:16]."

McDermott made an interesting observation regarding the knowledge required for R1:

"It is interesting that R1 needed twice as much knowledge to deal with special situations as it did to perform the basic task [McDermott:24]."

Michie notes three levels of knowledge which he believes could be engineered into computers. Level 1 or "transfer knowledge" is the algorithmic knowledge transferred to the machine by the programmer from books or the programmer's own knowledge. This level of knowledge would allow the computer to perform such tasks as interpreting mass spectograms. Level 2 or "generation knowledge" consists of the generation by the computer of descriptions or plans capable of bridging gaps in current book knowledge. Such programs, for example, could extend the theory of molecular bond stability. Level 3 or "acquisition knowledge" is that level whereby the computer teaches itself to do a new task or improve at an existing task by reading books. For example, a computer might improve its chess game by reading a book on the topic. Most of our expert systems today are at the level 1 knowledge equivalency [Michie:186].

Sell discusses "three different sorts of knowledge [Sell:29]."

"The first is the simplest, and goes by the name of 'perceptual knowledge.' This covers knowledge of simple facts and relationships, ... Strictly speaking expert systems do not need to hold these items ... The next level up we find what most people would consider knowledge: concepts and relationships. Here we find

scientific laws ... We also find heuristic observations ... But there is a third and extremely important level. Experts bring to bear on a problem not only their scientific knowledge and their experience, but also knowledge of how to set about a problem, how to go round difficulties, what else to try when they get stuck. This could be termed an expert's 'strategic knowledge' [Sell:29-30]."

Sell points out that these three levels represent in order, both the power of the knowledge and the difficulty involved in capturing it.

"Perceptual knowledge is the easiest, strategic the hardest. The levels also indicate their importance and usefulness [Sell:30]."

Teknowledge notes that an expert's knowledge is comprised of four different types of knowledge: control knowledge, facts and definitions, heuristics, and procedures [Teknowledge, Course]. The actual acquisition of this knowledge will now be discussed.

Methods for Acquiring Knowledge

Numerous authors refer to the actual acquisition of knowledge as the "bottleneck in the process of building expert systems [Boose:27]." Both Feigenbaum and Waterman make similar statements. For example, Waterman states:

"Acquiring the knowledge needed to power an expert system and structuring that knowledge into a usable form is one of the primary bottlenecks in expert system development [Waterman:152]."

Freiling et al. state that this is also "the most important phase of the expert system development process [Freiling:158]."

However, despite the importance and criticality of the knowledge acquisition phase,

"there is no science of knowledge acquisition. It could hardly even be called a discipline. What advice is available tends to be ad hoc and often no more than common sense. Many of the proposed methods appear to work only for some individuals or in some cases [Sell:30-31]."

Feigenbaum notes that although the expert's knowledge is "private," it

"can be uncovered by the careful, painstaking analysis of a second party, or sometimes by the expert himself, operating in the context of a large number of highly specific performance problems [Feigenbaum (1977):4]."

Further, Feigenbaum notes that the expert's knowledge is multifaceted." The

"expert brings to bear many and varied sources of knowledge in performance. The approach to capturing his knowledge must proceed on many fronts simultaneously [Feigenbaum (1977):4]."

Boose advises:

"It is almost always difficult for the expert to articulate problem-solving knowledge in terms which can be utilized by an expert system. Human interviewing processes elicit knowledge which is incomplete, inconsistent, and imprecise. The knowledge is often subconscious, and the expert may not be reliable when introspecting about problem-solving. The expert must come to trust the interviewer enough to overcome any fears or insecurities felt about the expert system building process. He may feel insecure about losing his job, or feel threatened by the encroachment of computers into his private domain, or he may not want to subject his problem-solving methods to the scrutiny of other human experts [Boose:28]."

Sell mentions three sources of knowledge which should be consulted: "literature, experts, and examples [Sell:28]." Waterman makes reference to a number of additional sources.

"Knowledge in an expert system may originate from many sources, such as textbooks, reports, data bases, case studies, empirical data, and personal experience. However, the dominant source of knowledge in today's expert systems is the domain expert [Waterman:152]."

Hayes-Roth et al., however, recommend that the knowledge engineer become "familiar with the problem before beginning extensive interaction with the expert [Hayes-Roth:160]." A "few weeks of informal study" should allow the knowledge engineer "to converse intelligently with the expert [Hayes-Roth:133]."

Also, "access to many specific examples of problems and solutions [Hayes-Roth:160]" is required.

Specifically, Hayes-Roth et al. suggest the following approach:

"Work intensively with a core set of representative problems ... Pick a half-dozen or so target problems, including both the input and the desired output. Pick several simple ones that focus on different aspects of the task, so that the resulting system will not be too special-purpose. Get the rules right for these problems before looking at other problems [Hayes-Roth:161-162]."

Protocol analysis is the recommended technique. "Record a detailed protocol of the expert solving at least one prototypical case [Hayes-Roth:161]." Such a protocol is particularly helpful in identifying the vocabulary and strategies of the expert. The knowledge engineer should be alert for

"terms that the expert uses in a well-defined, technical manner... A second kind of knowledge the knowledge

engineer listens for are the basic strategies the expert uses when performing the task. What facts does the expert try to establish first? What kinds of questions does the expert ask first? Does the expert make initial guesses about anything based on tentative information? How does the expert then determine which questions to use to refine the guess? In what order does the expert pursue each of the important subtasks, and does this order vary according to the case? [Hayes-Roth:134-135]."

In describing the methodology used in interviewing experts for the PRIDE expert system, Mittal and Dym state,

"The same problem would be posed to each of the experts in turn, with none of the other experts present in the room. The experts were then asked to carry out the design process, not necessarily doing detailed design, but as much as they could do in roughly two hours. It is important to emphasize that we were 'not' asking them to tell us how they solved the design problem but to do the sample design from the given specifications. We believe that experts cannot reliably give an account of their expertise: We have to exercise their expertise on real problems to extract and model their knowledge [Mittal:34]."

Similarly, Sell recommends that expert systems be used "for what they are good at, namely generating or scrutinizing examples [Sell:28-29]." However, Sell points out that "at the moment, most knowledge-based systems are built using interviewing and literature search techniques [Sell:29]."

Teknowledge offers the same guidance. "The key source of information ... is the set of sample problems and solutions we refer to as 'cases'.... Often cases reveal which pieces of information are crucial and what key questions get at that information [Teknowledge,Building:2-18]." Teknowledge lists the following as the minimum essential elements of a "design or development case":

- "1. all data relevant to the solution of the problem;
2. a list of hypotheses that could account for the symptoms presented;
3. the correct diagnosis; and
4. the recommended advice
[Teknowledge, Temperature:10]."

Examples of "'difficult' as well as 'routine' problems" are desired. This range of cases, from difficult to routine, helps the knowledge engineer properly position the design goal of the expert system along this spectrum.

Teknowledge adds that the number of cases actually used should depend on the complexity of the domain. Three categories of cases are usually established:

- "- design cases - a small set of typical problems that your first prototype will attempt to solve
- training cases - a larger set of cases which guide you as you expand and enhance your knowledge base.
- evaluation cases - a set you use to demonstrate the power and limitations of your Knowledge System (KS). This set includes cases your KS solves and also cases it cannot solve. A well-constructed KS will recognize cases beyond its scope and will inform its users that advice cannot be given. The KS that behaves in this manner is said to fail gracefully [Teknowledge, Building:2-19]"

Three to five design cases are recommended as "a good number with which to begin [Teknowledge, Building:2-19]." Waterman notes that the knowledge engineer can gain a wealth of knowledge from even such a small group of cases by "varying case facts and noting how the expert adjusts to the changing conditions [Waterman:153]."

The subject of intermediate-level abstractions or rules, which case analyses help to identify, is an important concept of knowledge acquisition. Waterman explains:

"Experts, it appears, have a tendency to state their conclusions and the reasoning behind them in general terms that are too broad for effective machine analysis. It is advantageous to have the machine work at a more basic level, dealing with clearly defined pieces of basic information that it can build into more complex judgments. In contrast, the expert seldom operates at a basic level. He makes complex judgments rapidly, without laboriously reexamining and restating each step in his reasoning process. The pieces of basic knowledge are assumed and are combined so quickly that it is difficult for him to describe the process. When he examines a problem, he cannot easily articulate each step and may even be unaware of the individual steps taken to reach a solution. He may ascribe to intuition or label a hunch that is the result of a very complex reasoning process based upon a large amount of remembered data and experience. In subsequently explaining his conclusion or hunch he will repeat only the major steps, often leaving out most of the smaller ones, which may have seemed obvious to him at the time. Knowing what to consider basic and relevant and not requiring further reevaluation is what makes a person an "expert" [Waterman:153-154]."

Hayes-Roth et al. provide explicit guidance relative to this behavior of experts.

"Look for intermediate-level abstractions: Intermediate-level concepts are perhaps the most important tool available for organizing the knowledge base, both conceptually and computationally. In many cases these concepts may not be explicitly mentioned by the expert; instead, they must be identified by looking for similarities in the ways that the expert describes different concepts [Hayes-Roth:164]."

Waterman refers to this as "the knowledge engineering paradox. The more competent domain experts become, the less able

they are to describe the knowledge they use to solve problems [Waterman:154]." Based on the paradox, Waterman cautions, "Don't believe everything experts say! [Waterman:154]."

Table 5 depicts those techniques which Waterman recommends for obtaining knowledge from the expert. On-site observation, problem discussion, problem analysis and system examination are particularly relevant to the knowledge acquisition portion of this research.

Waterman notes that on-site observation

"gives the knowledge engineer some insight into the complexity of the problem and type of interface facility needed by the expert to use the finished system in the field [Waterman:159]."

During problem discussion, the

"goal is to determine how the expert organizes knowledge about each problem, represents concepts and hypotheses, and handles inconsistent, inaccurate, or imprecise knowledge and data relating to the problem. Questions that may arise include:

- How does the problem differ from prototypical problems in the domain?
- What kinds of data does the problem require?
- What kinds of solutions are adequate for the problem?
- Can the problem be reduced to noninteracting subproblems?
- What kinds of knowledge are needed to solve the problem?
- What constitutes an adequate explanation or justification of a problem solution? [Waterman:159]"

Table 5
Techniques for Extracting Knowledge From a Domain Expert

Method	Description
On-site observation	Watch the expert solving real problems on the job.
Problem discussion	Explore the kinds of data, knowledge, and procedures needed to solve specific problems.
Problem description	Have the expert describe a prototypical problem for each category of answer in the domain.
Problem analysis	Present the expert with a series of realistic problems to solve aloud, probing for the rationale behind the reasoning steps.
System refinement	Have the expert give you a series of problems to solve using the rules acquired from the interviews.
System examination	Have the expert examine and critique the prototype system's rules and control structure.
System validation	Present the cases solved by the expert and prototype system to other outside experts.

Source: Donald A. Waterman, A Guide to Expert Systems (Reading, Massachusetts: Addison-Wesley Publishing Company, 1985), p. 158.

During problem analysis, the expert is confronted with real problems. The knowledge engineer attempts to determine which goals the expert is pursuing in solving the problems and how these goals "guide strategy selection [Waterman:160]." Waterman suggests that the knowledge engineer combine approaches and play

"an active rather than passive role, asking questions, suggesting possible rationales, and hypothesizing concepts and rules [Waterman:157-158]."

Schatz and Shpilberg approached problem analysis in a unique and realistic manner. During the development of an expert system, which is used internally by Coopers and Lybrand Corporation to provide tax advice, Schatz and Shpilberg actually simulated the consultation session. The expert and the user were seated on opposite sides of a table with a curtain separating them. The user and expert were permitted to communicate only verbally. A live simulation of the telephone test, discussed earlier, was in effect conducted.

The knowledge engineer played a passive role in this experiment. The user described the case to the expert and received advice. Schatz and Shpilberg report that these sessions yielded quite useful information regarding the way questions should actually be posed to the user, the user's ability to respond correctly, and the actual information necessary for problem solving [Schatz].

The ability to uncover the expert's intermediate results remains a problem. Mason (1969) found a fairly simple method for

exposing the underlying assumptions of managers in performing planning tasks. A similar approach might also be beneficial to unveil the expert's intermediate results. Mason termed his approach "dialectical." "A system may be said to be dialectical if it examines a situation from two different points of view [Mason:B-408]." The process is begun by identifying the prevailing or recommended plan. Then questions are raised as to what underlying assumptions make this world view 'optimal.' An attempt is made to explicitly specify these assumptions. Next, an examination is made as to whether or not other alternative assumptions are not just as plausible. This process is carried out as a structured debate, with the intent of stimulating thought. Certainly, a method of stimulating thinking appears quite valuable for purposes of uncovering the expert's intermediate rules.

However, McDermott argues

"...knowledge can apparently be extracted from the experts only as they see from mistakes the program makes what knowledge is lacking. It would seem that any attempt to develop a program that is not strongly recognition driven would be doomed to failure [McDermott:25]."

Smith suggests a similar theme and approach to knowledge acquisition:

"For each interaction, the intermediary gathers some understanding of a portion of the expert's knowledge, encodes it in a program, discusses the encoding and the results of its application with the expert, and refines the encoded knowledge. Discussion and refinement are facilitated when the knowledge is encoded in domain-specific terms and when it is presented in forms familiar to the domain expert [Smith:72]."

The next section will discuss the approach to validating and modifying the expert system in more detail.

Validation and Modification

As Basden notes,

"It has been implicitly assumed so far that the expert system will be found to have inaccuracies in its knowledge base when first used which will be corrected by a continuous process of feedback [Basden:66]."

Hayes-Roth et al. note that there are two approaches to this feedback. In the first, the "knowledge engineer shows the rules to the expert and asks for reactions [Hayes-Roth:137]." The second approach is for the knowledge engineer to actually execute the rules on real problems and show the results to the expert. This second approach appears to be a much truer form of validation.

Indeed, Smith addresses the

"necessity of an adequate set of generic examples with which to test the system as it evolves [Smith:70]."

Hayes-Roth et al. recommend that a "library" of such test cases be maintained.

"With each set of modifications, run the system on all the library cases to see if old problems are fixed or if new problems are introduced [Hayes-Roth:164]."

Further, Hayes-Roth et al. suggest:

"Once the prototype system runs from start to finish on two or three examples, it should be tested with a variety of examples to determine weaknesses in the knowledge base and inference structure. The experienced knowledge engineer will elicit from the domain expert those problems likely to challenge the system's

performance and reveal serious weaknesses or errors [Hayes-Roth:147]."

McDermott provides an excellent description of the approach to extending R1's knowledge base. R1 was given actual orders to configure.

"Its output was shown to configuration experts who were asked to evaluate the adequacy of the configurations. When an expert found a problem, we would talk about it. Such discussions always resulted in the characterization of the situations in which R1's actions were inappropriate, and an indication of what actions would be appropriate. Ordinarily, especially in the beginning, a considerable amount of configuration knowledge came to light during each interaction with an expert. Thus after each interaction several rules could be written; one to correct the problem manifestation and a number of others which, though not directly related to the problem at hand, were associated, in the mind of the expert, with the problem situation [McDermott:24]."

McDermott claims that the above approach "was essentially the same as the approach taken by other expert system builders [McDermott:24]."

Bachant and McDermott note that R1's development environment was ideal. R1 was initially used

"in an environment in which the initial demands on it were of the order of a few tens of orders per week for the first year [Bachant:32]."

This small volume kept the organization from "depending too much on a system that at the time was far from being an expert in the domain [Bachant:32]."

The formal evaluation of expert systems is the subject of the next section.

Testing and Evaluation

"Once the system is performing well on most cases with which it is presented, it is appropriate to turn to a more structured evaluation of its decision-making performance [Hayes-Roth:259]."

However, this evaluation is a very difficult process. The very nature of expert systems implies that there is no clear cut right or wrong answer to the problems which the system addresses. As Hayes-Roth et al. explain,

"In this context it is not always clear whether a correct solution (for an expert system) is one that a human expert would give, one that a group of experts would agree upon, or one that represents the ideal solution (after subsequent testing and analysis). No one knows how to evaluate human expertise adequately, let alone how to evaluate the expert systems that attempt to recreate that expertise [Hayes-Roth:277]."

Similarly, Waterman notes,

"Evaluating an expert system is difficult because there may be no formal way to prove a given answer is correct or the best possible choice. The validity of the answer may depend on the persuasiveness of the argument given to support that answer [Waterman:198]."

Therefore, the standard used to evaluate an expert system must be carefully selected. As Hayes-Roth et al. note, rarely is there a "gold standard" for expert systems, that is, a standard or criterion value which could be accepted as optimal or correct. Further, the standard finally selected "can itself affect the quality and results of the study [Hayes-Roth:251]."

"In general, there are two views of how to define the standard for an expert system's task domain: (1) what eventually turns out to be the correct answer for a problem (in some objective sense) or (2) what a human

expert (or a group of them), presented with the same information available to the program, say is the correct answer. It is unfortunately the case that for many kinds of problems with which expert systems are designed to assist, the first of these questions cannot be answered or is irrelevant [Hayes-Roth:262]."

Further,

"... there is no consensus about how to evaluate expert systems (or when or why) [Hayes-Roth:243]."

In Building Expert Systems, the guidance provided is that

"incremental assessments [Hayes-Roth:241]" are required.

Additionally, the evaluation process is viewed as continual.

"Validation should occur in stages as an expert system develops over time, from first feasibility demonstration, to formal testing, through field tests with live users solving real-world problems, to annual use statistics and retrospectives [Hayes-Roth:254]."

However, Hayes-Roth et al. argue:

"Some aspects of a computing system's performance are more appropriately evaluated than others at a particular stage in its development. By the time a system has reached completion, it is likely that every aspect will have warranted formal assessment, including (1) the quality of the system's decisions and advice, (2) the correctness of the reasoning techniques used, (3) the quality of the human-computer interaction (both its content and the mechanical issues involved), (4) the system's efficiency, and (5) its cost-effectiveness [Hayes-Roth:254]."

Evaluation of the prototype, in contrast with the completed system, "is typically very informal, simply showing that a few special cases can be handled by the prototype system [Hayes-Roth:259]."

Hayes-Roth et al. discuss "two primary methods" for comparing the expert system's performance against that of the human counterpart.

"The easier, and less formal, is the testimonial method, in which the evaluators put together a comprehensive set of test cases and perhaps a checklist of important features. The system is run on all the cases and if it is correct (or at least correctable) on all or most of them, the system passes. This testimonial method is widely used but is of limited utility because such results are difficult to interpret and generalize.

A better test design is the formal, blinded, statistical study. In this case the comparison would have to proceed event by event since a total process is being evaluated. The comparison would be between the program and its potential users: the three people at ORNL who can do the same job as the program, somebody from the night shift, and somebody from the field personnel. Protocols could be created by giving each tested agent step-by-step information about an incident and asking what response, if any, is best. Each protocol then could be rated by expert judges in a blind fashion. It is unrealistic to aim for results like 'The program is 89 percent as good as our top expert,' but this study could support a conclusion like 'The program can perform with more expertise than both an average night-shift person and an average field worker but not as well as a typical expert' [Hayes-Roth:275-276]."

Waterman discusses only the latter of the above two approaches.

"The knowledge engineer presents the cases solved by the expert and the prototype system to other experts. This provides a way to compare strategies of different experts and find essential points of disagreement [Waterman:160-161]."

Hayes-Roth et al. note further that there is another dimension of concern in addition to "the system's performance as an expert." This second dimension is the acceptability of the expert system to the users of the system. In particular, since a prototype system is usually far from complete, the prototype

"will perform less competently and much less acceptably than a completed system. The evaluators will need to be very clear about what they are testing and what they

expect to see. Although significant results might be obtained from testing a prototype system, they are not likely to predict much about the finished system [Hayes-Roth:275]."

In other words, although the finished system may be quite acceptable to the users, the prototype system may be totally unacceptable. For example, the initial XCON or R1 system contained only about 750 rules when first delivered to Digital Equipment in December of 1980. Today, XCON has grown to 8,000 rules [Digital:17] and is "far superior to the system that was delivered in 1980 [Polit:77]."

Any evaluation should explicitly state "what is being tested, why it is being tested, and for whom [Hayes-Roth:275]."

The checklist in Table 6 "... is intended to force evaluation designers to consider all the details and thereby leave the results less open to misinterpretation [Hayes-Roth:278]."

Sell emphasizes Point 4 of the Hayes-Roth et al. checklist in Table 6.

"If it turns out to be the case that our system does outperform experts, that is an added bonus not a rightful expectation [Sell:16]."

However,

"In many domains it is difficult to decide what level of performance qualifies as expert [Hayes-Roth:264]."

Hayes-Roth et al. note that "explicit statements of how the failure or success of the expert system will be gauged are required. Further, a warning is given that

"Each particular domain will most likely have unique characteristics that will affect evaluation procedures and measurements [Hayes-Roth:277]."

Table 6
Evaluation Checklist

-
1. Specify for whom the evaluation is intended. This greatly influences the design of the evaluation. Clearly, the informal evaluations usually performed for system builders and expert collaborators would not be sufficient for financial supporters or for society.
 2. Define precisely what is being evaluated. Isolate those aspects of the system that are being tested. Is it the quality of the system's decisions and advice, the correctness of the reasoning mechanism, the quality of the human-computer interaction, the system's efficiency, its cost-effectiveness, or some other aspect?
 3. Select an appropriate gold standard against which to compare the expert system's performance.
 4. Define realistic standards of performance; it may be unreasonable, for example, to expect better performance from the expert system than from a human expert.
 5. Specify who will be evaluating the results. It could be human experts or end users, it could be individuals or a group evaluating by consensus, and so on. (Note that persons evaluating the results need not be the same as those for whom the evaluation is intended.)
 6. Eliminate potential bias, for example by avoiding presenting the results in the form of computer output, which may bias judges who feel negative toward computer technology.
 7. Specify the type of test cases presented -- random cases or cases preselected to range over a broad spectrum of difficulty.

Source: Frederick Hayes-Roth, Donald A. Waterman, and Douglas B. Lenat, Building Expert Systems (Reading, Massachusetts: Addison-Wesley Publishing Company, Inc., 1983), pp. 278-279.

Teknowledge recommends that "ten to twenty actual cases" be used to test the system's performance. For each of these, the project expert should rate "the system's performance as:

- identical to what the expert would do,
- an acceptable alternative to what the expert would do,
- unacceptable [Teknowledge, Knowledge:1]."

In sharp contrast, Feigenbaum, in describing the validation of the PUFF expert system, notes:

"150 cases not studied during the knowledge acquisition process were used for a test and validation of the rule set. PUFF inferred a diagnosis for each. PUFF-produced and expert-produced interpretations were coded for statistical analysis to discover the degree of agreement. Over various types of disease states, and for two conditions of match between human and computer diagnosis ('same degree of severity' and 'within one degree of severity'), agreement ranged between approximately 90% and 100% [Feigenbaum (1977):2]."

A much different performance metric was used in evaluating the R1 system. Bachant and McDermott state:

"... 'percentage of totally correct orders' came to be accepted early as the metric for measuring R1's performance. The problem with this metric, of course, is that it does not discriminate between terrible performance (gargantuan errors) and near perfect performance (tiny, almost insignificant errors). In retrospect, it is clear that having some idea of the seriousness of each error would be helpful in evaluating R1 [Bachant:29]."

McDermott describes the actual procedure"

"The validation process consisted of giving R1 the 50 most recently booked orders and having a group of six experts carefully examine R1's output for correctness. The experts were given orders in groups of 10 [McDermott:24-25]."

Hayes-Roth et al. note that the selection criterion for the actual test cases was "naive;" as, the orders which were the last to be placed were selected. There was no attempt

"to look for difficult configuration tasks (many orders that come through are actually trivial) on which the system might fail. The evaluation team consisted of twelve people, drawn from the ranks of paper configurers, technicians, and engineering staff; of these, six or seven participated in the evaluation of any particular order. In an evaluation session the participants worked together, as opposed to working independently and then comparing conclusions. The process of evaluation required eight hours for the first order, four hours for the second, and one to two hours for the rest of the orders. McDermott reported that one of the things that the evaluators learned in processing the first few orders was that there was significant disagreement among themselves as to the right way to do the configurations. Here was a clear example of the lack of an objective, accepted gold standard [Hayes-Roth:270]."

The evaluation took two months to complete.

McDermott records that R1 made 12 mistakes in performing the 50 configuration tasks. Still, the "experts were extremely impressed with R1's performance [McDermott:25]." Although,

"...it is clear that at the end of the validation stage R1 was still a very inexperienced configurer. It had encountered only a tiny fraction of the set of possible orders, and consequently its knowledge was still very incomplete [McDermott:27]."

Further, Hayes-Roth et al. point out that the evaluation procedure used for R1 was lacking in that it did not include

"any real involvement by the user in the exercise of the system. There can be no better way to expose the weaknesses of a purported expert system than to invite those whose task domain it is to have a go at breaking the system. Real acceptance will come only when such a

system can gain the respect of the most skeptical of its potential users by surviving the worst trials that they can devise [Hayes-Roth:272]."

MYCIN is another expert system which has been exhaustively validated. In the first validation effort of the MYCIN system, MYCIN's conclusions were compared against the patient's actual blood disease. The system's performance, however,

"was very poor when judged by this criterion. The question that they had to ask was whether it is justifiable to judge its performance against actuality. Is it reasonable to expect MYCIN to perform better than leading experts in the field? Or should we judge its effectiveness against the performance of experts? Later trials compared its performance against that of specialists in the field and also against that of medically trained people who were not, however, specialists in the field of blood infection and bacterial meningitis. MYCIN performed better than the specialists and much better than the non-specialists [Sell:63]."

Hayes-Roth et al. note that the MYCIN evaluations taught the important lesson of "biasing and blinding." Two different evaluations were performed: "the bacteremia evaluation" and the "meningitis study."

"During the first of these evaluations, the expert physicians who were assessing MYCIN's performance knew they were examining the output of a computer program. Many of their comments and criticisms reflected their own biases regarding the proper role of computers in medical settings ('I don't think the computer has an adequate sense of how sick this patient is. You would have to see a patient like this in order to judge.'). As a result, the meningitis study design mixed MYCIN's recommendations with a set of recommendations from nine other individuals (ranking from infectious disease faculty members to medical students) asked to assess the case. When national experts later gave opinions on the appropriateness of therapeutic recommendations, they did

not know which proposed therapy was MYCIN's and which recommendations came from the human diagnosticians. This blinded study design removed an important source of potential bias and also provided a sense of where MYCIN's performance lay along a range of expertise from faculty specialists to medical students [Hayes-Roth:263-264]."

However, as Hayes-Roth et al. qualify, blinding also has inherent limitations.

"Since typescript protocol generated by an expert system cannot very well be disguised to resemble a human dialogue, the desire to blind a study necessarily limits the amount of evidence that can be made available to the panel of expert judges concerning the adequacy of the problem-solver's knowledge and methods [Hayes-Roth:251-252]."

Therefore, the evaluators of the MYCIN system were "asked to make their assessment of performance (of both physicians and the MYCIN program) based only on the decision-maker's final judgment about therapy [Hayes-Roth:252]." Such an approach permits only the conclusions of the system to be evaluated. However, frequently the reasoning is just as important as the conclusion. A blinded study rarely permits the inferencing of the expert system to be evaluated.

Still, most expert systems, including MYCIN, R1, and PROSPECTOR, "have tended to emphasize the program's performance at its decision-making task in their evaluation studies [Hayes-Roth:255]." However, numerous other requirements need to be evaluated.

Sell suggests "five basic requirements" which should be evaluated to determine the expert system's overall performance.

Consistency requires that the system's "pronouncements are free from contradiction." Completeness assumes that "it can tackle any problem within its domain." Precision is determined "if the strength of its conviction is commensurate with the data and the knowledge at hand." Soundness dictates that it "can deliver the right answers." Usability assumes that "it can be used with reasonable facility by those for whom it was designed [Sell:64]." Sell notes, however, that it is "not practicable [Sell:70]" to prove soundness. Further, Smith gauges utility in terms of whether the system solves "enough of the problem to be interesting and useful [Smith:66]."

Hayes-Roth et al. argue that

"the ultimate criterion of success is whether an expert system is actually used for expert consultation by individuals other than the system developers. This goal represents a formidable challenge for a young and developing field; only a few expert systems have reached this stage. A key ingredient of success is involving eventual users in evaluations of the system as it is being built. Without a clear understanding of the ultimate users' needs and requirements, system builders may fail to provide crucial capabilities and, consequently, the expert system may have limited utility [Hayes-Roth:245]."

Summary of the Literature and Relation to the Research

The objective of Chapter II was to review the literature for guidance on how to proceed in developing an expert system. An attempt is now made to summarize these findings.

First, a development methodology, or sequence of steps to be followed in the development of an expert system, was reviewed. Several versions of a methodology were presented. All methodologies, however, begin with some form of problem definition step, proceed to knowledge acquisition and then to the coding of a prototype system. None of the methodologies presented appeared to include all of the desired steps for development.

Several authors commented on the difficulty of the problem identification step. Determining the exact scope of the problem to be addressed appears to be an even more difficult task.

The importance of involving users early in the design of the expert system was also stressed. The knowledge engineer must understand the users' task environment and the users' desires, in order to create a system which will be acceptable to the users. Most authors suggested that expert systems are best conceived by the experts themselves.

A recommended approach to problem identification, which also served to involve the users, was company-wide briefings. During these briefings, the knowledge engineer discussed the potential of the expert systems technology and asked the users for recommended problems which the system might address. Another approach used by a knowledge engineer involved providing specific criteria for expert systems to the users. The users were then asked to recommend problems which met these criteria.

Several authors attempted to break a task down into sub-elements as a means of determining the proper scope of the problem to be addressed. Once this determination was made, a formal proposal was written. This proposal served to focus the task definition.

The peer group was recommended as the best source regarding identifying the real experts for a given task. Most systems have only used a single expert from whom to acquire the knowledge for the expert system. However, multiple experts may be better, especially for task definition. In terms of knowledge acquisition, multiple experts can enumerate more of the problem dimensions. Use of multiple experts, however, requires some means to determine consensus. No previous documented attempts to use consensus-driving techniques for either task selection or knowledge engineering could be found.

Knowledge-acquisition was described as an ill-structured process. A few weeks of informal study to become familiar with the problem and task environment before beginning extensive interaction with the expert was recommended. Further, access to cases, specific examples of problems and solutions is required. These cases are then analyzed with the expert. Protocol analysis is the recommended technique for reviewing the case with the expert. three categories of cases are suggested: design, training and evaluation.

As soon as the first part of the problem is understood, development of a rough prototype expert system should begin. This first version of the expert system is then used to further expand and refine the knowledge base. During this validation and modification phase, the knowledge engineer executes the expert system on real problems and reviews the results with the expert.

Testing involves a more structured evaluation. Evaluation, however, is difficult due to the nature of the problems that the expert system addresses. Human judgment is usually necessary to determine what constitutes a right or wrong answer.

The most common approach to testing is the blinded study. In a blinded study, the knowledge engineer presents the case responses of both the human expert and the expert system to a panel of other experts. The responses are blinded such that the panel cannot tell the human from the machine response. The panel of experts is then asked to judge which response is better. One author suggested, however, that the acceptability of the system to the users may be an even more important standard for evaluation.

Authors stressed the importance of a specific evaluation plan. What is being tested, how the expert system is being tested, and what constitutes success or failure of the system should be clearly specified in advance of testing. Again, most evaluations tend to emphasize the program's performance on the decision-making task.

These specific lessons and developmental experiences were incorporated into the methodology presented in Chapter III. Table 7 depicts the issues from the literature for each phase of the methodology and shows the manner in which these issues were resolved and the resultant methodological approach. This methodology will now be presented.

Table 7
Relationship of the Literature to the Research Methodology

Phase of the Research	Issues from the Literature	Resolution for the Methodology
Phase I - Problem Selection	Involving users early in the design of the expert system is important.	Conduct an Expert System Workshop.
	Expert systems are test conceived by the users and/or experts.	Provide users the criteria handout.
	Peer group may be the best source for identifying the real experts for a given task.	Have peer group nominate and select the experts.
Phase II - Knowledge Engineering	Most expert systems have been developed using a single expert.	Use seven experts for the knowledge engineering.
	Use of multiple experts may be better.	
	Use of multiple experts requires some means to determine consensus.	Use the Nominal Group Technique to help attain consensus.
	Access to specific examples of problems or cases is required.	Collect thirty cases to be used during the Knowledge Engineering Sessions.
	Development of a prototype expert system should begin early.	Conduct two weeks of initial knowledge engineering sessions and then develop a prototype expert system.
Phase III - Performance Measurement	The first version of the expert system should be used to further refine the knowledge base.	Conduct two weeks of validation sessions where the experts use the expert system to solve cases.
	An evaluation plan should be developed in advance of testing.	Prepare a formal evaluation plan prior to the conduct of the experiment.
	Evaluation is difficult due to the nature of the judgmental problems that the expert system addresses.	Have panel of experts develop test key in advance of testing.
	The most common approach to testing is the blinded study.	Use this test key to measure performance.
	Acceptability of the system to the users may be an even more important standard for evaluation.	Include a questionnaire for the users of the expert system to provide feedback.

CHAPTER III

METHODOLOGY

The purpose of this chapter is to explain how the hypotheses concerning the feasibility of applying the expert systems technology to an inventory management problem were addressed and tested. As discussed in Chapter I, the methodology involved three successive phases:

- Phase I - Problem Selection
- Phase II - Knowledge Engineering
- Phase III - Performance Measurement

Each of these phases is discussed in turn in the following sections.

Phase I - Problem Selection

Phase I was a critical phase which laid the foundation for the remainder of the research. The objectives of this phase were to select the problem to be addressed by the expert system and to select the experts whose knowledge would be encoded into the expert system. Five steps comprised Phase I:

- Step 1 - Domain Familiarization
- Step 2 - Domain Analysis
- Step 3 - Expert System Workshop

Step 4 - Task Selection

Step 5 - Expert Selection

These steps are explained in this order. A calendar of the major events of this research effort is contained in Appendix P.

Step 1 - Domain Familiarization

Step 1, Domain Familiarization, entailed soliciting and reviewing written documentation concerning the item management task. The objectives of this step were to gain familiarity with the overall nature of the item manager's task and to gain an understanding of the item manager's vocabulary.

The Air Force¹ was asked to provide training materials, reports, regulations, manuals, standard operating procedures, and job descriptions pertaining to item management. The documents listed in Table 8 were provided and reviewed.

The review of the documents listed in Table 8 provided an overall understanding of the item manager's job. The following questions were answered:

1. What are the tasks and duties of an item manager?
2. What are the responsibilities of an item manager?

¹A project focal point was established at the Air Force Logistics Command (AFLC) Headquarters. All requests for documentation and questions were addressed to this individual.

3. What are the problems which an item manager must solve?
4. What are the exceptions to normal operations?

Throughout this review an effort was made to learn the "language" of item management. The dictionary of terms was particularly useful for this purpose. Each time an acronym or special term was encountered during the review of the documents listed in Table 8, the acronym or term was entered on the appropriate checklist shown in Figures 9 and 10. These checklists were then used as review sheets. Terms which were unclear were highlighted. Clarification was obtained from the project focal point at the Air Force Logistics Command Headquarters.

Step 2 - Domain Analysis

Step 2, Domain Analysis, entailed telephone interviews with three individuals who were identified as being highly knowledgeable about the item manager's role. The objective of Step 2 was to gain a better understanding of the item manager's task environment.² Specifically, answers were sought to the questions listed in Table 9.

²The term "task environment" is used in this report to connote the circumstances which an item manager is faced with on a daily basis. These circumstances include the jobs or duties that are performed by the item manager, problems which may be encountered in performing these duties, exceptions to normal operating procedures, and the knowledge and skills which an item manager must possess to properly perform these duties.

Table 8

Documents Reviewed During the Domain Familiarization Step

AFLC Regulation 57-4 - "Recoverable Consumption Item Requirements System (D041)," 29 April 1983

SM-ALC MMOI 67-9 - "Supply Exception Processing," February 1985

LMMIMØ1 AFLC Logistics Systems Training Program - "Introduction to Item Management," 1 January 1985

SG-LMMIMØ1 AFLC Logistics Systems Training Program - "Introduction to Item Management, Student Study Guide," January 1979

AFLC On-the-Job Training Guide - "Item Management Specialist," 1 May 1984

AFLC Training Guide - "International Logistics Security Assistance, Foreign Military Sales, Grant Aid," 1 November 1985

MMI Training Aid - "Dictionary of Military and Associated Terms Frequently Used Within the Item Management Division," 10 November 1981

AFLC Pamphlet - "Logistics Command Requirements Process, Key to Logistics Support," September 1985

AFLC Pamphlet - "Data Systems Used by Materiel Management," 1 April 1985

AFLC Personnel Summary - "Work Center Description: Item Management," May 1985

AFLC Personnel Briefing - "Materiel Management, Item Management Functional Review Study (D041)," May 1985

AFLC Briefing - "Air Force Requirements Data Bank," October 1985

Warner Robbins Air Logistics Center, Materiel Management Briefing - "Item Management 1986," September 1985

Acronym	Short for	Meaning	Clear	Unclear

Figure 9. Review Sheet and Checklist for Acronyms

Term	Meaning	Clear	Unclear

Figure 10. Review Sheet and Checklist for Special Terms

Table 9

Questions Regarding the Item Manager's Task Environment

-
1. What are the types of things that item managers do (generic subtasks)? For example, item managers assign exception codes, issue purchase requests, etc.
 2. Which of these tasks require expertise on the part of the item manager?
 3. What is the nature of this expertise -- e.g., in depth knowledge of regulations, skill in situation assessment, etc.?
 4. What are the characteristics of a good item manager?
 5. List ten problems or more which item managers frequently solve or provide advice on, be specific.
 6. Prioritize these problems in terms of frequency of occurrence, with #1 assigned to the problem which occurs most frequently.
 7. Prioritize these problems in terms of importance to successful accomplishment of the item managers task, again, with #1 representing the most important problem.
 8. Talk through a flowchart of the item manager's tasks. That is, what is the temporal relationship of these tasks?
 9. What are the exceptions to the normal process?
-

A request was sent to the project focal point at AFLC Headquarters asking that three individuals be identified to participate as interviewees. Two of the three were to be experienced staff personnel who establish the policy to be followed by item managers. The third individual was to be someone with less experience, currently working as an item manager, who was considered a "bright, up and coming" manager. These three individuals were identified by the project focal point and their cooperation was enlisted by the focal point in advance of the interviews. A Delphi approach was used.

The series of nine questions listed in Table 9 was mailed to each of the three individuals, such that the questions were received at least one week in advance of a scheduled telephone interview. The advance mailing gave the interviewees time to consider the questions and make whatever notes were necessary for the actual interview.

The individuals were interviewed over the phone. The interviews were recorded with the knowledge and permission of the interviewees. Protocols of the recorded interviews were typed. All three of the typed protocols were then mailed to each of the interviewees. Each interviewee received three different transcripts and was asked to make any additions, deletions, or modifications to his or her transcript as appropriate and return only their own transcript. Appendix B contains the correspondence related to the telephone interviews.

As a result of this process, only one of the interviewees made changes to the initial interview protocol. The changes were of a minor nature, providing more detail in certain areas. The three protocols contained no major inconsistencies or differences of opinion.

This step did serve to further clarify the item manager's task environment. Information regarding day-to-day problems which an item manager faces was uncovered. This information was not contained in any of the written materials reviewed in Step 1. Information obtained from the interviews in Step 2 was also used to further evaluate the item manager's task environment to determine if the expert systems technology was appropriate. The criterion for this evaluation was the existence of knowledge intensive tasks. The interviews indicated that the item management job was highly knowledge intensive.

Step 3 - Expert System Workshop

An Expert System Workshop, Step 3, was conducted on-site at the Sacramento Air Logistics Center.³ The purpose of this workshop was

³Sacramento Air Logistics Center is one of five wholesale outlets or depots where item managers perform their tasks. At each of the Air Logistics Centers approximately 150 item managers each manage several hundred different recoverable items. The Air Force selected Sacramento Air Logistics Center as the site where this project would be conducted.

to prepare all the item managers with more than six months experience to recommend candidate problems which would be valuable expert system applications. The motivation was to gain user acceptance of the final expert system at the beginning of the project by involving the users in the project at the design stage. Item managers with less than six months experience were excluded due to their lack of experience on the job and assumed inability to recommend appropriate problems.

Two separate workshops were conducted. Each workshop was of the same duration and presented exactly the same material. The purpose of having two separate workshops was to keep the audience of manageable size of fifty or less.

Each workshop lasted three hours. Fifteen minute breaks were provided at approximately 45 minute intervals. Each 45 minute interval was considered a block of instruction. Appendix C contains a detailed outline of each of the three blocks. The first block was a briefing which introduced expert systems: what they are, advantages, uses, examples of existing systems, and steps in the development of an expert system.

The second block of instruction provided specific criteria for selecting good problems for which expert systems could be developed. Thirty-five millimeter color slides were used as visual aid support for both the first and second blocks of instruction. The item managers were given a handout which summarized the criteria briefing. This handout is contained in Appendix D.

The third block of the workshop was reserved for the item managers as a brainstorming session. The item managers were asked to refer to the handout describing the criteria and to suggest problems which would be good candidates for the first prototype expert system. To start this discussion and to help all the item managers to feel at ease making recommendations, two individuals were preassigned to each workshop with preconceived recommendations. Each of these preassigned individuals began the discussion by recommending a candidate problem. The preassigned recommendations, both insignificant problems, were the same for each of the workshops.

A brainstorming⁴ approach was used to obtain problem recommendations. All candidate applications were recorded on a blackboard by the researcher. Following brainstorming, each application was discussed in terms of how the application satisfied the selection criteria. The third block was tape recorded.

In addition, each item manager was given two three-by-five index cards. Following the discussion, each item manager was asked

⁴The brainstorming approach used was semi-structured. The researcher led the discussion by requesting suggestions from the item managers. Each suggestion was recorded on a blackboard. The item managers did not critique the suggestions until all of the item managers' suggestions had been recorded on the blackboard. The suggestions of the item managers who attended the morning workshop were not provided to the attendees of the afternoon workshop as part of this brainstorming session. The blackboard was erased after the morning workshop and before the beginning of the afternoon workshop.

to name his or her project of preference, with a brief description of the kinds of advice that an expert system for this task would provide. Item managers were instructed that a candidate application not previously mentioned in the discussion could be submitted on an index card. The motivation behind this instruction was to insure that potential applications were not overlooked because an item manager felt uncomfortable making a recommendation aloud. The item managers were instructed to take the second three by five card back to work with them along with the handout which described the criteria for good candidate problems. the item managers were asked to think about the workshop and submit the additional card the following day if the item managers thought of any additional potential problems.

A total of ninety item managers attended the expert system workshops. Forty-four item managers attended the morning session and forty-six item managers attended the afternoon session. Twenty-six different projects were recommended by the item managers. Nineteen of these were discussed during the workshops. Seven additional projects were submitted at the conclusion of the workshop. No additional three- by-five cards with project recommendations were submitted the following day.

Step 4 - Task Selection

Step 4, Task Selection, followed immediately after Step 3. A modified Delphi Technique was used for this step of the research.

The Delphi Technique

"is a method for the systematic solicitation and collation of judgments on a particular topic through a set of carefully designed sequential questionnaires interspersed with summarized information and feedback of opinions derived from earlier responses [Delbecq:10]."

Five days after the expert system workshop, a Delphi ballot of the candidate projects was given to each of the item managers who had attended the workshop. The ballot listed each of the twenty-six recommended applications and provided a brief description of each of these applications. The ballots used are included in Appendix E.

The item managers were requested to select five applications which were most preferred. Next, the item managers were asked to look at just the five candidate applications which they had selected from the list of twenty-six projects and rank order the five most preferred projects from one to five, with number one representing the most preferred alternative.

Eighty-six item managers completed the Phase I Task Selection Questionnaire. Demographics of the respondents are shown in Table 10. The statistics are self-reported.

A total weighted score was determined for each of the twenty-six candidate projects by weighting them as follows:

<u>Priority</u>	<u>Weight</u>
1	5 points
2	4 points
3	3 points
4	2 points
5	1 point

Table 10
Age and Experience of Item Managers Surveyed

<u>Age</u>	<u>Number of Item Managers</u>
Under 20	0
20 - 29	14
30 - 39	25
40 - 49	18
50 - 59	26
Over 60	3

<u>Years of Experience^a</u>	<u>Number of Item Managers</u>
Less than 2 years	43
2 - 5 years	21
5 - 10 years	11
10 - 15 years	3
15 - 20 years	6
More than 20 years	2

^aFifty percent of the respondents had less than two years experience as an item manager. Seventy-four percent of the respondents had less than five years experience as item managers.

As a result, the projects received the total weighted scores indicated in Table 11.

A weighted score of fifty points was used to determine which projects would be included on the Phase II Task Selection Questionnaire. Fifty points was used as it appeared to provide a fairly good separation of the projects. The nearest score below fifty points was forty-eight points. The nearest score above fifty was sixty-six. Hence, a separation of eighteen points between the projects resulted. Seven projects met this criterion.⁵ The researcher believed that seven remaining projects was a reasonable number for the second phase of task selection. The Phase II questionnaire is included in Appendix E. This questionnaire was provided to all the item managers who had attended the expert system workshop the day following the completion of the Phase I Task Selection Questionnaire.

The Phase II questionnaire provided feedback of the Phase I task selection activity. The item managers were asked to review this information and rank order three of the seven projects which they most preferred. Seventy-eight item managers completed the Phase II Task Selection Questionnaire.

⁵The preconceived projects which had been recommended in the expert system workshop to generate discussion were the PJJ/414 and Amended Shipping Instructions. Neither of these preconceived projects met the criterion for inclusion on the Phase II questionnaire.

Table 11

Total Weighted Project Scores, Phase One of Task Selection

<u>Project</u>	<u>Total Weighted Score</u>
1. Excesses	10
2. Allocation Decisions	13
3. Item Analysis	39
4. Controlled Exceptions	97
5. Backorder Listing	47
6. Repair Requirements	128
7. Cataloging Action	19
8. MICAP Support	18
9. Computer Products	48
10. Initial Provisioning	35
11. PR's	31
12. FMS Support	17
13. SO6's (Budget)	148
14. Critical Item Advisor	44
15. Project Focus	8
16. Shipment Advisor	13
17. Asset Reconciliation	83
18. Fill Rate Advisor	15
19. Scrubbing D041 Computation	207
20. General Training	66
21. D041 File Maintenance	109
22. Special Levels	19
23. Amended Shipping Instructions	5
24. PJJ/414	23
25. D032/J041 Reconciliation	36
26. Other Service Support	15

A total weighted score for each project was determined by weighting the projects as follows:

<u>Priority</u>	<u>Weight</u>
1	3 points
2	2 points
3	1 point

As a result, the projects received the total weighted scores indicated in Table 12. "Scrubbing the DØ41 computation"⁶ was selected as the task for which the expert system would be developed.

The response to the Phase I and II task selection questionnaires was quite high. The response to the Phase I questionnaire was 95.6 percent; response to the Phase II questionnaire was 86.7 percent. The way in which these questionnaires were administered most likely contributed to the high response rates. The item managers who had attended the expert system workshop were scheduled in groups of ten to report to a conference room to complete the questionnaires. The item

⁶The DØ41 Computation System is an Air Force information system which computes replenishment spares requirements for reparable items. Computations are performed quarterly. Future requirements are projected in the DØ41 system by multiplying the anticipated costs and usage rates by the anticipated operational hours for the total number of fielded systems which use the particular part. The item manager is responsible for validating or "scrubbing" the computation made by the DØ41 system to insure the accuracy of the computation. The function of the expert system is to insure that valid input data, such as unit price, administrative and production leadtimes, and repair cycle times, are used to generate a valid requirement.

Table 12
Total Weighted Project Scores, Phase Two of Task Selection

<u>Project</u>	<u>Total Weighted Score</u>
General Training	36
Asset Reconciliation	37
Controlled Exceptions	40
D041 File Maintenance	54
Repair Requirements	94
S06's (Budget)	87
Scrubbing the D041 Computation	126

managers completed the questionnaire, submitted the questionnaire to the researcher, and returned to work. The completion of all questionnaires was anonymous. Each group of ten item managers was scheduled into the conference room at 45 minute intervals. No attempt was made to prevent those item managers who had already completed the questionnaire from discussing the questionnaire with the item managers who had not yet been surveyed.

Step 5 - Expert Selection

The Delphi Technique was also used for Step 5, the selection of the experts whose knowledge of the task would be encoded in the expert system. The Expert Nomination and Expert Selection Questionnaires used in Step 5 are included in Appendix F. These questionnaires were administered in the same manner as the task selection questionnaires. Those item managers who had attended the expert system workshop were scheduled in groups of ten into a conference room at 45 minute intervals. The item managers completed the questionnaire in the conference room and submitted the questionnaire to the researcher before leaving the room. The completion of all questionnaires was anonymous.

The Expert Nomination Questionnaire required that the item managers list up to three names of individuals who were considered to be expert in the task of scrubbing the D041 computation. Eighty-nine item managers completed the nomination ballot. Fifty-one

different individuals received nominations. All nominated individuals who received less than five nominations were excluded from further consideration.

Twenty-one item managers at Sacramento Air Logistics Center were nominated by five or more of their peers. The names of these twenty-one individuals and the number of nominations each had received were included in the Expert Selection Questionnaire. This questionnaire was administered the next day in the same manner as the Expert Nomination Questionnaire.

The Expert Selection Questionnaire asked the item managers to select up to five individuals from the list of twenty-one and then to rank order the individuals selected. Number one represented the individual considered to be most expert at performing the task. A total weighted score was then determined for each individual in the same manner as before. As a result, nominees received the total weighted scores indicated in Table 13. Eighty-nine item managers completed the Expert Selection Questionnaire.

Names of the top eleven experts⁷ were then provided to management. Seven of the eleven experts were requested to be made available for the project. Correspondence concerning expert availability is contained in Appendix G. Table 14 depicts the range of total weighted scores for the top eleven experts. The seven

⁷There was a tie for the tenth expert.

Table 13
Expert Selection Total Weighted Scores

<u>Expert Number</u>	<u>Total Weighted Score</u>
1	117
2	82
3	145
4	41
5	52
6	29
7	57
8	67
9	79
10	15
11	76
12	33
13	17
14	35
15	267
16	18
17	152
18	31
19	26
20	29
21	52

Table 14
Range of Total Weighted Scores, Top Eleven Experts in Priority Order

<u>Expert Priority</u>	<u>Total Weighted Score</u>
** 1	267
* 2	152
* 3	145
4	117
* 5	82
* 6	79
7	76
* 8	67
9	57
* 10	52
* 10	52

* Indicates seven experts made available for the project.
 ** Indicates eighth expert made available for independent validation.

experts actually made available for the project are indicated with an asterisk. An eighth expert was made available for independent validation following system development. This expert is indicated in Table 14 by a double asterisk. Completion of this step concluded Phase I of the research.

Phase II - Knowledge Engineering

This phase of the research entailed obtaining the cases, extracting the actual facts and heuristics, encoding these in the knowledge base, and modifying the knowledge base as required. Four steps comprised Phase II:

Step 6 - Case Collection

Step 7 - Knowledge Engineering Sessions

Step 8 - Building the First System

Step 9 - Growing and Validating the System

These steps are discussed in this order.

Step 6 - Case Collection

Step 6, Case Collection, involved the collection of the thirty actual cases which were used during the knowledge engineering and validation steps. Correspondence concerning case collection is included in Appendix G. A case was a folder consisting of an actual computation and all supporting forms and computer documentation. Appendix H contains a sample case used during the knowledge engineering sessions.

The cases collected were divided according to the Teknowledge taxonomy of design cases, training cases, and evaluation cases. The first ten cases received were used for design as discussed in Step 7. The next twenty cases received were used during Step 9, the growth and validation of the expert system. Ten additional cases were collected from which to select the two evaluation cases used during Step 13.

A total of forty different cases were collected. All case folders were duplicated. Each of the seven experts was provided with a copy of the cases.

Step 7 - Knowledge Engineering Sessions

Step 7, Knowledge Engineering Sessions, entailed delimiting the task to be addressed by the expert system and working with the experts to obtain the heuristic decision rules used in scrubbing the D041 computation. The Nominal Group Technique combined with the case analysis method was used. The Nominal Group Technique (NGT) is a structured group meeting which involves the following steps:

- "1) Silent generation of ideas in writing.
- 2) Round-robin feedback from group members to record each idea in a terse phrase on a flip chart.
- 3) Discussion of each recorded idea for clarification and evaluation.
- 4) Individual voting on priority ideas with the group decision being mathematically derived through rank ordering or ratings [Delbecq:8]."

The seven experts always met and worked as a group throughout the knowledge engineering sessions. Forty hours total were spent with the seven experts over a three-week period during Step 7. During the first week of this period the experts met with the knowledge engineer four hours each day for five days. No knowledge engineering sessions were held during the second week. The experts again met with the researcher four hours each day for five days during the third week. All group sessions were recorded.

The first two days of week number one were used to clearly define and scope the task which the expert system was to address. Exercises one through four, contained in Appendix I, were used to accomplish these objectives.

The very first day was spent concentrating on the total task of scrubbing the DØ41 computation. Exercise one was used via an NGT method to insure that all the experts were in agreement regarding a basic understanding and definition of the task to be pursued. Exercise two was used via an NGT method to assist the researcher in better understanding the total breadth of the task such that the scope of the task could be appropriately delimited.

Exercises three and four were used on day two to determine the scope of the expert system. The Nominal Group Technique was used. Exercise three provided a listing of major subcategories of the task. Exercise four assisted in determining those elements of the task which were most important and those elements most frequently

incorrectly performed by novices. The expert system was designed to address those elements of the task which met both of these criteria. As a result of exercises three and four, the Inventory Manager Assistant (IMA) Expert System was designed to insure that the following data elements of the D041 requirements computation would be in agreement with what an expert would use:

- unit cost
- date of last procurement
- administrative leadtime
- production leadtime
- repair cycle times.

The remainder of week one, days three, four, and five, was spent discussing these elements of the computation with the experts. These discussions continued throughout week three. A total of ten cases were reviewed by the experts during the forty hours of initial knowledge engineering sessions. These cases were reviewed by having the experts silently generate their decision protocol and solution for the elements of the computation which the expert system was addressing. Solutions were then compared and discussed. Consensus of opinion was achieved via the discussion.

All of the knowledge engineering sessions were recorded and transcribed. A 370-page typewritten document resulted from these sessions. The researcher read this document several times in order to obtain a clearer understanding of the problem solving behavior of the experts. A small excerpt from the transcripts of the knowledge engineering sessions is included in Appendix J in order to provide

the reader with a better understanding of the manner in which the sessions with the experts were actually conducted.

Step 8 - Building The First System

Based upon the understanding of the problem-specific behavior obtained during the initial knowledge engineering sessions, the original knowledge base was encoded. The M.1 shell was used to develop the knowledge base. The M.1 shell was selected after consideration of twenty five other available shells.⁸

The transcripts of the initial knowledge engineering sessions were carefully reviewed. Rules were extracted from the transcripts. Several follow-up phone calls with the experts were required to clarify their statements which were recorded in the transcripts. These phone calls were made to one expert at a time. No conference calls were made. As a result, the first knowledge base or Mark-I system of the Inventory Manager Assistant (IMA) was developed. The Mark-I system contained fifty-five rules.

⁸The Williamson reference includes a discussion of the shells which were considered. The M.1 shell operates on any IBM compatible computer with at least 512 K of memory. As the researcher owned an IBM computer, this was one consideration. However, other criteria also influenced the selection of the M.1 shell. These criteria included the user friendly interface, production rule knowledge representation schema, ability to accommodate up to 1,000 rules, explanation facility, availability of training and support, and the existing use of this product by other Air Force agencies.

Step 9 - Growing and Validating the System

The small Mark-I system was then validated with the experts. As with the initial knowledge engineering sessions, the seven experts met as a group with the researcher in a conference room. The same three week schedule used during the initial knowledge engineering sessions was followed: four hour sessions each day of the first week, no sessions the second week, and four hour sessions each day of the third week. A portable computer served as the hardware environment for the expert system throughout these validation sessions.

During the first day of validation, the experts were each provided with a listing of the knowledge base, coded in M.1. The syntax of M.1 and the logic which M.1 used to draw conclusions were explained to the experts. The experts were then asked to carefully review the knowledge base listing, three separate times. The first review of the knowledge base listing was designed to check for any incorrect rules. On the second review of the knowledge base, the experts were asked to look at just the wording of the questions which M.1 asked and the advice statements given by M.1. The experts were asked to recommend any changes in terminology or additions which would make the questions and advice clearer to the user. Finally, during their third pass through the knowledge base listing, the experts were asked to look at the order in which questions were asked and advice given and to make any recommended changes which

would make an interactive consultation with the system more logical. For example, if eventually the expert system would need two different pieces of information from the same product which appear right next to each other, the expert system should query the user for both of these data elements at the same time. To ask the user for one data element from a product, then to ask for another data element from another product, and finally, to ask the user for still a third data element from the original product would not be a logical sequence of questioning. The paper validation surfaced minor disagreements among the experts, primarily in the area of terminology. These were discussed and consensus reached.

Following the paper validation of the knowledge base listing, the experts were formally introduced to the Inventory Manager Assistant (IMA) Expert System. The experts took turns going through interactive consultations with IMA for the remainder of the first day of validation. No actual cases were reviewed the first day.

The researcher used the remainder of the day, after the meeting with the experts, to make the changes to IMA recommended by the experts. This practice was followed each day such that the system was ready for further validation the next day. Approximately thirty rules were changed as a result of the first day's validation session with the experts. Changes were primarily made to correct or provide more appropriate wording of the questions which IMA asked. A few minor changes were made to the order in which the questions were asked.

The researcher again reviewed the M.1 syntax with the experts on the beginning of the second day. The remainder of that day and the remainder of the week, the experts worked through the original ten design cases and five new training cases in interactive sessions with IMA. The experts took turns sitting at the terminal, keying in inputs and reading IMA's questions and advice to the other experts. The other experts worked manually through the cases and based upon the answers derived would agree or disagree with the advice provided by IMA.

Each time an expert disagreed, the "show" command⁹ was used to find the rule which had been invoked. This rule was then reviewed for accuracy.

Frequently, five or six times each day, the experts would disagree about the correctness of the advice IMA had provided. The researcher would then interrupt the consultation with IMA and have the expert(s) who disagreed with IMA explain why to the other experts. Normally these discussions resolved the issue. Usually one expert or two had noticed an important piece of information which the other experts had overlooked. Additions to IMA were usually required.

⁹The "show" command is one of the M.1 commands. When entered, the expert system displays the conclusions reached to this point in the consultation and the rule number which caused the system to draw each conclusion. For example, "ALT = 9 because kb - 117."

When discussion alone did not resolve the issue,¹⁰ a vote of the experts was taken. Majority vote was used to decide these issues.

Working through the fifteen cases resulted in considerable additions, modifications, and deletions to the knowledge base. Approximately forty new rules were added each night by the researcher as a result of the day's validation session. Approximately another twenty of the existing rules were modified each night to clarify the rules and make the advice provided to the user easier to understand. Less than five rules were deleted each night. Frequently, a single rule which was deleted would be replaced by three or four rules of a more detailed nature. Each time a change was made to any knowledge base entry, all the cases were rerun against the expert system for revalidation. The majority of new rules were added, not because the particular case at hand required them, but rather because the case reminded the experts of a concept which had not been discussed with the researcher earlier. During the first week of validation the expert system grew from fifty-five to two hundred and seventeen rules.

During the second week of validation, an additional fifteen training cases were reviewed. Again, the experts compared IMA's

¹⁰During both the initial knowledge engineering sessions and the validation sessions, this situation only occurred two times.

advice to the decisions which were derived manually. Again, each time a change was made to any knowledge base entry, the expert system was rerun against all previous design and training cases.

By the end of the second week of validation, IMA had considered thirty cases, ten design cases and twenty training cases. IMA was now a system of four hundred and forty-one rules.

The last day of the two week validation an eighth expert¹¹ was introduced to IMA and asked to critique the system. This expert was able to provide an independent evaluation of the system as the expert had not participated in the earlier group discussions of the system's logic nor had the eighth expert discussed the logic in advance with any of the other experts. The expert spent four hours with IMA and went through four training cases in great detail. The other experts were present for this session. When the eighth expert disagreed, the other experts would explain IMA's reasoning.

As a result of this validation session, two errors in IMA's rules were noted. Further, the validation expert made several recommended changes to the wording of the questions.

¹¹This expert was originally selected by the peer group as the number one ranked expert at Sacramento Air Logistics Center. Because of other commitments, this expert could not be made available for the entire project. This expert, however, served a very useful role by providing an independent evaluation of the expert system.

A small pretest was also conducted as part of the validation effort. Two item managers¹² one with less than a year of experience and one with six years of experience were asked to select an item which each item manager currently managed. The item managers were introduced to IMA and asked to consult with IMA regarding the item each had selected. In both cases, IMA found errors. The experts concurred that IMA's advice was correct. The item of the item manager with six years of experience had a \$600,000 error which IMA found. The item manager was unaware of the error.

The item managers were timed during the pretest, without knowledge that the consultation was being timed. Times to complete the consultation were 19 minutes for the item manager with less than a year of experience and 16 minutes for the item manager with six years of experience. This information on the times to complete a consultation was used to determine how subjects should be scheduled for the formal test of IMA. At the conclusion of the validation sessions and the pretests both the original seven experts and the eighth validation expert agreed that IMA performed adequately and that formal testing should begin.

¹²The item managers were selected by the supervisor of the work area nearest to the conference room where the experts were working.

Phase III - Performance Measurement

This phase involved the conduct of the formal test to determine if research hypotheses three and four were true or false. The hypotheses are:

Research Hypothesis 3 - Expert systems can significantly improve the performance of inventory managers.

Research Hypothesis 4 - Expert system will allow inventory managers to more efficiently solve complex or difficult problems.

Five steps comprised Phase III:

Step 10 - Evaluation Plan Development

Step 11 - Test Case Selection

Step 12 - Test Key Development

Step 13 - Validation Panel

Step 14 - Effectiveness/Efficiency Experiment.

Step 10 - Evaluation Plan Development

A formal evaluation plan was prepared prior to the conduct of the experiment. Appendix K contains this evaluation plan. The development of the plan surfaced issues of exactly what was being evaluated, how test cases would be selected, how subjects would be selected, and how successful and unsuccessful performance would be differentiated. The plan addressed each of these issues. In addition, the location of testing, scheduling of subjects, and required resources were discussed.

Step 11 - Test Case Selection

Two cases were selected as the cases to be used for testing by the seven experts, whose knowledge was encoded in the expert system. This section explains the process of case selection.

Five different company¹³ supervisors were asked to select two item computations, one which the supervisor considered to be an easy item to manage and the other item was to be a very complex case. In total, ten cases were provided by the five supervisors. Copies of these case folders were provided to each expert. The experts were asked to grade each of the ten cases, in accordance with the grading scale shown in Table 15, by giving each case two overall grades. One grade was to reflect how frequently the case might be encountered and the other grade was to reflect how difficult the expert believed the case to be.

A complex case was defined as a very difficult case which would be very infrequently encountered. A simple case was defined as a very easy case which would be very frequently encountered. The grading sheet had been established such that low scores on each of the dimensions of frequency and difficulty represented a complex case. High scores on each of the dimensions represented a simple case.

¹³A company is an organizational element at Sacramento Air Logistics Center. Each company manages different types of items. For example, one company manages radars. Another company manages all airframe items managed by Sacramento ALC.

Table 15
Case Grading Scale Used to Determine Case Complexity

Frequency	
<u>Descriptor</u>	<u>Grade</u>
Very Infrequently Encountered	0
Infrequently Encountered	1
Moderately Encountered	2
Frequently Encountered	3
Very Frequently Encountered	4

Difficulty	
<u>Descriptor</u>	<u>Grade</u>
Very Difficult	0
Difficult	1
Moderately Difficult	2
Easy	3
Very Easy	4

A total score for the frequency dimension and a total score for the difficulty dimension was determined for each case by adding together the experts' grades. No attempt was made to determine a consensus grade for each dimension of each case. The total scores for each case on each dimension are shown in Table 16. Case 4 ranked highest on both dimensions. Case 7 ranked lowest on both dimensions. Therefore, Case 4 was selected as the simple case and Case 7 was selected as the complex case to be used during the performance test of IMA.

One further check had to be made to insure that there were no unique features of the cases which were outside the limits of IMA's expertise. The experts each ran both cases with IMA. IMA simulated the experts manual results on both cases with high congruence.

Step 12 - Test Key Development

The next step was the development of the test key against which performance would be evaluated. The researcher's intent was to make the evaluation as objective as possible. Objectivity was introduced by creating a test key in advance of the actual testing. Since IMA gives advice on ten different quantitative elements of the D041 computation, as shown in Table 17, an objective test key could be developed. The experts were asked to review the two cases selected in Step 11 and for each case to complete the form shown in Figure 11 by providing the number or range of numbers which correspond to a

Table 16

Total Frequency and Difficulty Scores for the Candidate Test Cases

<u>Case Number</u>	<u>Frequency Score</u>	<u>Difficulty Score</u>
1	19	13
2	20	15
3	19	22
4	26	24 *
5	22	19
6	19	18
7	11	8 **
8	20	15
9	21	16
10	17	14

* Denotes simple test case

** Denotes complex test case

Table 17

The Nature of Advice Provided by the Inventory Manager Assistant
(IMA) Expert System

<u>ELEMENT</u>	<u>UNITS</u>
Unit Cost	Dollars
Date of Last Procurement	Days
Administrative Leadtime	Months
Production Leadtime	Months
Base Repair Cycle Time	Days
Base Processing Time	Days
Reparable Intransit Time	Days
Supply to Maintenance Time	Days
Shopflow Time	Days
Maintenance Turn-In Time	Days

Element	Very Poor	Poor	Mediocre	Good	Very Good
1. Unit Cost					
2. DOLP					
3. ALT					
4. PLT					
5. Base RCT					
6. Base Precessing					
7. Reparable Intransit Time					
8. Supply to Maintenance					
9. Shop Flow					
10. Turn In Time					

Figure 11. Grading Sheet Completed by Each Expert for Each Case

very poor, poor, mediocre, good, and very good answer for each of the ten elements. Each expert completed two forms, one for each case. Responses were generated without discussion. The researcher then went through each element of each case having the experts read their responses for each block and writing the given responses on the blackboard. That is, first unit cost was considered. The blackboard appeared as shown in Figure 12. Each expert's answer was entered, in the spaces provided, for comparison. Any differences were discussed and consensus achieved through discussion. Majority voting was not required. Tables 18 and 19 depict the final test keys used for the simple and complex case, respectively.

Realizing that all of these elements are not necessarily of equal importance, the experts were next asked to assign weights to each of the elements. The experts completed the form shown in Figure 13 by distributing 100 points among each of the ten elements on which IMA provides advice. Again, each expert completed a separate form for each case without discussion. The results were summarized on the blackboard as shown in Figure 14. A separate summarization was presented for each case and a discussion followed. The experts decided that the weights should be the same for both cases. Consensus decision on the weights was achieved through discussion. The weights given to each of these elements by the experts are shown in Table 20.

	UNIT COST						
	<u>Expert 1</u>	<u>Expert 2</u>	<u>Expert 3</u>	<u>Expert 4</u>	<u>Expert 5</u>	<u>Expert 6</u>	<u>Expert 7</u>
Very good	_____	_____	_____	_____	_____	_____	_____
Good	_____	_____	_____	_____	_____	_____	_____
Mediocre	_____	_____	_____	_____	_____	_____	_____
Poor	_____	_____	_____	_____	_____	_____	_____
Very poor	_____	_____	_____	_____	_____	_____	_____

Figure 12

Blackboard Summary of Expert Case Grading

Table 18. Test Key Used to Evaluate the Simple Case

Element	Very Poor	Poor	Mediocre	Good	Very Good
1. Unit \$ Cost	0 - 804.36 and 1304.38 - 9999.00	804.37 - 1029.36 1079.38 - 1304.37	1029.37 - 1044.36 1064.38 - 1079.37	1044.37 - 1054.36 1054.38 - 1064.37	1054.37
2. DOLP	0-76331 77328 - 99999	76332 - 77056 77238 - 77327	77057 - 77116 77178 - 77237	77117 - 77146 77148 - 77177	77147
3. ALI	9-999	6, 7, 8	4, 5	1, 3	2
4. PLI	21-999 and 0-7 0-7	8, 9, 10, 18, 19, 20	11, 12, 16, 17	13, 15	14
5. Base RCT	12-999	8, 9, 10, 11	1, 2, 6, 7	3, 5	4
6. Base Processing	11-999	8, 9, 10	1, 5, 6, 7	2, 4	3
7. Reparable Intransit: Time	0-6 22-999	7, 8, 9, 19, 20, 21	10, 11, 12, 16, 17, 18	13, 15	14
8. Supply to Maintenance	1, 2 18-999	3, 4, 5, 6, 14, 15, 16, 17	7, 8, 12, 13	9, 11	10
9. Shop Flow	1, 2 40, 999	3, 4 24-39	5, 6, 7 11-23	8, 10	9
10. Turn In Time	25-999	1, 2 18-24	3-8 12-17	9, 11	10

Table 19. Test Key Used to Evaluate the Complex Case

Element	Very Poor	Poor	Mediocre	Good	Very Good
1. Unit Cost	0 - 3799.21 4799.23 - 999999	3799.22 - 4199.21 4399.23 - 4799.22	4199.22 - 4256.21 4342.23 - 4399.22	4256.22 - 4299.21 4299.23 - 4342.22	4299.22
2. DOLP	0 - 84093 85090 - 99999	84094 - 84183 84365 - 85089	84184 - 84243 84305 - 84364	84244 - 84273 84275 - 84304	84274
3. ALT	0	1, 2, 3 11, 12	4, 5 9, 10	6, 8	7
4. PLT	0 - 8 22 - 999	9, 10, 11 19, 20, 21	12, 13 17, 18	14, 16	15
5. Base RCT	0 - 4 20 - 999	5, 6, 7, 8 16, 17, 18, 19	9, 10 14, 15	11, 13	12
6. Base Processing	12 - 999	1, 9, 10, 11	2, 6, 7, 8	3, 5	4
7. Repairable Intransit Time	1, 2, 3 19 - 999	4, 5, 6 16, 17, 18	7, 8, 9 13, 14, 15	10, 12	11
8. Supply to Maintenance	1, 2 18 - 999	3, 4, 5, 6 14, 15, 16, 17	7, 8 12, 13	9, 11	10
9. Shop Flow	1, 2 39 - 999	3, 4 23 - 38	5, 6 10 - 22	7, 9	10
10. Turn In Time	25 - 999	1, 2 18, 24	3 - 8 12 - 17	9, 11	10

Please allot 100 points among the following elements. Your total must equal 100.

<u>Element</u>	<u>Points</u>
1. Unit Cost	_____
2. DOLP	_____
3. ALT	_____
4. PLT	_____
5. Base RCT	_____
6. Base Processing	_____
7. Reparable Intransit	_____
8. Supply to Maintenance	_____
9. Shop Flow	_____
10. Turn In	_____
TOTAL	_____

Figure 13

Weight Allocation Form

<u>Element</u>	<u>E 1</u>	<u>E 2</u>	<u>E 3</u>	<u>E 4</u>	<u>E 5</u>	<u>E 6</u>	<u>E 7</u>
1. Unit Cost	_____	_____	_____	_____	_____	_____	_____
2. DOLP	_____	_____	_____	_____	_____	_____	_____
3. ALT	_____	_____	_____	_____	_____	_____	_____
4. PLT	_____	_____	_____	_____	_____	_____	_____
5. Base RCT	_____	_____	_____	_____	_____	_____	_____
6. Base Processing	_____	_____	_____	_____	_____	_____	_____
7. Repairable Intransit	_____	_____	_____	_____	_____	_____	_____
8. Supply To Maintenance	_____	_____	_____	_____	_____	_____	_____
9. Shopflow	_____	_____	_____	_____	_____	_____	_____
10. Turn In	_____	_____	_____	_____	_____	_____	_____

Figure 14

Blackboard Summarization of Experts Weights

Table 20
Experts' Weighting of IMA's Components

<u>Element</u>	<u>Weight</u>
1. Unit Cost	23
2. DOLP	18
3. ALT	18
4. PLT	18
5. Base RCT	3
6. Base Processing	3
7. Reparable Intransit	5
8. Supply to Maintenance	5
9. Shop Flow	5
10. Turn In	2

Step 13 - Validation Panel

Prior to the conduct of the formal test of the expert system's performance, a validation panel was convened. The panel had two objectives. First, the panel provided a second independent validation of the expert system's logic prior to the performance test. Second, the panel validated the test key developed by the experts in Step 12. The validation panel also developed weights for the ten elements on which IMA provides advice.

The Air Force project focal point at AFLC Headquarters was contacted and asked to assemble a panel of three individuals considered to be "expert" in the area of item management. The panel was convened at AFLC Headquarters in Dayton, Ohio. The researcher demonstrated IMA to the validation panel and instructed the panel on how to conduct a consultation. Members of the panel then took turns consulting IMA. A sample consultation session with IMA is provided in Appendix O. The two test case folders were made available for this purpose. The validation experts also made up numbers in attempts to break the system. The attempts failed and the experts were satisfied that the logic was sound. All members of the panel concurred that formal testing could begin. Next, the experts were presented the test keys, Tables 18 and 19, determined by the development experts and asked to make any changes deemed appropriate. Each validation expert was provided his own copy of the test case and the test key for this purpose. After some

discussion and debate, the validation experts decided that no changes were necessary to the test keys.

Next the experts were asked to complete the same element weighting form, previously completed by the development experts, by allotting 100 points among the ten elements. See Figure 13. The validation experts performed this task in the same manner as the development experts. Each expert generated a form for each case without discussion. Summarization followed exactly as before. The discussion which followed again determined that the same weighting schema could be used for both of the test cases. Consensus regarding the weights was achieved through discussion. The weights assigned to each element by the validation panel are shown in Table 21. The weights previously determined by the development experts are also presented in this figure for comparison purposes.

Step 14 - Effectiveness/Efficiency Experiment

The effectiveness/efficiency experiment was conducted at two sites: Sacramento Air Logistics Center and Ogden Air Logistics Center (ALC). Sacramento ALC was the primary test site as the expert system had been developed at Sacramento. The expert system was also tested at Ogden ALC to obtain a measure of how generic the expert system was. A generic expert system could be implemented for all organizations which performed this task, with no need to first tailor the expert system to the specific organization.

Table 21
Comparison of Validation Panel and Experts' Weighting of IMA's
Components

<u>Element</u>	<u>Validation Panel Weight</u>	<u>Development Experts' Weight</u>
1. Unit Cost	23	23
2. DOLP	16	18
3. ALT	19	18
4. PLT	19	18
5. Base RCT	4	3
6. Base Processing	4	3
7. Reparable Intransit	4	5
8. Supply to Maintenance	4	5
9. Shop Flow	4	5
10. Turn In	3	2

A single experiment was used to measure decision effectiveness and efficiency. The experiment was a between-subjects, two-by-two-by-three factorial design. The three treatments and levels of each treatment are shown in Figure 15.

The performance of each subject within each cell was measured on only one case, the simple case or the complex case, performed either manually or with the expert system. Each subject was provided a trial case for practice prior to beginning the case on which the performance measure was taken. Subjects were selected randomly and prescheduled, as explained in Appendix K. Eighty-eight subjects were tested at Sacramento ALC. Sixty subjects were tested at Ogden ALC.

The directions contained in Appendix L, as appropriate for either manual subjects or subjects assisted by the expert system, were read to all subjects. All subjects completed the appropriate questionnaire contained in Appendix M.

Each subject received a score between 0 and 100 points for the case the subject completed. The score was determined by comparing the individual's score to the test key generated by the experts and then applying the point values contained in Table 22. This procedure was followed for each of the ten answers provided by each subject, and the scores on all ten elements were then totaled. Table 23 demonstrates this scoring procedure for the simple case. Effectiveness was operationalized as the subject's score on the case

<u>Task Method</u>	<u>Type of Case</u>	<u>Subject Experience</u>	<u>Cell Size n</u>
Manual	Simple	Novice	10
		Journeyman	20
		Advanced	8
	Complex	Novice	12
		Journeyman	18
		Advanced	7
Expert System	Simple	Novice	10
		Journeyman	16
		Advanced	10
	Complex	Novice	12
		Journeyman	18
		Advanced	7

Figure 15

Cells and Cell Sizes of the Effectiveness/
Efficiency Experiment

Table 22
Point Values Assigned to Test Subjects' Answers

<u>Quality of Answer</u>	<u>Point Value</u>
Very Poor	0 points
Poor	2.5 points
Mediocre	5 points
Good	7.5 points
Very Good	10 points

Table 23
A Demonstration of the Scoring Process, Simple Case

<u>Subject #12's Answers</u>		<u>Expert's Rating</u>	<u>Points Assigned</u>
1. Unit Cost	1054.00	Good	7.5
2. DOLP	77147	Very Good	10
3. ALT	2	Very Good	10
4. PLT	14	Very Good	10
5. RCT	4	Very Good	10
6. Base Processing	21	Very Poor	0
7. Reparable Intransit Time	14	Very Good	10
8. Supply to Maint.	10	Very Good	10
9. Shop Flow	9	Very Good	10
10. Turn In	10	Very Good	<u>10</u>
		TOTAL SCORE	87.5

completed. The analysis of the effectiveness measure was used to test research hypothesis three.

In addition, the time each subject took to complete a case was recorded. The researcher obtained this measure via observation of the subjects. The time was measured from when the subject actually began the test case until the subject completed the test case. Time to complete questionnaires was not included in the time. Times were recorded without the subject's knowledge. The efficiency measure was recorded as the time to complete the case.

A univariate ANOVA procedure was used to assess the statistically significant factor effects of the task method, user experience, and type of case on the two dependent variables: 1) A subject's total score or effectiveness, and 2) a subject's time to completion or efficiency. All of the interaction effects of the three factors were included in the model.

The number of years the subject had worked as a D041 item manager was self-reported. A subject was categorized as a novice if the subject had been an item manager for less than one year. A subject was categorized as a journeyman if the subject had one to four years experience as an item manager. Finally, a subject was categorized as an advanced item manager if the subject had been an

item manager for more than four years.¹⁴ Years of experience were then treated as a blocking factor in the data analysis.

As seen in Appendix M, the subject's experience in interacting with a computer and the subject's confidence in interacting with a computer were also self-reported measures. Computer confidence and computer experience were treated as continuous variables and used as covariates in the data analysis.

A univariate ANOVA was performed on each dependent performance variable, score and time, with the aid of the Statistical Package for the Social Sciences (SPSS). The recode statement was used to automatically convert each subject's answers, raw data, to an effectiveness score for each of the ten elements.

Subjects who were assisted by IMA were asked to complete a critique of the expert system. The critiques are summarized in Appendix N. No formal analysis of the critiques was performed.

Summary

This chapter has discussed the methodological approach which was followed in the conduct of this research. Lessons learned from numerous previous developments of expert systems, as documented in the literature review, were incorporated into this fourteen-step

¹⁴The experts at Sacramento ALC provided the year categories defining a novice, journeyman, and advanced item manager. The validation panel concurred with the operationalization.

process. The key lessons incorporated were: involve the users early, let the users decide which applications are best, take advantage of multiple experts, use a case analysis approach to acquire the knowledge, and clearly specify what is to be evaluated and how.

The methodology was unique in that consensus driving techniques from the social sciences were used to select the task, elect the experts, and derive the heuristics of multiple experts. Further, the methodology included a new, objective approach to the evaluation of the expert system's performance.

A 441-rule expert system to assist with an inventory management task has been developed. An experimental design was devised and implemented to determine if use of the expert system can enable item managers to make more effective and efficient decisions. The results of the effectiveness/efficiency test are the subject of Chapter IV.

CHAPTER IV

RESULTS AND OTHER FINDINGS

This chapter first presents the results of the ANOVA procedures on the effectiveness/efficiency test. Following the presentation of the ANOVA procedure results, other findings from the research, for which no formal hypotheses had been established in advance, are discussed.

Results of ANOVA Procedures

As explained in the discussion of the research methodology, the data collected during the effectiveness/efficiency test were submitted to statistical analysis in a full factorial ANOVA design. A fixed effect, two-by-two-by-three factorial model was used with the aid of the Statistical Package for the Social Sciences (SPSS). The subject's experience in interacting with a computer and the subject's confidence in interacting with a computer were treated as continuous variables and used as covariates in the data analysis. A univariate ANOVA was performed on each of the ten element scores for which IMA provided advice, on the total performance score, the development experts' weighted total score, the validation panel's weighted total score, and the time to completion. Forty-two ANOVAs were run, fourteen for each test site,

and fourteen with the data combined from both of the test sites. An alpha level of .05 was used to judge significance. The covariates of experience and confidence were not significant. The covariates were not even significant at an alpha level of .1. As the covariates did not explain any significant amount of variance, the covariates were eliminated from further analysis of the data.

The initial forty-two ANOVAs were rerun with the covariates eliminated. In addition, nine other ANOVAs were run, three for each test site, and three with the data combined from both of the test sites. These additional nine ANOVAs provided the total performance score less the scores for production leadtime and reparable intransit time, according to the three weighting schemas. Figure 16 depicts the fifty-one ANOVAs which were submitted to additional analysis. Production leadtime and reparable intransit time were eliminated from the computation of the total performance score since the use of the expert system significantly decreased performance on these elements. The researcher assumed that management probably would not want to implement an expert system for an element or aspect of a task for which use of the expert system degraded performance. This assumption may or may not be valid and will be discussed in Chapter V. Given the researcher's assumption, the objective of the analysis which excluded production leadtimes and reparable intransit times was to determine the magnitude of the increase in total performance which could be realized if the expert

MEASURE	DATA FROM		
Total Scores	Sacramento	Ogden	Both Sites
Total Equal Weighting	.	.	.
Total Experts' Weighting	.	.	.
Total Validation Panel's Weighting	.	.	.
Total Less PLT and RITT Equal Weighting	.	.	.
Total Less PLT and RITT Expert's Weighting	.	.	.
Total Less PLT and RITT Validation Panel's Weighting	.	.	.

Figure 16

Fifty-one ANOVAs Submitted to
Further Analysis

SCORE	DATA FROM		
Element Scores	Sacramento	Ogden	Both Sites
COST	•	•	•
DOLP	•	•	•
ALT	•	•	•
PLT	•	•	•
RCT	•	•	•
BPT	•	•	•
RITT	•	•	•
STMT	•	•	•
SFT	•	•	•
TINT	•	•	•
COMPLETION TIME	•	•	•

Figure 16. (Continued)

system were only used for those elements where performance was improved. The total performance scores will first be reported and then the performance scores for each of the ten elements will be reported. Following the report of the performance scores, the results of the ANOVA tests for the subjects' completion time will be reported.

Overall Performance Scores

The eighteen ANOVAs which reflected some form of total score, see Figure 16, did not result in any significant three-way interaction of experience by difficulty by method. However, all eighteen ANOVAs did reflect a consistent significant two-way interaction of difficulty by method. Full results of the experience by difficulty by method ANOVAs, with the Sacramento and Ogden data combined, appear in Tables 38 through 53 in Appendix Q. Each of these tables includes the means, standard deviations, and cell sizes for each of the twelve cells of the analysis as presented in Figure 15. The full ANOVA tables are also presented.

Tables 38 through 43 of Appendix Q present the total performance scores, aggregating the scores first on all ten elements and then on only the eight elements which demonstrated an increase in performance. The results for all three weighting schemas are included. A review of Tables 38 through 43 reveals that the experience factor was not significant as a main effect and in only one of these ANOVAs was experience significant as an interaction.

Table 39 reflects a significant experience by method interaction. This interaction was significant at an alpha level of 0.05. The cell means in Table 39 appear to indicate that for the manual method of performance, journeymen perform better than both novices and advanced personnel. However, when the expert system is introduced, advanced personnel again appear to perform better than either journeymen or novices. Further, Table 39 seems to indicate little difference in performance between a novice and a journeyman when the expert system is used.

Difficulty by Method Interaction

The difficulty by method interaction will now be more closely examined. Tables 24 through 31, on the following pages, present the means for the difficulty by method table for Sacramento and Ogden, respectively, for the aggregate performance scores, which reflect the two-way interaction. The tables reveal the consistent result that use of the expert system improved performance on the complex case more than on the simple case.

Tables 24 and 25 portray the ANOVA cell mean results for the total performance score, with all of the ten individual elements weighted equally for Sacramento and Ogden, respectively. As seen in Table 24, even with production leadtime and reparable intransit time, which exhibited decreased performance, overall performance at Sacramento exhibited an increase of 7.66 points when cases were

Table 24
 Mean Total Score
 All Elements Weighted Equally
 Sacramento

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	87.72 (23)*	87.02 (21)	87.39 (44)
COMPLEX	66.25 (22)	82.84 (22)	74.55 (44)
BOTH CASES	77.22 (45)	84.88 (43)	80.97 (88)

* Parentheses indicate number of observations

Table 25

Mean Total Score
All Elements Weighted Equally
Ogden

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	91.33 (15)*	92.00 (15)	91.67 (30)
COMPLEX	69.50 (15)	80.33 (15)	74.92 (30)
BOTH CASES	80.42 (30)	86.17 (30)	83.29 (60)

* Parentheses indicate number of observations

Table 26
Mean Score
Without RITT and PLT
All Elements Weighted Equally
Sacramento

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	69.24 (23)*	72.86 (21)	70.97 (44)
COMPLEX	50.34 (22)	68.07 (22)	59.20 (44)
BOTH CASES	60.00 (45)	70.41 (43)	65.09 (88)

* Parentheses indicate number of observations

Table 27
Mean Score
Without RITT and PLT
All Elements Weighted Equally
Ogden

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	72.50 (15)*	76.17 (15)	74.33 (30)
COMPLEX	51.67 (15)	66.83 (15)	59.25 (30)
BOTH CASES	62.08 (30)	71.50 (30)	66.79 (60)

* Parentheses indicate number of observations

Table 28
Mean Score
Without RITT and PLT
Development Experts' Weighting
Sacramento

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	67.5 (23)*	68.4 (21)	67.9 (44)
COMPLEX	42.2 (22)	57.3 (22)	49.8 (44)
BOTH CASES	55.1 (45)	62.7 (43)	58.8 (88)

* Parentheses indicate number of observations

Table 29
 Mean Score
 Without RITT and PLT
 Development Experts' Weighting
 Ogden

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	69.5 (15)*	72.7 (15)	71.1 (30)
COMPLEX	39.0 (15)	54.2 (15)	46.6 (30)
BOTH CASES	54.2 (30)	63.4 (30)	58.8 (60)

* Parentheses indicate number of observations

Table 30
 Mean Score
 Without RITT and PLT
 Validation Panel's Weighting
 Sacramento

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	67.5 (23)*	68.2 (21)	67.8 (44)
COMPLEX	41.9 (22)	57.4 (22)	49.6 (44)
BOTH CASES	55.0 (45)	62.6 (43)	58.7 (88)

* Parentheses indicate number of observations

Table 31
Mean Score
Without RITT and PLT
Validation Panel's Weighting
Ogden

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	69.2 (15)*	72.6 (15)	70.9 (30)
COMPLEX	38.9 (15)	54.4 (15)	46.6 (30)
BOTH CASES	54.0 (30)	63.5 (30)	58.8 (60)

* Parentheses indicate number of observations

solved with the expert system. Table 25 also includes production leadtime and reparable intransit time in the overall analysis. Total performance at Ogden showed an increase in the performance score for both the simple and complex case. The increased performance was greater for the complex case than the simple case.

Tables 26 through 31 portray the ANOVA cell mean results for the total performance score less the scores for production leadtime and reparable intransit times. Cell means in Tables 26 through 31 reflect the performance score means out of a possible eighty points, rather than one hundred points, as two elements have been eliminated.

Tables 26 and 27 portray the ANOVA cell mean results for the total performance score less the scores for production leadtime and reparable intransit times, for Sacramento and Ogden, respectively. All eight elements are weighted equally. As shown in Table 26, use of the expert system at Sacramento resulted in an improvement of 3.62 points for the simple case and 17.73 points for the complex case. Table 27 shows that similar results were achieved at Ogden. Use of the expert system resulted in a 3.67 point improvement for the simple case and a 15.16 point improvement for the complex case.

Tables 28 and 29 portray the ANOVA cell mean results for the total performance score less the scores for production leadtime and reparable intransit times, for Sacramento and Ogden, respectively. The included elements are weighted in accordance with the

development experts' weighting schema. Performance on the complex case showed a 15.1 point improvement at Sacramento and a 15.2 point improvement at Ogden.

Tables 30 and 31 portray the ANOVA cell mean results for the total performance score less the scores for the production leadtime and reparable intransit time elements, for Sacramento and Ogden, respectively. The included elements are weighted in accordance with the validation panel's weighting schema. Performance on the complex case showed a 15.5 point improvement at both Sacramento and at Ogden.

The ANOVA results reported in Tables 24 through 31 were reviewed in reference to research hypothesis three. Research hypothesis three was expressed as null; that is, that the expert system solution method had no effect on the performance variable. The ANOVA results reported in Tables 24 through 31 demonstrate a statistically significant improvement when the expert system is used to solve the complex case. The null hypothesis is thus rejected in favor of the alternative hypothesis that use of an expert system has a significant effect on inventory management performance particularly for the more difficult cases. The method of aggregation did not affect the result. The effect of each of the individual element scores on the total performance score will now be examined.

Individual Element Scores

Tables 44 through 53 in Appendix Q present the full results for the ten individual element scores with the data for Sacramento and Ogden combined. Table 32 summarizes the results presented in ANOVA Tables 44 through 53. No significant three-way interactions of experience by difficulty by method were present for any of the individual elements. The method by difficulty interaction that was consistently present in the total performance scores, only exhibited a significant effect for administrative leadtime, shop flow time and turn in time. The effect of the use of the expert system for these three elements was a significant improvement in performance for the complex case.

A review of Table 32 also shows that there was a significant main effect of method for six other elements: cost, production leadtime, repair cycle time, base processing time, reparable intransit time, and supply to maintenance time. Of the six elements which exhibited a significant simple main effect of method, four demonstrated improved performance when the expert system was used. However, two elements, production leadtime and reparable intransit time, exhibited a significant decrease in performance when the expert system was used. Three elements exhibited a significant simple main effect of difficulty: cost, date of last procurement, and base processing time.

Table 32
 Significant Effects of Individual Elements
 Sacramento and Ogden Combined

<u>Individual Element</u>	<u>Method</u>	<u>Difficulty</u>	<u>Experience</u>	<u>MxD</u>	<u>ExM</u>
COST	**	**			
DOLP		**			
ALT				**	
PL1	- **				
RCT	**				
BPT	**	**			
RIT1	- **				
STMT	*		*		
SFT				*	*
TINT				*	*

- * Indicates that the Significance of $F < 0.05$
 ** Indicates that the Significance of $F < 0.01$
 - Indicates that the expert system degraded performance

Experience appears to be a weak blocking factor. Table 32 shows that there were only three significant effects of experience. Supply to maintenance time exhibited a significant simple main effect of experience. Shop flow time and turn in time both exhibited a significant experience by method interaction.

A review of Table 51 in Appendix Q shows the main effect of experience on supply to maintenance time. The journeyman's overall performance is better than the performance of both the novice and the advanced person.

Table 52 in Appendix Q portrays the experience by method interaction for shop flow time. Use of the expert system enabled novices to improve performance more than journeymen and advanced personnel. The performance of journeymen was the least improved with the use of the expert system. Novices exhibited better performance on shop flow time for both the simple and complex cases. Note that on the complex case, the novice's average performance was increased from 5.21 points to perfect performance of 10 points when the expert system was used.

Table 53 in Appendix Q portrays the experience by method interaction for turn in time. Again, use of the expert system resulted in the greatest increase in performance being attained by novices. Again, the performance of journeymen exhibited the least increase in performance when the expert system was used.

Table 33 portrays the cell means from the ANOVA results for each of the ten elements, with the data for Sacramento and Ogden combined. The table provides a comparative review of the results, indicating the expert system's ability to increase the inventory manager's performance on both simple and complex cases as well as the manager's overall performance on both cases. The decrement in performance for the elements of production leadtime, PLT, and reparable intransit time, RITT, for both the simple and complex case should be noted.

Completion Time

As there appeared to be a significant difference in the completion times of subjects at Sacramento and at Ogden on both the simple and the complex case, an additional ANOVA was run on the combined data which included location as a fourth blocking factor. The result revealed no significant four-way interaction of experience by difficulty by location by method. However, a significant three-way interaction of difficulty by location by method was present at an alpha level of 0.05. Because of the significant three-way interaction, the analysis of completion time is presented for Sacramento separately and Ogden separately. The results of the combined data are not presented.

Tables 54 and 55 in Appendix Q present the complete breakdowns and ANOVA tables for the analysis of completion time for Sacramento

Table 33

Table of Cell Means of Individual Element Scores
Sacramento and Ogden Combined

ELEMENT	SIMPLE CASE		COMPLEX CASE		OVERALL	
	MANUAL	IMA	MANUAL	IMA	MANUAL	IMA
COST	7.96	9.09	3.04	5.81	5.53	7.43*
DOLP	9.47	9.59	6.35	7.03	7.94	8.29
ALT	9.61	8.34	5.14	7.09	7.40	7.70**
PLT	9.41	7.92	9.05	7.84	9.23	7.87*
RCT	8.68	9.37	7.30	9.19	8.00	9.28*
BPT	7.96	9.37	5.47	8.58	6.74	8.97 ^{tr}
RITT	9.21	6.94	7.63	6.42	8.44	6.68*
STMT	9.01	9.44	8.72	10.00	8.87	9.73*
SFT	8.55	9.44	6.89	9.86	7.73	9.66**
TINT	9.28	9.58	7.97	10.00	8.64	9.80**

** Indicates significant difficulty by method interaction.

* Indicates significant main effect of method.

and Ogden, respectively. Table 54 shows that use of the expert system at Sacramento resulted in a significant two-way interaction of difficulty by method. Subjects who used the expert system at Sacramento to solve the simple case required more time than subjects who performed the case manually. However, subjects who used the expert system to solve the complex case required less time than subjects who performed the case manually.

Table 55 shows that at Ogden use of the expert system resulted in a significant simple main effect of method on completion time at an alpha level of 0.000+. The effect was an increase in the time required to solve both the simple and the complex case when the expert system was used.

Tables 34 and 35 portray the ANOVA cell mean results, for the two-by-two analysis of solution method by case difficulty, for time to completion at Sacramento and Ogden, respectively. As shown in Table 34, use of the expert system on a simple case at Sacramento resulted in solution times which were two minutes longer than the manual solution method. However, use of the expert system on a complex case at Sacramento resulted in a reduction in solution times of 9 minutes over the manual method. Overall solution times were reduced by 3.5 minutes at Sacramento when subjects were assisted by the expert system.

Table 35, however, portrays conflicting results from the Ogden sample. Use of the expert system on a simple case at Ogden resulted

Table 34
Mean Times to Complete
(In Minutes)
Sacramento

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	22.87 (23)*	24.71 (21)	23.75 (44)
COMPLEX	34.23 (22)	25.14 (22)	29.68 (44)
BOTH CASES	28.42 (45)	24.93 (43)	26.72 (88)

* Parentheses indicate number of observations

Table 35
Mean Times to Complete
(In Minutes)
Ogden

CASE DIFFICULTY	SOLUTION METHOD		
	MANUAL	EXPERT SYSTEM	BOTH METHODS
SIMPLE	12.93 (15)*	21.93 (15)	17.43 (30)
COMPLEX	16.07 (15)	23.93 (15)	20.00 (30)
BOTH CASES	14.50 (30)	22.93 (30)	18.72 (60)

* Parentheses indicate number of observations

in solution times which were nine minutes longer than the manual solution method. Use of the expert system on a complex case resulted in solution times which were eight minutes longer than the manual solution method. Overall solution times at Ogden were increased by 8.4 minutes when subjects were assisted by the expert system.

Research hypothesis four was also expressed as null; that is, that the expert system solution method had no effect on the time to completion or efficiency variable. The ANOVA results reported in Tables 54 and 55 include statistically significant effects of method. However, the direction of the effect is not clear. The null hypothesis can neither be accepted nor rejected on the basis of this test.

Other Findings

During the conduct of this research four other findings were discovered for which no formal hypotheses had been established in advance. The first three findings relate to the use of multiple experts during a knowledge engineering project. The fourth finding concerns user acceptance of an expert system.

First, when using multiple experts in a knowledge engineering project, a range of expertise, operationalized as years of experience performing the task, is helpful. The experience of the seven experts selected to assist with the development of IMA ranged

from two years¹ to more than twenty years. This fortuitous circumstance enabled the expert with only two years experience to, when necessary, remind the other experts that a trainee or novice might not understand the questions or advice as stated by these experts. Necessary clarifications to terminology resulted. Further, the expert with only two years experience recommended several help screen options.

The second unanticipated finding concerned the secondary benefits which accrue to an organization when multiple experts work as a group on a knowledge engineering project. Providing the experts with an opportunity to discuss how the job was actually performed, by the experts, revealed a number of deviations from standard operating procedures and company policy. Several policies were found to be antiquated and in need of review and revision. The knowledge engineering sessions allowed the organization's best experts to challenge the existing corporate policies and recommend improved operating practices and procedures.

The third finding was the result of another fortuitous circumstance. On the fourth day of the knowledge engineering sessions one of the seven experts was called away due to a family

¹The individual with only two years experience was a retired Chief Master Sergeant who had performed related work for over twenty years. However, this expert had only performed the task for which IMA was developed for two years.

emergency. This expert returned for the second week of the initial knowledge engineering sessions, having been absent for two days of sessions. Not having been a participant in the discussions which generated several new heuristics, the returning expert strongly challenged the logic of two of the new heuristics. The other experts readily agreed with the returning expert's criticism of the heuristics. One expert stated that the expert who originally proposed the erroneous heuristics had argued so strongly and presented the argument so well that agreement was the natural consequence.

As a result, the seven experts were cautioned to distinguish the soundness of the argument from the delivery. Management at Sacramento ALC was asked to permit the expert who had been ranked number one by the peer group, but who had been unable to participate in the entire project, to serve as an independent validation check of the knowledge base of the expert system. The validation panel of corporate experts was also designed into the methodology to provide an additional logic check.

The fourth finding concerns the importance of involving future users in the earliest design stages of an expert system development project. As was discussed in the research methodology section of this report, future users of the expert system at Sacramento recommended and selected the specific task for which the expert system was designed to provide assistance. Future users at Ogden,

however, were not involved in the project until the testing phase of the project. Although no formal analysis was performed to validate this finding, the critiques of the Sacramento test subjects who were assisted by IMA appear to be much more positive than the critiques of the Ogden test subjects. Further, several Ogden test subjects returned blank critique forms. Test subjects' critiques of the Inventory Manager Assistant (IMA) Expert System are contained in Appendix N.

Summary

Chapter IV has presented the results of this research project. As discussed, inventory managers who were assisted by the expert system achieved higher performance scores than inventory managers who performed the test manually. A 10 percent improvement in overall performance was demonstrated when subjects were assisted by IMA. On complex cases, 15 to 18 percent improvements resulted. Results concerning time to completion were inconclusive. A significant increase in efficiency was demonstrated at Sacramento with the use of the expert system to solve complex cases. However, at Ogden a significant reduction in efficiency resulted. Chapter V presents the conclusions drawn from these results.

CHAPTER V

SUMMARY AND CONCLUSIONS

This chapter provides an overview of the complete research project. The first section reiterates the objectives and methodology. The second section summarizes the research findings. The third section presents conclusions which can be drawn from the study and relates the research questions addressed in the study to the contributions made by the study. The final section proposes further research to validate and expand the present research effort.

Summary of the Research Effort

The artificial intelligence technology of expert systems has emerged from the research laboratory and demonstrated quite successful results in terms of better and more efficient decision-making. Practical business applications of expert systems have been in daily use since 1979. Today, many companies, including Digital Equipment Corporation, IBM, Westinghouse, and Campbell Soup Company, use expert systems to leverage rare in-house expertise and provide competitive advantage. Despite this record of success, expert systems have seen limited practical application in the logistics discipline. The applications are currently utilized primarily in the maintenance area.

The purpose of this research was to investigate the potential application of expert systems to the management of inventory. Inventory management was believed to offer a pervasive and potentially rewarding area in which to apply expert systems. Materials management and inventory problems are common to all business organizations: retailers, wholesalers, distributorships, and manufacturers. Further, inventory represents a substantial cost to an organization. The NCPDM study, Measuring and Improving Productivity in Physical Distribution 1984 reported that the estimated U.S. logistics expenditures for inventory carrying cost for 1982 were \$130 billion [NCPDM:19]. Therefore, even a small percentage improvement in the effectiveness of managing inventories could be transformed into huge savings.

Although inventory management has been primarily treated as a quantitative discipline, this research proposed that expert inventory managers, in fact, use a number of heuristic decision rules, which have been gained from years of experience. The primary objective of this research was to discover the expert decision heuristics for a limited inventory management task. A second objective was to incorporate these heuristics into an expert system and measure the performance level of this expert system, both in terms of the effectiveness and the efficiency of the decisions which resulted.

Four research hypotheses were investigated:

1. Expert inventory managers use task-specific knowledge and heuristics in decision-making.
2. This knowledge and these heuristics can be captured and programmed as an "expert system."
3. Inventory managers who are assisted by expert systems can make more effective decisions.
4. Use of expert systems will enable inventory managers to more efficiently solve complex problems.

The majority of the research was conducted at the Sacramento Air Logistics Center (ALC), a wholesale support activity of the United States Air Force. The Ogden Air Logistics Center served as an additional test site for the expert system which was developed. The Air Force is an excellent research setting due to the complexity and worldwide scale of the task environment.

The methodological approach to the study entailed a fourteen-step process, grouped into three general phases. Phase I, Problem Selection, required the researcher to gain a general understanding of the overall tasks and responsibilities of the inventory managers at Sacramento ALC. Workshops were conducted with all of the inventory managers to explain the expert systems technology and allow the inventory managers to nominate candidate problems for the development of an expert system. The inventory managers then selected the preferred problem from the nominated alternatives and also nominated and elected the experts from whom the knowledge for the expert system was later obtained. Protocol Analysis and the Delphi Technique were used.

Phase II, Knowledge Engineering, entailed deciding the actual scope and objectives of the expert system and encoding and validating the expert system. The Nominal Group Technique, combined with case analysis, was used. Seven experts worked as a group with the researcher to determine the decision heuristics and make necessary modifications to the resultant expert system. The expert system which was developed contained 441 rules and recommended advice to the user on ten separate elements. The development of the expert system provided tests of research hypotheses one and two.

During Phase III, Performance Measurement, standards of performance were determined and the expert system was tested to determine the effect of the expert system on decision effectiveness and efficiency. Effectiveness was operationalized as a performance score of between 0 and 100 obtained by each individual on the problem solved. The grading key was determined in advance of testing. Efficiency was operationalized as the time required to reach the problem solution. Tests were performed at both Sacramento and Ogden.

The experiment designed to measure efficiency and effectiveness was a between-subjects, two-by-two-by-three factorial design. The three treatments were: (1) task method with levels of (a) the expert system and (b) manually; (2) problem difficulty with levels of (a) a simple problem and (b) a complex problem; and (3) user experience with levels of (a) novice, (b) journeyman, and (c)

advanced. Figure 15 depicts the twelve cells of the experiment. The performance data collected were evaluated through analysis of variance techniques to gauge the effect of the expert system on decision effectiveness and efficiency. These analyses provided tests of research hypotheses three and four.

Univariate ANOVA procedures were performed on each of the ten scores for the elements on which the expert system provided advice, and on the total score of all ten elements combined. Analyses of the total scores were conducted with the ten elements weighted equally and with the ten elements weighted according to two different groups of experts' weighting schemas. Analyses of the total score less two of the elements for which performance was degraded by use of the expert system were also conducted according to the three weighting schemas. In addition, ANOVA procedures were performed on the time to completion. Separate analyses were performed for Sacramento, for Ogden, and for the combined data of both Sacramento and Ogden. Figure 16 depicts the procedures which were performed. The test subjects' self-reported confidence in using a computer to make decisions, and experience in interacting with a computer were treated as continuous variables and used as covariates in the analyses. The analysis was also performed without the covariates as the covariates did not explain any significant amount of variance.

Review of the Research Findings

The eighteen ANOVA procedures which reflected some form of total score, as per Figure 16, did not result in any significant three-way interaction of experience by difficulty by method. However, the results of all eighteen ANOVA procedures did reflect a significant two-way interaction of difficulty by method. Use of the expert system resulted in a greater improvement in performance on the complex case than on the simple case.

Surprisingly, experience was not significant as a main effect and in only one of the eighteen ANOVA procedures was experience significant as an experience by method interaction. Journeymen appeared to perform better than both novices and experts when the case was performed manually. However, experts appeared to perform better than both novices and journeymen when the case was performed with the expert system. Further, the performance differential between novices and journeymen seemed to be substantially reduced when the expert system was used.

The analyses of the individual elements showed that the expert system improved performance on all but two of the ten elements for which advice was provided. These two elements were deleted from further detailed analyses. The remaining effectiveness analyses, without these two elements, are summarized in Table 36. As shown, inventory managers who were assisted by the expert system exhibited significant performance improvements on the complex problem.

Overall performance was improved between 7.6 and 10.4 percent. On complex cases, performance improvements of 15.1 to 17.73 percent were demonstrated. These findings strongly support the hypothesis that expert systems can improve the performance or decision effectiveness of inventory managers.

Table 37 summarizes the results of the findings concerning the ability of expert systems to improve decision efficiency. As indicated, overall decision efficiency showed a significant improvement of 9.09 minutes on complex cases at Sacramento. However, at Ogden a significant decrease in efficiency resulted on both the complex and the simple problem. The findings were inconclusive. The hypothesis concerning the ability of expert systems to increase decision efficiency could neither be accepted nor rejected.

Conclusions and Logistics Implications

This study addressed four research questions and provided theoretical, methodological, and managerial contributions. The results of this study led to five conclusions concerning the potential of expert systems for inventory management tasks. The conclusions are presented as answers to the research questions. Each conclusion is discussed in terms of the contribution made.

Research Question 1: Do inventory managers use heuristic decision rules?

The researcher hypothesized that expert inventory managers use task-specific knowledge and heuristics in decision-making.

Interaction with the experts revealed that expert inventory managers do, in fact, develop heuristics which are used to make inventory management decisions. Thirteen of the heuristics discovered for forecasting future unit prices and administrative and production leadtimes from past contracts' information, that is, a purchasing history of the item, appear to be applicable to many businesses and types of items. These general heuristics are:

1. If the latest procurement of the item was any of the following, a more accurate estimate of a future price may be obtained by using an older contract which was a standard routine procurement:
 - contractor minimum cost,
 - contractor minimum quantity,
 - contractor excess,
 - surplus material,
 - price break,
 - quantity discount,
 - off-the-shelf, or
 - priority procurement.
2. If the unit price included one-time cost of tooling, or one-time special engineering test requirements, an appropriate adjustment to subtract the one-time costs should be made before using the cost of the item to determine future budgetary requirements.
3. If you have a number of standard routine procurements, the latest contract price should be used.
4. The date of the contract used to determine the cost for budgetary purposes should serve as the basis for inflating the contract unit cost to the forecasted unit price.
5. If the latest contract for the item was with a surplus source and the surplus source will continue to supply this item, this surplus price should be used.

6. If the only contracts available in the purchasing history are the initial contract buy of the item and a contractor excess price, the contractor excess price should be used.
7. If the only contracts available in the purchasing history are the initial contract and a priority procurement price, the initial contract purchase price of the item should be used.
8. Three percent should be added to all contractor unit prices, except an initial purchase contract price, to cover first destination and handling charges.
9. Administrative leadtime is the time from the initiation of a contract requirement by the inventory manager to the date the contract is actually awarded by the purchasing department.
10. Production leadtime is the elapsed time from the date of contract award to the date when at least ten percent of the total contract quantity has been routinely delivered.
11. Urgently awarded or priority procurements do not provide good estimates of future administrative and production leadtimes.
12. If you have a routine delivery on a priority procurement, you could use the date of the routine delivery to compute the estimated production leadtime.
13. If the latest procurement of the item represents a contract which was contractor excess, contractor off-the-shelf, or surplus material, the appropriate dates can be used to establish the administrative leadtime. However, the production leadtime must be determined from another routine contract or appropriate standard values must be used.

Conclusion 1: Expert inventory managers do possess task-specific knowledge and do apply decision heuristics in the performance of inventory management tasks. The requirements determination aspect of inventory management has been demonstrated to involve considerable knowledge that is subjective and partly judgmental.

Numerous other tasks in the area of inventory management were also nominated by the inventory managers at Sacramento ALC based upon the tasks' satisfaction of this criterion. These tasks require symbolic reasoning and cannot be solved by standard computational approaches alone.

Conclusion 1 and the more generic heuristics presented provide a theoretical contribution to the study of inventory management. Inventory management has been shown to be a qualitative as well as a quantitative discipline. Important decision variables for a part of an inventory management task have been elucidated. Some of the actual decision heuristics used have also been presented.

Research Question 2: Can the heuristic decision rules of inventory managers be programmed and captured as an expert system?

The researcher hypothesized that the knowledge and heuristics used by inventory managers could be captured and programmed as an expert system. Development of the Inventory Manager Assistant expert system demonstrated the validity of hypothesis two.

Conclusion 2: Expert systems can be developed to assist inventory managers with inventory tasks. An expert system containing 441 rules was developed to assist with a limited task. Because of the complexity of both the various types of items managed and the various possibilities of sources and users, expert systems for inventory management tasks will require large numbers of rules.

However, generic systems, systems applicable to different types of items, can be developed. The Inventory Manager Assistant (IMA) Expert system was a generic system capable of handling numerous types of items and was demonstrated to be applicable to inventory management at different locations.

The development of the Inventory Manager Assistant (IMA) expert system demonstrated that expert systems can be developed in six months or less at reasonably low cost when such systems are developed on microcomputers using existing AI software development tools. The development of expert systems does not necessarily require extensive development periods and high dollar outlays.

Further, user acceptance of the expert system was high. As can be seen from the test subjects' critiques of the expert system which are included in Appendix N, users found the expert system to be a beneficial system and noted the potential value of the expert system in a training role. Users appeared willing to accept and use the technology of expert systems.

Conclusion 2 and the managerial implications which derive from Conclusion 2 provide a managerial contribution. Expert systems have been demonstrated to be a feasible means of alleviating manpower shortages. The potential use of expert systems for training has also been demonstrated.

Research Question 3: Can expert systems for inventory management provide effective decisions?

The researcher hypothesized that expert systems could significantly improve the performance of inventory managers. An implicit assumption of hypothesis three is that expert systems must perform at least as well as, and preferably better than, the expert system's human counterpart in order for the expert system to be considered a success. The researcher made this assumption regarding expert systems for inventory management for two reasons. First, given the high costs of carrying inventory, inventory mismanagement can result in large negative financial impacts to an organization. The researcher would argue that an expert system which exists to replace inventory managers who are not present for work, regardless of the expert system's level of performance, is not necessarily a benefit to the organization. Expert systems for inventory management are not necessarily better than no management, especially if use of the expert system results in inventory mismanagement. However, logistics tasks may exist for which use of the expert system might be beneficial even if the expert system cannot attain a level of performance equivalent to the human counterpart.

The second reason the researcher assumed that expert systems must attain an equivalent or higher level of performance than the human counterpart on inventory management tasks concerns the cost of developing and maintaining the expert system. Since considerable cost may be incurred in developing and maintaining expert systems, the expert system should be capable of recapturing some of this

cost. Expert systems which result in inventory mismanagement would only add to the existing cost burden of maintaining the expert system.

Conclusion 3: Expert systems have the potential to degrade and disrupt logistics functions if not properly applied and supported.

The research findings revealed that inventory managers who were assisted by the expert system made poorer decisions on two elements for which the expert system provided advice. These elements were production leadtime and reparable intransit times. Poor performance in both of these elements is attributed to the improper manner in which questions were posed to the subjects by the expert system. In the case of production leadtime, the expert system asked very general questions which were difficult to answer. A much more detailed level of questioning should have been used for this element. For example, the expert system asked, "What was the date of this first significant delivery?" As first significant delivery is the first delivery which accumulates a delivered quantity of at least ten percent of the total contract quantity, the expert system should have perhaps asked for the details of the total contract quantities and deliveries and then drawn internal conclusions regarding first significant delivery. Further, much of this information could be accessed directly from internal data bases with no need to draw out the consultation by introducing the additional detail.

Regarding reparable intransit time, the expert system requested that the user respond yes or no to the question, "Is this item not-airlift coded?" The double negative confused many inventory managers. The corrections are easily made.

However, the implication is clear. Logistics managers must carefully field test expert systems before implementing them for day-to-day business operations. Further, expert systems for inventory management will require update to insure that the decision heuristics are appropriate for current economic conditions.

Conclusion 4: Productivity gains of up to 15 percent can be achieved through the use of expert systems for complex inventory management problems. Actual gains may, in fact, be much higher. The improved effectiveness demonstrated in this research resulted from the application of an expert system which was only at the research prototype stage of development. Certainly, before placing such a system in operational use, extensive field testing would have to be conducted and resultant enhancements made to the expert system.

Further, as was discussed in Chapter IV under the section entitled Other Findings, the participation of an organization's best experts in a knowledge engineering project frequently results in additional improvements to operating procedures as a result of the experts' recommendations.

Conclusions 3 and 4 also contribute to the managerial aspects of inventory management. Use of an expert system to better manage inventory has been demonstrated. A 10 percent productivity gain in inventory management could be equated to annual savings for inventory carrying costs of \$9 to \$13 billion per year for the United States alone according to the National Council of Physical Distribution Management (NCPDM) study, Measuring and Improving Productivity in Physical Distribution 1984 [NCPDM:19]. IMA has demonstrated productivity gains of up to 15 percent on a complex task. In a single pretest a \$600,000 error was found in one item by using the expert system.

Research Question 4: Can expert systems for inventory management suggest solutions as quickly as human experts?

The researcher hypothesized that the use of an expert system would allow inventory managers to solve complex or difficult problems more efficiently. However, the researcher implicitly related efficiency to effectiveness in terms of successful performance of the expert system. An expert system which suggested solutions more quickly than the human counterpart would not be considered to perform successfully if the solutions resulted in inventory mismanagement or less effective management than were achievable by the inventory manager alone. The reverse situation, expert systems which required longer solution times but resulted in improved management decisions, might be considered to be

successful. The differential in solution times would have to be considered.

Conclusion 5: The use of expert systems will enable inventory managers to more efficiently solve complex problems. Although the findings did not conclusively support this assertion, several factors must be taken into consideration. Subjects tested were allowed to perform only one practice consultation with the expert system. This consultation was different from the test case the subject was required to solve. Therefore, some of the questions presented to the subject by the expert system during the test case were seen by the subject for the very first time. As with any new system, time is required to gain familiarity and speed in using the system. A single practice case was probably not sufficient to draw conclusions on this hypothesis from the ANOVA procedures alone. During the validation sessions with the experts, time benchmarks were taken. During these validation sessions, the experts were completing consultations in ten to fifteen minutes. At the time these benchmarks were taken, the experts had been through more than fifty interactive consultations with the expert system. These statistics can be compared with manual solution times of 23 and 34 minutes for a simple and complex case, respectively, at Sacramento, 22 and 24 minute solution times for a simple and complex case, respectively, at Ogden. Further, run time efficiencies had not yet been designed into the expert system.

Conclusion 5 also provided a managerial contribution. Efficiency improvements attainable with the use of the expert system can further increase overall productivity gains. The potential for efficiency improvements was demonstrated.

Conclusions and Implications for Future Knowledge Engineering Projects

The conduct of this research led to six additional conclusions concerning the conduct of future knowledge engineering projects in any discipline:

Conclusion 6: Multiple experts should be used to discover the heuristics for complex tasks. Complex task situations are those where the same task is performed by large numbers of individuals in numerous locations and each case may be slightly different. In such areas, even the best experts probably have limited experience dealing with particular or special cases. A number of experts are required to insure the variability in the decision-making stimuli is accounted for. A single expert will likely suffice for tasks which are much more repetitive and have fewer possible dimensions in a decision-making scenario.

Conclusion 7: Evaluations of an expert system's performance must be based on the user's ability to obtain correct answers, not on the degree to which the expert system simulates the experts' conclusions. The Inventory Manager Assistant (IMA) Expert System provides an excellent example. IMA perfectly imitated the conclusions reached by the experts on both the simple and the complex test case. However, test subjects did not achieve consistent scores of 100. Mean test scores ranged from 80 to 92 on the complex and simple case, respectively. Individuals both fail to read the questions correctly and to properly answer the questions asked. As long as the human remains in the decision process, the possibility of error introduction remains high, no matter how sound the logic of the expert system. The implication for expert system developers is to insure that when questions are occasionally improperly answered, the impact is not worse performance than would have been achieved before the introduction of the expert system. As much work needs to be done improving the human-machine interface as needs to be done validating the expert system's internal logic.

Conclusion 8: The development of a first prototype expert system early in the knowledge acquisition process speeds the knowledge acquisition process.

The first two weeks of knowledge engineering sessions were spent working with the experts to develop a 55-rule prototype expert

system. After two additional weeks growing and validating the expert system, the present 441-rule system evolved. Early introduction of an expert system and actual use of the expert system in the knowledge acquisition process is a highly efficient approach to knowledge engineering.

Conclusion 9: Future users should play a key role in selecting the application for which the expert system is to be developed. The critiques of IMA provide strong evidence that users who are brought in early in an expert system development project will positively support the implementation of the expert system.

Conclusion 10: The Nominal Group Technique provides an effective means of establishing consensus among multiple experts and extracting the intermediate steps and assumptions of the experts. Frequently, when the experts disagreed during the knowledge engineering sessions, the cause was the different goal structures which the experts were using or the different assumptions that the experts had made about the decision situation. The Nominal Group Technique served to surface these underlying sources of disagreement. As a result, at times, numerous rules would be established to replace the single rule over which the experts had originally disagreed.

Conclusion 11: The knowledge base of the expert system should be validated by an independent expert or experts, especially when multiple experts are used as a group to derive the knowledge base.

Group discussions can result in group think. The experts may then draw conclusions which none of the experts would have made or agreed to as individuals. Further, one of the potential problems of using the Nominal Group Technique as a method to drive consensus is that an expert who is more vocal or better able to argue for or against a position may influence the other experts to accept improper heuristics. However, this potential problem is outweighed by the efficient and effective acquisition of knowledge resulting from the synergism of the group discussions. An independent validation by an additional expert or experts helps insure that the correct heuristics are obtained.

Conclusions 6 through 11 provide a methodological contribution for the future development of expert systems. The use of multiple experts as a group, use of the Nominal Group Technique to achieve consensus, and use of the Delphi Technique for task and expert selection have all been demonstrated. In addition, a fourteen step approach to the development and testing of expert systems which incorporates many of the lessons learned from past developmental efforts has been provided.

Suggestions for Future Research

This research has only begun to explore the potential contribution of the expert systems technology to improved inventory management. The conduct of this research has suggested five additional investigations which would validate and extend the present study.

First, the result of a possible 15 percent improvement in the performance effectiveness of inventory managers on complex problems should be substantiated either through the development of other similar expert systems, an improved and expanded version of IMA, or through further testing of the existing expert system. If the existing expert system is retested, corrections should first be made to the knowledge base for the two elements on which the expert system is known to provide erroneous results. Subjects tested with the expert system should be provided numerous pretest consultation interactions with the expert system. The expert system could be used by the test group on a daily basis for six months. The same performance and time to completion measures could then be made both on the test subjects and on a control group who had not used the expert system previously. The control group would constitute the manual subjects for the experiment.

A second investigation, closely related to the first investigation proposed for further study, would address the differential in performance between the design experts who achieve a

score of 100 points with the expert system and other users who achieve much lower scores. The specific research question to be asked would be: Can this performance gap between the experts who developed the system and individuals who use the system be closed with practice?

During the pretests of the expert system a performance measure was taken for each expert on both the simple and complex cases. Each expert scored 100 points on both cases. However, a confounding of the development experts' expertise and practice with the system exists. By the time the pretest measure was taken, each of the experts had been through more than fifty consultations with the expert system.

A researcher might hypothesize that with enough practice any user could score 100 points or as a minimum that a user's score would increase significantly with practice. A test group who would use the expert system might be established at a location and performance measures taken and compared at three month intervals for a year.

A third important investigation relates to the variability in performance of individuals who use the expert system. A visual inspection of the tables presented in Appendix Q suggests that the within cell variances are reduced when the expert system is used. In addition to improving performance on certain inventory tasks, use of the expert system may also reduce variability in performance. This hypothesis should be tested.

A fourth possible investigation would further examine the one significant interaction between experience and method found in the present study. Table 39 in Appendix Q depicts this interaction. The resultant relationship was not what might have been anticipated. The researcher assumed that novices would benefit most from the use of expert systems, followed in turn by journeymen and then more advanced inventory managers. However, Table 39 shows that journeymen did not appear to benefit as much as did novices and advanced inventory managers. Speculation for further research suggests that an expert system may help an advanced user more in discouraging the advanced user from being casual. An expert system may help a novice more as the novice lacks the procedural knowledge which the expert system provides.

A fifth important investigation would address the researcher's assumption that an expert system for inventory management must be as good as, or better than, the human counterpart for the expert system to be considered a success. The issue of what constitutes successful performance for an expert system needs to be resolved. The possibility exists that different tasks may have much different tolerances for performance. Accordingly, successful performance of the expert system would be defined according to the task performed.

The tradeoff between effective performance for an expert system and efficient performance also needs to be addressed. Again, the possibility would appear likely that different tasks have different

tradeoff tolerances. Tolerance levels for the performance of an expert system need to be defined.

Four other areas where further research might be conducted are also presented. Further research in these areas are not as closely related to the present research effort.

First, since inventory management requires both symbolic manipulation and computational logic, a more appropriate application of the expert systems technology to inventory management than stand-alone expert systems might be to embed the knowledge base of the expert system in an existing inventory decision support system or modeling tool. Such systems should be developed and tested to determine the resultant increase in effectiveness and efficiency.

Second, this research effort has examined only one small task which an inventory manager performs. Expert systems remain to be developed and tested for other aspects of the inventory management function. Among such systems might be an expert distribution system. Such a system would use expert decision heuristics to determine, for example, how to distribute scarce resources among competing requirements. A distribution expert system could base decisions on criteria other than the priority of the demand and the age of the requisition. For example, information on retailers past sales records and ability to use the asset to improve customer service standards could be considered. An expert system might also be developed to advise inventory managers on how to redistribute or

make disposition decisions regarding excesses. Numerous alternatives exist in the inventory management area alone. A host of other opportunities awaits in the purchasing, warehousing, and transportation arenas.

Third, the area of the performance measurement of expert systems remains a fertile ground for research. Within subjects designs should be developed and tested. Subjects should be queried when the decision logic of the expert system disagrees with the subject's decision logic as to whether or not the subject is willing to change to concur with the expert system's advice. Such experiments would provide valuable insight into the ability of expert systems to influence human decision-making and the willingness of subjects to use expert systems if the advice or solutions disagree with the subject's.

Finally, much research remains to be done concerning the maintenance and support of expert systems in daily business use. The proper timeframes for review and update of the decision heuristics is an important question. No doubt the decision heuristics of inventory management expert systems will need to be carefully reviewed and possibly revised as economic conditions and the relative costs of inventory and transportation change. One of the advantages of the use of expert systems will be the modular construction of the knowledge base which permits the expert system to be easily modified or expanded.

Artificial intelligence systems will play a prominent role in the logistics systems of the 1990's. Much academic research remains to be done to support the future business applications. This research has demonstrated the potential of the application of the expert systems technology to enhance logistics operations and management.

APPENDIX A
PRERAU'S SELECTION CRITERIA FOR
AN APPROPRIATE DOMAIN
FOR AN EXPERT SYSTEM

PRERAU'S SELECTION CRITERIA FOR AN APPROPRIATE DOMAIN FOR AN EXPERT SYSTEM

BASIC REQUIREMENTS

- The domain is characterized by the use of expert knowledge, judgment, and experience. The goal of the project is to extract a portion of an expert's knowledge, judgment and experience, and put it in a program.

- Conventional programming (algorithmic) approaches to the task are not satisfactory. If a conventional approach will work well, there is usually less technical risk to using it rather than an expert system approach. Note, however, that expert system methodology may offer some additional advantages over conventional techniques, such as the expected ease of updating and maintaining a knowledge base and the ability to explain results.

- There are recognized experts that solve the problem today. If an area is too new or too quickly changing, there may be no real experts. However, these are often the areas that are suggested for expert system developments.

- The experts are probably better than amateurs in performing the task. Thus, the task does require expertise.

- Expertise is not or will not be available on a reliable and continuing basis, i.e., there is a need to "capture" the expertise. Thus, there is a need for the expert system. For example: (1) expertise is scarce, (2) expertise is expensive, (3) there is a strong dependence on overworked experts, and/or (4) expertise is available today, but will be unavailable, or less available, in the future.

- The completed system is expected to have a significant payoff for the corporation.

- Among possible application domains, the domain selected is that one that best meets overall project goals regarding project payoff versus risk of failure. For example, a conservative approach would be to attempt to develop a system that would meet some criterion for minimum payoff if successful, and that seems to offer the best chance of success.

TYPE OF PROBLEM

- The task primarily requires symbolic reasoning. For a task that primarily involves numerical computation, consideration should also be given to other programming approaches.

- The task requires the use of heuristics, e.g., rules of thumb, strategies, etc. It may require consideration of an extremely large number of possibilities or it may require decisions to be based upon incomplete or uncertain information. A strength of expert systems is their ability to handle heuristics. Problems with very large numbers of possibilities or with incomplete or uncertain information are difficult to attack by conventional approaches, but may be amenable to expert system methodologies.

- The system development has as its goal either to develop a system for actual use or to make major advances in the state of the art of expert system technology, but does not attempt to achieve both of these goals simultaneously. Doing both simultaneously is laudable, but more difficult.

- The task is defined very clearly: At the project outset, there should be a precise definition of the inputs and outputs of the system to be developed. This is a good attribute of any task. However, it is not necessary that the task definition be fixed for all time. As the system evolves and task situations change, it should be possible to change the task definition accordingly.

THE EXPERT

- There exists an expert to work with the project. This is the source of expertise.

- The expert's knowledge and reputation must be such that if the expert system is able to capture a portion of the expert's expertise, the system's output will have credibility and authority. Otherwise, the system may not be used. (This may not be necessary in a domain where an accepted test for "goodness" of result exists.)

- The expert has built up expertise over a long period of task performance. Thus, the expert has had the amount of experience necessary to be able to develop the insights into the area that result in heuristics.

- The expert will commit a substantial amount of time to the development of the system. This is often a problem. The best experts, in the most important corporate areas, are usually the ones that can be least spared from their usual position.

- The expert is capable of communicating his knowledge, judgment, and experience, and the methods used to apply them to the particular task. It is important to find an expert that has not only the expertise, but also the ability to impart it to the project team, whose members probably know little or nothing about the subject area. The expert should be able to introspect to analyze his reasoning process, and then should be able to describe the reasoning process clearly to the project team, and to discuss it with them.

- The expert is cooperative. The expert should be eager to work on the project or, at worst, nonantagonistic.

- The expert should be easy to work with. The project team and the expert will be spending a lot of time together.

- The expertise for the system, at least that pertaining to one particular sub-domain, is to be obtained primarily from one expert. This avoids the problem of dealing with multiple experts whose conclusions or problem-solving techniques do not agree. However, there may be some advantages to using multiple experts--e.g., strength of authority and breadth of expertise in sub-domains.

- If multiple experts contribute in a particular sub-domain, one of them should be the primary expert with final authority. This allows all the expertise to be filtered through a single person's reasoning process. (Note that some techniques have been developed, in disciplines such as economic modeling and technological forecasting, to allow combining inputs from multiple experts.)

PROBLEM BOUNDS

- The task is neither too easy (taking a human expert less than a few minutes) nor too difficult (requiring more than a few hours for an expert). If the task is too easy, the development of the system may not warrant the effort; if too difficult, the amount of knowledge needed may be beyond the state of the art in knowledge base size.

- The amount of knowledge required by the task is large enough to make the knowledge base developed interesting. If it is too small, the task may be more amenable to another approach--e.g., a decision tree.

- The task is sufficiently narrow and self-contained: the aim is not for a system that is expert in an entire domain, but for a system that is an expert in a limited task within the domain. This more tightly bounds the task, which should help keep the size of the knowledge base bounded.

- The number of important concepts (e.g., rules) required is bounded to several hundreds. This is a reasonable size for an expert system, though the number can go into the thousands.

DOMAIN AREA PERSONNEL

- Personnel in the domain area are realistic, understanding the potential of an expert system for their domain, but also realizing that thus far few expert systems have resulted in actual production programs with major industrial payoff. The system recipients should not be overly pessimistic. The project team may have to educate them to understand what are reasonable expectations.

- Domain area personnel understand that even a successful system will likely be limited in scope and, like a human expert, may not produce optimal or correct results 100% of the time. The expert system will probably be no better than a limited version of the expert--this must be enough.

- There is strong managerial support from the domain area, especially regarding the large commitment of time by the expert(s), and their possible travel or temporary relocation, if required. This should all be agreed upon up front.

- The specific task within the domain is jointly agreed upon by the system developers and the domain area personnel. This helps ensure that the system, if successful, will be useful and will be used.

- Managers in the domain area have previously identified the need to solve the problem which the system attacks. This is strong evidence that the system is needed and makes managerial support more likely.

- The project is strongly supported by a senior manager, for protection and follow-up.

- Potential users would welcome the completed system. If not, will the system ever be used? The project team should consider how to make the system unthreatening to the users and welcomed by them.

- The system can be introduced with minimal disturbance of the current practice. This will make the users' acceptance of the system more likely.

- The user group is cooperative and patient.

- The introduction of the system will not be politically sensitive or controversial. If not, the potential resulting problems should be considered in advance. One typical problem: The control or use of the system goes across existing organizational boundaries.

- The knowledge contained by the system will not be politically sensitive or controversial. For example, there may be certain practices, embodied in heuristics, which may prove embarrassing if written down, such as how certain customers are treated relative to other customers.

- The system's results will not be politically sensitive or controversial. If there will be corporate parties who will challenge the system if its results do not favor them politically (e.g., on appropriation of funds), then it will be much harder to gain system acceptance.

OTHER DESIRABLE FEATURES

- The system can be phased into use gracefully: Some percentage of incomplete coverage can be tolerated (at least initially), and the determination of whether a sub-problem is covered by the present system is not difficult. If the system does not have to do everything in order to do something, it can be put in place much sooner. The more difficult problems can be solved later, if at all.

- The task is decomposable, allowing relatively rapid prototyping for a closed small subset of the complete task; and then slow expansion to the complete task. This makes development much easier.

- The task is not all-or-nothing: Some percentage of incorrect or nonoptimal results can be tolerated. The more toleration for incorrect results, the faster the system can be deployed and the easier it will be to win system acceptance. For example, in a domain where even the best experts are often wrong, system users will not be as upset by an incorrect result from the system.

- The skill required by the task is taught to novices. Thus, the task is not "unteachable," and there is some experience with teaching the domain knowledge to neophytes, such as the project team (and, ultimately, the system). Furthermore, this usually means that there is an organization to the knowledge that can prove useful (at least initially) in building the system.

- There are books or other written materials discussing the domain. If this is true, then an expert has already extracted and organized some of the domain expertise. As in the previous point, this organized knowledge might prove useful (at least initially) in building the system. Note, however, that one benefit of capturing an expert's domain knowledge might be to make a step toward formalizing a domain that has not been treated in a formal manner before.
- The task's payoff is measurable. If not, it is harder to demonstrate success to skeptics.
- Experts would agree on whether the system's results are good (correct). If not, the system's results are open to challenge, even if the system accurately embodies the expert's knowledge.
- Test cases are available. This makes development much easier.
- The need for the task is projected to continue for several years. The need must exist enough beyond the period of system development to generate the payoff.
- The domain is fairly stable. Expected changes are such that they utilize the strengths of expert systems (e.g., ease of updating or revising specific rules in a knowledge base, but will not require major changes in reasoning processes). An unstable domain may yield a situation where a large number of previously developed knowledge structures (e.g., rules) are no longer valid but cannot easily be changed without redoing the entire development process.
- The effects of corporate developments that will significantly change the definition of the task can be foreseen and taken into account.
- No alternative solution to the problem is being pursued or is expected to be pursued. However, if a project goal is to compare expert system technology to other technologies this may be just what is desired.
- The project is not on the critical path for any other development, and has no absolute milestones for completion. The use of expert system technology for real corporate applications is still relatively new, and so any development has some risk. Thus, the less dependent other activities are, the better.
- At the outset of the project, the expert is able to specify many of the important concepts. This gives good promise of project success.

- The task is similar to that of a successful existing expert system. This also makes success more likely.

- Any requirement for real-time response will not involve extensive effort. Though it is certainly possible to develop a system for a problem with a real-time requirement, the considerations involved divert effort from the primary task knowledge acquisition.

- The user interface will not require extensive effort. As with a real-time requirement, if the work required is excessive, it could divert effort from knowledge acquisition.

Source: David S. Prerau, "Selection of an Appropriate Domain for an Expert System," The AI Magazine, Summer, 1985, pp. 27-30.

APPENDIX B
CORRESPONDENCE CONCERNING
TELEPHONE INTERVIEWS



The Ohio State University

Academic Faculty of Marketing

1775 College Road
Columbus, Ohio 43210-1399
Phone 614-422-8808

11 December 1985

Mr. Eddie Young
Sacramento ALC/MICD
McClellan AFB, California 95652-5990

Dear Mr. Young:

You have been identified as one of three individuals at Sacramento ALC who is highly knowledgeable about the item manager's role and task environment. Your assistance is, therefore, requested as part of a research effort underway at Sacramento Air Logistics Center to develop an expert system to aid item managers.

An important preliminary step in this research requires that I gain a better understanding of the tasks which item managers perform. To accomplish this objective, I am asking that you participate in a telephone interview. The nine questions that you will be asked during this interview are included as Attachment 1 to this letter. I ask that you review these questions and think about them. I will call you during the next day or two to insure that you have received this letter, clarify any questions that you may have, and schedule the actual interview for a time, about one week from your receipt of this letter, which is most convenient for you.

With your permission, I would like to record the actual telephone interview. Following this phone conversation, I will type the transcribed interview and mail to you a copy of your interview session and that of the other two interviewees. Similarly, the other two interviewees will receive your answers. Anonymity can be maintained, if you would prefer. Based on your review of all three responses, I would like you to make any modifications, additions, or deletions to your answers and return your replies to me. Hopefully, all of this can be concluded by 31 December 1985.

Your participation is vitally important! Few individuals have the wealth of knowledge which you possess concerning item management. The information obtained from this activity will be used not only in this project but throughout the command and by Air Staff in shaping the future role of item managers. Further, the responses will be published as part of this dissertation. I thank you in advance for your invaluable contribution to this ground-breaking research.

Most sincerely,

MARY K. ALLEN, Capt., USAF
Expert System Project Officer

1/Atch List of Questions

ATTACHMENT 1

Interview Questions

1. What are the generic subtasks which item managers perform? For example, item managers assign exception codes, issue purchase requests, etc. Generic here refers to a task which all item managers perform.
2. Which of these tasks require expertise on the part of the item manager?
3. What is the nature of this expertise - e.g., in depth knowledge of regulations, skill in situation assessment, etc.?
4. What are the characteristics of a good item manager?

5. List ten problems or more, which item managers frequently solve or provide advice on, be specific.
6. Prioritize these problems in terms of frequency of occurrence, with number one assigned to the problem which occurs most frequently.
7. Prioritize these problems in terms of importance to successful accomplishment of the item manager's task, again with number one representing the most important problem.
8. Talk through a flowchart of the item manager's tasks. That is, what is the temporal relationship of these tasks?

9. What are the exceptions to the normal process? That is, when would an item manager deviate from the normal process, discussed in your answer to question eight, and what is the nature of this deviation?



The Ohio State University

Academic Faculty of Marketing

1775 College Road
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Phone 614-422-8808

January 7, 1986

Ms. Suzi Morrison
SM-ALC/MW11068
McClellan AFB, California 95652-5990

Dear Ms. Morrison:

Attached to this letter you will find a copy of your typewritten protocol from the telephone interview you participated in regarding the item manager's task environment. Also attached are copies of the responses from the other two interviewees. I request that you carefully review all three of these protocols.

Please make any desired additions or modifications to only your own protocol and return it to me on or before Tuesday, January 14, 1986. I will be on-site at Sacramento ALC during this period. Therefore, I ask that you return your response directly to me. Please do not mail it.

Once again, I thank you for your invaluable contribution to this research effort. Your responses have provided significant insight.

Sincerely,

MARY K. ALLEN, Capt. USAF
Expert System Project Officer

Attch: Copies of Protocols

APPENDIX C

LESSON PLAN FOR THE EXPERT SYSTEM ORIENTATION

LESSON PLAN FOR THE EXPERT SYSTEM ORIENTATION

Block 1: Overview of Expert systems
duration - 45 minutes

Objectives: The teaching objectives of Block 1 were:

1. Explain what an expert system is.
2. Discuss the advantages of expert systems.
3. Discuss the generic tasks for which expert systems are used, e.g., planning, diagnosis, design, control.
4. Discuss actual examples of expert systems, e.g., R1 and MYCIN. Show sample questions presented to the users and sample responses provided by the expert system.
5. Discuss the steps in the development of an expert system and the evolutionary stages of an expert system from demonstration prototype to commercial system.

These objectives were pursued in this order.

Break: 15 minutes

Block 2: Criteria for Determining the Applicability of Good

Problems.
duration - 45 minutes

Objectives: The teaching objectives of Block 2 were:

1. Provide an understanding of basic requirements which expert systems must meet, e.g., a solution exists, there is a need to capture the expertise, etc.
2. Provide an understanding of the type of problem which expert systems can be designed to solve, e.g., the task requires the use of heuristics, the task does not require perception, etc.

3. Provide an understanding of the appropriate scope for an expert system, e.g., the task is sufficiently narrow and self-contained, the task would not take a human expert more than a few hours to solve, etc.
4. Provide an understanding of other features which make expert system development more desirable, e.g., the skill required by the task is taught to novices, there are written materials on the subject, and test cases are available.

A handout listing the criteria in each of these four areas: basic requirements, type of problem, appropriate scope, and other desirable features was provided to each of the orientation workshop attendees. This handout was available for the attendees to refer to during Block 3. The handout used is contained in Appendix D.

Break: 15 minutes

Block 3: Brainstorming Session
duration - 60 minutes

Objectives: The objectives of Block 3 were:

1. Have the inventory managers suggest candidate problems.
2. Discuss with the inventory managers how each candidate problem meets the criteria explained during Block 2.

APPENDIX D
CRITERIA HANDOUT PROVIDED
DURING THE EXPERT SYSTEM ORIENTATION

CRITERIA HANDOUT PROVIDED
DURING THE EXPERT SYSTEM ORIENTATION

CRITERIA FOR DETERMINING GOOD CANDIDATE APPLICATIONS

BASIC REQUIREMENTS

1. A solution to the problem or task exists.
2. There are recognized experts who perform the task or solve the problem.
3. There is a need to capture this expertise. The expertise may not be available on a continuing basis.
4. Pockets of knowledge or knowledge bottlenecks regarding the task exist.
5. The task or problem solution requires the use of expert knowledge, judgment, and experience.
6. Substantial variability exists in people's ability to perform the task. Novices gain competence with experience. Experts are better than amateurs at performing the task.
7. A successful expert system capable of performing this task is expected to have a significant payoff for the Air Force.

TYPE OF PROBLEM

1. The task or problem passes the telephone test. That is, a competent performer could over the telephone, help the intended user by posing questions to the user and offering advice.
2. The task is clearly understood by the experts.
3. The task requires the use of heuristics, e.g., rules of thumb, strategies, etc. It may require decisions to be based on incomplete or uncertain information.

4. The task primarily requires symbolic reasoning versus numerical computation.
5. The task does not require perception or common sense.
6. The task requires large amount of distinguishing or signal data to be interpreted.
7. The task is performed on a frequent and repetitive basis.

PROBLEM SCOPE

1. The task is sufficiently narrow and well bounded. It represents a narrow area of specialization.
2. The task is neither too easy (taking a human expert less than a few minutes) nor too difficult (requiring more than a few hours for an expert to perform).
3. The task is reasonably self-contained. it can be separated from the other problems of the experts.
4. The task is of manageable size.
5. The number of important concepts (e.g., rules) required is bounded to a few hundred.

OTHER DESIRABLE FEATURES

1. Potential users would welcome and use the completed system to perform this task.
2. The need for the task is projected to continue for several years.
3. Expertise on the task is needed in many locations. For example, this same task is performed at several locations.
4. Inadequate human resources capable of performing this task are available.
5. At the outset of the project, the experts will be able to specify many of the important concepts. That is, the experts can articulate their methods.

6. Experts can agree on what constitutes a good or correct solution to the problem.
7. Some percentage of incorrect or nonoptimal results can be tolerated. The problem requires a satisfactory versus an optimal solution.
8. The task is decomposable. A system which performs a closed small subset of the complete task could be developed and then slowly expanded to the complete task.
9. The skill required by the task is taught to novices.
10. There are books or other written materials discussing the domain.
11. Test cases are available.

APPENDIX E
EXPERT SYSTEM TASK SELECTION
QUESTIONNAIRES

EXPERT SYSTEM
TASK SELECTION
PHASE ONE

1. Check one category. My age is:

_____ under 20
_____ 20 - 29
_____ 30 - 39
_____ 40 - 49
_____ 50 - 59
_____ 60 or over

2. I have had the following number of years experience as an item manager. (Include time as a D039, D062, and D041 IM):

_____ less than 2 years
_____ 2 - 5 years
_____ 5 - 10 years
_____ 10 - 15 years
_____ 15 - 20 years
_____ more than 20 years

Note: The 26 candidate applications recommended by all the item managers in the Expert System Workshop are listed below. Please THINK about these applications CAREFULLY. You may have to live with the system you choose. Choose the applications which would help you the most to do a better job and which you would most prefer to use.

3. Place a check by five of the following applications which you most prefer. Do not rank order them at this time. The attachment to this questionnaire provides a brief description of each project to assist you.

- _____ 1. Excesses
- _____ 2. Allocation Decisions
- _____ 3. Item Analysis
- _____ 4. Controlled Exceptions
- _____ 5. Backorder Listing
- _____ 6. Repair Requirements
- _____ 7. Cataloging Actions
- _____ 8. MICAP Support
- _____ 9. Computer Products Training
- _____ 10. Initial Provisioning
- _____ 11. PRs
- _____ 12. FMS Support
- _____ 13. S06's (Budget)
- _____ 14. Critical Item Advisor
- _____ 15. Project Focus
- _____ 16. Shipment Advisor
- _____ 17. Asset Reconciliation
- _____ 18. Fill Rate Advisor
- _____ 19. Scrubbing the D041 Computation
- _____ 20. General Training System
- _____ 21. D041 File Maintenance
- _____ 22. Special Levels Advisor
- _____ 23. Amended Shipping Instructions Advisor
- _____ 24. PJJ/414 Advisor
- _____ 25. D032/J041 Reconciliation
- _____ 26. Other Service Support

4. Look at the five applications you have selected in your answer to question #3. Now rank order these from one to five, with number one representing the most preferred alternative.

1. -----
2. -----
3. -----
4. -----
5. -----

Thank you very much for your time and assistance.

PROJECT DESCRIPTION

1. Excesses - instructions on working excesses. How to make a determination as to whether to retain or dispose of an item. Decisions on credit, whether to RDO and where, etc.
2. Allocation Decisions - Such a system would make decisions regarding the shipment of a limited quantity of serviceable assets to satisfy MICAP and other priority requisitions, e.g., prioritizing asset shipments to which activity, quantity to be shipped to each activity and in total based on depot and worldwide asset availability, assets due from TRC within 30 - 60 days, number of and age of Priority 01, 02, 03 requisitions, etc.
3. Item Analysis - A general guide to item analysis. Such a system would answer questions such as what are the problems with the item and what to do about them. The objective of such a system would be to allow IM's to avert problems before they occur.
4. Controlled Exceptions - A system to explain what caused the exception code to be generated and what actions are necessary to clear the exception and permit the transaction to process.
5. Backorder Listing - A system to explain how to work the backorder listing. Such a system would determine how requirements can be filled, e.g., what actions can be taken to expedite, what other actions to take to support the item, how to determine if the backorder is legitimate, etc.
6. Repair Requirements - A system providing step by step instructions on how to work the X-21's, e.g., how do you determine what projected usage will be by past experience, how to forecast repair requirements, etc. A system to help determine whether to repair or not repair, should repair be contract or organic, should more or fewer assets be driven to repair. The system would also provide recommendations on what additional actions need to be taken.
7. Cataloging Actions - A checklist to explain procedures on cataloging actions e.g., how to complete the automated Form 86.
8. MICAP Support - A system describing what actions to take to alleviate MICAP conditions.
9. Computer Products Training - A system to explain the various computer products and what to do with each of them.
10. Initial Provisioning - A system describing what actions to take to insure provisioning actions are correctly accomplished.

11. PR's - A system to develop a rational order of actions involved in doing a PR. Such a system would aid the IM in making decisions on whether to buy or not buy. Further, it would aid in preparation of J&A's, e.g., where an item might be sourced.
12. FMS Support - How to determine whether to buy, request a funded MIPR, or release assets from stock. System would also provide an explanation of FMS monies.
13. SO6's - A system to provide step-by-step instructions on what you should check, what to do with POS/WSK/OWRM, what adjustments to make, etc.
14. Critical Item Advisor - A system to help analyze critical items. Such a system would help determine the real problem behind a critical item situation and what actions an item manager should pursue to ensure all possible courses of action are taken.
15. Project Focus - A system to provide item visibility and action on these items as backorders occur. System would help to insure that spares are available at the right place at the right time and in the right quantity.
16. Shipment Advisor - A system which describes what actions to take if a "glitch" is encountered in attempting to ship an asset from the depot. The system would provide troubleshooting assistance when an asset fails to ship.
17. Asset Reconciliation - A system to assist item managers in conducting the reconciliation process. Such a system would guide the item manager through the research which needs to be conducted and suggest actions such as a worldwide inventory, etc. which should be taken.
18. Fill Rate Advisor - A system to describe how to understand the fill rate product and analyze it. Objective of the system would be to improve the fill rate.
19. Scrubbing the D041 Computation - A system which aids in performing the actual scrub. Questions to be addressed would include: Are assets correct? Is leadtime correct? Is actual usage correct? etc.
20. General Training System - A system which would provide step-by-step training on all the tasks which an item manager performs.
21. D041 File Maintenance - A system which aids the IM in performing file maintenance.

- 22. Special Levels Advisor - A system to assist in decisions regarding special levels.
- 23. Amended Shipping Instructions Advisor - A system to aid the IM in making transportation decisions.
- 24. PJJ/414 Advisor - A system to aid IM's in clearing PJJ's.
- 25. D032/J041 Reconciliation - A system to help research and correct discrepancies.
- 26. Other Service Support - A system to aid with other service support, to include the Army, Navy, and Marines.

EXPERT SYSTEM
TASK SELECTION

PHASE TWO

1. Check one category. My age is:

- _____ 20 - 29
 _____ 30 - 39
 _____ 40 - 49
 _____ 50 - 59
 _____ 60 or over

2. I have had the following number of years experience as an item manager. (Include time as a D039, D062, and D041 IM):

- _____ less than 2 years
 _____ 2 - 5 years
 _____ 5 - 10 years
 _____ 10 - 15 years
 _____ 15 - 20 years
 _____ more than 20 years

The results of the first phase of task selection resulted in the weighted values for projects as given below. Only those projects which received more than 50 total points are included. The total score you see was arrived at by weighting projects according to the priority for preference you assigned them as follows:

<u>Priority</u>	<u>Weight</u>
1	5 points
2	4 points
3	3 points
4	2 points
5	1 point

For example, then, a project which you ranked as #2 received 4 points, etc. These weighted scores were totaled for all the item managers who responded to the first questionnaire. The seven projects which received more than 50 points are listed below along with the total points each received.

Please review these projects and rank order only the three you most prefer. Again, an attachment is provided which describes each project.

1. General Training (66 points)
 2. Asset Reconciliation (83 points)
 3. Controlled Exceptions (97 points)
 4. D041 File Maintenance (109 points)
 5. Repair Requirements (128 points)
 6. S06's (Budget) (148 points)
 7. Scrubbing the D041 Computation (207 points)
3. I would prefer the following three projects in this order:
1. _____
 2. _____
 3. _____

Thank you again for your input and valuable contribution.

PROJECT DESCRIPTION

1. General Training System - A system which would provide step-by-step training on all the tasks which an item manager performs.
2. Asset Reconciliation - A system to assist item managers in conducting the reconciliation process. Such a system would guide the item manager through the research which needs to be conducted and suggest actions such as a worldwide inventory, etc. which should be taken.
3. Controlled Exceptions - A system to explain what caused the exception code to be generated and what actions are necessary to clear the exception and permit the transaction to process.
4. D041 File Maintenance - A system which aids the IM in performing file maintenance.
5. Repair Requirements - A system providing step-by-step instructions on how to work the X-21's, e.g., how do you determine what projected usage will be by past experience, how to forecast repair requirements, etc. A system to help determine whether to repair or not repair, should repair be contract or organic, should more or fewer assets be driven to repair. The system would also provide recommendations on what additional actions need to be taken.
6. S06's (Budget) - A system to provide step-by-step instructions on what you should check, what to do with POS/WRSK/OWRM, what adjustments to make, etc.
7. Scrubbing the D041 Computation - A system which aids in performing the actual scrub. Questions to be addressed would include: Are assets correct? Is leadtime correct? Is actual usage correct? Etc.

APPENDIX F
EXPERT NOMINATION AND SELECTION
QUESTIONNAIRES

NOMINATION QUESTIONNAIRE

EXPERT SYSTEM
"EXPERT" NOMINATION

1. During the Initial File Maintenance Cycle of the D041 if you are having trouble in scrubbing the comp and could go to any D041 item manager, item manager lead, or supervisor within MM (both MMI and MMC) to help you, who would you go to for help?

Please list up to 3 names of individuals you might ask for advice or assistance. Include the individual's office symbol or company name if you know it. PLEASE PRINT.

	NAME	OFFICE
1.	_____	_____
2.	_____	_____
3.	_____	_____

Thank you for your help.

SELECTION QUESTIONNAIRE

EXPERT SYSTEM
"EXPERT" SELECTION

Listed below are the names of the D041 item managers, item manager leads, and supervisors within MM who were identified yesterday as being "experts" in scrubbing the D041 comp.

1. Debbie Alexander (MMID)
2. Vera Anderson (MMIDAC)
3. Vicki Assad (MMCEB)
4. Evelyn Berglund (MMIDAA)
5. Otis Blankenship (MMIDAC)
6. Bob Buckles (MMIDAA)
7. Tom Dixon (MMMTR)
8. Sally Flanagan (MMIDBB)
9. Pam Goodwin (MMIDBC)
10. Gavin Hamilton (MMIDBB)
11. Neda Hurst (MMIDCC)
12. Elly Jones (MMIDCA)
13. Laverne Jones (MMIDCC)
14. Diane Kowal (MMCDS)
15. Alix Marquez (MMMLP)
16. Suzi Morrison (MMIDBB)
17. Barbara Schlafer (MMIDBC)
18. Jan Simonsen (MMCDBB)
19. Shirley Sweden (MMIDBA)
20. Richard Thompson (MMCDBB)
21. Lola Warrick (MMIDBA)

1. Please review this list carefully and select up to five individuals who you consider to be the most expert at performing this task.

2. Look at your response to question number one above. Now prioritize these individuals with number one representing the individual you consider to be the most expert at performing this task.

1. _____
2. _____
3. _____
4. _____
5. _____

This concludes the overall IM participation in the IMA-1 expert system project. Thank you all very much for being such an important part of this project. It has truly been a pleasure working with you!

APPENDIX G

**CORRESPONDENCE CONCERNING
CASE COLLECTION, EXPERT AVAILABILITY,
AND KNOWLEDGE ENGINEERING SESSIONS**



The Ohio State University

Academic Faculty of Marketing
1775 College Road
Columbus, Ohio 43210-1399
Phone 614-422-8808

30 January 1986

Ms. Barbara Schlafer
SM-ALC/MMIDBC
Sacramento Air Logistics Center
McClellan AFB, California

Dear Ms. Schlafer:

This letter will confirm the telephone conversation between Ms. Anita Clevenger and myself of 28 January 1986 regarding the knowledge engineering sessions and required cases for the IMA-1 expert system. It is my understanding that you will be the acting point of contact for this project until 10 February 1986.

I will be returning to Sacramento on Sunday, 9 February. I have requested that ten cases be available for my review and use at that time. Each case is a document package that includes at least the following information:

1. a complete copy of an actual requirements computation to include the pre-initial, initial, and final comp. as well as the past quarter's comp. for comparison.
2. a detailed protocol or narrative analysis of exactly how each particular comp. was reviewed and explanation of any problems encountered in the review.
3. the recommended advice or action taken on each problem encountered.
4. the final action taken as a result of each comp. (e.g., buy, termination, etc.) and the rationale for this action.

In total, thirty such "cases" will be required. However, only the first ten are required for use in February; and, it is important that the quality of the cases to be made available be stressed as opposed to the quantity. The cases should cover a wide variety of scrub problems, and should include examples of "most difficult" comps. as well as "routine" comps. Both aircraft items and communications electronics items should be included. The remaining twenty cases will be required by April 1986.

The following "experts" in the area of scrubbing the computation, in order of their expertise, were identified 17 January:

1. Alix Marquez (MMNLP)
 2. Barbara Schlafer (MMIDBC)
 3. Vicki Assad (MMCEB)
 4. Debbie Alexander (MMID)
 5. Vera Anderson (MMIDAC)
 6. Pam Goodwin (MMIDBC)
 7. Neda Hurst (MMIDCC)
 8. Sally Flanagan (MMIDBB)
 9. Tom Dixon (MMMTR)
 10. Lola Warrwick (MMIDBA)
- tie
10. Otis Blankenship (MMIDAC)

It is my understanding that seven of these individuals will actually be made available for the knowledge engineering effort. The firm commitment of these seven individuals to the project and their continued involvement cannot be overstressed.

The actual knowledge engineering sessions will be conducted 10-14 February and 24-28 February. Half day sessions will be required each of these ten days. It is important that all seven experts be present at all of these sessions. I understand that Sacramento has decided to schedule the sessions for the afternoon hours of 1230 to 1630 each day and that Sacramento will choose the actual seven experts from the above list based on their availability for all the sessions and will notify these individuals of this tasking and the location and times of the sessions.

A conference room will be required for the sessions. A blackboard is also required. If possible, a room away from the actual workplace (such as in the Headquarters Bldg.) is desired such that the experts are not called away from the sessions for phone calls or other problems.

After completing the initial knowledge engineering sessions with the experts in February, I will spend March actually coding the expert system. Some of the experts will need to be available for periodic telephone conferences during this period. I will return to Sacramento in early April and will require similar half day sessions with the same seven experts to have them use the expert system to modify and expand the facts and rules of IKA-1 as necessary.

Thank you for all your assistance in managing the case collection effort and arranging for the sessions with the experts. Please call me if you have any questions regarding this request. I can be reached at 614-422-0797 (office) or [REDACTED]. Thanks again!

Sincerely,

MARY K. ALLEN, Capt., USAF

copy to: AFLC/MMM
AFLC/SIT
SM-ALC/MM
SM-ALC/MMI
SM-ALC/MMC

APPENDIX H

**A SAMPLE CASE USED DURING
THE KNOWLEDGE ENGINEERING SESSIONS**

SM-MMR NO	MASTER STOCK NO	BY MANAGER BY MASTER S-N				INDEX OF ACTIONS				Q1 NOV 85 PAGE 1484	PCN A-0041--PQA-CZ-82G C4-INITIAL			
		UNIT PRICE	D I E M F S	P C	NET BUY QNTY	NET BUY VALUE +5% OP	CONTRACT TERMINATION QNTY	IF UNECONOMICAL EXCESS VALUE	ERPC	BUDGET CODE	MGR CODE	ACT CEDE		
15600008129298J		3811.16	C	3M	10	38111.60			T	1532442200	KRG	K1		
15600008180608J		363.23	C	I	00				T	1532442200	KRG	L1		
15600010254918J		1696.67	C	1M					T	1532442200	KRG	K1		
15600010234928J		1696.67	C	1M					T	1532442200	KRG	K1		
15600011392048J		24180.28	C	I	3M			1696.67	T	1532442200	KRG	K1		
15600011392058J		4470.98	C	S	00				T	1532442200	KRG	L2		
15600012833028J		18629.00	C	I	00				T	1532442200	KRG	L1		
15600012833098J		18629.00	C	I	00				T	1532442200	KRG	L1		
15600019335608J		27661.00	C	3M	18	497898.00			T	1532442200	KRG	C8		
15600019335618J		27661.00	C	3M	16	442576.00			T	1532442200	KRG	C8		
15600022580688J		10202.96	C	I	2	20406.92			T	1532442200	KRG	L1		
15600022580748J		10202.96	C	I	1	10202.96			T	1532442200	KRG	L1		
15600023844358J		48409.60	C	00	9	435688.40			T	1532442200	KRG	K3		
15600023844398J		22613.11	C	00				1	T	1532442200	KRG	K1		
15600025930428J		5732.00	C	I	00				T	1532442200	KRG	L2		
15600032214758J		8523.48	C	I	3	42617.40			T	1532442200	KRG	L2		
15600032937368J		10031.00	C	I	00				T	1532442200	KRG	L3		
15600032937458J		9563.84	C	I	3M				T	1532442200	KRG	L2		
15600032937468J		9563.84	C	I	00				T	1532442200	KRG	L3		
15600032937538J		10561.21	C	I	00				T	1532442200	KRG	L3		
15600032937598J		3148.55	C	I	12	37758.60			T	1532442200	KRG	L4		
15600033551078J		10185.76	C	I	00				T	1532442200	KRG	L2		
15600033551088J		28745.71	C	I	3M				T	1532442200	KRG	L2		
15600040289418J		2732.89	C	I	1M				T	1532442200	KRG	L4		

INDEX OF ACTIONS - REPORT									
MCR KBC BY APPORTIONMENT YEAR VALUE									
14-000000									
PAGE 131									
C4-FINAL									
STOCK NUMBER	UNIT	REPAIR COST	INPUT QTY	TOTAL M-HRS	DOLLAR VALUE	INPUT QTY	TOTAL M-HRS	DOLLAR VALUE	ITEM I G SP CO CI
150000103350-0J	133	7175	27	193725	3591	21	150675	2793	22 157850 2926 SM 100 24E K 96 9M C9
150000103350-0J	132	6407	22	140954	2904	19	102212	2312	19 115220 2376 SM 100 31E K 86 9M C9
15000023044350J	144	6610	21	72710	1984	21	13220	288	21 13220 288 SM 100 34E K 86 9M K3 OSMD02
1500004002070J	142	6014	12	72160	1704	10	60140	1420	10 60140 1420 SM 100 34E K 86 9M C8
1500004002080J	153	6434	10	64340	1530	11	70224	1603	11 70224 1603 SM 100 31E K 86 9M C8
1650001063380J	2461	6	21	51681	126	19	46759	114	19 39376 96 SM 100 30F K 86 9M E9
16500114074870J	2543	0	17	43234	0	16	40490	0	16 49777 0 UM 100 34E K 96 70 K2
16500115500730J	1612	0	14	22274	0	13	20962	0	13 22274 0 UM 100 34E K 86 70 K1
16500112100200J	16174	0	1	16125	0	2	32250	0	1 16125 0 UM 100 34E K 86 70 K3
16500112014000J	2543	0	6	15254	0	3	7627	0	3 7627 0 UM 100 34E K 86 70 K3
16500108010700J	538	10	24	22912	240	22	11036	220	22 12374 250 SM 100 31E K 96 9M C9
15000000120200J	1251	31	9	11249	279	5	6305	155	4 5044 124 SM 100 34E K 86 9M K1
16500010793100J	770	9	4	3680	36	6	4620	54	3 2310 27 SM 100 34E K 96 9M K1
16500010793200J	408	0	3	2340	0	2	936	18	2 1872 38 SM 100 31E K 86 9M K2
16500010793400J	1186	19	0	0	0	4	4744	76	3 3939 57 SM 100 20F K 86 9M K3
TOTAL MCR-KCLIS				12039	8933			9263	
TOTAL ITEMS				14	15			15	
TOTAL M-HRS				183	232			192	
TOTAL VALUE				727,501	579,607			579,554	

YEL new / MCRDAS / 28 Jan 84

ASSET RECONCILIATION INVESTMENT ITEMS					
1. Name, Stock Number	Item Activity Code	as of Date	as of Date	as of Date	as of Date
1560 00 081 292925		Mar 85	June 85	Apr 85	
TOTAL ACQUIRED ASSETS					
2. STARTING POSITION (Line 1)		21	21	20	
3. ASSET LOSSES					
Concessions		9	9	9	
Stock loss					
Procedures/SPRA			1	1	
Contract (Contract)					
Tax (Contract)					
Shipment to IRS/SA Programs					
Shipment to Reg Reporting Station					
Sale of Property					
Modification					
Other (Line 1)		3	3	3	
Transfer to Reg					
Other (Report in Remarks)					
TOTAL ASSET LOSSES		12	13	13	
4. ASSET GAINS					
Put in V					
Modification					
Other (Report in Remarks)					
TOTAL ASSET GAINS		0	0	0	
5. BALANCE ACCOUNTABLE ASSETS		9	8	11	
6. DUE-IN ASSETS					
On loan (PR/MPR if used)				3	
On loan (Contract)					
Unrecovered PR (Contract) (Line 1)		(3)	(1.9)	(1.5)	
ISSP					
Reconciliation					
Contract Termination					
Other (Report in Remarks)					
TOTAL DUE-IN ASSETS		0	0	3	
7. NET BALANCE ACCOUNTABLE		9	8	8	
8. CURRENT SB & CP ASSETS					
Serviceable (Include DFR)		4	2	3	
Unrecovered		1	1	1	
Contract (Serviceable)					
Contract (Unrecovered)					
WRM (Serviceable)			1		
Other					
TOTAL CURRENT SB & CP ASSETS		5	4	4	
9. DFR (Include in Line 8)		3	0	0	
10. NET SB & CP ASSETS (Line 8 - Line 9)		2	4	4	
11. DIFFERENCE (Line 7 - Line 10)		-2	-4	-2	
12. ADJUSTMENT TO REPORTED ASSETS AFTER RESEARCH		-2	-2	-2	
13. NET DIFFERENCE (Line 11 - Line 12)					
14. PERCENTAGE OF NET DIFFERENCE (Line 13 - Line 12)					
15. ON HAND ASSETS USED IN COMPUTATION		5	4	4	
16. REMARKS (Include in Remarks)		Mar 84 - Unrecovered in Remarks not reported			

SCRJ3 WORKSHEET/SUMMARY						
1. NATIONAL STOCK NUMBER						
1560 00 081 2929 BJ						
		UNITS				
2. BUY OPERATING LEVEL	2	28				
3. ADJUSTED FOR						
A. SCRUB ACTION (State reason)	2					
B. MGT DECISION (State reason)	2					
C. WRSK BLSS REQUIREMENT						
4. ADJUSTED BUY OPER LEVEL	2	28				
5. REQUIREMENTS AND ASSET APPLICATION						
		OPER	FMS	WRSK	BLSS	PRESTOCK
A. REQUIREMENTS		28	—	—	—	—
B. ASSETS						
111 ON HAND	-	7				
121 ON CONTRACT	-	3				
31 ON PR	-					
C. DEFICIT		18				
D. OVERAGE						
F. REAPPLIED ASSETS	1					
F. NET BUY	2	18				
MEMO DATA WRSK BLSS PROTECTABLE						
6. REMARKS ACTION TO BE TAKEN						
Buy 182w POS - 12 AYPOS 1285-60779 - 3 BY POS 1286-50557 <u>3</u> Additional buy						

SB-MAX 86		REQUIREMENTS COMPUTATION														14 DEC 85 PAGE 41903		PCN A-DO41 -PR2-C2-67G C4-FINAL		
MASTER STOCK NO 15800008129298J		NOP NBR																		
LINE IDENTIFICATION		SEP 85	DEC 85	MAR 86	JUN 86	SEP 86	DEC 86	MAR 87	JUN 87	SEP 87	DEC 87	MAR 88	JUN 88	SEP 88	BUY PO	TERM	PO	RETN		
SEP 88 DEC 88 MAR 89 JUN 89 SEP 89 DEC 89		SEP 88	DEC 88	MAR 89	JUN 89	SEP 89	DEC 89	MAR 90	JUN 90	SEP 90	DEC 90	MAR 91	JUN 91	SEP 91						
QIM PRE3		110	319	336	450	562	672	782	894	1004	1114	1224	1334	1444	1660	2092	4156			
QIM OP RMT		1334	1444	1552	1660	1768	1876	1984	2092	2200	2308	2416	2524	2632	2848	3280	6560			
QIM VSL BASE (1)		9	9	10	11	11	12	13	13	14	15	15	16	17	17	17	17			
TOT QIM BASE S-L		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			
VSL DEPT (1)		18	18	17	17	17	17	16	16	16	16	15	15	15	15	15	15			
POM NON JR PROG		1	2	2	4	5	6	7	8	9	10	11	11	11	11	11	11			
POM NON JR RMT		12	13	14	15	16	17	18	19	20	21	22	23	24	24	24	24			
POM JR PROG		5	10	17	26	31	40	51	62	67	76	89	102	107	120	135	165			
POM JR RMT		102	107	120	135	140	149	158	165	174	181	192	201	210	210	210	210			
TOTAL CIVIL COMBAT		3	4	4	4	4	4	5	5	5	5	6	6	6	6	6	6			
AF GROSS RMT		22	23	26	28	30	31	34	35	37	39	42	42	42	42	42	42			
TOT GROSS RMT		44	45	47	49	50	52	54	55	57	59	60	62	64	64	64	64			
SVC ASSETS		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3			
ON ORDER		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3			
TOT SVC		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6			
IST SHORT		19	20	23	25	27	28	31	31	31	31	33	36	36	36	36	36			
BASE PROCESSED		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			
BASE REPAIR		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			

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SM-BRRC BC		REQUIREMENTS COMPUTATION												14 DEC 85 PAGE 41604		PCN A-DO41 -PR2-C2-02G C4-FINAL		
MASTER STOCK NO 15000008129280J		MCR KRG																
LINE IDENTIFICATION		SEP 85	DEC 85	MAR 86	JUN 86	SEP 86	DEC 86	MAR 87	JUN 87	SEP 87	DEC 87	MAR 88	JUN 88	SEP 88	DEC 88	BUY PD	1EDM PD	DETN
SEP 88		DEC 88	MAR 89	JUN 89	SEP 89	DEC 89	MAR 90	JUN 90	SEP 90	DEC 90	MAR 91	JUN 91	SEP 91					
2ND SHORT	16	19 27	20 39	23 41	24 42	26 44	27 45	30 46	30 46	30 46	30 46	32 51	34 53	41 55	46 81			
DEP UNSVC ASSETS	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5			
DEP COMMON	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
NET DEP UNSVC	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4			
GIN REP GEN(MRITS)	7	7	8	9	9	10	10	10	10	10	10	12	13	14	10			22
GIN REP GEN COMMON	2	2	2	2	2	2	2	2	2	2	2	3	3	3	2			5
NET GIN REP GENS	5	5	6	7	7	8	8	8	8	8	8	9	10	11	8			17
NET SLIP GIN GENS	5	5	6	7	7	8	8	8	8	8	8	9	10	11	8			17
NAJ REP GENS	12	13	14	15	16	17	17	18	19	20	20	21	22	24	19			35
NAJ REP GEN COMMON	3	3	3	3	3	4	4	4	4	4	4	5	5	5	4			8
NET NAJ REP GENS	9	10	11	12	12	13	13	14	15	16	16	17	18	19	15			27
NET SLIP NAJ REP GENS	8	10	11	12	12	13	13	14	15	16	16	17	18	19	15			27
TOT AVAIL DEP REPR	18	19	21	23	23	25	26	27	27	29	29	30	32	34	27			48
2ND SHORT	18	13	13	15	15	16	16	18	18	19	19	21	21	21	19			32
MISTR INPUT AC	6	7	8	9	9	10	11	12	12	14	14	15	17	18	23			48
MISTR INPUT D-AC	18	19	21	23	23	25	26	27	27	29	29	30	32	34	27			48
MISTR OUTPUT AC	18	19	21	23	23	25	26	27	27	29	29	30	32	34	27			48
MISTR OUTPUT D-AC	18	19	21	23	23	25	26	27	27	29	29	30	32	34	27			48
PT MISTR INPUT AC	18	19	21	23	23	25	26	27	27	29	29	30	32	34	27			48
PT MISTR INPUT D-AC	18	19	21	23	23	25	26	27	27	29	29	30	32	34	27			48

SM-MGR BG	14 DEC 85														PCN A-0041--PM2-C2-62G		Y													
	PAGE 41605														CA-FINAL		Y													
REQUIREMENTS COMPUTATION																														
MASTER STOCK NO 15800008129298J MGR K8G																														
LINE IDENTIFICATION	SEP 85	DEC 85	MAR 86	JUN 86	SEP 86	DEC 86	MAR 87	JUN 87	SEP 87	DEC 87	MAR 88	JUN 88	SEP 88	DEC 88	MAR 89	JUN 89	SEP 89	DEC 89	MAR 90	JUN 90	SEP 90	DEC 90	MAR 91	JUN 91	SEP 91	DEC 91	PO TERM	PO	RETN	
PT MISTR OUT AC	18	6	7	21	23	8	9	10	11	12	14	15	17	18	23	27	27	27	27	27	27	27	27	27	27	27	27	27	27	48
PT MISTR OUT D-AC		19	21	23	25	26	27	29	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72
TIME PHASED USERS	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

SM-MWK BG PCN A-DO41 -PW2-CZ-67G
C4-FINAL

14 DEC 85
PAGE 41606

REQUIREMENTS COMPUTATION

MASTER STOCK NO 15600008129298J MGR KBG

QUANTITY DOLLAR VAL WORLDWIDE LEVELS

BUY..... 18 162896.58 BUY OPERATING.....
TERMINATION..... .00 TERMINATION.....
EXCESS..... .00 MINIMUM RETENTION.....
PR/MIPR(1). 2 27149.43 GROSS RETENTION.....
Control and select RETENTION.. 72

DEPOT LEVELS

28 TERMINATION.....
20 MINIMUM RETENTION.....
72 GROSS RETENTION.....
72

DISTRIBUTION LEVELS

CONTROL.....
SUPPORT.....
ROUTED REPR REPL.....

30
2

SOURCES OF REPAIR AND PERCENTS
SM 100

DELIVERY SCHEDULE

PT BUY PT BUY DEL BEGIN
INIT DATE QTY DATE
8801 0000018 8801

PHASED DELIVERY QUANTITY

QTR 1 QTR 2 QTR 3
0000000 0000018 0000000

QTR 4 QTR 5
0000000 0000000

REVIEWED-BY

DATE BY DATE BY DATE BY

CSN

PR/MIPR PR/MIPR
NUMBER NUMBER

15600008129298J F020408556318 00000002 85072 15600008129298J 00000001 85072

CURRENT STOCK NUMBER
15600008129298J

SR-MMR BG

14 DEC 95
PAGE 41607

REQUIREMENTS COMPUTATION

MASTER STOCK NO 19800008129298J MGR MGR

AV BY WHN OVRN FMS/INFO ENTRY ONLY

AP POS RONT (INCLUDING FMS)

DEFERALS S PHASE OUT PR QTY PR QTY

AP POS RONT S WHN RONT NET OVRN NET FMS

PR QTY S PR QTY S

NET AP POS NET WHN

S S

TOTAL DOLLARS TO BE APPROVED: S

UNIT	SECTION	SIGNATURE	DATE	BRANCH	SIGNATURE	DATE	DIVISION	SIGNATURE	DATE	DIRECTORATE	SIGNATURE	DATE

QUANTITY DEFERRED FROM BUY DUE TO NO ACTUAL EXPERIENCE.

- BASE SAFETY LEVEL
- DEPOT STOCK LEVEL
- BASE CONDEMNATIONS
- DEPOT B/W CONDEMNATIONS

APPLICATION DATA

APPLICATION NO	PCN	APPL	DEV	PCN	BEG	OPA	APPL	X
	SEL	ESM	CODE	DATE	DATE			
F111A	1800	48EE		7006	0002	100		

SM-MMR BG	REQUIREMENTS COMPUTATION										14 DEC 85	PCN A-DOA1 - PW2-CZ-62G
											PAGE 41808	C4-FINAL
MASTER STOCK NO 15600008129298J	MGR KBG											Y
..... APPLICATION DATA												
APPLICATION NO.	PGM	SEL	APPL	DEV	PGM	BEG	QPA	APPL	%			
			ESSN	CODE	DATE							
EF111A	1200		3AEE		7806		0002	100			Y	
15600046052078J	1200		4AEE		7009		0001	100			Y	
15600046052088J	1200		4AEE		7009		0001	100			Y	

1560 00 081 2929 BJ

MMIDA				
COMPARISON CHART FOR 8509 COMP CYCLE				
	MAR 85	SEPT 85	DIFFERENCE +/-	
OLM BASE O/ST RQMT				
OLM BASE R-C RQMT				
OLM BASE VSL	2	2		
SPECIAL LEVELS	-	-		
VSL DEPOT	16	17	+ 1	
NJR STK LVL RQMT	-	-		
TOTAL OVHL S/L RQMT	-	-		
PREPOSITIONED RQMT	-	-		
PRESTOCK	-	-		
ADDITIVE RQMT	-	-		
OLM DEPOT REP CYCLE	0	-		
NJR DEPOT REP CYCLE	1	-	- 1	
OPERATING RQMT AT WEAROUT				
OLM REP GEN COND	1	2	+ 1	
NJR REP GEN COND	1	3	+ 2	
TOTAL OVHL COND	1	4	+ 3	
TOTAL CROSS RQMT	22	28	+ 6	
REASON FOR INCREASE/DECREASE:				

PCN A-0143F-3PB-03-C3			MMSC(18)			BASE REPAIR CYCLE TIME			PRINT DATE 20 SEP 85		
NON-DESIGN PBO											
MASTER STOCK NO	TOTAL MIS	TOTAL DAYS	ORCY AVE	TOTAL MNTS	TOTAL DAYS	TOTAL CENUS	TOTAL DAYS	TOTAL CONJUNCTS	TOTAL DAYS	BASE PROC AVE	
156000081:525HJ	1	2	2	2	2	0	0	2	2	1	
156000102:4510J	1	4	4	0	0	0	0	0	0	0	
156000102:4528J	1	8	8	0	0	0	0	0	0	0	
156000193:5604J	3	15	5	0	0	0	0	0	0	0	
156000193:5610J	12	56	5	1	10	0	0	1	10	10	
156000225:4358J	2	4	2	0	0	0	0	0	0	0	
156000254:4359J	2	16	8	1	4	0	0	1	4	4	
156000335:0558J	2	14	7	0	0	0	0	0	0	0	
156000341:20352K	2	22	11	0	0	0	0	0	0	0	
156000440:2079J	1	1	1	1	7	0	0	1	7	7	
156000440:2080J	6	24	5	0	0	0	0	0	0	0	
156000497:1550J	7	142	20	0	0	0	0	0	0	0	
156001030:2227J	2	5	5	1	1	0	0	1	1	1	
156001055:2259J	21	120	6	0	0	0	0	0	0	0	
156001355:3600J	231	1211	6	0	0	0	0	0	0	0	
156001455:7300J	15	54	4	0	0	0	0	0	0	0	
156001557:022J	24	115	5	0	0	0	0	0	0	0	
156001957:1230J	25	167	4	0	0	0	0	0	0	0	
156001055:73042J	45	778	16	0	0	0	0	0	0	0	
156001050:5218J	30	636	18	0	0	0	0	0	0	0	
156011131:4792J	7	73	10	0	0	0	0	0	0	0	
156001126:2018J	11	51	5	0	0	0	0	0	0	0	
156000100:1336J	7	25	5	17	78	0	0	17	78	4	
1560001157:160J	2	2	1	2	13	0	0	2	13	6	
1560001208:7540J	2	16	3	0	0	0	0	0	0	0	

SM-NNK 80 CONSOLIDATED ASSETS AND REQUIREMENTS 04 MAY 85 A-0041.-EJ1-F7-87D P 16941
WORK UNIT F7

MASTER STOCK NO...1580000812928RJ WGR...RBC ERRC...T ASSET CUTOFF DATE...8503

CURRENT STOCK NUMBER 1580000812928RJ
OAS PUMP
CODE CODE
0A SVC BASE & DEPOT... 4 UNSVC CONTR SCH... 0 TOC... 0 SVC VRM BASE... 0
UNSVK BASE... 0 UNSVC CONTR UNSCH... 0 UNSVC ON LOAN... 0 SVC VRM DEPOT... 0
UNSVK DEPOT... 1 SVC INTRANSIT... 0 DUE IN FROM OVAL... 0 UNSVC VRM DEPOT... 0
SVC CONTRACTOR... 0 UNSVC INTRANSIT... 0 DOIM... 0 PRESTOCKED... 1E
SVC ON LOAN... 0 NO OF USERS... 2

PR/NIPR STAT QTY DOLLAR ORIGIN
CODE VALUE DATE

FD20408558318 R 1 1,260.00 85072

FD20408558318 R 2 2,520.00 85072

QUARTERLY TIME PHASED SCHEDULE

TOTAL	JUN 85/86	SEP 85/86	DEC 85/86	MAR 86/89	JUN 86/89	SEP 86/89	DEC 86/89	MAR 87/90	JUN 87/90	SEP 87/90	DEC 87/90	MAR 88/91	JUN 91
PHASED NBR OF USERS.....	2	2	2	2	2	2	2	2	2	2	2	2	2

..... BACHELOR ITEM

PCN A-0143N-28C-01-010 WMS (2)	REPARABLE ITEM TRANSPORTATION TIME	AS OF DATE 85 SEP 27
SUBGROUP MASTER STOCK NUMBER	TOTAL NUMBER OF SHIPMENTS	AVERAGE DAYS
180000012928J	10	28
180000010284028J	1	3
180000011302048J	1	44
180000010230008J	4	31
180000010230018J	4	31
180000010044308J	2	27
180000010044308J	2	41
180000010280418J	1	13
180000011203008J	1	8
1800000100101308J	1	21
180000010002078J	8	30
180000010001008J	8	29
180000010230728J	1	36
180000010230728J	7	39
180000010230728J	4	43
1800000100010748J	21	301
1800000112300738J	1	11

[illegible]

OWN COMPUTATION WORKSHEET										14 DEC 85	PCN A-DO41.-PD2-C2-62G	
										PAGE 4429	C4-FINAL	
SM-MAX BG	ASSET CUTOFF DATE 0509	MASTER STOCK NO	WGR EQUIP	ITEM NAME	UNIT PRICE	ERRC CODE	PART NUMBER-CODE	VSL EXCL	WORK UNIT	MI BUDGET CODE	PROG SEL	
15600008129298J	WGR 9M	TIP TE	8594.22E	T	12P8220-3	R1755				DAE 15324A2200	1X00	
.STR LVL DAYS. .BASE. (-----DEPOT REPAIR CYCLE DATA-----)												
0/ST	WGR JR	R-C B-PROC	REP-INT	SUP-MA	S-FLOW	TURIN	IN TOT	DEP		DEPOT		
VAR	205 14P 14P	85	2P	305	75	45	2P	45		FLYING SL		
235				235				38				9049.81
PEACE	165 14S 14S	75	2C	25A	105	5A	25	44				
(- - - FACTORS----- 2ND - - 2ND - -)												
TOTAL QIN DEMAND RATE			.0064P					VAR	2P	2P	2P	2P
QIN DEPOT DEMAND RATE			.0051					PEACE	2	2	2	2
QIN BASE REPAIR RATE			.0013									
BASE MITS PERCENT		80P						BOC				
BASE CONDN PERCENT		P						C				
DEPOT Q-H CONDN%		22P						22C				
BASE PROCESSED %		20						20				
POM JR LUNDRN %		2P						2C				
ENG Q-H JR CONDN% %		P										
MMA MISTR JR CONDN %		P										
ENG Q-H NON JR REPL %		P										
MMA MISTR NON JR REPL %		P										
POM NON JR REPL %		100P						100C				
POM NON JR PROG %		9P						9C				
EDM NON JR PROG %		P										
MISTR NON JR PROG %		P										

PHASED USERS

OWN COMPUTATION WORKSHEET														14 DEC 85		PCN A-0041.-PD2-CZ-6ZG		Y									
ASSET CUTOFF DATE 8509 WPP1: 50 WPP2: 25														PAGE 4430		C4-FINAL		Y									
RSM 15600008125228J														MTM 1	MTM 2	MTM 3	MTM 4	MTM 5	MTM 6	MTM 7	MTM 8	MTM 9	MTM 10	MTM 11	MTM 12	Y	
WAR OIM PROG														127	64	63	65	65	64	51	51	50	39	39	39	38	Y
WAR POM PROG														2	2	2	4	3	3	5	5	4	5	5	5	4	Y
WAR JR OVAL COND														0	0	0	1	0	0	0	0	0	0	0	0	1	Y
TOTAL WAR COND														0	0	0	1	0	0	0	0	0	0	0	0	1	Y
WAR OIM BASE STK LEVEL														7	5	5	3	3	3	3	3	3	2	2	3	3	Y
WAR VSL DEP														3	6	5	0	0	3	3	0	0	6	6	6	3	Y
WAR OIM DEP REP CYCLE														1	1	1	0	0	0	0	0	0	0	0	0	1	Y
TOTAL WAR LEVELS														11	12	11	3	3	6	6	3	3	9	9	9	7	Y
COMPUTED WAR ASSETS														11	12	12	11	11	11	11	11	11	11	11	11	10	Y
GROSS WAR RMT														11	1	0	0	0	0	0	0	0	0	0	0	0	Y
NET WAR RMT														11	1	0	0	0	0	0	0	0	0	0	0	0	Y
NET WAR RMT ACH														11	12	12	12	12	12	12	12	12	12	12	12	12	Y
PEACE OIM PROG														37	37	36	37	37	36	37	37	36	37	37	37	36	Y
PEACE POM PROG														2	2	2	4	3	3	5	5	4	5	5	5	4	Y
PEACE JR OVAL COND														0	0	0	0	0	0	1	0	0	0	0	0	0	Y
TOTAL PEACE COND														0	0	0	0	0	0	1	0	0	0	0	0	0	Y
PEACE OIM BASE STK LEVEL														2	2	2	3	2	2	2	2	2	2	2	2	2	Y
PEACE VSL DEP														19	15	14	21	15	15	21	17	18	18	17	17	18	Y
PEACE NJR DEP REP CYCLE														1	0	0	1	0	0	1	0	0	0	0	0	0	Y
PEACE OIM DEP REP CYCLE														0	0	0	1	0	0	0	0	0	0	0	0	0	Y
TOTAL PEACE LEVELS														22	17	16	26	17	17	24	19	20	20	19	19	20	Y
COMPUTED PEACE ASSETS														22	22	22	26	26	25	25	25	25	25	25	25	25	Y
PEACE RMT														22	0	0	4	0	0	0	0	0	0	0	0	0	Y
PEACE RMT ACH														22	22	22	26	26	26	26	26	26	26	26	26	26	Y
WAR MINUS PEACE RMT														11-	10-	0	0	0	0	0	0	0	0	0	0	0	Y
B-P DEFICIT														0													Y
LESS PREP-RMT AT NOV														0													Y
EQUALS PRESTOCKED RMT														0													Y

SN-MMM 9M
 EOPT SPEC ...MM
 FACTORS PRINTOUT
 MASTER STOCK NUMBER...15800008129298J MGR DES...KRG
 04 MAY 85 A-DO41...EF1-F7-B7D P 18165
 WORK UNIT F-

. PAST FACTORS
 JUN 83 SEP 83 DEC 83 MAR 84 JUN 84 SEP 84 DEC 84 MAR 85

BASE CONCENTRATION %.....BY QUARTER
 BASE CONCENTRATION %.....MOVING AVERAGE
 DEPOT O/H COND %.....BY QUARTER
 DEPOT O/H COND %.....MOVING AVERAGE

. APPLICATION DATA
 JUN 83 SEP 83 DEC 83 MAR 84 JUN 84 SEP 84 DEC 84 MAR 85

APPLICATION	APPL MISC	PCM SEL	PCM DEV	PCM BEG DATE	QPA	APPL %
EF111A	-AEC	1X00		7006	0002	100
EF111A	3AEE	1X00		7806	0007	100
1580004603078J	4AEE	1X00		7009	0001	100
1580004603088J	4AEE	1X00		7009	0001	100

Refuel Against Inventory / 5533/2200015

F A C T O R S P R I N T O U T										04 MAY 85 A-0041...EF1-F7-B7D P 18164															
DEPT	MASTER STOCK NO	MGR	ITEM NAME	ACT CODE	ERRC	NEW ITEM CAT	REPAIR CYCLE	PCN	ITEM	ICS	WDRK UNIT F7														
SPEC							BASE	DEPOT	SEL	MISC	RTV	PROG BEGIN DATE...	7008												
CON	15600008120206J	WBO	TIP TE	KIE	T	FEEMS	0075	046	1200	3AEC	ASSET CUTOFF DATE...	8503													
UNIT PRICE	UNIT REPAIR COST	UNIT REPAIR MANHOURS																							
1280.00A	1220.00A	32.0A																							
RATES AND PERCENTS													FORECAST												
LAST USED	12 MTHS	CURRENT	1ST	FORECAST		2ND	3RD	CURRENT		1ST	2ND	3RD													
MEAN TIME BETWN DMD...	37037	10417	10526	10526	10526	10526	10526	PCN JR CONDEMN %	2C	2C	2C	2C													
TOTAL DTM DMD RATE...	0.0027C	0.0095C	0.0095C	0.0095C	0.0095C	0.0095C	0.0095C	ENG OH JR CONDEMN %	0	0	0	0													
QIM DEPT DMD RATE...	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	0.0041	NMA MISTR JR CONDEMN %	0	0	0	0													
QIM BASE REPAIR RATE...	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	0.0055	PCN NON/JR REPL %	100C	100C	100C	100C													
BASE MTHS %	OC	43C	43C	43C	43C	43C	43C	ENG OH NON/JR REPL %	0	0	0	0													
BASE PROCESSED %	100	57	57	57	57	57	57	NMA MISTR NON/JR REPL %	0	0	0	0													
BASE CONDEMN %	OC	OC	OC	OC	OC	OC	OC	PCN NJR PCM %	13C	13C	13C	13C													
DEPOT OH CONDEMN %	15C	17C	17C	17C	17C	17C	17C	ENR NON/JR PCM %	0	0	0	0													
								NMA MISTR NON/JR PCM %	0	0	0	0													
. PAST USAGE HISTORY													TOTAL USAGE												
INTERCHG STK NR	DBS CODE	TYPE USAGE	JUN 83	SEP 83	DEC 83	MAR 84	JUN 84	SEP 84	DEC 84	MAR 85															
15600008120206J		BASE RTS	ACT F/M	2	1	0	0	0	0	1	0	4													
		BASE MPTS	ACT F/M	0	1	0	2	0	0	0	0	3													
		BASE REP GENS	ACT F/M	2	2	0	2	0	0	1	0	7													
		DEPOT REP GENS	ACT F/M	2	2	2	0	0	1	0	2	9													
		DEPOT OH REPAIRED THIS ITEM MISTR	ACT F/M	6	3	3	3	4	4	1	1	25													
		DEPOT OH CONDEMNATIONS THIS ITEM MISTR	ACT F/M	0	0	0	0	1	4	0	0	5													
		DEPOT CONDEMNATIONS	ACT F/M	0	0	0	0	1	4	0	1	6													

12-

SM-MK 9M	FACTORS PRINTOUT									
EQPT SPEC...K9M	MASTER STOCK NUMBER...1560000129290J MGR DES...K9G									
	TOTAL PAST USAGE HISTORY FOR MASTER STOCK NUMBER									
	04 MAY 85 A-DOA1-(F1-F7-B7D) P 18165 WORK UNIT F7									
TOTAL	BASE RTS	2	1	0	0	0	0	1	0	4
TOTAL	BASE MPTS	0	1	0	2	0	0	0	0	3
TOTAL	BASE REP GEMS	2	2	0	2	0	0	1	0	7
TOTAL	DEPOT REP GEMS	2	2	2	0	0	1	0	2	9
TOTAL	DEPOT DM REPAIRED THIS ITEM MISTR	6	3	3	3	4	4	1	1	25
TOTAL	DEPOT DM CONFIRMATIONS THIS ITEM MISTR	0	0	0	0	1	4	0	0	5
TOTAL	DEPOT CONDEMNATIONS SBACR	0	0	0	0	1	4	0	1	6

QUARTER OF LAST DEMAND.....8503

. TOTAL ITEM PAST INSTALLED PROGRAM											
TYPE PROGRAM	JUN 83	SEP 83	DEC 83	MAR 84	JUN 84	SEP 84	DEC 84	MAR 85	TOTAL PROG		
OIM	92	90	88	84	90	90	96	94	734		
POM	18	14	2	8	4	8	8	4	64		
ENG DM	0	0	0	0	0	0	0	0	0		
NMA MISTR	0	0	0	0	0	0	0	0	0		
. PAST FACTORS											
TOTAL OIM DEMAND RATE....BY QUARTER	JUN 83	SEP 83	DEC 83	MAR 84	JUN 84	SEP 84	DEC 84	MAR 85			
TOTAL OIM DEMAND RATE....MOVING AVERAGE	0.0217	0.0222	0.0000	0.0213	0.0000	0.0000	0.0000	0.0104	0.0000		
BASE MPTS %.....BY QUARTER	0.0042	0.0071	0.0071	0.0071	0.0097	0.0098	0.0098	0.0096	0.0095		
BASE MPTS %.....MOVING AVERAGE	0	30	40	40	100	0	0	0	0		
	33	40	40	40	57	57	57	43	43		

SM-MMR BG
 ASSET CUTOFF DATE 8909
 MASTER STOCK NO MGR EQUIP ITEM NAME UNIT PRICE ENRC CODE PART NUMBER-CODE
 CPEC
 1560000812298J KRG 9M TIP TE 1280 00A 7 1280320-3 81755
 .5% LVL DAYS .BASE (-----DEPOT REPAIR CYCLE DATA-----)
 0/ST MGR JR R-C-B-PROC REP-INT SUP-MA S-FLOW TURN IN TOT DEP
 2-5 14P 14P 85 2P 305 75 45 2P 45
 275 275 225 225 105 5A 25 38 44
 PEACE 165 145 145 75 2C 25A 105 5A 25 38 44
 VAR PEACE
 (- - - - - FACTORS - - - - - 2ND - - - - - 2ND - - - - -)
 TOTAL OIM DEMAND RATE .0015P .0015C
 OIM DEPOT DEMAND RATE .0012 .0012
 OIM BASE REPAIR RATE .0003 .0003
 BASE MITS PERCENT 80P 80C
 BASE CONOM PERCENT P C
 DEPOT O-M CONOM% 22P 22C
 BASE PROCESSED X 20 20
 POM JR CONOM X P C
 ENG O-M JR CONOM X P
 M-M MISTR JR CONOM X P
 ENG O-M NON JR REPL X P
 M-M MISTR NON JR REPL X P
 POM NON JR REPL X 100P 100C
 POM NON JR PROB X 2P 2C
 EGM NON JR PROB X P
 MISTR NON JR PROB X P

01 NOV 85
 PAGE 4145
 PCN A-DO41--PD2-C2-62G
 C4-INITIAL
 VSL WORK M1 BUDGET CODE PROG
 EXCL UNIT LC
 3AF 153242200 1A00
 DEPOT (.....FUP.....)
 FLING SL 3811.16
 PHASED USERS
 QTR 1 QTR 2 QTR 3 QTR 4
 2P 2P 2P 2P
 2 2 2 2
 PEACE

SM-MARK BG CONSOLIDATED ASSETS AND REQUIREMENTS 01 NOV 85 A-DOA1-EJ1-F7-87D P 17046
 MASTER STOCK NO...15800008129298J WORK UNIT F7

CURRENT STOCK NUMBER 15800008129298J DBS PUMP WCR...KRG EPRC...T ASSET CUTOFF DATE...8509

ASSETS AND REQUIREMENTS

PR/MIPR	STAT CODE	QTY	DOLLAR VALUE	ORIGIN DATE	TOC	SVC VRM BASE	SVC VRM DEPT	SVC VRM DEPT	PRESTOCKED	NO OF USERS
F02040858318	R	2	2,520.00	85072	0	0	0	0	0	0
F02040858318	R	1	1,260.00	85072	0	0	0	0	0	0

Contract and 85273, 85 funds ✓

QUARTERLY TIME PHASED SCHEDULE

TOTAL	DEC 85/88	MAR 86/89	JUN 86/89	SEP 86/89	DEC 86/89	MAR 87/90	JUN 87/90	SEP 87/90	DEC 87/90	MAR 88/91	JUN 88/91	SEP 88/91	DEC 88/91
PHASED NOB OF USERS	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2

JV (1001)

***** BACKLOG ITEM *****

SM-BKZ E2	ITEM FUTURE PROGRAMS (BY APPLICATION)										PCN A-DO41.-PN2-C2-826
MANAGER	MASTER STOCK NO.	COMPUTATION START DATE				PAGE		11702	01 NOV 85	Y	
KBG	19600008129298J	FY	86	QTR	1					Y	
APPLICATION NO.	PROG SERV DEV	PROG	FISCAL	1ST QTR	2ND QTR	3RD QTR	4TH QTR	RETENTION		Y	
CODE	CODE	CODE	YEAR							Y	
F111F	4	A	1X00	86	8	8	14	6		Y	
				87	10	10	10	8		Y	
				88	12	10	8	8		Y	
				89	14	16	8	6		Y	
				90	14	8	4	12		Y	
				91	14	12	10	6	126	Y	
EF11A	1	A	1X00	86	58	56	62	58		Y	
				87	58	58	58	60		Y	
				88	58	58	58	58		Y	
				89	58	58	58	58		Y	
				90	58	58	58	58		Y	
				91	58	58	58	58	788	Y	
EF11A	4	A	1X00	86	2	4	2	6		Y	
				87	2	4	8	6		Y	
				88	4	4	8	4		Y	
				89	4	6	6	4		Y	
				90	4	6	4	4		Y	
				91	4	6	4	6	60	Y	
FB11A	1	A	1X00	86	102	104	104	104		Y	
				87	96	96	96	96		Y	
				88	96	96	96	96		Y	
				89	94	96	96	96		Y	
				90	98	102	102	102		Y	
				91	104	102	102	102	1334	Y	
FB11A	4	A	1X00	86	6	8	8	6		Y	
				87	8	8	8	4		Y	
				88	10	6	6	6		Y	
				89	8	6	8	8		Y	
				90	8	6	6	6		Y	
				91	6	6	8	6	78	Y	
TOTAL	1	A		86	400	402	436	434		Y	
				87	416	412	408	400		Y	
				88	404	404	404	394		Y	
				89	402	402	402	394		Y	
				90	402	404	502	486		Y	
				91	494	492	492	486	7538	Y	

MANUAL DESIGNATOR	KG
1	1
2	2
3	3
4	4
5	5
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9	9
10	10
11	11
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94	94
95	95
96	96
97	97
98	98
99	99
100	100

10-03-85 A-J041-5VB-MS-M50 PG 579

A-J041 - 5YB - MS - M50 PG

50-60-01

A-J041 - 5YB - MS - M50 PG

579

[illegible]

PCN: A-CTJ4-111-01-MFF

RAMAGER KRG

SUB GROUP E AC
MASTER MSN R CO
CURRENT MSN C U1 SRAM TE

IM QUARTERLY WORLDWIDE ASSETS AND LEVELS REPORT

FSC 1560

AS OF 30 SEP 85

RUN DATE 31 OCT 85

	SEP BAL	UNSTRV BAL	DIFM BAL	VM BAL	VM DEMAND LVL	REQSN OBJ	DOTM BAL	TDC BAL	DUE IN FM O/M	FLOAT STR	SPRAM LVL	GAL
15600000129298J	0	1	0	0	0	0	0	0	0	0	0	0
15600000129298J T EA FB2049 09	1	0	0	0	0	0	0	0	0	0	0	0
15600000129298J T EA FB2049 0A	1	1	0	0	0	1	0	0	0	0	0	0
SRAM TOTAL												
15600000129298J T EA FB4897 01	2	0	0	0	0	8	0	0	0	0	0	0
SUB/GRP MISTR FSM TOTAL	2	1	0	0	0	8	0	0	0	0	0	0
15600000180608J												
15600000180608J T EA FB2049 09	14	0	0	0	0	0	0	0	0	0	0	0
SUB/GRP MISTR FSM TOTAL	14	0	0	0	0	0	0	0	0	0	0	0
15600010214018J												
15600010214018J T EA FB3587 01	1	0	0	0	0	2	0	0	0	0	0	0
SUB/GRP MISTR FSM TOTAL	1	0	0	0	0	2	0	0	0	0	0	0
15600010214028J												
15600010214028J T EA FB2049 09	0	1	0	0	0	0	0	0	0	0	0	0
SUB/GRP MISTR FSM TOTAL	0	1	0	0	0	0	0	0	0	0	0	0
15600011792048J												
15600011792048J T EA FB2049 09	1	0	0	0	0	0	0	0	0	0	0	0
SUB/GRP MISTR FSM TOTAL	1	0	0	0	0	0	0	0	0	0	0	0
15600012235408J												
15600012235408J T EA FB2049 09	0	0	0	0	0	0	0	0	0	0	0	0

PCN 1-0143H-2PA-04-C3P MUMS
 BCS 023: H00

REPAIRABLE SHIPMENTS TO AF REPAIR FACILITIES
 QUARTERLY SUMMARY (SM-ALC)

PROCESSING DATE: 27 SEP 89
 PAGE 190

1 & 2 SUBGROUP MASTER	SCPP	ACTUAL MSW	AF ACT	CONTR	FMS-SAP	OTHER SERVICES	TOTAL RETURNS
18000010204920J		18000010204920J	1	0	0	0	1
18000010208010J	ABA	18000010208010J	1	0	0	0	1
1800002004300J	AAA	1800002004300J	1	0	0	0	1
18000000730000J		18000000730000J	1	0	0	0	1
1800002022337J		1800002022337J	1	0	0	0	1
1800000010740J		1800000010740J	4	0	0	0	4
18000012300730J		18000012300730J	1	0	0	0	1

SCRUB WORKSHEET/SUMMARY						
1. NATIONAL STOCK NUMBER 156000 081 2929 BJ						
		UNITS				
2. BUY OPERATING LEVEL	=	22				
3. ADJUSTED FOR						
A. SCRUB ACTION (State reason)	:	+ 1				
B. MGT DECISION (State reason)	:					
C. WRSK/BLSS REQUIREMENT						
4. ADJUSTED BUY OPER LEVEL	=	23				
5. REQUIREMENTS AND ASSET APPLICATION						
		OPER	FMS	WRSK	BLSS	PRESTOCK
A. REQUIREMENTS		23	-	-	-	-
B. ASSETS						
(1) ON HAND	-	8				
(2) ON CONTRACT	-	0				
(3) ON PR	-	0				
C. DEFICIT		15				
D. OVERAGE						
E. REAPPLIED ASSETS	:					
F. NET BUY	=	15				
MEMO DATA: WRSK/BLSS PROTECTABLE						
6. REMARKS/ACTION TO BE TAKEN 3 IN AY PR 85-56318 Buy 15 IN PO 12 IN AY 85-60774 3 IN BY 86-50557						

SM-NUM 8: ASSET CL OFF DATE 8509
 REQUIREMENTS COMPUTATION
 AF PROG DOCUMENT NO PAGE-4
 PCN A-DO41-PK2-C7-62G
 C4-INITIAL
 MASTER STOCK NO MOD EQUIP ITEM NAME UNIT PRICE ENRC U-I NEW ITEM LEADTIME ICS VSL ACT B104 MI BUDGET CODE PROG DEFER PM CODE
 SPEC
 1800000 20290J HRC NW TIP TE 8509-33 1380.000 Y EA 24 240
 PI 5TH LVL DAYS. BASE. (-----DEPOT REPAIR CYCLE DATA-----) REP. DEPOT. DEFER. ITEMS. (.....FUP.....) DLM. . .
 MC 2/51 NJR JR B-C B-PROC REP-INT SUP-NA S-FLOW TURN IN TOT DEP L-1 FLING SL LEVEL ITEM 3811.18
 B 105 145 145 75 2C 25A 105 3A 25 44C 17
 (----- TIME-PHASED DEPOT REPAIR CYCLE DATA-----) .REP.
 EFF DATE TB-PROC REP-INT SUP-NA S-FLOW TURN-IN TOT DEP L-1
 (----- BASE PERIOD DATA -----) SERVICEABLE ASSETS TOC ASSETS
 PROG BASE REP BASE DEPOT BASE
 GEN'S CONOM DYNL CONO REPAIRED MNTS BASE / DEPOT 3
 332C 8 5 18 4 WRM BASE
 (----- FACTORS----- CURRENT - 1ST - 2ND - 3RD -)
 TOTAL OIN DEMAND RATE .0015C .0015C .0015C .0015C INTRAMITY
 OIN DEPOT DEMAND RATE .0012 .0012 .0012 .0012 CONTRACTOR
 OIN BASE REPAIR RATE .0003 .0003 .0003 .0003 SVC ON LOAN
 BASE MNTS PERCENT 80C 80 80 80 TOTAL NOM MHS 3
 BASE CONOM PERCENT C DUE IN SERVICEABLE
 DEPOT O-+ CONOMATE 22C 22 22 22 ISSP
 BASE PROCESSED % 20 20 20 20 RECL
 POM JR CONOM % C C C C TERM
 ENB O-N A3 CONOM % SAP
 M-A MISTE JR CONOM % TOT DUE IN SVC
 ENB O-N MOW JR REPL %
 M-A MISTE MOW JR REPL % ON ORDER ASSETS
 POM MOW JR REPL % 100C 100C 100C 100C PR FUNDED 3
 POM MOW JR PROB % 2C 2C 2C 2C CONTRACTOR
 CON MOW JR PROB % WRM PR FUND
 MISTE MOW JR PROB % WRM CONTR
 TOTAL ON ORDER
 PICA-SICA-NIMSC CODES
 PICA EFF DATE 83272
 NIMSC
 ARMY SICA
 NIMSC
 AF SICA
 NAVY SICA
 NIMSC

[illegible]

REQUIREMENTS COMPUTATION										O1 NOV 85		PCN A-0041 -PK2-CZ-6ZG	
										PAGE 40635		C4-INITIAL	
MASTER STOCK NO 15600008129298J													
QUANTITY		DOLLAR VAL		WORLDWIDE LEVELS		MGR		KGB					
BUY.....	10	36111.60	BUY OPERATING.....	14	TERMINATION.....	15		DISTRIBUTION LEVELS					
TERMINATION		.00	TERMINATION.....	17	MINIMUM RETENTION...	22		CONTROL.....					
EXCESS.....		.00	MINIMUM RETENTION...	48	GROSS RETENTION...	58		SUPPORT.....					
PR/MIPR(R).	3	10832.48	GROSS RETENTION...	60				ROUTED REPR REPL					
			SELECT RETENTION...	48									
SOURCES OF REPAIR AND PERCENTS													
SM 100													
DELIVERY SCHEDULE													
PT BUY		DEL BEGIN		PHASED DELIVERY		QUANTITY		DATE		BY		DATE	
INIT DATE	QTY	DATE	QTY	QTR 1	QTR 2	QTR 3							
8801	0000010	8701	0000010	0000000	0000010	0000000							
DATE		BY		DATE		BY		DATE		BY		DATE	
PR/MIPR		QUANTITY		DATE OF		CSN		PR/MIPR		QUANTITY		DATE OF	
NUMBER		00000002		85072		15600008129298J		NUMBER		00000001		85072	
15600008129298J		FD20408556318						FD20408556318					
CURRENT STOCK NUMBER													
15600008129298J													

SM-MWK BC		REQUIREMENTS COMPUTATION		01 NOV 85 PAGE 40636		PCN A-0041-PK3-CZ-8ZG C4-INITIAL	
MASTER STOCK NO 1360000812929BJ		MGR KBC					
AY	BY	VRM	OVRM	FMS(INFO ENTRY ONLY)			
AF POS RQMT (INCLUDING FMS)							
*DEFERRALS	\$		PHASE OUT	PR QTY	PR QTY		
AF POS RQMT	\$		VRM RQMT	NET OVRM	NET FMS		
PR QTY	\$		PR QTY	\$			
NET AF POS			NET VRM				
\$			\$				
TOTAL DOLLARS TO BE APPROVED: \$							
UNIT	SECTION	BRANCH	DIVISION	DIRECTORATE			
SIGNATURE	DATE	SIGNATURE	DATE	SIGNATURE	DATE	SIGNATURE	DATE
* QUANTITY DEFERRED FROM BUY DUE TO NO ACTUAL EXPERIENCE.							
BASE SAFETY LEVEL							
DEPOT STOCK LEVEL							
BASE CONDEMNATIONS							
DEPOT B/M CONDEMNATIONS							
APPLICATION NO. PGM APPL DEV PGM REQ OPA APPL \$							
P111A 1200 4AEE 7008 0002 100							
APPLICATION DATA							

SM-MARK BG

MASTER STOCK NO 15800008129298J

MGR KBC

REQUIREMENTS COMPUTATION

01 NOV 85
PAGE 40637PCN A-COM1, -PM2-C2-62G
C4-INITIAL

***** APPLICATION DATA *****

APPLICATION NO.	PCN SEL	APPL ESSN	DEV CODE	PGM BEG DATE	OPA	APPL X
F111D	1200	4AEE		7004	0002	100
F111E	1000	3AEE		9006	0002	100
F111F	1200	3AEE		7004	0002	100
F111A	1200	3AEE		7806	0002	100
F111A	1200	3AEE		7004	0002	100
15600048052078J	1200	4AEE		7009	0001	100
15600048052088J	1200	4AEE		7009	0001	100

Gerry

16 Nov 85

On NSN 1520 00 081 2929BJ, PN 12F8320-3, tip -
the application is wrong - It only goes on small
spike. Application shows it is used on F111a.

12F8320-3

Please correct in D041.

D	D	} DELETED J.R. VULL
E	D	
F	D	
FB	D	

Hamber
Bar E.

SIR-BANK DC		REQUIREMENTS COMPUTATION												OS MAY 85 PAGE 34016		PCN A-D041--PK2-C2-62C C4-INITIAL	
MASTER STOCK NO 15600008128298J		MGR K86															
LINE IDENTIFICATION		SIP 84	DEC 84	MAR 85	JUN 85	SEP 85	DEC 85	MAR 86	JUN 86	SEP 86	DEC 86	MAR 87	JUN 87	SEP 87	DEC 87	BUY PD	TERM PD
MET DEP UNVVC		SIP 87	DEC 87	MAR 88	JUN 88	SEP 88	DEC 88	MAR 89	JUN 89	SEP 89	DEC 89	MAR 90	JUN 90	SEP 90	DEC 90	90	90
		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
OIM REP GEN(MRTS)		4	5	5	6	6	7	7	7	8	8	9	9	9	10	3	5
OIM REP GEN CONDOM		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3
MET OIM REP GEN		3	4	4	5	5	6	6	7	7	7	7	7	7	8	2	4
MET SLIP OIM GEN		3	3	4	4	4	5	5	6	6	7	7	7	7	7	2	3
OIM REP REP CYCLE		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NJR REP GEN		11	12	14	16	17	18	20	22	24	26	27	28	29	30	12	45
NJR REP GEN CONDOM		2	2	2	3	3	3	3	3	4	4	4	4	4	5	2	8
MET NJR REP GEN		9	10	12	13	14	15	17	18	19	20	20	22	22	24	10	37
MET SLIP NJR GEN		8	9	11	12	13	14	16	17	18	19	21	22	22	23	9	37
NJR REP REP CYCLE		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TOT AVAIL REP REPR		12	13	16	17	19	20	22	24	26	27	29	30	31	31	8	90
3RD SHORT		5	8	7	9	9	9	8	11	10	12	12	10	16	4	8	20
MISTR INPUT AC		12	14	16	17	19	21	23	24	26	27	29	30	31	31	14	50
MISTR INPUT D-AC		2	2	2	1	1	1	1	1	2	1	2	1	1	2	2	19
MISTR OUTPUT AC		12	12	16	17	19	20	23	24	26	27	29	30	31	31	13	90
MISTR OUTPUT D-AC		2	1	3	1	1	1	1	1	2	1	2	1	1	1	1	19
PT MISTR INPUT AC		12	14	16	17	19	21	23	24	26	27	29	30	31	31	14	90
PT MISTR INPUT D-AC		2	2	2	1	1	1	1	1	2	1	2	1	1	2	2	19
PT MISTR OUT AC		12	13	16	17	19	20	23	24	26	27	29	30	31	31	13	90

SM-MAN 80		REQUIREMENTS COMPUTATION										OS MAY 85 PAGE 34017		PCN A-DO41-PK2-C2-62G C4-INITIAL		
MASTER STOCK NO 15800008129298J		NOR KBC														
LINE IDENTIFICATION		SEP 84	DEC 84	MAR 85	JUN 85	SEP 85	DEC 85	MAR 86	JUN 86	SEP 86	DEC 86	MAR 87	JUN 87	SEP 87	DEC 87	PCN
PT MISTR OUT D-AC		2	1	3	1	1	2	1	1	2	1	1	2	1	1	19
TIME PHASED USERS		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

SW-MMR EQ		REQUIREMENTS COMPUTATION		OS MAY 85 PAGE 34018	PCN A FINAL - PW2-C2-62G CA INITIAL
MASTER STOCK NO 15600008129298J		MOR KBO			
AY	BY	VRM	OVVM	FMS(IMPD ENTRY ONLY)	
AF POS POINT (INCLUDING FMS)					
DEFERRALS		PHASE OUT	PR QTY	PR QTY	
AF POS POINT		VRM POINT	MET OVVM	MET FMS	
PR QTY		PR QTY			
MET AF POS		MET VRM			
TOTAL DOLLARS TO BE APPROVED: \$		\$			
UNIT	SECTION	BRANCH	DIVISION	DIRECTORATE	
SIGNATURE	DATE	SIGNATURE	DATE	SIGNATURE	DATE
QUANTITIES DEFERRED FROM BUY DUE TO NO ACTUAL EXPERIENCE.					
BASE SAFETY LEVEL					
DEPOT STOCK LEVEL					
BASE CONDEMNATIONS					
DEPOT B/W CONDEMNATIONS					
APPLICATION NO PER APPL DEV PER BEG OPA APPL %					
SEL ESUM CODE DATE					
P111A	1200	4AEC	7008	0002	100
APPLICATION DATA					

SM-NM-88

REQUIREMENTS COMPUTATION

05 MAY 85
PAGE 34070

PCN A-0041-PM2-C2-82G
C4-INITIAL

MASTER STOCK NO 15600008129296J

NCR K8C

***** APPLICATION DATA *****

APPLICATION NO.	PCN SEL	APPL ESSN	DEV CODE	PCN REC DATE	OPA	APPL %
871114	1200	34EE		7808	0007	100
15600048052078J	1200	44EE		7009	0001	100
15600048052088J	1200	44EE		7009	0001	100

Y
Y
Y
Y
Y
Y
Y

SM-MARK BG	REQUIREMENTS COMPUTATION												06 JUN 85 PAGE 32971	PCM 3-DOH1-PM3-CZ-82G CA-FINAL	Y
MASTER STOCK NO 19800008123296J	MOB MOB														Y
LINE IDENTIFICATION	SEP 84	DEC 84	MAR 85	JUN 85	SEP 85	DEC 85	MAR 86	JUN 86	SEP 86	DEC 86	MAR 87	JUN 87	SEP 87	DEC 87	Y
	SEP 87	DEC 87	MAR 88	JUN 88	SEP 88	DEC 88	MAR 89	JUN 89	SEP 89	DEC 89	MAR 90	JUN 90	SEP 90		Y
DEP UNVVC ASSETS	5	5	5	5	5	5	5	5	5	5	5	5	5	5	Y
DEP CONOM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Y
MET DEP UNVVC	4	4	4	4	4	4	4	4	4	4	4	4	4	4	Y
QIM REP GEN(MRTS)	4	5	5	6	6	6	7	7	8	9	9	9	10	10	Y
QIM REP GEN CONOM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Y
MET QIM REP GENS	3	4	4	5	5	5	6	6	7	7	7	7	8	8	Y
MET SLIP QIM GENS	3	3	4	4	5	5	5	6	6	7	7	7	7	7	Y
QIM DEP REPR CYCLE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Y
NUM REP GENS	11	12	14	16	17	18	20	22	23	24	26	27	29	30	Y
NUM REP GEN CONOM	2	2	2	3	3	3	3	3	4	4	4	5	5	5	Y
MET NUM REP GENS	9	10	12	13	14	15	17	18	19	20	22	22	24	24	Y
MET SLIP NUM GENS	8	9	11	12	12	14	16	17	18	19	21	22	23	23	Y
NUM DEP REPR CYCLE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Y
TOT AVAIL DEP REPR	15	16	18	20	22	23	25	27	28	30	32	33	34	34	Y
3RD SHORT	18	19	16	20	17	18	22	22	26	28	30	27	27	27	Y
MISTR INPUT AC	15	17	19	20	22	23	25	27	28	30	32	33	34	34	Y
MISTR INPUT D-AC	2	2	2	1	1	1	2	2	1	1	1	1	1	1	Y
MISTR OUTPUT AC	15	16	18	20	22	23	25	27	28	30	32	33	34	34	Y
MISTR OUTPUT D-AC	2	1	3	1	1	1	2	2	1	1	2	1	1	1	Y
PT MISTR INPUT AC	18	17	18	20	22	23	25	27	28	30	32	33	34	34	Y

SM-NMK 80
MASTER STOCK NO 18600008129298J

PCN A-0041.-PK2-CZ-67G
C4-FINAL

REQUIREMENTS COMPUTATION

06 JUN 85
PAGE 23873

QUANTITY DOLLAR VAL WORLDWIDE LEVELS MGR K86

BUY..... 18 84187.40 BUY OPERATING.....
TERMINATION..... .00 TERMINATION.....
EXCESS..... .00 MINIMUM RETENTION.....
PR/MIPR(B). 3 10823.48 GROSS RETENTION...
SELECT RETENTION..

DEPOT LEVELS

22 TERMINATION.....
26 MINIMUM RETENTION...
86 GROSS RETENTION...
86

DISTRIBUTION LEVELS

CONTROL 26
SUPPORT..... 1
ROUTED REPR REPL

SOURCES OF REPAIR AND PERCENTS

SM 100

DELIVERY SCHEDULE PT BUY INIT DATE PT BUY QTY DEL BEGIN DATE
8907 0000015 8907
REVIEWED-BY *Blair* DATE 14/85 BY *Blair* DATE 6/87
CSM PR/MIPR NUMBER QUANTITY DATE OF ORIGIN
18600008129298J FD20408558318 00000002 85072
PHASED DELIVERY QUANTITY
QTR 1 QTR 2 QTR 3 QTR 4 QTR 5
0000000 0000015 0000000 0000000 0000000
BY DATE BY DATE BY DATE
PR/MIPR NUMBER QUANTITY DATE OF ORIGIN
FD20408558318 00000001 85072

CURRENT STOCK NUMBER
18600008129298J

ALT = 9mm per mmmt ltr. 1 May 85 (DOU/ALT)

Buy = AY 322 PL 85-56318
1222 85-60779
(pousa) BY 322 86-50557
1822 865,000.81

SM-WRK BG	REQUIREMENTS COMPUTATION										OS JUN 85	PCN A-0041.-PK2-C2-6ZG
MASTER STOCK NO 15600008129298J	MGR KBQ										PAGE 33375	C4-FINAL
APPLICATION NO. PGM SEL APPL DEV PGM BEG DATE OP4 APPL % APPLICATION DATA												
EF1111	1X00	3AEE	7808	0002	100							
156000-16052078J	1X00	4AEE	7009	0001	100							
156000-16052088J	1X00	4AEE	7008	0001	100							

APPENDIX I

EXERCISES USED DURING THE
INITIAL KNOWLEDGE ENGINEERING
SESSIONS TO DETERMINE
THE SCOPE OF THE PROBLEM

EXERCISES USED DURING THE INITIAL KNOWLEDGE ENGINEERING
SESSIONS TO DETERMINE THE SCOPE OF THE PROBLEM

EXERCISE ONE

Please answer the following questions. Be as specific as possible. Read all questions first.

1. Define "scrubbing the comp". What does this statement mean to you?

2. Is "scrubbing the comp" different in the initial comp cycle from the final comp cycle?

_____ YES

_____ NO

If yes, how is it different?

3. Is any quarterly comp (e.g., March, June, September, December) more important for scrub purposes than any other?

_____ YES

_____ NO

If yes, which quarter/quarters are more important and why?

4. What is the objective of "scrubbing the comp" in the initial cycle?

5. What is the objective of "scrubbing the comp" in the final cycle?

EXERCISE TWO

In the folder in front of you is a "case." This is an actual comp and all the required supporting data. All seven experts have the same "case" as you. Use the tablet provided and "scrub this comp" in accordance with the following instructions.

Be very specific and very detailed. Write out how you scrub the comp in procedural order (e.g., first I, next I). Number each step. Don't just say first I check assets or nomenclature, etc. Be specific. Where do you find the information (e.g., on the _____ printout, page _____, line _____, under column _____, it says _____)? Highlight this data element. Indicate the appropriate step number next to it. What specifically do you check? What is the question you are attempting to answer (e.g., How many assets are located at the depot?). How do you answer this question? Where exactly do you look for the information? Why are you doing this? What are you trying to find out or establish?

Please try to explicitly list all the detailed intermediate steps you go through.

EXERCISE THREE

What are the elements in order that you review in scrubbing the comp? Please list them.

EXERCISE FOUR

1. What are the ten most important items to scrub on the D041 computation?

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.
- 7.
- 8.
- 9.
- 10.

2. What are ten items most frequently incorrectly scrubbed by novices?

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.
- 7.
- 8.
- 9.
- 10.

APPENDIX J
SAMPLE TRANSCRIPTS
FROM THE KNOWLEDGE
ENGINEERING SESSIONS

SAMPLE TRANSCRIPTS FROM THE KNOWLEDGE
ENGINEERING SESSIONS

- MK: Expert 2, I would like you to instruct me, a new IM, on how I file maintain the unit cost and date of last procurement.
- Expert 2: When you get your comp, you look at your unit price and validate it by going to your 318, 339 card, and your last AF contract price. You multiply this price by 103 percent for storage and handling. That's what should be in the computation.
- Expert 1: Unless -
- MK: First, tell me when I go to the 318 what do I look at?
- Expert 2: On the far right hand side of the 318, you look at "contr. unit cost." That should be the contractor's actual price.
- MK: Okay, on the 318 from Case #1, I have a unit cost of \$8344 and then right underneath that I have \$18212.91 with an asterisk. Which one of those do I use?
- Expert 2: This is one of those unless or unique situations. This has tooling. Tooling is supposedly a one-time cost.
- MK: How do I know it has tooling?

- Expert 1: See the note in parentheses on the 318 right underneath the cost.
- Expert 2: It would also be in the contract. If everything were normal on this item, there would only be one price. In a situation like this I would still use the \$8344 because that's what the cost is since tooling is normally a one-time expense. The price you want to file maintain as the standard price is 1.03 times the cost.
- MK: Okay, now what's the 339?
- Expert 2: The 339 card is where you get this information from. It's a J041 product.
- Expert 1: It's keypunched from the contract with the unit cost and with the estimated delivery date.
- Expert 2: As a keypunched document it can be in error so that's why you back it up against the contract. The 318 is just a ready reference guide. You put all your information on it that you get from everywhere else. If a person's done the 318 right, all they should have to look at is the 318. If it's right all they need to look at is the standard price on the top block of the 318. They're supposed to put this price in pencil and refigure it (multiply by 1.03) every time they have a contract. You're safer to tell a new person to look at the contr. unit cost and multiply it by 1.03.

- MK: Then what are some of the other exceptions besides tooling?
- Expert 2: There's the quantity discount. You get a price break if you buy X amount of items. You buy 100 items it cost \$8000. You buy 200, it's only going to cost you \$4000.
- MK: How do I know if I have a quantity discount? Will that be in the remarks?
- Expert 2: It might be in the remarks. But also your PR will be written as a quantity discount PR.
- MK: And if the price is a quantity discount price?
- Expert 2: Then I would temper using the unit cost with a little bit of judgment.
- MK: For example?
- Expert 2: First, I need to know if the item will always be reprocured in the future using quantity discounts.
- MK: Does it matter how much the quantity discount is for?
- Expert 2: Yes, especially if the discount is significant.
- MK: What's significant?
- Expert 2: If I'm only going to get a \$50 price break on something, big deal.
- Expert 6: No, on quantity discount if we do not accept the most advantageous quantity, it has to be justified and approved at branch level or higher. So, you are going

to be buying the most advantageous quantity on a quantity discount.

MK: Is significant a 5 percent change, a 10 percent change?

Expert 4: There's not an Air Force definition?

Expert 6: I personally would not use the quantity discount price if I did not believe I was going to purchase quantity discount in the future.

Expert 1: I think I would always use the regular price in the computation because even if you're going to be buying at quantity discount in the future, you're going to have an escalation of cost.

Expert 2: You get three quotes, a regular price, a second price, and the third price which is usually the most advantageous price. If you file maintain the first price all the time, that is what you normally will be buying. That can be documented and justified.

MK: Are you saying that regardless of whether or not it's a quantity discount, I still file maintain the normal price not the quantity discount price?

Expert 1: Kind of.

Expert 7: Yes.

Expert 6: Except where you're always buying an item on quantity discount.

- MK: So, Expert 6, if you think you're always going to buy this item on quantity discount you use the quantity discount price?
- Expert 6: Yes.
- Experts: Always.
- Expert 6: Yes. If past history shows we've always gone out for quantity discount, I would use the quantity discount price. If this appears to be the first time it's been bought on quantity discount and I don't think that it will be bought on quantity discount in the future, I'd use the standard price.
- Expert 2: I disagree with that.
- Expert 1: I disagree with that also.
- Expert 2: If you use the quantity discount price all the time on a steady, regular item, the quantities change from year to year. The more quantity you buy, the cheaper it's going to be. Your inflation changes after three years when you go back in a buy. I would feel a lot safer using the standard regular price.
- Expert 7: Unless you're using the provisioning price.
- MK: What is the provisioning price?
- Expert 2: Provisioning prices are estimates of what the contractor is going to charge us for the first few items' production. The prices are usually way out of line.

- Expert 6: It's not necessarily an estimate. You can get an actual out of provisioning, but it's based on the production of the end item and all the spares that that contractor is manufacturing. It can be totally wrong.
- Expert 5: I think the price that can be substantiated should be used.
- Expert 7: I'm with Expert 2 as far as the quantity discount is concerned unless you had to go back to a provisioning price. But if you had a contractor quote, you could use that. That's fine. You don't ever want to go back to a provisioning price if you have anything else.
- MK: Expert 4, how do you feel about this?
- Expert 4: I don't know that much about QD.
- Expert 5: If you bought an item on QD the last ten times, you can substantiate that price. If you can substantiate it, you can use it.
- MK: If I bought it QD the last ten times, then I use the QD price. Otherwise, I use the actual price. Is that a good rule to follow?
- Expert 5: Nobody can argue with that.
- Expert 4: If you bought it QD the last ten times though, isn't the actual price on your comp going to be the QD price?

- Expert 1: Yes.
- Expert 5: Yes, except for the inflation.
- Expert 4: Except for the inflation which you're going to pick up anyway.
- Expert 6: I'm saying I'd use that.
- Expert 4: If we didn't change it, the computer would still use that. It would pick it up as an actual.
- Expert 2: I always check my actuals too though. The system is not infallible. They are overlaying junk.
- MK: How do you check your actuals?
- Expert 6: Contract.
- MK: Will every IM have a copy of the contract?
- Expert 2: They should.
- Expert 6: We don't necessarily get the whole contract. We get the pages that are important to us.
- Expert 5: This is a good example of an actual. As you can see this comp has an actual price, but this actual price is not correct, so you would have to change it. The actual price in here is probably from the previous contract.
- MK: I still am hearing a disagreement regarding which price to use. Some of you appear to be using the regular price and others, the quantity discount price.
- Expert 2: They're both right.

- MK: Why are they both right?
- Expert 2: If it's a steady QD item, where you've always bought it on QD and you're always going to buy on QD, then I would use the QD price. If anything changes, like it's the first time you've ever bought QD, I wouldn't use it. I wouldn't use it for items that sometimes you're going to buy for five, sometimes you are going to buy for one hundred. The really fluctuating stuff, I wouldn't use it.
- MK: Does everyone agree with that?
- Experts: Yes.
- Expert 2: Okay, price breaks are another unless. Price breaks are different from QD.
- Expert 6: Price breaks involve different quantities. The contractor is offering to sell one more item to us at a lower cost than the rest of the contract quantity.
- Expert 2: I would use the regular price, not a price break price.
- Expert 7: I agree with that.
- Expert 2: Another thing is an urgent requirement. Sometimes they charge you more for an urgent requirement. They build in their overtime costs. There again, I'd only use a last actual regular contract price.
- MK: How would I know if it was an urgent requirement?

- Expert 2: Because you'd have had to do all the documentation to justify it as urgent.
- Expert 6: Expert 2, are you saying not to use the unit price off of a priority A, or B, or C PR?
- Expert 2: An unpriced order.
- Expert 1: I think anything other than routine would qualify. Normally, the IMS will make a comment in the remarks block, urgent PR.
- MK: If this price of \$8344 represented an urgent PR and the last time I bought the item on a routine basis, over two years ago, the cost was \$6500, which cost would I use?
- Expert 2: I would use the \$6500 and the date of the last procurement (DOLP) for that \$6500 because it will inflate it.
- Expert 6: You might want to temper that based on the contractor's quoted delivery. Just because we wrote a priority PR doesn't mean that the contractor has quoted for overtime. He may be going to deliver it in 12 months which is his normal leadtime, regardless of our priority.
- Expert 1: Then you would annotate on your 318 treated like a routine PR.

- Expert 2: That's when you'd use your regular leadtime and everything else.
- Expert 6: Yes. So you have to look at more than whether the PR is marked urgent or routine.
- Expert 1: We're talking about the ones where you wrote the PR as an urgent requirement and it was treated like an urgent requirement in procurement also and the contractor treated it like an urgent requirement.
- Expert 7: Such as a brickbat.
- MK: What's a "brickbat"?
- Expert 7: A brickbat gives a contractor authority to work overtime and put a priority on it. Therefore, your costs will probably be more.
- Expert 6: We're talking about looking at leadtime for people who don't know. And you're saying they'll know it's routine. But we're looking at the priority, and you're going to give them a rule if it's an urgent PR, you don't consider that unit cost.
- What I'm saying is they don't know. You've got to tell them more than that to say that this leadtime has always taken 24 months, the contractor's quoting 24 months. Therefore, he didn't treat it as urgent.
- Expert 2: How about an urgently awarded contract or an urgently delivered contract?

- Expert 1: Just an urgent contract.
- Expert 6: Based on my experience right now with priority PR's, the contractor is not adding in any cost for overtime or anything else. If we want overtime costs included, we go with an ADR and its added on afterwards.
- Expert 1: Because procurement's treating those as routine rather than urgent requirements. But remember there are times when they do treat those as urgent requirements and you do get charged for them.
- Expert 6: I admit there are very few. They are the exception rather than the rule. I agree, like Expert 7 said, there are brickbat.
- Expert 7: It's my understanding that on brickbat, the contractor has been turned on and told that brickbat will be worked overtime. That does affect the cost. I don't know what other things there are that might turn procurement on to giving us a bigger price. I do know that brickbat will.
- Expert 2: Brickbat is always FAD1. We have cases other than FAD1 when procurement treats it like an overtime requirement. When the contract is awarded and you talk to the buyer on the contract award and the price, he's supposed to call you on this anyway. You're going to know.

- Expert 1: And on your 318 it should be annotated as urgent contract.
- Expert 2: That's right. Then you don't use that leadtime, you don't use that price, because it's nonstandard.
- MK: That's if it's awarded as an urgent contract. Also, are you telling me that an IM will know that? I thought Expert 6 said she didn't feel they would know it.
- Expert 6: This type of urgent, yes, they will know. They will be justifying the urgency of the award and the urgency of the delivery.
- MK: Does everyone agree?
- Experts: Yes.
- MK: Okay, then are there other exceptions?
- Expert 6: Contractor's minimum quote. We want to buy 6 each and the contractor says sorry, smallest minimum quantity we'll build is 10 each. You would not want to use that quantity.
- Expert 1: Why not?:
- Expert 6: Because most probably you are going to a sole source contractor. The next time we buy it, we're going to have data available and we'll buy our 6 each that we need and not the 10 each.
- Expert 1: You can't make that assumption.

Expert 2: What the contractor is saying is whether you buy 2 or you buy 10, you're going to get charged a thousand dollars. So the 2 can cost you \$500 a piece or the 10 can cost you \$100 a piece.

Expert 6: Ours are coming back saying I will only build 10.

Expert 1: At the same unit cost?

Expert 6: No, the unit cost will be different. They say it's uneconomical for them as a contractor to build less than 10. Because of them buying their materials, if we're willing to pay for the uneconomical material.

Expert 1: So it's not changing the unit cost.

Expert 2: See in the instance that I brought up, sometimes the contractor will say, okay you're going to spend \$10,000 no matter how many. It's a minimum cost. It's not a minimum quantity.

Expert 1: That would be an exception a minimum cost.

Expert 2: More likely, they'll give you a minimum cost than a minimum quantity.

Expert 6: No, Fairchild gives you minimum quantities.

MK: Assuming the situation was one of minimum cost, which price would you use?

Expert 2: The last standard cost from a regular contract.

Expert 7: I agree.

MK: What if you didn't have a last standard cost?

Expert 6: Average cost, prorated cost.

Expert 7: I don't know.

Expert 2: Ask your supervisor.

Expert 7: You could use your provisioning estimate.

Expert 2: I would use the last regular AF contract price provided I had one. If not, I'd use the provisioning cost. That's better than anything else.

Expert 1: The thing we must say there is we do not add the 3 percent to a provisioning price.

Expert 4: Right.

Expert 7: That's a good rule.

Expert 1: The IMs must annotate in the remarks block that they did not add the 3 percent (first destination transportation) to provisioning cost or contractor's quotes.

MK: Does everyone agree with this on contractor's minimum price?

Experts: Yes.

MK: Any other exceptions?

Expert 7: Yes, contractor's excess. We're buying material that's bought from the contractor as excess. But they shouldn't use that price.

MK: How would an IM know if it was a case of contractor's excess?

- Expert 7: Because they have to amend their PR to show that they're buying excess from the contractor.
- MK: In this case what price would they use?
- Expert 7: The last contract standard price and/or provisioning estimate.
- Expert 6: Along those same lines, the IM knows when we go out of production. We buy a lot of residual material back from the contractor that's on hand at his facility.
- Expert 7: But that's excess.
- Expert 6: But they're not quoting. They're offering it back to us.
- Expert 2: I can't think of any other exceptions.
- Expert 5: What about FMS?
- Expert 1: Don't use an FMS price.
- Expert 7: We don't use the FMS price if we're procuring direct ship for a foreign government.
- MK: Do you go back to the standard price again?
- Expert 5: Yes.
- Expert 6: We do use the FMS price if we're buying for case levels.
- Expert 7: In this case, you're buying and it's coming in to the Air Force.
- Expert 2: Anything that's coming into our account . . .
- Expert 7: If it's not a direct ship.

- Expert 1: If it's procured with AF funds, you would use the unit cost from that contract even if it's going to be for a case level because it doesn't become the property of the foreign government until they order it and pay for it at that time.
- MK: So if I'm buying with AF funds . . .
- Expert 5: That creates a problem for new IMs. They look at BP18 as FMS funds.
- Expert 7: They sure do.
- Expert 2: The easiest way to express it is you don't use an FMS price.
- Expert 7: FMS price means direct cite.
- Expert 1: Right. That's where you're using that country's bank account. You do not use an FMS price when the item is procured with direct cite funds.
- MK: Does everyone agree with that?
- Experts: Yes.
- MK: Is an IM going to know what direct cite funds are?
- Experts: Yes.
- MK: How do they know?
- Expert 7: Some of them may not know the difference between direct cite funds and when you're shipping on a requisition.
- Expert 2: Direct cite funds are 4F funds.

- Expert 6: Direct cite would be anytime you're buying for shipment to that country. If you're buying and it's being shipped to McClellan, and going to then be shipped to a foreign country, you would use that cost. Whenever it is being received by the U.S. Air Force, you would use that cost.
- Expert 2: Not necessarily. You can have a direct ship without a direct cite.
- Expert 6: How?
- Expert 2: Let's say you've got a case level, and you've got a PR/contract working and you have to put in an ASI because it's priority two and they want it right away. Why have it shipped in here? Have it go straight from the contractor to them.
- Expert 6: But when you do the ASI, you're also going to do an amendment that changes the fund cite.
- Expert 2: Not for a case level.
- Expert 7: I think the best way to clarify it is to put 4F fund code in brackets right after cite. All the IMs will know that.
- MK: Would this satisfy your concern, Expert 6?
- Expert 6: I have to think about it.
- MK: Does everybody else agree with that?

- Expert 1: You did say we'll get to see the knowledge base and critique it?
- MK: Yes.
- Expert 1: Then we'll all go home and read up on this.
- MK: For now, then, are there any other exceptions?
- Expert 1: I think we've got them all.
- MK: Going back for a moment then, is contractor's excess the same as out of production or not?
- Expert 6: No. They're different.
- Expert 1: I think Expert 6's talking about contractor surplus not contractor excess.
- Expert 6: That's right. But what happens on the surplus? On some of the older aircraft, that's the only people that you buy from. Then, why wouldn't you want to use that cost, if that's the only way that you can support that item?
- Expert 7: But you don't know what the next cost is going to be. I've bought from the same surplus dealer on different occasions and paid totally different prices.
- Expert 2: Yes, and sometimes you get a surplus one time and a regular contract another.
- Expert 7: I don't think surplus prices are very good to use.
- Expert 2: Especially now with them advertising so much with the small businesses.

- Expert 6: But some of this we don't own the data. We can't go and get data so we don't have the capability of getting someone to manufacture this item, unless we reverse engineer it.
- Expert 1: I always go back to the standard price.
- Expert 2: You might want to add a note on surplus that if you know that that's your only means of support, you treat the surplus price as a standard price.
- Expert 7: But that surplus dealer can charge any price he wants. So I wouldn't use a surplus price at all.
- Expert 4: But in this case if you say you're not going to use it because it's surplus. You're going to use your standard. In the situation we're talking about where it's always a surplus contractor, it's going to be your standard price anyway. You just don't need to put that statement in.
- MK: Any other exceptions?
- Silence
- What about the tooling we just had on case #1?
- Expert 1: Oh, you're right. The one right in front of our faces.
- Expert 2: Tooling and first articles.
- MK: Are these two separate things?

Expert 2: Yes. Tooling is usually a separate cost but it's not always identified though. We're going to know at the time of contract award though if we need to buy tooling.

Expert 6: No, we're not. We're finding out after the fact. Then, it's only because we ask procurement.

Expert 2: Then maybe we need a little note to the IMs' when they're doing the prices, to ask procurement about the tooling.

Expert 6: You will know if it's an item where we have to provide tooling to the contractor, on refurbishment tooling, because they have to quote that separately.

Expert 1: I just thought of another one, GFM. We'll talk about that next.

Relative to tooling, with CV helping us sort our prices, we're more likely to know now when we have tooling on an item.

Expert 6: If it's identified either on the copy of the contract which the IM receives or identified by the buyer, it should be annotated on the 318, those additional one-time costs.

The other thing is, sometime you may get that identified as a tooling cost but it's a repetitive tooling cost. For example, a casting that's going to last for 50 items then you're going to need a new one for the next 50 items.

Expert 2: That type of tooling should be included in the price of the item.

Expert 6/
Expert 1: I agree.

Expert 2: But when you're buying one-shot type tooling, it should not be included in the unit price.

Expert 1: Shouldn't we get that tooling back if we pay for it?

Expert 6: Yes, we own it. Usually, you'll find out that there's tooling costs because they'll ask for disposition of that tooling. That's usually at the end of the contract.

Expert 7: Why don't we say don't include the cost of one-time tooling?

MK: Will the IM know if it's one-time tooling?

Expert 2: They should.

Expert 6: If it's identified to them.

Expert 2: If one-time cost of tooling is identified in the item, then that standard price should not include the tooling cost.

MK: Okay, what about the first articles?

- Expert 7: I have another thing that relates to that, system compatibility testing.
- Expert 1: Couldn't that be covered under first article. Those kinds of things are all the same, for example, special engineering or testing requirements.
- Expert 6: They're on a data line, aren't they?
- Expert 2: Well, not always. See J041 only accepts one cost and that's the price that J041 puts in as an actual. They add the costs, e.g., \$100,000 for tooling, plus \$5,000 per item. They add it all together. They divide it by the quantity you're buying and they put that number in as the cost of the item. That's why we want to make sure that the item managers don't always believe the actual J041 prices. Contract and line item number should really be used for first article testing and engineering, etc. to make sure that they watch out for that.
- Expert 1: I'd refer to it as special engineering/test requirements. If you have these, you should either use the last standard price or subtract the special cost from the total unit cost.
- MK: Okay, what about GFM?

Expert 2: Whenever you furnish GFM, they lower the price of the item because you are giving them parts of that to make it, so you can't use the unit cost that they're quoting you. Because they're giving you a price break per se for GFM. There again, you use the last standard price.

MK: What if you've always given them GFM?

Expert 2: If you've always given them GFM and you always will be giving them GFM . . .

Expert 1: Add the unit cost of the GFM in the unit cost.

Expert 7: If you know what it is.

Expert 1: You look it up in the ML, the military listing, you'll know which items are GFM, you have to make out the paperwork to send it to them.

MK: Does everyone else agree with what Expert 1 said?

Experts: Yes

Expert 2: Who would have thought that unit cost was this complicated! How do we know all this?

Expert 7: Along with this, are we addressing the DOLP too?

Expert 2: Yes. Okay. Whatever unit price you use, you use the contract award date for that unit price as the DOLP.

Expert 6: Exactly.

Expert 7: That's right.

APPENDIX K

FORMAL EVALUATION PLAN
FOR THE INVENTORY MANAGER ASSISTANT
(IMA) EXPERT SYSTEM

FORMAL EVALUATION PLAN FOR THE INVENTORY MANAGER ASSISTANT (IMA) EXPERT SYSTEM

Objective of the Evaluation

The evaluation of the Inventory Manager Assistant (IMA) Expert System will be designed to test hypotheses three and four of this research. Specifically, these hypotheses are:

Research Hypothesis 3: The use of expert systems will have no effect on the ability of inventory managers to make more effective decisions.

Research Hypotheses 4: The use of expert systems will have no effect on the ability of inventory managers to more efficiently make inventory management decisions.

Experimental Model

A single experiment will be used to measure decision effectiveness and efficiency. This experiment will be a between-subjects, two-by-two-by-three factorial design. The three treatments and levels of each will be:

<u>Treatment</u>	<u>Levels</u>
1. Task Method	1. With Expert System 2. Manually
2. Task Difficulty	1. Simple 2. Complex
3. User Experience	1. Novice 2. Journeyman 3. Advanced

Hence, twelve cells comprise the experiment and each subject will participate in only one cell.

The experimental model then becomes

$$X_{ijkl} = \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ij} + \alpha\gamma_{ik} + \beta\gamma_{jk} + \alpha\beta\gamma_{ijk} + \epsilon_{ijkl}$$

Where i = 2 levels of task method
 j = 2 levels of task difficulty
 k = 3 levels of user experience
 l = cell replicate

Effectiveness/Efficiency Defined

Efficiency will be operationalized as time to complete the task. Effectiveness will be operationalized as a performance score ranging between 0 and 100 points. Scores will be determined by comparing each subject's answers on the task completed with a test key for each task determined by the IMA developmental experts and validated by a panel of three other experts.

Each task, simple and complex, will require the subject to determine the correct values for the following ten parameters:

1. Unit Cost
2. Date of Last Procurement
3. Administrative Leadtime
4. Production Leadtime
5. Repair Cycle Time
6. Base Processing Time
7. Reparable Intransit Time
8. Supply to Maintenance Time
9. Shop Flow Time
10. Turn In Time

Each of these parameters is expressed as a quantitative value and can be objectively rated based upon the amount of deviation of the subject's answer from the correct answers. The experts will be asked to determine the answer or range of answers for each of these ten parameters for both the simple and complex case that fit the following descriptive categories: very good answer, good answer, mediocre answer, poor answer, very poor answer. Answers which fall in these ranges will be assigned the following respective point values: 10, 7.5, 5, 2.5, and 0. Hence, a subject can score between 0 and 100 points. All scoring will be computerized to keep the evaluation as objective as possible.

Evaluation

Results will be evaluated via ANOVA procedures with the use of the Statistical Package for the Social Sciences. Separate ANOVA procedures will be performed for each of the ten elements for which IMA provides advice as well as for the total score. Since all ten of these elements are not necessarily of equal weight, both the development experts and the independent validation panel will be asked to provide weightings by distributing 100 points among these ten elements. ANOVA procedures will then be performed for these weighted scores as well. An additional ANOVA will be performed for completion time as the dependent variable.

Other Data Collected/Analyzed

Additional data collected from each subject will include experience in interacting with a computer, and confidence in making decisions with a computer. Subjects who perform the task with the assistance of the expert system will also be asked to complete an unstructured critique. These data will be treated as continuous and used as covariates in the data analysis.

Successful Performance

As IMA is a research prototype, testing is expected to uncover areas of weaknesses. Therefore, any elements which result in poorer performance when the expert system is used than the performance when the expert system is not used, will be excluded from the evaluation of successful performance, provided use of the expert system improves performance on at least five of the ten elements. If less than five elements are improved, this project will not be considered a success. Total scores for the remaining five elements must result in a significant improvement for the project to be considered a success. An alpha level of .05 will be used to determine significance.

Time to completion, although measured and analyzed, will not be considered in the determination of successful performance. A number of other factors, including hardware, software, and user familiarity considerations, affect the times required by subjects who are assisted by the expert system.

Location of Testing

Testing will be conducted at both the Sacramento Air Logistics Center and the Ogden Air Logistics Center. Ogden will serve as an additional test site to determine how generic the expert system is. Testing will be conducted in the same manner at both sites. The same test cases will be used at both sites. Data for each site will be analyzed separately. Data for both sites will also be combined and analyzed.

Resources Required

At each site five fully compatible IBM computers with at least 512K of memory will be required. The computers need to be located in a separate room. Enough space should be available to permit subjects to complete questionnaires. Manual subjects will need space for any regulations, documentation, or calculators they bring with them for assistance.

Selection and Scheduling of Subjects

In advance of testing, each site should identify and schedule subjects for testing. A range of subject experience is desired. The development experts have determined that the following year-groups match the desired experience ranges:

- novice - less than one year's experience as an item manager

- journeyman - one to four years' experience as an item manager
- advanced - more than four years' experience as an item manager

Equal representation of item managers in these groupings is desired if possible. Supervisors should be asked to identify their item managers who will be available for testing with one of these categories.

The list of item managers provided should be sorted by experience and alphabetized. Each of the three resultant alphabetized lists of names should then be matched systematically to a treatment, one through four. This sequence should be repeated until all individuals have been assigned a treatment. Hence, the first individual on the list will be assigned to treatment one, the second to treatment two, etc.

Subjects should then be scheduled five at a time, at hour intervals, by treatment number. Manual subjects should always be scheduled immediately after subjects who will be assisted by the expert system. Manual subjects should be told that the subject may bring with them any items which might normally be used to complete the task: regulations, a calculator, etc.

APPENDIX L
DIRECTIONS PROVIDED TO
TEST SUBJECTS

DIRECTIONS PROVIDED TO TEST
SUBJECTS WHO WERE ASSISTED BY
THE EXPERT SYSTEM

The purpose of this exercise is to field test the Inventory Manager Assistant (IMA). IMA was developed to assist item managers with the initial file maintenance of the D041 computation. This test is designed to determine if item managers do a better job of initial file maintenance when assisted by IMA.

You have been randomly preassigned to file maintain a case with the assistance of IMA. IMA's performance in advising you on the file maintenance of this case will be graded in accordance with answers predetermined by a panel of experts. The case you file maintain will receive a grade between 0 and 100 points. Your IMA-assisted performance will be compared with the performance of item managers who file maintain this same case without the assistance of IMA.

At this time, please complete the questionnaire entitled SUBJECT INFORMATION. When you are finished, await further instructions. Do NOT begin the case until told to do so.

SUBJECTS COMPLETE THE SUBJECT INFORMATION QUESTIONNAIRE

A practice case has been provided so that you may learn to use IMA. You will file maintain this case first. IMA will ask you a series of questions about your computation and the supporting documentation. IMA asks very specific questions. Please read the questions carefully and accurately answer the questions which IMA asks.

You answer by typing the correct answer and depress the ENTER key. You do not need to type the complete response. Usually the first letter of the response is sufficient for IMA to distinguish your answer. For example, if IMA asks you a yes/no question, you would answer yes by typing "y" and depressing the ENTER key.

Based upon your responses, IMA will provide advice on the correct file maintenance of ten data elements. Enter the answers which IMA provides on the questionnaire entitled FILE MAINTENANCE SUMMARY. You MUST enter the value which IMA suggests regardless of whether or not you agree. If you have any questions, raise your hand. One of the test administrators will assist you.

Please raise your hand when you finish the practice case. You will then be provided the test case on which IMA's performance will be measured. Again, enter your responses on the questionnaire entitled FILE MAINTENANCE SUMMARY. When you finish this case, please provide your feedback by completing the page entitled IMA

CRITIQUE. Then you may leave. Please leave quietly as others may still be working.

Please comply with the following rules:

1. Do not write in the case folder. Use the back of your questionnaire if you need to make notes.
2. Do not talk with anyone about this case or what you believe to be the correct answers.
3. You may ask questions only of a test administrator. To do so, raise your hand.
4. Do not talk with anyone else in the room or make any comments aloud.
5. Do not worry about others finishing before you. Performance in terms of actual file maintenance is the primary concern. Time should not be considered as a factor.
6. Do not put your name on any of the forms. This exercise is anonymous.
7. Remember to complete all the entries on the file maintenance summary.
8. A test administrator will verify that all entries on the questionnaires are complete before you leave.
9. Please do not remove anything from this room. If you took notes on the case, you must turn them in to an administrator with your questionnaires.

Are there any questions before you begin?

Please begin the practice case. When you are finished, raise your hand to receive the test case.

DIRECTIONS PROVIDED TO TEST
SUBJECTS WHO WERE NOT ASSISTED
BY THE EXPERT SYSTEM

The purpose of this exercise is to field test the Inventory Manager Assistant (IMA). IMA was developed to assist item managers with the initial file maintenance of the D041 computation. This test is designed to determine if item managers do a better job of initial file maintenance when assisted by IMA.

You have been randomly preassigned to file maintain a case without the assistance of IMA (manually). Your performance in file maintaining this case will be graded in accordance with answers predetermined by a panel of experts. The case you file maintain will receive a grade between 0 and 100 points. Your performance will be compared with item managers who file maintain this same case with the assistance of IMA.

At this time, please complete the questionnaires entitled SUBJECT INFORMATION and MANUAL PROPS. When you are finished, await further instructions. Do NOT begin the case until told to do so.

SUBJECTS COMPLETE THE
SUBJECT INFORMATION AND MANUAL PROPS
QUESTIONNAIRES

A practice case has been provided. You will file maintain this case first. Enter your answers on the questionnaire entitled FILE MAINTENANCE SUMMARY. If you have any questions, raise your hand.

Please raise your hand when you finish the practice case. You will then be provided the test case on which your performance will be measured. Again, enter your responses on the questionnaire entitled FILE MAINTENANCE SUMMARY. You may leave when you are finished with this case. Please leave quietly as others may still be working.

Please comply with the following rules:

1. Do not write in the case folder. Use the back of your questionnaire if you need to make notes.
2. Do not talk with anyone about this case or what you believe to be the correct answers.
3. You may ask questions only of a test administrator. To do so, raise your hand.
4. Do not talk with anyone in the room or make any comments aloud.
5. Do not worry about others finishing before you. Performance in terms of actual file maintenance is the primary concern. Time should not be considered as a factor.
6. Do not put your name on any of the forms. This exercise is anonymous.
7. Remember to complete all the entries on the file maintenance summary.

8. A test administrator will verify that all entries on the questionnaires are complete before you leave.
9. Please do not remove anything from this room. If you took notes on the case, you must turn them in to an administrator with your questionnaires.

Are there any questions before you begin?

Please begin the practice case. When you are finished, raise your hand to receive the test case.

APPENDIX M

QUESTIONNAIRES COMPLETED
BY TEST SUBJECTS

QUESTIONNAIRE COMPLETED BY TEST SUBJECTS
WHO WERE ASSISTED BY THE EXPERT SYSTEM

SUBJECT INFORMATION

Please answer the following questions:

1. I have been a D041 item manager for _____ years.
2. I am performing case number _____.
3. I am doing this case (check one)
_____ manually
_____ with the expert system
4. I would rate my experience in interacting with a computer as:
(check one)
_____ No experience at all
_____ Limited experience
_____ Mediocre
_____ Experienced
_____ Very experienced
5. I would rate my confidence in interacting with a personal
computer as: (check one)
_____ No experience at all
_____ Limited experience
_____ Mediocre
_____ Experienced
_____ Very experienced

PRACTICE CASE

FILE MAINTENANCE SUMMARY

In the space provided, enter the value which IMA tells you to file maintain for each of the following data elements.

1. Unit Cost _____
2. DOLP _____
3. ALT _____
4. PLT _____
5. Base Repair Cycle Time _____
6. Base Processing Time _____
7. Reparable Intransit Time _____
8. Supply to Maintenance Time _____
9. Shop Flow Time _____
10. Turn in Time _____

THANK YOU!

TEST CASE

FILE MAINTENANCE SUMMARY

In the space provided, enter the value which IMA tells you to file maintain for each of the following data elements.

1. Unit Cost _____
2. DOLP _____
3. ALT _____
4. PLT _____
5. Base Repair Cycle Time _____
6. Base Processing Time _____
7. Reparable Intransit Time _____
8. Supply to Maintenance Time _____
9. Shop Flow Time _____
10. Turn in Time _____

THANK YOU!

IMA CRITIQUE

Please use the space below to make any comments about IMA (e.g., what you liked or didn't like about it, if it helped you, or how it might be improved).

QUESTIONNAIRE COMPLETED BY TEST SUBJECTS
WHO WERE NOT ASSISTED BY THE EXPERT SYSTEM

SUBJECT INFORMATION

Please answer the following questions:

1. I have been a D041 item manager for _____ years.
2. I am performing case number _____.
3. I am doing this case (check one)
_____ manually
_____ with the expert system.
4. I would rate my experience in interacting with a computer as:
(check one)
_____ No experience at all
_____ Limited experience
_____ Mediocre
_____ Experienced
_____ Very experienced
5. I would rate my confidence in interacting with a personal
computer as: (check one)
_____ No experience at all
_____ Limited experience
_____ Mediocre
_____ Experienced
_____ Very experienced

MANUAL PROPS

1. I brought the following items with me to assist in file maintaining this case: (check all that apply)

_____ AFLCR 57-4

_____ List of current standards

_____ Local directions for performing file

maintenance

_____ Scratch paper

_____ Pencil

_____ Calculator

_____ Other. Please specify

Answer Question 2 only if you brought a programmable calculator with you.

2. My calculator has been preprogrammed to perform the required calculations.

_____ Yes
_____ No

PRACTICE CASE

FILE MAINTENANCE SUMMARY

In the space provided, enter the value which IMA tells you to file maintain for each of the following data elements.

1. Unit Cost _____
2. DOLP _____
3. ALT _____
4. PLT _____
5. Base Repair Cycle Time _____
6. Base Processing Time _____
7. Reparable Intransit Time _____
8. Supply to Maintenance Time _____
9. Shop Flow Time _____
10. Turn in Time _____

THANK YOU!

TEST CASE

FILE MAINTENANCE SUMMARY

In the space provided, enter the value which IMA tells you to file maintain for each of the following data elements.

1. Unit Cost _____
2. DOLP _____
3. ALT _____
4. PLT _____
5. Base Repair Cycle Time _____
6. Base Processing Time _____
7. Reparable Intransit Time _____
8. Supply to Maintenance Time _____
9. Shop Flow Time _____
10. Turn in Time _____

THANK YOU!

APPENDIX N

TEST SUBJECTS'
CRITIQUES OF THE INVENTORY
MANAGER ASSISTANT (IMA)
EXPERT SYSTEM

TEST SUBJECTS' CRITIQUES OF THE
INVENTORY MANAGER ASSISTANT EXPERT SYSTEM

Sacramento Subjects' Comments

'IMA' was very helpful in determining these file maintenance factors for input. I did not realize that all these factors were required to be updated or file maintained. This program makes these inputs easier to compute and update for more accurate data. 'IMA' will be very useful for the new item managers such as myself.

I believe this would be a useful tool to any inventory manager. I hope it is adopted.

I liked it very much; it would help me a lot and help me to understand the D041 system.

It has been very helpful to find information I need; otherwise I would not have known how to go about finding the answers.

I liked it; with practice it could speed up file maintenance.

It was helpful to me as it helped me understand the D041 system better. I'm new in the D041 system and I like the 'IMA' program; it was very helpful to me.

Having never worked a D041 comp. before and being new at D041, I thought 'IMA' was helpful but would be more useful if I already understood how the computation worked.

'IMA' seems to be a beneficial tool that would help the inventory manager to accomplish tasks in a shorter amount of time; very impressive for a new system.

I liked it! I liked that it had descriptions of certain things in plain, easy to understand language. I think it will make the job much easier.

I think its great. As a new inventory manager, I'm unsure as to how I would figure out these factors.

I found the system to be very helpful in performing file maintenance and in answering questions that you are not knowledgeable about, for example, if an item is airlift coded. The system was very helpful as it explained where to find out if an item was airlift coded on the AFRAMS RIMCS data.

I see 'IMA' as a tool for the managers and veterans. New inventory managers like any system that improves their chance to learn.

I believe 'IMA' is going to be of tremendous value. It's a little slow, but it lets you have time to think about the information required.

Love at first sight! You are on the right track, Major Allen. Keep up the great work. You are the answer to my prayers.

I liked being able to see if things were correct and what had to be file maintained. One problem I noticed was where I had made a mistake on an entry and did not discover it until it was too late and couldn't back up to correct my error. I think this program would help very much.

'IMA' will be a big help to new inventory managers. I found it very interesting and I found that it is fun to work the computer; it will be a much faster way to file maintain all of our routine work. I loved it!

I think it is very helpful to the inventory manager; a good system.

It is an excellent system; the drawback is that you cannot make corrections after you have entered an error.

I like computers and I think this system is very user friendly. I'm sure it would help us to have more accurate info. in less time.

The 'IMA' is a unique software system; I enjoyed working the problem. It helped with easy-to-understand step-by-step instructions. If I were more familiar with the terminology, this test would have been very easy and self-explanatory.

I think this is a good idea. With all the new people in D041, it should help explain to them what to look at and it would also help more experienced people if they have questions.

I thought it was great and it really does help. Questions are simple and straight forward. Even a new inventory manager would be able to look at the different products and be able to know what information to input into the computer. There was nothing I did not like. Let's keep going with this!

It's good. I learned a lot about products I didn't previously know - just in this test. This is heading in the right direction in terms of being user friendly and work applicable. Bravo! Good Job!

Fantastic! More! More! I see lots of possibilities for this.

I think it will prove very useful, especially since our experienced people are retiring. The user friendly language was just that, very friendly. 'IMA' was very easy to use. Shine on!

Great! Easy to use. Extremely helpful.

I was impressed with the ease of computing these elements using 'IMA'; I think it will be very useful and time saving.

Computer was very helpful. Saves time. Will give the IMs more time to work on other problems. An asset for the USAF and other DOD agencies.

Great idea; I hope we see this in our office soon.

It was good for checking your work and showing where you erred.

I enjoyed 'IMA' as it provided helpful hints as to the reasons we file maintain data to the D041. It is especially helpful for the IMS with limited experience as well as a helpful tool for the experienced inventory manager!

Liked it a great deal. should make file maintenance much simpler after familiarity is accomplished.

What I didn't like was the fact that if I made an error, I had to start all over. I assumed that IMA will have memory capacity in the future to alleviate this. I liked it; I hope if this is implemented on a larger scale that turnaround time (response time) will be just as fast.

Its perfect so far as I'm concerned. I love it! I can't call this an it; she's IMA Genius to me!!

IMA would be a help to "new" D041 inventory managers. Although slow, it would help identify problem areas in data areas covered.

I believe we need this system for new item managers and as a reinforcement for the ones who have been on the job longer.

I do like the computer help and it did help me. I'm very slow but working more at the computer will help us all.

Blue against black screen was hard on the eyes.

Somewhat time consuming.

Very helpful product which I believe will be a good tool for the inventory managers.

I enjoyed using the IMA. It was very useful in doing D041 file maintenance.

Ogden Subjects' Comments

Yes, it would be very beneficial; but it would also make us lazy. It was logical and easy to follow.

I liked it very much, and I would strongly urge this be implemented ASAP. It is an excellent help for inventory managers, old and new. I learned a lot today.

I really enjoyed taking this test, and I feel it will be a great help to me in doing my computations. I learned a lot today.

I enjoyed the test. It was well suited for beginners.

I enjoyed working with 'IMA.' Being relatively new, IMA answered a few questions in areas I have not encountered yet. IMA is easy to communicate with.

The system provided an easy guide to the computation procedure.

It will sure make things a lot easier for inventory managers and everyone will figure the computation in the same way.

This program would be an excellent tool for new or relatively untrained inventory managers. The explanations that are built in are great for even experienced inventory managers. As a training tool, it has potential. As an ongoing program for routine use, it would be too time consuming.

IMA was very user friendly and would be extremely beneficial for new employees. This would be an excellent tool for training purposes.

Liked the way it converted the standard times to actual.

IMA would be very helpful to any inventory manager because there are so many elements to remember during file maintenance and so many changes to regulations that it is very hard to retain all the information from quarter to quarter. This would help eliminate many of the common errors made during file maintenance and be a learning device as well.

It could be helpful for pinpointing areas where training is necessary.

APPENDIX 0

A SAMPLE CONSULTATION
WITH IMA

This Artificial Intelligence Expert System was developed by the U.S. Air Force Directorate of Logistics and Engineering with the help of seven experts from Sacramento Air Logistics Center.

Have we ever had the pleasure of working together before? (Answer by typing in "yes" or "no" and then hit the carriage return.)

yes
no
>> n

[illegible]

Hi! I'm IMA. My job is to assist you during the initial file maintenance cycle of the D041 comp. Together we can determine the correct unit cost, date of last procurement, administrative leadtime, production leadtime, and repair cycle times to be file maintained. I will work with you step by step through each of these elements. Occasionally, I will recommend specific actions to you. I can't provide advice on every problem. Sometimes you may still have to ask your supervisor. However, I can help you with most things. I'll do my very best.

[illegible]

When you are ready to continue, type "c" and hit the carriage return.

>> c

What I'm going to do is ask you several questions regarding the information on your comp and supporting documentation. For Insurance/NSO items, you will not have a comp. Use the Insurance/NSO Status Listing as your comp. PLEASE NOTE: A particular SRC (e.g., A or D) does not necessarily mean that this entry is valid. These entries still need to be verified. Further, you must have appropriate documentation to support these. When I ask a question, answer with one of the suggested answers which follow each question, then hit the carriage return. Now, let's get started.

When you are ready to continue, type "c" and hit the carriage return.

>> c

Look at the front page of your comp, bottom right-hand corner. Is this item coded as Air Force SICA NIMSC 5?

yes
no
>> n

Look at your 318. Has there been any contract for this item since the provisioning contract?

yes
no
>> y

Was the LATEST procurement of this item any of the following?

depot manufactured
contractor estimated cost
contractor minimum cost
contractor minimum quantity
price break
contractor excess
surplus material
FMS direct cite (4F fund code)
contractor off the shelf
priority procurement (A or B)
quantity discount

included one-time cost of tooling
included GFM
included one-time special engineering/test requirements

Note if you have a contract which is one of these types, it should be indicated as such on the 318.

yes
no
explain

>> y

Have you had a procurement which was not one of these? In other words, have you had a standard routine Air Force procurement? Note this would include MIPRs where the Air Force acts as the procuring agency.

yes
no

>> n

Which of the following describes your LATEST contract? Answer with the number or numbers which correspond to the appropriate answer(s). If you answer with more than one number, include a comma between the numbers. If you do not understand what is meant by these types of contracts and would like an explanation, type in "16" now.

1. depot-manufactured
2. contractor-estimated-cost
3. contractor-minimum-cost
4. contractor-minimum-qty
5. price-break
6. contractor-excess
7. surplus-material
8. direct-cite-fms
9. contractor-off-the-shelf
10. priority-procurement
11. quantity-discount
12. included-one-time-tooling
13. included-gfm
14. included-one-time-special-eng-test-rqmnts
15. other
16. help

>> 13

What was the cost of the material furnished to the contractor as GFM? If you don't know, you can look it up on the ML. Enter your answer in dollars and cents, e.g., 645.00

>> 678.00

What is the contractor unit cost shown on your AFLC Form 318 for that contract? Enter your answer in dollars and cents, e.g., 67.90

>> 6742.89

Was this contract an unpriced order?

yes
no
unsure
explain

>> e

An unpriced order is a contract which originally was assigned only a not-to-exceed (NTE) price. It will be definitized as a firm price later.

Was this contract an unpriced order?

yes
no
unsure
explain

>> n

What is the contract award date shown on your AFLC Form 318 for this contract? Enter your answer as a Julian date. For example, December 31, 1985 would be entered as 85365.

>> 83247

What is the unit price of this item as shown on the front page of the comp? Enter your answer in dollars and cents, e.g., 745.05

>> 8499.00

What is the DOLP shown on the front page of the comp? Enter your answer as a Julian date, e.g., 82134.

>> 83247

\$7643.52 is the correct unit price which should be file maintained on the comp. Take appropriate action to correct this and update the standard price on the AFLC Form 318.

83247 is the correct date of last procurement. No file maintenance is required. Shine on!

Look at the front page of the comp under LEADTIME ADM. What is the administrative leadtime?

>> 9

Look at your 318 under the column, DATE INIT. When was this PR initiated? Enter the Julian date.

>> 83189

Look at the 318. Has 10% or more of the ROUTINE portion of this contract been delivered?

yes

no

>> y

What was the Julian date of this first significant delivery?

>> 84322

2 months is the correct administrative leadtime which should be file maintained on the comp. Please take action to correct this.

2 months is the actual ALT. You may file maintain up to 9 months PROVIDED you can justify this in writing. If you do so, you must document your justification on the comp.

Look at the front page of the comp under LEADTIME PROD. What is the production leadtime?

>> 3

15 months is the production leadtime which should be file maintained on the comp. Please take action to correct this.

Look at the front page of the comp, under Base R-C. What is the base repair cycle time? Enter your answer as the number of days, e.g., 21

>> 7

Look at the front page of the Factors Printout under PGM SEL. What is the first digit of the program select code?

>> 1

Look at the front page of the comp under the FACTORS data for the current quarter, BASE NRTS PERCENT. Is this item 100% NRTS?

yes
no

>> n

Does this stock number appear on this quarter's Base Repair Cycle Time product?

yes
no

>> y

Look at the Base Repair Cycle Time Product. Have there been five or more Total RTS actions?

yes
no

>> n

7 days is the correct base repair cycle time. No file maintenance is required. Shine on!

Look at the front page of the comp under B-PROC. What is the base processing time?

>> 9

Look at the Base Repair Cycle Time product. Have there been five or more actions recorded under the column Total Cond/NRTS?

yes
no

>> y

Look at the Base Repair Cycle Time product under the column Base Proc Ave for this stock number. What is the average Base Processing days?

>> 5

5 days is the correct base processing time which should be file maintained on the comp. Please take appropriate action to correct this.

Which of the following apply to this item? Enter the number or numbers of all that apply. If your answer requires more than one number, place commas between the numbers (e.g., 1,2,3).

1. not-airlift-coded
2. must-be-routed-to-prime-alc-prior-to-routing-to-repair-site
3. all-reparables-generate-from-conus
4. none-of-these-apply
5. help

>> 5

1. not-airlift-coded

This item is coded in RIMCS (the Reparable Item Movement Control System) such that it will be transported by means other than airlift. Because of this an additional 13 days may be added to the standard number of days or the actual transit time. However, you MUST document that these days are added. IMA automatically recommends them if they are applicable.

You can determine how your item is coded by looking at the D143H-T4A, WK-G2F, AFRAMS RIMCS DATA product. Look under the column C-A. If an A appears in this column, the item is airlift coded. If this column is blank, the item is not airlift coded.

When you are ready to continue, type "c" and hit the carriage return.

c
>> c

2. must-be-routed-to-prime-alc-prior-to-routing-to-repair-site

The item is not shipped directly to the repair site. It must be returned to the prime ALC first. If this is the case, 14 additional days may be added to the standard number of days or the actual transit time. Again, you MUST document that these days are added. IMA automatically recommends them if they are applicable.

You can determine the item's routing by looking at the AFRAMS RIMCS DATA product. The item is shipped direct to the repair site if an EZ rather than an FB is in the SRAN field. If this field does not have an EZ SRAN and the item is contract repair or the item is contract repair and is not loaded in RIMCS then the item is routed through the prime ALC prior to routing to the actual repair site.

When you are ready to continue, type "c" and hit the carriage return.

```
      c
>> c
```

3. all-reps-generate-from-conus

CONUS is the continental United States. This does not include Alaska and Hawaii. If this is the case, 11 days is used (rather than 14) as the baseline to determine the total reparable transit time. This MUST be documented. IMA uses 11 days as the baseline if applicable.

You can determine if this applies by looking at the NRTS History on the D073.X21. This will show where reparables generate. If you can't tell for sure, assume this condition does not apply.

When you are ready to continue, type "c" and hit the carriage return.

```
      c
>> c
```

Which of the following apply to this item? Enter the number or numbers of all that apply. If your answer requires more than one number, place commas between the numbers (e.g., 1,2,3).

1. not-airlift-coded
2. must-be-routed-to-prime-alc-prior-to-routing-to-repair-site
3. all-reparables-generate-from-conus
4. none-of-these-apply
5. help

>> 1

Look at the Repairable Item Transportation Time product. Does this stock number appear on this product?

yes

no

>> n

Look at the front page of the comp, under Depot Repair Cycle Data, Rep-Int. What is the repairable intransit time?

>> 31

27 days is the correct repairable intransit time which should be file maintained. Please take appropriate action to correct this.

Look at the last page of the comp under Sources of Repair and Percents. How is this item repaired?

1. organic-repair-only
2. contract-repair-only
3. both-organic-and-contract-repair
4. there-is-no-repair

>> 3

Look at the front page of the comp under Depot Repair Cycle Data, SUP-MA. What is the supply to maintenance time?

>> 8

10 days is the supply to maintenance time which should be file maintained on the comp. Please take action to correct this.

Look at the front page of the comp under Depot Repair Cycle Data, S-FLOW. What is the source reference code?

a

e

s

>> e

What is the shop flow time?

>> 27

Does last quarter's comp contain documentation concerning this estimated shop flow time?

yes
no

>> y

Is this documentation still valid?

yes
no

>> n

Look at your MISTR Repair Notice Listing, the D073.R51. Is this item on this product?

yes
no

>> y

Look at the D073.R51, MISTR Repair Notice Listing, the bottom right hand corner across from SFTS. What are the shop flow days?

>> 22

Is there a repair contract for this item?

yes
no

>> y

Look at the D073.X21, IM Intermediate Range Projection Worksheet from the previous quarter. How many of this item did the contractor repair (contractor production output)?

>> 29

How many were repaired organically (organic production output)?

>> 16

Look at your repair contract. What is the quoted repair time?

>> 14

17.0 days is the shop flow time which should be file maintained on the comp. Document this as a weighted average.

Look at the front page of the comp under DEPOT REPAIR CYCLE DATA, TURN-IN. What is the serviceable turn-in time?

>> 10

15 days is the serviceable turn-in time which should be file maintained on the comp. Please take action to correct this.

APPENDIX P
CALENDAR OF THE
MAJOR EVENTS OF THIS RESEARCH
EFFORT

MAJOR EVENTS

<u>Activity</u>	<u>Date</u>
Domain Familiarization	1 October - 15 December, 1985
Telephone Interviews	(1) December 23, 1985 (2) December 24, 1985 (3) January 2, 1986
Expert System Workshop	January 8, 1986
Task Selection, Phase I Survey	January 13, 1986
Task Selection, Phase II Survey	January 14, 1986
Expert Nomination Survey	January 16, 1986
Expert Selection Survey	January 17, 1986
Week One of Initial Knowledge Engineering	February 9-14, 1986
Week Two of Initial Knowledge Engineering	February 23-28, 1986
Validation Session, Week One	June 2-6, 1986
Validation Session, Week Two	June 23-27, 1986
Pretest of Two Item Managers	June 27, 1986
Selection of Test Cases/ Development of Test Key	June 27, 1986
Validation Panel	June 30, 1986
Experiment Conducted at Sacramento Air Logistics Center	July 7-8, 1986
Experiment Conducted at Ogden Air Logistics Center	July 9-10, 1986

APPENDIX Q
BREAKDOWNS AND ANOVAS

Table 38

Mean Total Score and Standard Deviation
All Elements Weighted Equally
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 82.00 18.25 (10)*	Manual 59.79 17.24 (12)	77.16 18.57 (44)
	87.75 10.37 (10) Expert System	81.67 14.71 (12) Expert System	
JOURNEYMAN	Manual 92.50 6.93 (20)	Manual 71.53 11.92 (18)	83.30 14.98 (72)
	89.53 11.45 (16) Expert System	79.31 18.04 (18) Expert System	
ADVANCED	Manual 89.69 11.68 (8)	Manual 70.71 14.84 (7)	85.31 13.70 (32)
	89.75 7.68 (10) Expert System	88.57 13.53 (7) Expert System	

* Parentheses indicate number of observations

Table 38 (continued)

* * * A N A L Y S I S C F V A R I A N C E * * *							
BY	S10 EXP DIF METH	EXPERIENCE LEVEL TASK DIFFICULTY SOLUTION METHOD	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF CF F
SOURCE OF VARIATION							
MAIN EFFECTS							
EXP			10654.236	4	2663.709	14.280	0.
DIF			1026.842	2	513.421	3.036	0.051
METH			7390.364	1	7390.364	41.284	0.000
			1373.516	1	1373.516	10.466	0.002
2-WAY INTERACTIONS							
EXP			2991.230	5	598.246	3.342	0.007
DIF			167.683	2	83.842	0.462	0.627
METH			927.027	2	463.513	2.589	0.079
			1757.958	1	1757.958	9.220	0.002
3-WAY INTERACTIONS							
EXP			87.655	2	43.828	0.245	0.783
DIF			87.655	2	43.828	0.245	0.783
			13733.721	11	1248.520	6.974	0.
EXPLAINED							
RESIDUAL							
TOTAL							
			24345.797	136	179.013		
			38079.519	147	259.044		

*S10 = Total score for all ten elements, weighted equally.

Table 39

Mean Score and Standard Deviation
Without RITT and PLT
All Elements Weighted Equally
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY			
	SIMPLE		COMPLEX	
NOVICE	Manual		Manual	
	64.25 15.81 (10)*		43.13 17.94 (12)	
JOURNEYMAN	Manual		Manual	
	73.38 5.40 (20)		55.56 9.80 (18)	
ADVANCED	Manual		Manual	
	71.25 11.10 (8)		52.14 13.65 (7)	
Expert System		Expert System		ALL CASES
74.75 6.61 (10)		66.04 11.94 (12)		61.36 17.97 (44)
73.91 7.53 (16)		66.25 14.23 (18)		67.26 12.11 (72)
74.25 6.57 (10)		73.57 11.35 (7)		68.52 13.42 (32)

* Parentheses indicate number of observations

Table 39 (continued)

ANALYSIS OF VARIANCE							
BY		S8	EXPERIENCE LEVEL				
		EXP	TASK DIFFICULTY				
		DIF	SOLUTION METHOD				
		METH					
SOURCE OF VARIATION				SUM OF	DF	MEAN	SIGNIF
				SQUARES		SQUARE	F
MAIN EFFECTS							
EXP				11151.566	4	2789.392	21.934
DIF				946.654	2	473.327	3.706
METH				6170.105	1	6170.105	48.314
				3975.732	1	3975.732	30.348
2-WAY INTERACTIONS							
EXP				2520.555	5	504.111	3.947
DIF				121.893	2	60.946	0.477
METH				863.798	2	431.899	3.382
				1454.203	1	1454.203	11.387
3-WAY INTERACTIONS							
EXP				93.166	2	46.583	0.365
DIF				93.166	2	46.583	0.365
METH							
EXPLAINED				13767.287	11	1251.572	9.800
RESIDUAL				17368.354	136	127.702	
TOTAL				31135.642	147	211.807	

*S8 - Total score for eight elements, weighted equally.

Table 40
Mean Total Score and Standard Deviation
Development Experts' Weighting
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 84.98 16.23 (10)*	Manual 58.65 17.01 (12)	74.23 21.69 (44)
	85.63 15.39 (10) Expert System	71.35 25.35 (12) Expert System	
JOURNEYMAN	Manual 91.43 7.72 (20)	Manual 62.25 12.77 (18)	78.23 20.19 (72)
	88.70 13.22 (16) Expert System	70.25 25.95 (18) Expert System	
ADVANCED	Manual 91.88 7.03 (8)	Manual 61.89 13.52 (7)	82.82 17.68 (32)
	88.83 8.11 (10) Expert System	84.82 24.30 (7) Expert System	

* Parentheses indicate number of observations

Table 40 (continued)

*** ANALYSIS OF VARIANCE ***

		E10		EXPERIENCE LEVEL		TASK DIFFICULTY		SOLUTION: 4ETWCD			
		BY	EXP	DIF	4ETH						
SOURCE OF VARIATION		SUM OF SQUARES		DF	MEAN SQUARE	F		SIGNIF			
MAIN EFFECTS											
EXP		191.115		4	47.777	16.966		0.			
DIF		7.027		2	3.513	1.248		0.290			
METH		168.854		1	168.854	59.952		0.000			
		5.721		1	5.721	3.452		0.065			
2-WAY INTERACTIONS											
EXP DIF		24.808		5	4.962	1.762		0.125			
EXP METH		2.799		2	1.399	0.497		0.609			
DIF METH		2.692		2	1.346	0.478		0.621			
		18.942		1	18.942	6.726		0.011			
3-WAY INTERACTIONS											
EXP DIF METH		3.380		2	1.690	0.600		0.550			
		3.380		2	1.690	0.600		0.550			
EXPLAINED		219.303		11	19.937	7.079		0.			
RESIDUAL		323.006		136	2.816						
TOTAL		602.308		147	4.097						

*E10 = Total score for all ten elements, development experts' weighting.

Table 41

Mean Score and Standard Deviation
Without RITT and PLT
Development Experts' Weighting
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 63.43 15.84 (10)*	Manual 37.85 15.67 (12)	55.40 20.76 (44)
	70.03 11.48 (10) Expert System	54.06 23.14 (12) Expert System	
JOURNEYMAN	Manual 69.35 7.02 (20)	Manual 43.25 12.20 (18)	59.15 17.46 (72)
	70.33 8.91 (16) Expert System	53.79 21.48 (18) Expert System	
ADVANCED	Manual 71.69 5.82 (8)	Manual 40.07 14.09 (7)	62.84 17.56 (32)
	70.03 7.80 (10) Expert System	65.25 21.50 (7) Expert System	

* Parentheses indicate number of observations

ANALYSIS OF VARIANCE . . .

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*E8 = Total score for eight elements, development experts' weighting.

Table 42

Mean Total Score and Standard Deviation
Validation Panel's Weighting
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 85.05 15.80 (10)*	Manual 58.77 16.99 (12)	74.24 21.50 (44)
	85.55 15.80 (10) Expert System	71.29 24.83 (12) Expert System	
JOURNEYMAN	Manual 91.24 7.63 (20)	Manual 62.13 12.17 (18)	78.22 20.00 (72)
	88.58 13.59 (16) Expert System	70.63 25.67 (18) Expert System	
ADVANCED	Manual 91.88 6.52 (8)	Manual 61.46 12.68 (7)	82.85 17.64 (32)
	88.95 8.19 (10) Expert System	85.21 24.19 (7) Expert System	

* Parentheses indicate number of observations

Table 42 (continued)

* * * A N A L Y S I S C F V A R I A N C E * * *						
BY	H10 EXP DIF METH	EXPERIENCE LEVEL TASK DIFFICULTY SOLUTION METHOD	SUM OF SQUARES	DF	MEAN SQUARE	SIGNIF F OF F
SOURCE OF VARIATION						
MAIN EFFECTS						
EXP			189.832	4	47.458	17.244 0.
DIF			7.063	2	3.531	1.283 0.281
METH			166.858	1	166.858	60.627 0.000
			10.438	1	10.438	3.792 0.054
2-WAY INTERACTIONS						
EXP			25.321	5	5.064	1.840 0.109
DIF			2.512	2	1.256	0.456 0.635
METH			2.035	2	1.017	0.433 0.615
			19.878	1	19.878	7.223 0.008
3-WAY INTERACTIONS						
EXP			3.564	2	1.782	0.647 0.525
DIF			3.564	2	1.782	0.647 0.525
			218.718	11	19.883	7.225 0.
EXPLAINED						
RESIDUAL						
TOTAL						
			374.302	136	2.752	
			593.019	147	4.034	

*H10 = Total score for all ten elements, validation panel's weighting.

Table 43

Mean Score and Standard Deviation
Without RITT and PLT
Validation Panel's Weighting
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 63.33 15.57 (10)*	Manual 37.73 15.65 (12)	55.31 20.54 (44)
	69.85 11.76 (10) Expert System	54.10 22.45 (12) Expert System	
JOURNEYMAN	Manual 69.15 6.92 (20)	Manual 43.03 11.24 (18)	59.04 17.22 (72)
	70.14 9.36 (16) Expert System	53.94 21.12 (18) Expert System	
ADVANCED	Manual 71.84 5.23 (8)	Manual 39.57 13.47 (7)	62.77 17.55 (32)
	70.00 7.99 (10) Expert System	65.29 21.22 (7) Expert System	

* Parentheses indicate number of observations

Table 43 (continued)

* * * A N A L Y S I S C F V A R I A N C E * * *							
H3							
BY	EXP	EXPERIENCE LEVEL					
	DIF	TASK DIFFICULTY					
	METH	SOLUTION METHOD					
SOURCE OF VARIATION				SUM OF	MEAN	SIGNIF	
				SQUARES	SQUARE	F	CF F
MAIN EFFECTS							
EXP				190.269	47.717	23.032	0.
DIF				4.894	2.442	1.175	0.311
METH				154.950	154.950	74.790	0.000
				27.427	27.427	13.233	0.000
2-WAY INTERACTIONS							
EXP	DIF			20.510	4.122	1.980	0.085
EXP	METH			0.478	0.239	0.115	0.891
DIF	METH			2.551	1.276	0.615	0.542
				17.121	17.121	8.264	0.005
3-WAY INTERACTIONS							
EXP	DIF	METH		4.801	2.401	1.159	0.317
				4.801	2.401	1.155	0.317
EXPLAINED				216.180	19.653	9.486	0.
RESIDUAL				221.766	2.072		
TOTAL				497.947	147		

*H8 = Total score for eight elements, validation panel's weighting.

Table 44

Unit Price, Mean and Standard Deviation
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 7.25 3.43 (10)*	Manual 3.13 3.39 (12)	5.97 4.15 (44)
	8.50 3.16 (10) Expert System	5.63 4.66 (12) Expert System	
JOURNEYMAN	Manual 7.88 2.72 (20)	Manual 3.06 2.65 (18)	6.39 3.75 (72)
	9.53 1.01 (16) Expert System	5.28 4.19 (18) Expert System	
ADVANCED	Manual 9.06 1.29 (8)	Manual 2.86 3.36 (7)	7.34 3.75 (32)
	9.00 2.42 (10) Expert System	7.50 4.33 (7) Expert System	

* Parentheses indicate number of observations

Table 4A (continued)

ANALYSIS OF VARIANCE									
BY		F1	UPRICE		CF		VARIANCE		
		EXP	EXPERIENCE LEVEL						
		DIF	TASK DIFFICULTY						
		METH	SOLUTION METHOD						
SOURCE OF VARIATION			SUM OF	DF	MEAN	SIGNIF			
			SQUARES		SQUARE	F	CF	F	
MAIN EFFECTS									
EXP			773.895	4	193.474	19.066	0.		
DIF			14.422	2	7.211	0.711	0.493		
METH			603.143	1	603.143	59.931	0.000		
			138.351	1	138.351	13.634	0.000		
2-WAY INTERACTIONS									
EXP			33.655	5	6.739	0.664	0.651		
DIF			7.604	2	3.802	0.375	0.688		
METH			0.298	2	0.149	0.015	0.985		
			25.076	1	25.076	2.471	0.118		
3-WAY INTERACTIONS									
EXP			23.970	2	11.985	1.121	0.310		
DIF			23.970	2	11.985	1.181	0.310		
			821.560	11	75.596	7.450	0.		
EXPLAINED									
RESIDUAL			1380.053	136	10.147				
TOTAL			2211.613	147	15.045				

Table 45

Date of Last Procurement, Mean and Standard Deviation
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 9.00 3.16 (10)*	Manual 5.83 5.15 (12)	7.73 4.24 (44)
	Expert System 10.00 0.00 (10)	Expert System 6.67 4.92 (12)	
JOURNEYMAN	Manual 9.50 2.24 (20)	Manual 6.67 4.85 (18)	8.06 3.90 (72)
	Expert System 9.38 1.71 (16)	Expert System 6.67 4.85 (18)	
ADVANCED	Manual 10.00 0.00 (8)	Manual 6.43 4.76 (7)	8.75 3.11 (32)
	Expert System 9.50 1.58 (10)	Expert System 8.57 3.78 (7)	

* Parentheses indicate number of observations

Table 45 (continued)

ANALYSIS OF VARIANCE							
BY	F	DCLP					
EXP	EXP	EXPERIENCE LEVEL					
DIF	DIF	TASK DIFFICULTY					
METH	METH	SOLUTION METHOD					
SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF	OF F	
MAIN EFFECTS							
EXP	313.186	4	78.296	5.816	0.000		
DIF	5.507	2	2.753	0.353	0.703		
METH	289.231	1	289.231	21.487	0.000		
	5.252	1	5.252	0.391	0.533		
2-WAY INTERACTIONS							
EXP	15.294	5	3.059	0.227	0.950		
DIF	5.063	2	2.531	0.182	0.829		
METH	7.112	2	3.556	0.264	0.768		
	3.044	1	3.044	0.226	0.635		
3-WAY INTERACTIONS							
EXP	10.778	2	5.389	0.400	0.671		
DIF	10.778	2	5.389	0.400	0.671		
EXPLAINED	339.258	11	30.842	2.291	0.013		
RESIDUAL	1831.012	136	13.463				
TOTAL	2170.270	147	14.764				

Table 46

Administrative Leadtime, Mean and Standard Deviation
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 9.25 1.21 (10)*	Manual 5.42 2.34 (12)	7.33 3.02 (44)
	8.50 3.37 (10) Expert System	6.67 3.26 (12) Expert System	
JOURNEYMAN	Manual 9.63 1.68 (20)	Manual 5.28 2.08 (18)	7.53 3.10 (72)
	8.13 4.03 (16) Expert System	6.94 2.65 (18) Expert System	
ADVANCED	Manual 10.00 0.00 (8)	Manual 4.29 1.89 (7)	7.89 3.18 (32)
	8.50 3.37 (10) Expert System	8.21 3.13 (7) Expert System	

* Parentheses indicate number of observations

Table 46 (continued)

• • • A N A L Y S I S C F V A R I A N C E • • •									
B1		F3	ALT	EXPERIENCE LEVEL		TASK DIFFICULTY		SOLUTION METHOD	
		EXP	DIF						
		DIF	METH						
SOURCE OF VARIATION		SUM OF		DF		MEAN		SIGNIF	
		SQUARES				SQUARE		F	
								CF	
								F	
MAIN EFFECTS									
EXP		310.579		4		77.645		10.934	
DIF		1.083		2		0.542		0.076	
METH		301.475		1		301.475		42.452	
		4.259		1		4.259		0.600	
2-WAY INTERACTIONS									
EXP		103.423		5		20.685		2.513	
DIF		0.194		2		0.097		0.014	
METH		5.848		2		2.924		0.412	
METH		99.896		1		99.896		14.067	
3-WAY INTERACTIONS									
EXP		13.560		2		6.780		0.955	
DIF		13.560		2		6.780		0.955	
EXPLAINED		427.561		11		38.869		5.473	
RESIDUAL		965.809		136		7.102			
TOTAL		1393.370		147		9.479			

Table 47
Production Leadtime, Mean and Standard Deviation
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 9.75 0.79 (10)*	Manual 9.58 1.44 (12)	8.41 2.75 (44)
	7.00 3.07 (10) Expert System	7.29 3.61 (12) Expert System	
JOURNEYMAN	Manual 9.63 0.92 (20)	Manual 8.47 2.99 (18)	8.51 2.80 (72)
	8.13 2.96 (16) Expert System	7.64 3.58 (18) Expert System	
ADVANCED	Manual 8.44 1.29 (8)	Manual 9.64 0.94 (7)	8.91 2.10 (32)
	8.50 3.16 (10) Expert System	9.29 1.89 (7) Expert System	

* Parentheses indicate number of observations

Table 47 (continued)

ANALYSIS OF VARIANCE									
SOURCE OF VARIATION		SUM OF SQUARES		DF	MEAN SQUARE				
MAIN EFFECTS									
91	F4	PLT	EXP	EXP	18.261				
		EXPERIENCE LEVEL	DIF	2	2.999				
		TASK DIFFICULTY		1	1.326				
		SOLUTION METHOD		1	69.165				
2-WAY INTERACTIONS									
				5	9.212				
				2	7.315				
				2	13.922				
				1	1.270				
3-WAY INTERACTIONS									
				2	0.813				
				2	0.818				
EXPLAINED									
				11	11.231				
RESIDUAL									
				136	6.637				
TOTAL									
				147	6.981				

Table 48

Base Repair Cycle Time, Mean and Standard Deviation
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		ALL CASES
	SIMPLE	COMPLEX	
NOVICE	Manual 7.00 4.22 (10)*	Manual 6.04 4.19 (12)	7.90 3.57 (44)
	Expert System 10.00 0.00 (10)	Expert System 8.75 2.92 (12)	
JOURNEYMAN	Manual 9.00 3.08 (20)	Manual 7.92 3.24 (18)	8.68 2.81 (72)
	Expert System 8.59 2.88 (16)	Expert System 9.17 1.92 (18)	
ADVANCED	Manual 10.00 0.00 (8)	Manual 7.86 2.67 (7)	9.53 1.48 (32)
	Expert System 10.00 0.00 (10)	Expert System 10.00 0.00 (7)	

* Parentheses indicate number of observations

Table 48 (continued)

ANALYSIS				VARIANCE			
BY	FS	EXPT	BRCT	SUM OF	DF	MEAN	SIGNIF
			EXPERIENCE LEVEL	SQUARES		SQUARE	F OF F
			TASK DIFFICULTY				
			SOLUTION METHOD				
SOURCE OF VARIATION							
MAIN EFFECTS							
EXP				127.203	4	31.801	4.178 0.003
DIF				43.165	2	21.523	2.236 0.062
METH				18.655	1	18.655	2.451 0.120
				59.750	1	59.730	7.855 0.006
2-WAY INTERACTIONS							
EXP DIF				58.171	5	11.634	1.529 0.185
EXP METH				6.055	2	3.027	0.399 0.673
DIF METH				38.584	2	19.292	2.535 0.083
				12.754	1	12.754	1.676 0.198
3-WAY INTERACTIONS							
EXP DIF METH				8.736	2	4.368	0.574 0.565
				8.736	2	4.368	0.574 0.565
EXPLAINED				194.110	11	17.646	2.319 0.012
RESIDUAL				1035.071	136	7.611	
TOTAL				1229.181	147	8.362	

Table 49

Base Processing Time, Mean and Standard Deviation
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY			ALL CASES
	SIMPLE		COMPLEX	
NOVICE	Manual 8.00 1.58 (10)*		Manual 5.00 5.22 (12)	7.56 3.83 (44)
	9.25 1.69 (10) Expert System		8.33 3.89 (12) Expert System	
JOURNEYMAN	Manual 7.87 2.19 (20)		Manual 6.11 4.64 (18)	7.95 3.37 (72)
	9.53 1.36 (16) Expert System		8.47 3.55 (18) Expert System	
ADVANCED	Manual 8.13 1.16 (8)		Manual 4.64 5.09 (7)	7.97 3.14 (32)
	9.25 1.21 (10) Expert System		9.29 1.89 (7) Expert System	

* Parentheses indicate number of observations

Table 49 (continued)

* * * A N A L Y S I S O F V A R I A N C E * * *									
		F6		9PT					
		EXP		EXPERIENCE LEVEL					
		DIF		TASK DIFFICULTY					
		4ETH		SOLUTION: METHCD					
SOURCE OF VARIATION		SUM OF		DF		MEAN		SIGNIF	
		SQUARES				SQUARE		F	
MAIN EFFECTS								CF	
EXP									
DIF									
METH									
2-WAY INTERACTIONS									
EXP									
DIF									
METH									
3-WAY INTERACTIONS									
EXP									
DIF									
METH									
EXPLAINED									
RESIDUAL									
TOTAL									
		290.614		4		72.653		6.995	
		4.137		2		2.068		0.199	
		99.332		1		99.332		9.566	
		190.463		1		190.463		18.341	
		31.434		5		6.287		0.605	
		2.281		2		1.140		0.110	
		3.300		2		1.650		0.159	
		26.993		1		26.993		2.599	
		11.297		2		5.649		0.544	
		11.297		2		5.649		0.544	
		333.345		11		30.304		2.918	
		1412.263		136		10.384			
		1745.608		147		11.875			

Table 50
 Repairable Intransit Time, Mean and Standard Deviation
 Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 8.00 4.22 (10)*	Manual 7.08 4.37 (12)	7.39 4.35 (44)
	6.00 5.16 (10) Expert System	8.33 3.89 (12) Expert System	
JOURNEYMAN	Manual 9.50 2.24 (20)	Manual 7.50 4.20 (18)	7.53 4.19 (72)
	7.50 4.47 (16) Expert System	5.42 4.79 (18) Expert System	
ADVANCED	Manual 10.00 0.00 (8)	Manual 8.93 2.83 (7)	7.89 4.07 (32)
	7.00 4.83 (10) Expert System	5.71 5.35 (7) Expert System	

* Parentheses indicate number of observations

Table 50 (continued)

* * * A N A L Y S I S C F V A R I A N C E * * *							
BY	F7	RITT	EXP	EXP	LEVEL		
	DIF	TASK	DIF	DIF	DIFFICULTY		
	METH	SOLUTION	METH	METH	METHOD		
SOURCE OF VARIATION							
				SUM CF	DF	MEAN	SIGNIF
				SQUARES		SQUARE	F OF F
MAIN EFFECTS							
EXP				159.711	4	39.928	2.369 0.056
DIF				1.364	2	2.182	0.129 0.879
METH				39.257	1	39.257	2.329 0.129
				113.517	1	113.517	6.735 0.010
2-WAY INTERACTIONS							
EXP				100.440	5	20.090	1.192 0.316
DIF				50.583	2	25.291	1.500 0.227
METH				38.787	2	19.393	1.151 0.320
				7.114	1	7.114	0.422 0.517
3-WAY INTERACTIONS							
EXP				21.814	2	10.907	0.647 0.525
DIF				21.814	2	10.907	0.647 0.525
				281.973	11	25.634	1.521 0.131
EXPLAINED							
RESIDUAL				2292.351	136	16.856	
TOTAL				2574.324	147	17.512	

Table 51
Supply to Maintenance Time, Mean and Standard Deviation
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY			
	SIMPLE		COMPLEX	
NOVICE	Manual	Expert System	Manual	ALL CASES
	8.00 4.22 (10)*	9.00 3.16 (10)	6.67 4.92 (12)	8.41 3.70 (44)
JOURNEYPMAN	Manual	Expert System	Manual	ALL CASES
	10.00 0.00 (20)	10.00 0.00 (16)	9.58 1.29 (18)	
ADVANCED	Manual	Expert System	Manual	ALL CASES
	7.81 4.11 (8)	9.00 3.16 (10)	10.00 0.00 (7)	

* Parentheses indicate number of observations

Table 51 (continued)

* * * A N A L Y S I S O F V A R I A N C E * * *										
BY		FOR	STMT		EXPERIENCE LEVEL		TASK DIFFICULTY		SOLUTION: 4ETMCD	
		EXP	DIF	METH						
SOURCE OF VARIATION					SUM OF	DF	MEAN			
					SQUARES		SQUARE			
MAIN EFFECTS					92.022	4	23.006			
EXP					64.138	2	32.069			
DIF					0.965	1	0.965			
METH					29.602	1	29.602			
2-WAY INTERACTIONS					53.642	5	10.728			
EXP					18.618	2	9.309			
EXP					28.663	2	14.331			
DIF					3.804	1	3.804			
3-WAY INTERACTIONS					14.582	2	7.291			
EXP					14.582	2	7.291			
EXPLAINED					160.246	11	14.568			
RESIDUAL					752.760	136	5.535			
TOTAL					913.007	147	6.211			

Table 52

Shop Flow Time, Mean and Standard Deviation
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 7.50 3.33 (10)*	Manual 5.21 4.58 (12)	8.13 3.46 (44)
	10.00 0.00 (10) Expert System	10.00 0.00 (12) Expert System	
JOURNEYMAN	Manual 9.50 1.54 (20)	Manual 7.78 3.82 (18)	9.03 2.54 (72)
	9.06 2.56 (16) Expert System	9.72 1.18 (18) Expert System	
ADVANCED	Manual 7.50 4.63 (8)	Manual 7.50 4.33 (7)	8.67 3.24 (32)
	9.50 1.58 (10) Expert System	10.00 0.00 (7) Expert System	

* Parentheses indicate number of observations

Table 52 (continued)

* * * A N A L Y S I S C F V A R I A N C E * * *						
BY		F9	SFT			
		EXP	EXPERIENCE LEVEL			
		DIF	TASK DIFFICULTY			
		METH	SOLUTION METHOD			
SOURCE OF VARIATION			SUM OF SQUARES	DF	MEAN SQUARE	SIGNIF F OF F
MAIN EFFECTS						
		EXP	176.015	4	44.004	5.802 0.000
		DIF	24.165	2	12.083	1.593 0.207
		METH	13.768	1	13.768	1.815 0.180
			141.295	1	141.295	18.631 0.000
2-WAY INTERACTIONS						
		EXP	105.401	5	21.080	2.780 0.020
		DIF	8.456	2	4.228	0.557 0.574
		METH	58.905	2	29.452	3.884 0.023
			34.916	1	34.916	4.604 0.034
3-WAY INTERACTIONS						
		EXP	5.269	2	2.635	0.347 0.707
		DIF	5.269	2	2.635	0.347 0.707
EXPLAINED			286.685	11	26.062	3.437 0.000
RESIDUAL			1031.389	136	7.584	
TOTAL			1318.074	147	8.966	

Table 53

Turn In Time, Mean and Standard Deviation
Sacramento and Ogden Combined

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 8.25 3.74 (10)*	Manual 5.83 5.15 (12)	8.35 3.61 (44)
	Expert System 9.50 1.58 (10)	Expert System 10.00 0.00 (12)	
JOURNEYPMAN	Manual 10.00 0.00 (20)	Manual 9.17 2.57 (18)	9.72 1.43 (72)
	Expert System 9.69 1.25 (16)	Expert System 10.00 0.00 (18)	
ADVANCED	Manual 8.75 3.54 (8)	Manual 8.57 3.78 (7)	9.22 2.57 (32)
	Expert System 9.50 1.58 (10)	Expert System 10.00 0.00 (7)	

* Parentheses indicate number of observations

Table 53 (continued)

ANALYSIS OF VARIANCE									
		F17	TINT						
3Y	EXP	EXP	EXPERIENCE LEVEL						
	DIF	DIF	TASK DIFFICULTY						
		4ETH	SOLUTION: METHCD						
SOURCE OF VARIATION				SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF	
MAIN EFFECTS									
	EXP			109.923	4	27.481	4.845	0.001	
	DIF			52.385	2	26.193	4.618	0.011	
				6.272	1	6.272	1.106	0.295	
	METH			52.932	1	52.932	9.332	0.003	
2-WAY INTERACTIONS									
	EXP			74.292	5	14.858	2.612	0.027	
	DIF			6.072	2	3.036	0.535	0.597	
	EXP			42.894	2	21.447	3.731	0.025	
	DIF			22.667	1	22.667	3.996	0.048	
3-WAY INTERACTIONS									
	EXP			7.300	2	3.653	0.644	0.527	
	DIF			7.306	2	3.653	0.644	0.527	
				191.521	11	17.411	3.062	0.001	
EXPLAINED									
				771.443	136	5.672			
RESIDUAL									
				962.965	147	6.551			
TOTAL									

Table 54
Mean Times to Complete (In Minutes)
And Standard Deviations
Sacramento

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 23.14 9.62 (7)*	Manual 27.29 10.32 (7)	26.35 8.75 (26)
	27.80 11.50 (5) Expert System	27.57 3.91 (7) Expert System	
JOURNEYMAN	Manual 21.83 9.82 (12)	Manual 36.58 10.01 (12)	26.09 10.14 (47)
	21.08 6.71 (12) Expert System	24.73 4.54 (11) Expert System	
ADVANCED	Manual 25.50 7.59 (4)	Manual 41.00 3.61 (3)	29.33 9.95 (15)
	31.75 12.63 (4) Expert System	22.00 1.15 (4) Expert System	

* Parentheses indicate number of observations

Table 54
Mean Times to Complete (In Minutes)
And Standard Deviations
Sacramento

USER EXPERIENCE	CASE DIFFICULTY		
	SIMPLE	COMPLEX	ALL CASES
NOVICE	Manual 23.14 9.62 (7)*	Manual 27.29 10.32 (7)	26.35 8.75 (26)
	27.80 11.50 (5) Expert System	27.57 3.91 (7) Expert System	
JOURNEYMAN	Manual 21.83 9.82 (12)	Manual 36.58 10.01 (12)	26.09 10.14 (47)
	21.08 6.71 (12) Expert System	24.73 4.54 (11) Expert System	
ADVANCED	Manual 25.50 7.59 (4)	Manual 41.00 3.61 (3)	29.33 9.95 (15)
	31.75 12.63 (4) Expert System	22.00 1.15 (4) Expert System	

* Parentheses indicate number of observations

Table 54 (continued)

* * * A N A L Y S I S C F V A R I A N C E * * *							
B/		TIME EXP DIF METH	TIME TO COMPLETE EXPERIENCE LEVEL TASK DIFFICULTY SOLUTION METHOD				
SOURCE OF VARIATION				SUM OF SQUARES	DF	MEAN SQUARE	SIGNIF F CF F
MAIN EFFECTS							
EXP				1224.844	4	306.211	4.340 0.003
DIF				161.349	2	80.674	1.143 0.324
METH				816.957	1	816.957	11.579 0.001
				307.298	1	307.298	4.355 0.040
2-WAY INTERACTIONS							
EXP		DIF		1309.010	5	261.802	3.711 0.005
EXP		METH		290.836	2	145.418	2.061 0.134
DIF		METH		366.206	2	183.103	2.595 0.081
				724.519	1	724.519	10.274 0.002
3-WAY INTERACTIONS							
EXP		DIF		255.812	2	127.906	1.813 0.170
		METH		255.812	2	127.906	1.813 0.170
EXPLAINED				2789.666	11	253.606	3.594 0.000
RESIDUAL				5362.232	76	70.556	
TOTAL				8151.898	87	93.700	

Table 55
Mean Times to Complete (In Minutes)
And Standard Deviations
Ogden

USER EXPERIENCE	CASE DIFFICULTY			ALL CASES
	SIMPLE		COMPLEX	
NOVICE	Manual 10.67 6.66 (3)*		Manual 18.20 4.27 (5)	18.06 6.46 (18)
	18.40 4.51 (5) Expert System		22.00 7.48 (5) Expert System	
JOURNEYMAN	Manual 13.50 4.00 (8)		Manual 14.83 1.17 (6)	18.00 6.39 (25)
	22.75 1.71 (4) Expert System		23.14 7.69 (7) Expert System	
ADVANCED	Manual 13.50 2.52 (4)		Manual 15.25 2.06 (4)	20.47 9.78 (17)
	24.33 13.22 (6) Expert System		29.00 2.65 (3) Expert System	

* Parentheses indicate number of observations

Table 55 (continued)

* * * A N A L Y S I S C F V A R I A N C E * * *									
TIME		TIME TO COMPLETE							
B1	EXP	EXP	LEVEL						
	DIF	TASK	DIFFICULTY						
	METH	SOLUTION	METHOD						
SOURCE OF VARIATION				SUR CF	DF	MEAN	SIGNIF	F	CF F
				SGLARES		SQUARE			
MAIN EFFECTS				1248.583	4	312.146		8.020	0.000
EXP				82.950	2	41.475		1.066	0.353
DIF				119.137	1	119.137		3.061	0.037
METH				1055.552	1	1055.552		27.121	0.000
2-WAY INTERACTIONS				151.055	5	30.211		0.776	0.572
EXP				50.112	2	25.056		0.644	0.530
EXP				86.914	2	43.457		1.117	0.336
DIF				2.021	1	2.021		0.052	0.821
3-WAY INTERACTIONS				24.355	2	12.177		0.313	0.733
EXP				24.355	2	12.177		0.313	0.733
EXPLAINED				1423.993	11	129.454		3.326	0.002
RESIDUAL				1868.190	48	38.921			
TOTAL				3292.183	59	55.800			

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