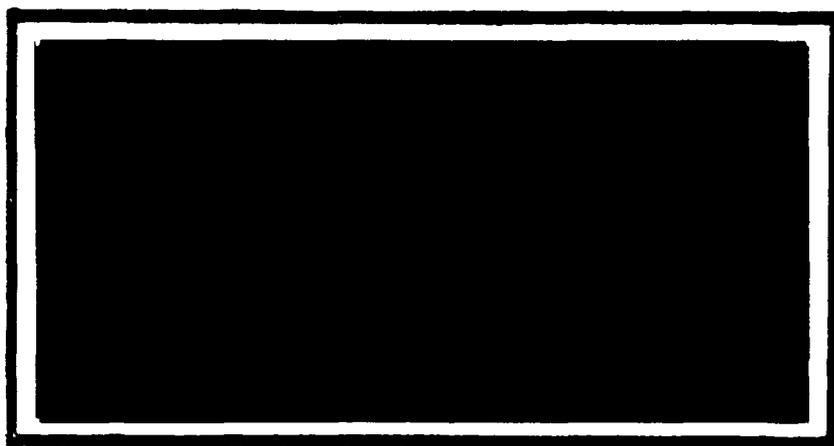


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A COMPARISON OF KNOWLEDGE ACQUISITION  
TECHNIQUES USED IN THE  
DEVELOPMENT OF EXPERT SYSTEMS

THESIS

James R. Heatherton  
Captain, USAF

AFIT/GLM/LSR/90S-23

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A COMPARISON OF KNOWLEDGE ACQUISITION TECHNIQUES  
USED IN THE DEVELOPMENT OF EXPERT SYSTEMS

THESIS

Presented to the Faculty of the School of Systems and Logistics  
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the  
Requirements for the Degree of  
Masters of Science in Logistics Management

James R. Heatherton, B.A.

Captain, USAF

September 1990

Approved for public release; distribution unlimited

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Captain James R. Heatherton

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Abstract

The primary objective of this thesis was to compare three knowledge acquisition techniques used to gather knowledge for the development of an expert system. The goal was to determine which technique produced knowledge in a form most suitable for incorporation into an expert system.

The three acquisition techniques compared were interviewing, task observation, and concept mapping. Three experts were selected and randomly paired with a technique. Knowledge acquisition sessions were then conducted with each expert using the technique assigned to that expert. The knowledge extracted from these acquisition sessions was then compared.

Overall, concept mapping produced more rules, in less time, and with fewer inferences than the interview or task observation techniques. Additionally, the knowledge base acquired through the concept mapping technique was more complete. Finally, concept mapping required one less translation of the knowledge to arrive at a form necessary for programming the expert system.

An expert system was developed using the concept mapping technique and was validated in a field test. Results showed that the solutions provided by the expert system matched those provided by the human experts.

# A COMPARISON OF KNOWLEDGE ACQUISITION TECHNIQUES USED IN THE DEVELOPMENT OF EXPERT SYSTEMS

## I. Introduction

### Background

An expert system is "an artificially intelligent computer program that solves problems at an expert level by using the knowledge and problem solving logic of human experts" (9:68). The popularity of expert systems as tools in decision making is growing rapidly in business and industry (25:152). Corporations are committing significant resources to the development and application of expert systems in order to achieve improvements in operational effectiveness and efficiency (9:68). In the Air Force, expert systems are being developed to solve a variety of problems in areas such as aircraft maintenance, acquisition, supply, and civil engineering.

One of the most difficult and time-consuming activities in the development of these expert systems is the process of knowledge acquisition (20:269). Kim and Courtney define knowledge acquisition as "the process of gathering knowledge about a domain, usually from an expert, and incorporating it into a computer program" (20:269). While this knowledge can come from a number of different sources such as text books, journals, and data bases, the emphasis in knowledge

acquisition continues to be placed on the human expert (19:53). Because of the time and difficulty associated with extracting knowledge from the human expert, knowledge acquisition has been cited throughout the literature as a critical "bottleneck" in the development of expert systems (4:144; 5:228; 20:269; 25:152).

Despite continued advances in expert system technology, the process of knowledge acquisition remains ill-defined. There is much written in the literature on how to build expert systems, but little written about knowledge acquisition (7:152). Even books that describe in detail how to build an expert system do not say much about the subject of knowledge acquisition (7:152). This lack of direction can have a negative impact on the successful development of expert systems the Air Force.

#### Problem Statement

The power of an expert system is directly dependent on the quality and completeness of its knowledge base (20:269). The acquisition of this knowledge base is the problem that most limits the application of expert system technology. Many acquisition techniques have been identified in the literature, but very little data is available on which technique, or combination of techniques, may be more effective or more useful given different situations.

### Research Objective

The purpose of this research was to evaluate and compare the effectiveness of three knowledge acquisition techniques used to gather knowledge from an Air Terminal Operations Center (ATOC) in an Air Force Transportation Squadron. The goal was to determine which of those techniques produced knowledge in a form most suitable for incorporation into an expert system.

### Research Questions

The following questions were answered to solve the specific problem.

1. What are the current and most widely recognized techniques used to acquire knowledge from experts?
2. What current Air Force issue in the ATOC was appropriate for building a prototype expert system and what software development tool could be used to build it?
3. Given a selected application and software development tool, which extraction technique among three evaluated was more effective in producing the knowledge which would be programmed into a prototype expert system?
4. After developing a prototype expert system using one of the three predetermined acquisition techniques, was the knowledge base complete and the prototype system valid?

### Scope of the Study

Although there are several knowledge acquisition techniques, this research compared only three. The expert system developed from the knowledge acquisition process was a prototype system focusing on a specific problem related to the activities of the Air Terminal Operation Center in an Air Force Transportation Squadron.

### Method of Organization

Chapter I introduces the concept of expert system technology and provides background information on the process of knowledge acquisition. This chapter also defines the specific problem, research objective, research questions, and scope of the study. Chapter II discusses background information on the development of expert systems and the process of knowledge acquisition. Chapter III presents the specific methodology that was followed to compare different knowledge acquisition techniques and to evaluate their effectiveness. Chapter IV reviews the findings and analyzes the results of the research effort. Chapter V presents the conclusions and recommendations.

## II. Literature Review

### Overview

The purpose of this chapter is to review some of the literature written about expert systems and the knowledge acquisition methods used in their development. This chapter is divided into three main parts. The first part discusses expert systems in general by defining an expert system and providing a description of its major components. Next, the steps required in the development of expert systems and some of the programming tools used to build them are presented. Finally, some of the benefits and limitations of experts systems are discussed. The next major part in the review deals with the issue of knowledge acquisition. The importance of knowledge acquisition is discussed and some of the difficulties associated with the process are presented. Then, some of the methods for knowledge acquisition are introduced. The final section in this chapter addresses the appropriateness of applying expert system technology in an Air Terminal Operations Center (ATOC).

### Background on Expert System

Definition of an Expert Systems. There are many definitions for experts systems offered in the literature. Saylor defines an expert system as "a problem-solving or decision making computer program designed to perform the same evaluation as a human expert in a specified, defined

area" (27:450). Carpenter describes an expert system as "a form of computer software that relies on stored facts and rules of thumbs to mimic the decision making of human experts" (6:64). Cook defines an expert systems as "an artificially intelligent computer program that solves problems at an expert level by utilizing the knowledge and problem solving logic of human experts" (9:68).

Expert systems differ significantly from conventional computing systems. While conventional computer programs deal primarily with quantitative data and are based on clearly defined, step-by-step procedures, expert systems deal primarily with qualitative information and are able to reason about data and draw conclusions employing heuristic rules (28:17). Heuristics are sometimes characterized as the "rules of thumb" that one acquires through practical experience to solve everyday problems (28:17).

Components of an Expert System. Every expert system consists of three major components: a knowledge base, an inference engine, and some form of user interface. The heart of the expert system is its knowledge base. The knowledge base contains the facts, rules, and other knowledge required to solve a problem (32:8). The inference engine works on the knowledge base to reach conclusions about the problem (1:18). The inference engine can work forward through a problem from an initial set of conditions to a specific goal (13:87-88). This is called forward chaining. The inference engine can also work backward from

a goal to a set of premises that support that specific goal (13:87-88). This is referred to as backward chaining. Some expert systems incorporate both forward and backward chaining strategies (13:87-88). The user interface is the part of the program that allows the user to communicate with the system. The user interface will ask questions, present menu driven choices, and communicate to the user the answer or solution once it has been found (32:18). Figure 1 illustrates the basic structure of an expert system.

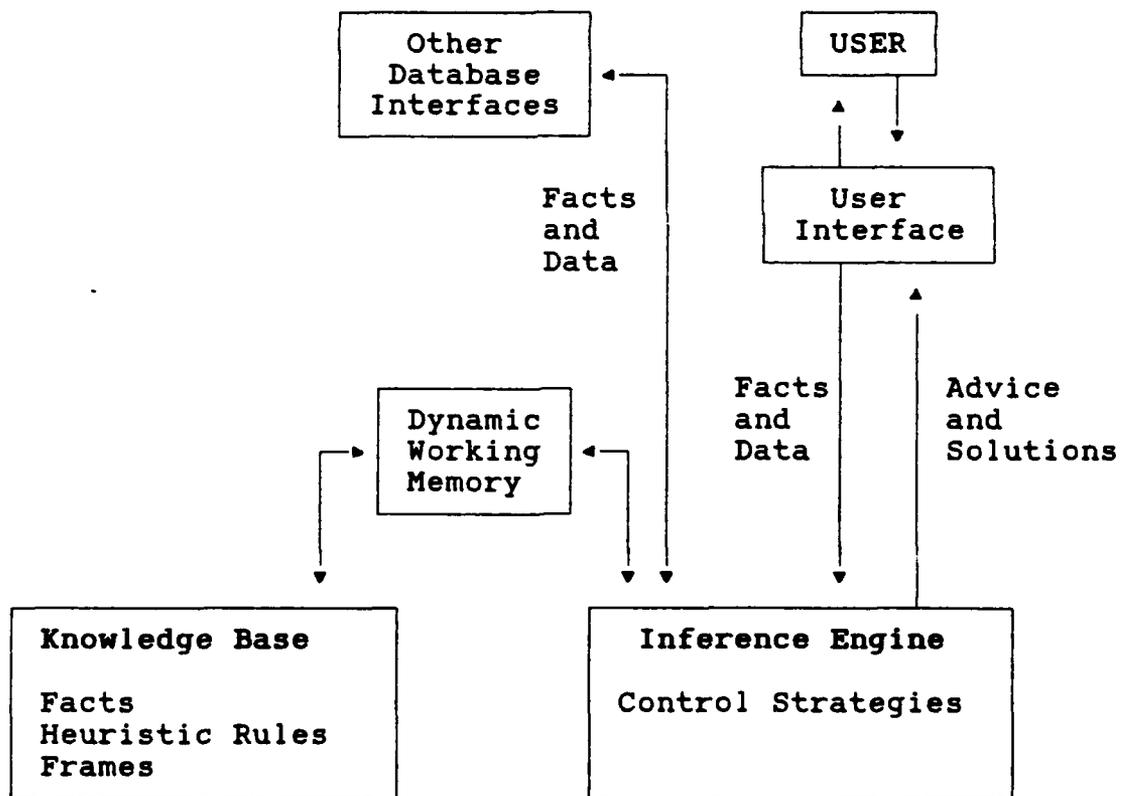
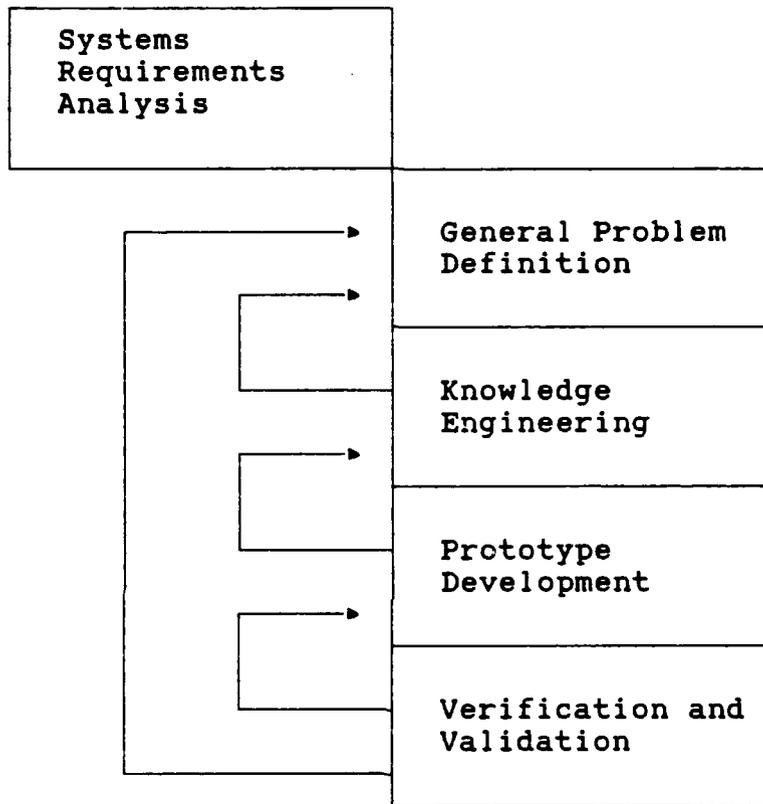


Figure 1. Basic Structure of an Expert System (2:27)

Developing an Expert System. The development of expert systems is an iterative process, as illustrated in Figure 2 (2:107).

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Figure 2. Expert System Development Process (2:107)

Analyze System Requirements. The first step in the development process is to determine the user's needs and develop an understanding of the problem area to be addressed by the system (2:106).

General Problem Definition. Because of the uncertain and qualitative nature of the problems typically addressed by expert systems, the problem is first defined in very general terms (2:106-107). A more in-depth definition

of the problem is then developed through a series of knowledge engineering sessions with the human expert (2:107).

Knowledge Engineering. Knowledge engineering can be defined as the process of acquiring the knowledge from the human expert and then translating that knowledge to a form that can be used in the search for and generation of solutions to problems (29:357). It is also an interactive process in which many meetings with the expert may be required to gather all the pertinent data needed for the knowledge base (21:8).

Prototype Development. After one or two knowledge acquisition sessions with the expert, a working prototype system should be developed (2:107). This prototype system can then be used in subsequent knowledge acquisition sessions to determine if there is any missing knowledge or if any modifications are required (2:107).

Verification and Validation. With each session, the prototype is refined and enhanced. The system is verified for consistency and completeness (22:70). Redundant, conflicting, circular, and unnecessary conditions and rules are either changed or removed (22:70). Eventually a complete system will emerge. One final step at this point is to validate the expert system's overall value and to answer the question of just how closely the system performs to human expert levels (24:91).

Development Tools (Software). When the decision is made to develop an expert system, a software development tool will be required to help create the system. Expert systems can be created using any of the common programming languages, such as BASIC, Fortran, C, Pascal, Forth, PROLOG, LISP, and Assembly Language (14:824). Programming languages can address highly complex problems and provide a great deal of flexibility (2:120). However, the use of programming languages can be a complex process which may involve special programmers, special operating environments, extensive hardware, extended development time, and a great deal of money (14:824). An alternative to programming languages is expert system shells. Expert system shells can address a wide range of problems and can be very inexpensive and easy to program (29:9).

Expert System Shells. Expert system shells are special software packages created specifically to help build expert systems. They are similar in some respects to conventional software packages like data base management systems or spreadsheets. A shell provides the basic framework in which data or knowledge can be entered and manipulated in predefined ways (14:824).

An expert system shell does not contain a knowledge base. The major distinguishing difference among expert systems built using expert system shells is the content of the knowledge base. The inference engine, data base, and user interface will work with many different knowledge

bases. Knowledge is simply coded in the designated format and entered into the knowledge base (16:45).

Benefits of Expert Systems. Expert systems offer several benefits. They can preserve the crucial expertise of the human expert that could otherwise be lost (27:451). This expertise can be easily transferred by simply copying the program (27:451). Expert systems are less expensive than human expertise, less likely to make mistakes, and can be easily documented (27:451). Finally, expert systems can free human experts from the performance of routine or simple tasks (27:451).

Limitations of Expert Systems. Despite these benefits, there are limitations to expert systems. Expert systems work best when applied to narrowly defined tasks (6:64-65). They are less successful when dealing with larger, more complex problem domains (6:64-65). Additionally, expert systems are only computer programs, and their decisions can be very unimaginative when compared to the decisions of a human expert (27:451). The biggest limitation of expert systems, however, is the difficulty of extracting the expertise from the human expert (27:451).

### Knowledge Acquisition

Kim and Courtney define knowledge acquisition as "the process of gathering knowledge about a domain, usually from an expert, and incorporating it into a computer program" (20:269). The power of any expert system comes from the

knowledge contained in its knowledge base (20:269). While this knowledge can come from many sources such as text books, journals, and data bases, the emphasis in knowledge acquisition has been placed on the human expert (19:53). Because of the time and difficulty associated with extracting knowledge from the human expert, knowledge acquisition has been cited throughout the literature as a critical bottleneck in the development of expert systems (4:144; 5:228; 20:269; 25:152). Knowledge acquisition is the most important process in the development of expert systems (16:158).

Difficulties with Knowledge Acquisition. The process of knowledge acquisition is dependent upon the expert's abilities, availability, and willingness to cooperate (26:44). There are several difficulties associated with those requirements. Human experts have a difficult time explaining how they make decisions (27:451). This inability of an expert to verbalize how he or she goes about solving a problem is a difficulty in knowledge acquisition cited most often in the literature (4:144; 5:228; 20:269; 25:152). The availability of the expert is another reason why knowledge acquisition is difficult (5:228). The process of knowledge acquisition takes time (5:228). The expert or the expert's supervisors may not be willing to spend the time required to complete the project (5:230). The willingness of the expert to participate in the knowledge engineering project is another difficulty in knowledge acquisition (25:153). An

unwilling expert will cause the knowledge acquisition process to fail (25:153). An expert may be unwilling to participate for any number of reasons (25:153). The expert may fear his or her job may be eliminated if a computer can capture their expertise (25:153). The expert may also fear the loss of esteem others hold for him or her if the task he or she performs is reduced to something simple through the knowledge acquisition process (25:153). Finally, the expert may not know how to explain his or her problem solving expertise and may fear being seen as inarticulate (25:153).

Methods of Knowledge Acquisition. According to Teft, expertise consists of knowledge accumulated through experience. With the possible exception of those who teach, few experts spend very much time explaining their knowledge. To elicit knowledge from the expert, the knowledge engineer must understand the ways in which the expert relates objects, relationships, conditions, constraints, and events within the area of expertise and then apply the appropriate knowledge acquisition tool (29:203).

The literature discusses several methods of knowledge acquisition. Olson categorized these methods into direct and indirect methods of acquisition. Direct methods focus on the explicit knowledge, knowledge that the expert can communicate verbally. The direct methods include interviews, questionnaires, protocol analysis, interruption analysis, task observation, drawing closed curves and inferential flow analysis (25:153-166). Indirect methods

focus on implicit knowledge, knowledge that cannot be easily verbalized. They collect information that requires inferences to be made about the exact nature of the expert's knowledge. The indirect methods include multidimensional scaling, hierarchical clustering, general weighted networks, ordered trees from recall and repertory grid analysis.

This list of direct and indirect methods is not all inclusive. However, it should give the reader an idea of the variety of techniques available to the knowledge engineer. Heatherton and Vikan provide a summary of each of these direct and indirect methods and a list of sources where the reader can find additional information on each technique (17:32-46). In addition, the three techniques selected for examination in this research project are described in Chapter III and Appendix B.

#### Air Terminal Operations Center

Expert system technology is being applied to solve problems in a variety of Air Force organizations and activities (8:1). One activity in which expert system technology has potential usefulness is in an Air Terminal Operations Center (ATOC). The ATOC in an Air Force Aerial Port Squadron or Transportation Squadron is responsible for coordinating and directing all transportation activities in support of airlift operations (11:5-1). These activities include airlift mission setup, load planning, fleet

services, cargo loading and unloading, hazardous cargo handling, passenger processing, and baggage handling.

The ATOC is a complex operation, requiring close monitoring of many different events which must be completed in sequence and on time to ensure the success of the airlift mission. Besides ensuring the successful completion of the sequence of events, personnel in the ATOC are often faced with a variety of problems which have an impact on the sequence. Weather, maintenance problems, and traffic delays are only a few of the variables ATOC personnel must deal with.

Given the complexity of the ATOC operation, reliance on experienced and expert personnel in the positions of duty officers, shift supervisors and information controllers is commonplace. Unfortunately, ATOCs are often unable to retain the expertise of the personnel they train because of rapid turnover due to PCS moves, separation, retirement, or in-house promotions to different positions.

One way to retain the expertise of the experienced personnel would be the application of an expert system. This expert system would assist the inexperienced person by automatically monitoring the status of the transportation activities, insuring all steps in checklists were completed, identifying potential problems and recommending solutions to those problems.

## Summary

This literature review provided a description of an expert system and its major components. It presented some of the advantages of expert systems and some of the limitations. It pointed out the importance of knowledge acquisition in the development of an expert system and identified some of the difficulties associated with the process of knowledge acquisition. Some of the methods used to extract knowledge from the human expert were listed. Finally, the reasons for applying expert system technology in and Air Terminal Operations Center were discussed.

### III. Methodology

#### Overview

The purpose of this chapter is to explain the methodology that was used to solve the research problem. In order to determine which knowledge acquisition technique among three selected for study produced more effective results when compared with the other two techniques, several major steps were required. These steps consisted of conducting a literature review, selecting the problem area to be addressed by the expert system, selecting three human experts, selecting an expert system shell, and selecting the three knowledge acquisition techniques to use in the study. After these steps were completed, a comparative study was made in which the selected acquisition techniques were used in knowledge acquisition sessions with human experts. The results of these sessions were then compared and the one technique considered more effective among the three was selected and used to build a prototype expert system. The accuracy of the knowledge base in the prototype expert system was then validated in a field test to further support the effectiveness of the selected technique.

#### Literature Review

The initial phase of the study consisted of conducting a literature review to examine current concepts in expert system technology and knowledge acquisition. The review

provided a definition of expert systems, a description of their components and an explanation on how an expert system works. It presented the steps which are necessary to build expert systems and the programming tools used to develop them. The review also examined the issue of knowledge acquisition as a critical process in the development of expert systems. It identified the difficulties and problems related to knowledge acquisition and listed some of the methods of knowledge acquisition. Finally, the review provided some background information on the Air Terminal Operations Center.

#### Selecting the Problem Area

The Air Terminal Operations Center (ATOC) in the Transportation Division of the 2750th Logistics Squadron, Wright-Patterson Air Force Base, Ohio was selected as the functional area in which the expert system was applied. Although this ATOC is not the largest or the busiest ATOC in the Air Force, it possesses the characteristics that make the application of expert system technology appropriate.

The ATOC is an area in which valuable human expertise is scarce and is often in jeopardy of being lost. Many of the tasks performed are complex, unstructured and rely on heuristic solutions. Heuristics are sometimes characterized as the "rules of thumb" that one acquires through practical experience to solve everyday problems (28:17). There is also substantial variability in the ability of assigned

personnel to perform tasks. At one end of the spectrum are the newly assigned personnel who are just beginning to gain competence through experience. At the other end are the recognized experts, or at least those personnel who are recognized as being the most experience. It is not always possible to get a good mix of experienced/inexperienced personnel on each shift. An expert system could reduce this variability.

An additional reason for selecting this ATOC is that it is located in close proximity to the School of Systems and Logistics. This eliminated the need to spend TDY funds to conduct the knowledge acquisition sessions and made the data used in the study readily assessable.

The Specific Problem. In order to determine one or more specific problem or decision areas which might be effectively addressed by an expert system, an interview was conducted with Mr. John Altick, the Air Terminal Manager at Wright Patterson AFB, OH. One area that has received a great deal of attention recently is the movement of space available passengers.

Extreme care must be taken when determining the number of seats available for use by space available passengers. Space available travel is considered a special service benefit and offering seats to space available travelers, only to have to cancel them because of some mistake, is not only a matter of providing poor customer service, it can also be damaging to morale. The number of variables which

must be considered when making a determination on the number of seats to release is large. The type of aircraft, destination, number of seats, service facilities, planned cargo and fuel load, crew size, and crew complement are just a few of the variables which must be considered in every seat release. Even experienced personnel must be careful not to overlook any of the decision factors. An expert system could check known variables against requirements and consistently determine an accurate seat release.

#### Expert Selection

The next step was to select three human experts. An expert is defined as "one who is probably better at performing in a domain than those who are not considered to be expert" (18:34). The domain experts must be, besides experts in their field, available and willing to participate in the study. Given these criteria, the three experts selected for this study were Master Sergeant (MSgt) James M. McDonald, Technical Sergeant (TSgt) Stephen A. Chatfield and Staff Sergeant (SSgt) James R. Ratliff. According to Mr. Altick, these three individuals were exceptionally well qualified, available, and willing to participate in the study.

MSgt McDonald is currently the Superintendent of the Air Passenger Terminal at Wright Patterson AFB, OH. He has more than 15 years experience in air transportation and has worked in air terminal operations for 10 years. Prior to

his current assignment he was the Noncommissioned Officer in Charge (NCOIC) of the ATOC at Anderson AFB, Guam.

TSgt Chatfield is currently the Superintendent of the ATOC at Wright Patterson AFB, OH. He has more is 12 years experience in air transportation and has worked in air terminal operations for 7 years. Prior to his current assignment, he was a Shift Supervisor in the ATOC at Clark Air Base the Philippines.

SSgt Ratliff is currently a Shift Chief in the ATOC at Wright Patterson AFB. He has more than 9 years experience in air transportation and has worked in air terminal operations for 5 years. Prior to his current assignment, he was a Senior Controller in the ATOC at Elmendorf AFB, Alaska.

#### Selection of an Expert System Shell

VP Expert, version 2.1, by Paperback Software International was selected as the expert system shell. VP Expert is one of the least expensive (\$88) of all the commercially available shells, yet has many of the qualities of more expensive software and meets all requirements for this project. The software is widely available through commercial software sources and is also available on many of the computers in AFIT School of Systems and Logistics.

#### Selection of the Knowledge Acquisition Techniques

Three knowledge acquisition techniques were selected from among the many techniques identified in literature.

The techniques selected were the interview, task observation, and concept mapping. A brief description of each technique and the reasons for selecting it are provided below. A more complete description of these techniques can be found in Appendix B.

The Interview. Interviewing for knowledge involves a direct dialogue between the expert and the knowledge engineer. Simply, the knowledge engineer asks questions and the expert answers them. Through this process, exchange knowledge is transferred.

The interviewing technique is the technique cited most often in the literature. Of 19 sources which identified known knowledge acquisition techniques, all identified interviewing as a means of collecting knowledge from human experts. According to Waldron, "the interview remains the primary knowledge acquisition tool" (31:31). Given this universal recognition of the interview as a knowledge acquisition technique, it seems only proper to select it as one of three to study.

Task Observation. In task observation, the knowledge engineer watches the expert solve a real problem or perform a task. Only after the task is complete does the knowledge engineer ask questions about what occurred.

At the beginning of the study, task observation appeared to be a technique that would lend itself to the problem area selected for the study. Many of the activities and decisions made in the ATOC are repetitive and readily

observable. The ATOC is also a busy place which functions best when personnel are not interrupted. Task observation had the potential to capture the processes experts use as they go about dealing with recurring situations and decisions. The expert would be allowed to work freely with little, if any, interruption.

Concept Mapping. Concept mapping is a graphical approach to knowledge acquisition. Real problems are represented in the form of drawings showing the objects in the problem area and the connections between these objects.

Concept mapping appeared to be a good method for extracting knowledge in a form which would facilitate meeting the syntax requirements of the expert system shell, VP Expert. As described in Appendix B, the concept map is constructed of several "concept words" connected by "linking words." VP Expert dictates that rule labels and variable names contain no more than 40 characters (30:4.3). The fact that the concepts are already in an abbreviated form in the concept map had the potential to make formatting rules for VP Expert easier.

#### Knowledge Acquisition

The next major step in the research process was to perform knowledge acquisition using each of the three techniques. One knowledge acquisition technique was randomly matched with each of the three experts. This was accomplished by writing the names of each technique and each

expert on 3 x 5 cards. One technique card was pulled from a hat and matched with one expert card also pulled from a hat. The interview technique was assigned to MSgt McDonald, concept mapping was assigned to TSgt Chatfield, and the task observation method was assigned to SSgt Ratliff.

The Interview Technique. The interviews were conducted over five sessions, each lasting approximately one hour. Each session was recorded with a tape recorder. Written notes were also taken. The first 22 minutes of the first session were used to get acquainted with the expert and to explain the purpose of the research. This was followed by an open-ended question concerning passenger seat release procedures. The purpose was to get a general feel for the procedures and to find a starting point from which to develop more specific questions. Because the researcher had an idea of the type of information that was needed, the remaining interviews were largely unstructured, allowing the expert to cover topics in his own way.

Shortly after each session, the tapes were transcribed and reviewed for the purpose of preparing for the next interview session.

The Task Observation Technique. The expert was observed performing his tasks over a period of five one hour sessions. During the observation sessions, the expert was permitted to perform his duties uninterrupted. Only after the task was complete was the expert questioned about any part of the task not clearly understood by the researcher.

Written notes were taken throughout the observations and the sessions were also tape recorded. During the first session, 15 minutes were used to get acquainted with the expert and to explain the research project. The expert was then asked to explain the basic procedures for releasing seats to the passenger terminal. This took another 37 minutes. The remaining time in the first session and subsequent sessions was spent in the actual observation of tasks and follow up questions.

The Concept Mapping Technique. Because the researcher had no previous experience using concept mapping, the technique was practiced on persons unrelated to this research using many of the examples provided in Gowin and Novak's book, Learning How To Learn (23). The concept mapping sessions were conducted over five sessions, each lasting approximately one hour each. Each session was also recorded with a tape recorder. During the first session, 16 minutes were spent getting acquainted with the expert and explaining the research project. This was followed by 51 minutes of practice using the concept mapping technique. The examples provided in Gowan and Novak's book were again used for this purpose. Some ATOC examples, not related to passenger seat releases, were also used during the practice. Shortly after each session, the maps were cleaned up and redrawn and in some cases restructured in preparation for the next session. Each session built upon the map produced

in the previous session until a complete map had been produced.

### The Comparative Study

The results of the knowledge acquisition sessions were recorded and compared using both quantitative and qualitative data. Quantitative data included the time taken to prepare for each knowledge acquisition session, the actual time spent in interaction with the expert, the time spent transcribing and integrating information from the tapes, written notes and drawings, the number of expert system rules generated by each knowledge acquisition technique, the number of translations necessary to convert the original data to expert system rules, and the time to formulate those rules. Qualitative data included the researcher's judgment about the advantages and disadvantages of using each of the techniques as well as the ease of use and data translation. The results of the analysis are presented in Chapter IV.

### Building the Prototype System

Based on the results of the comparative analysis of the knowledge acquisition techniques, one technique was selected to use in the actual development of a prototype expert system. This expert system, called the "ATOC Advisor," was programmed to find the number of seats that could be released to the Air Passenger Terminal for use by space available travelers. In addition to finding the correct

number of seats to release, the system was designed to make recommendations on inflight meal orders for the passengers, on passenger restrictions and limitations, and on passenger comfort. Because of the limited time allotted for the actual programming of an expert system and the overall purpose of this research effort--evaluating knowledge acquisition techniques--most the programming effort was spent on rule development and inferencing strategies.

#### Verification and Validation

Verification and validation are essential steps in the development of expert systems. Verification refers to building the system right, while validation refers to building the right system (24:90). Both issues were used to further support the usefulness of the technique selected to develop the ATOC Advisor.

Verification. Verification is accomplished throughout the encoding process. Each rule in the expert system must be checked for completeness and consistency (22:70). Verification was conducted by the researcher and involved checking the transcribed computer code line-by-line for redundant, conflicting, or incomplete rules. It also involved running the expert system with the "rules and values windows" of VP Expert in the active mode. This mode allowed the researcher to observe the execution of each rule as the inference engine worked through the knowledge base and assigned values to the variables involved in the

passenger seat release process. With the expert system verified, the next step was to validate the system.

Validation. Validation seeks to answer the question of just how closely the system performs to human expert levels (24:91). To validate the ATOC Advisor, a test was conducted in the field with the cooperation of personnel assigned in the ATOC at Wright Patterson AFB. Six seat release scenarios (Appendix C) were developed by the researcher and other experienced transportation officers. These scenarios were presented to the experts, who were asked to solve each of the scenarios manually while three other non-experts were selected and asked to solve the scenarios using the expert system. Discrepancies, if any, between the two sets of solutions were evaluated to determine if they resulted from errors in encoding the system, faulty assumptions made by the researcher while programming the system, or errors in the transfer of knowledge.

### Summary

Chapter III described the methods that were used to evaluate and compare the effectiveness of three knowledge acquisition techniques used to gather knowledge from an Air Terminal Operations Center in an Air Force Transportation Squadron. Interview, concept mapping, and task observation method were selected for the study and evaluated based on both quantitative and qualitative data.

A prototype expert system was developed using VP Expert and the knowledge gathered from one the three techniques. The system was validated in a field test to further support the effectiveness of the technique selected as the more effective among the three studied.

#### IV. Analysis of Results

##### Overview

The purpose of this chapter is to analyze the results of this study and determine which of the three knowledge acquisition techniques compared--interview, task observation, or concept mapping--was most useful in developing an expert system for the Air Terminal Operations Center (ATOC). The results are presented in four main parts: technique implementation, rule production, qualitative judgements, and expert system validation.

##### Technique Implementation

The results presented in this section are concerned with the actual execution of each knowledge acquisition technique. In addition to the actual time spent interacting with the experts, the time spent transcribing and integrating information from written notes and audiotapes, as well as the total time involved in preparing for each technique was recorded. Table 1 presents the results of this phase of the evaluation.

Interaction Time. Interaction time included only the actual time spent engaged in the activity of knowledge transfer. The time taken to get acquainted with the experts, to brief them on the purpose of this research, or to practice a technique was not included in this time. Additionally, any interruption time for such things

Table 1  
 Knowledge Acquisition Technique  
 Implementation Times (in minutes)

|                   | Interview    | Concept<br>Mapping | Task<br>Observation |
|-------------------|--------------|--------------------|---------------------|
| Interaction Times | 209.9        | 192.0              | 227.0               |
| Transcription     | 238.5        | 367.2              | 253.6               |
| Preparation Times | 41.3         | 51.0               | 18.2                |
| <b>Total Time</b> | <b>489.7</b> | <b>610.2</b>       | <b>498.8</b>        |

as unrelated phone calls or personal breaks was also not included in the interaction times.

Task observation had the highest interaction time of the three techniques. This can be attributed to the fact that there was less conversation between the researcher and the expert and that most activity in which the expert engaged was a target for observation and considered as interaction time. Concept mapping had the lowest interaction time because the first of the five one hour sessions was primarily used to practice the concept mapping technique.

Transcription Time. Transcription time consisted of the time spent transcribing information from audiotapes, integrating that information with written notes, and redrawing concept maps. It should be noted here, that the audiotapes were not transcribed word-for-word. If they had been, transcription times, especially for the interviews,

would have been considerably longer. A sample of a "word-for-word" transcription of 10 minutes of interview time is provided in Appendix D. This particular transcript took 30 minutes to produce.

As indicated in Table 1, transcription time was the most time consuming component of the three time factors recorded. It accounted for 60% of the total concept mapping time, 50% of the interview time, and 49% of the task observation time. Compared with the interview and task observation techniques, concept mapping took about one and one half times longer to transcribe than the other two. This can be attributed in part to the requirement to clean up and redraw the concept maps after each session.

Preparation Time. The interview preparation time consisted of identifying questions to start each interview session. Questions arising during the transcription of the interview tapes were noted and addressed during the following interview. The preparation time for concept mapping was spent teaching the expert about the concept mapping technique and having the expert generate some unrelated practice concept maps. Questions used during the actual concept mapping sessions were generated as individual maps were drawn. For the task observations, very little preparation time was required. Some questions resulting from previous observations were developed and used when the results of the next actual observations were still not

clear. The time required to prepare those particular questions was minimal, as the results in Table 1 indicate.

Total Time. Overall, interviewing took the least time to implement, followed by task observation and then concept mapping. If time were the major factor to consider when choosing among knowledge acquisition techniques, then the interview would appear to be the more useful among the three compared in this research.

#### Rule Production

This part of the analysis presents the results of five quantitative measures used to evaluate the usefulness of each knowledge acquisition technique in producing rules.

These quantitative measures were:

1. The time required to formulate rules;
2. The total number of rules generated;
3. The number of inferences necessary to complete rules;
4. The number of gaps in the information contained in each knowledge set; and
5. The number of translations necessary to convert the expert knowledge to reasonably correct expert system rules.

Description of Rule Production. Rule production begins with reading through the transcripts produced with each knowledge acquisition technique and identifying "chunks" of meaning (3:72-73). These chunks then need to be sorted and

grouped according to their relationship with other chunks (3:73-74). Finally, the sorted chunks of information are transformed and represented as production rules (3:74).

A production rule is a rule that follows an "If-Then" format, but is in a narrative form that does not necessarily match the syntax required for the expert system software.

For example:

```
IF: Hazardous cargo has been scheduled to move on
    the aircraft AND the hazardous cargo has been
    designated "cargo aircraft only" AND no waiver of
    hazardous restriction has been obtained from
    higher headquarters
```

```
THEN: No seats can be released
```

This same rule would then need to be converted to a syntax acceptable for encoding in the VP Expert Shell, such as:

```
IF   Hazard = yes
     AND Cargo_Only = yes
     AND Waiver = no
     OR Waiver = unknown
THEN Release = 0
```

Rule Formulation Time. The first measure of a technique's usefulness in rule formulation consisted of the time that it took to formulate three production rules from each of the three knowledge acquisition data sets. For this measure, the task of releasing seats to the passenger terminal was broken down into four categories representing the types of aircraft which offer seats for space available passengers. The first category consisted of releasing seats on a C-5 aircraft; the second, releasing seats on a C-141

aircraft; the third, releasing seats on a C-130; and the fourth, releasing seats on "all other" types of aircraft. The process of releasing seats is similar in all four categories, but each category has some differences from the other categories. Using the last number in each aircraft's designator and the number 9 for "all other" aircraft, a random number generator was used to randomly select one of the four categories. Then, three production rules were generated for the selected category using the knowledge data set collected from the interviewing technique. After the three rules had been generated for the interview data set, the process was repeated. Again, one of the four categories was randomly selected and three more production rules were generated using the knowledge from the concept mapping technique. Finally, the same procedure was used to generate three production rules using the knowledge acquired from task observations.

The procedure of randomly assigning a different category of the seat release process to each knowledge acquisition technique was necessary, so that the researcher was forced to look for new "chunks" of knowledge when formulating rules from each knowledge acquisition technique and was not influenced by what had been learned from producing a previous set of rules. These selection and assignment procedures for rule formulation are illustrated in Figure 3. The times required to formulate each production rule are presented in Table 2.

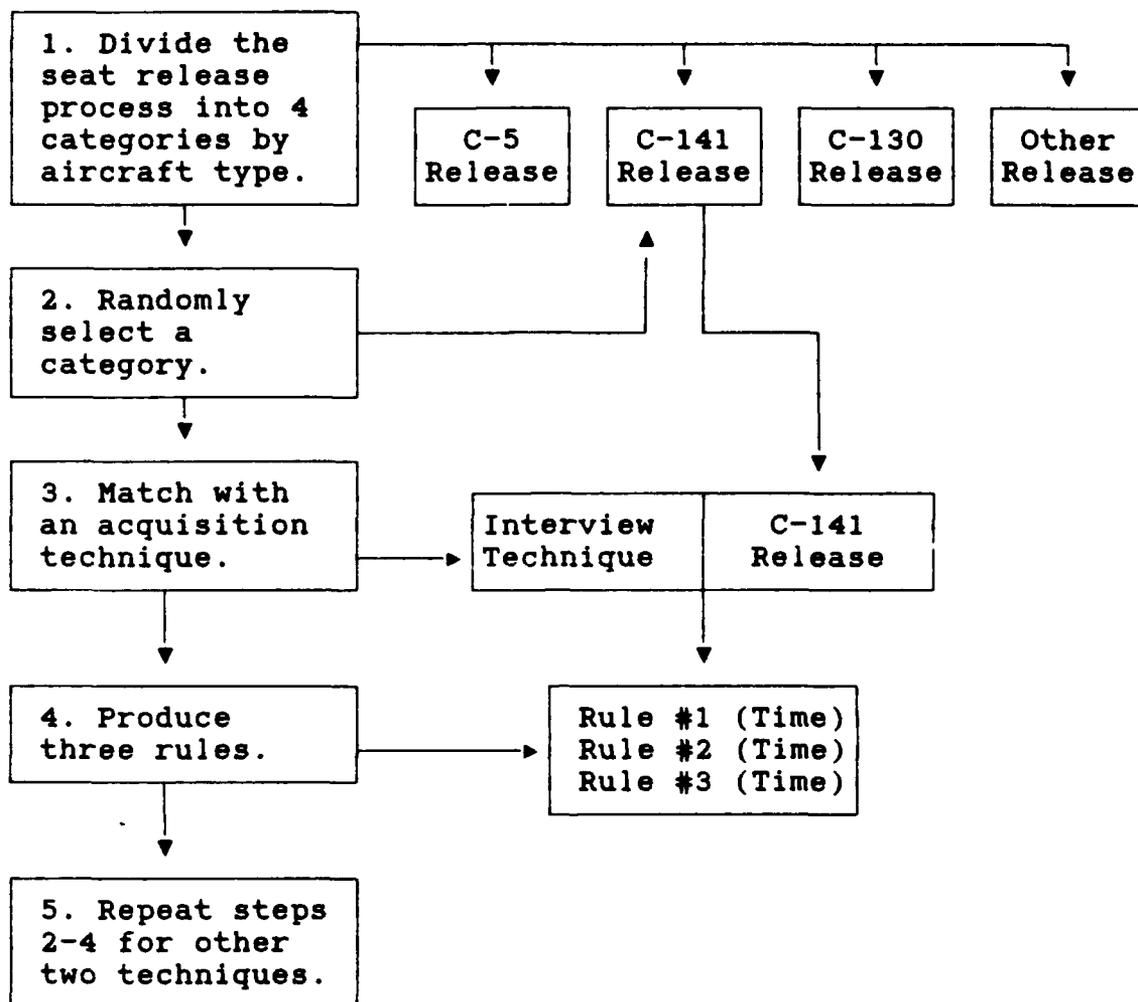


Figure 3. Procedure for Measuring Rule Formulation Time

Concept mapping required the least time to formulate production rules for an expert system. Concept mapping also demonstrated the least variation in time for the first,

Table 2  
Rule Formulation Times  
(in minutes)

| Rule    | Interview | Concept Mapping | Task Observation |
|---------|-----------|-----------------|------------------|
| 1       | 9.72      | 3.12            | 6.07             |
| 2       | 3.60      | 2.08            | 4.98             |
| 3       | 2.44      | 2.36            | 3.53             |
| Total   | 15.76     | 7.56            | 14.58            |
| Average | 5.25      | 2.52            | 4.86             |

second, and third rules among the three techniques. The higher times for the first rules in each of the techniques were caused by having to search through the transcripts to find related chunks of information. The times are much higher for the interview and task observation techniques because of the way the material was organized after transcription. It was easier to locate the needed information on the concept map than in the pages of the interview and task observation transcripts. While it appears that the subsequent formulation times approach those of the concept map, the unorganized data from the interviews could be expected to increase required time as more complex rules were formulated. Additionally, the initial search time to identify related data could be expected each time a different portion of the seat release process was attempted.

Total Rules Generated and Inferences Required. This measure consisted of 1), the number of rules which could be generated with each technique given a particular category of the seat release procedure and 2), the number of inferences which were required to complete each rule. Inferences are required whenever the knowledge engineer cannot find an explicit statement of relationship in the data and thus must establish the relationship by inferential reasoning. Knowledge engineers seek to minimize the number of inferences they draw.

Again, the task of releasing seats to the passenger terminal was broken down into the four categories described earlier: releasing seats on a C-5 aircraft, releasing seats on a C-141 aircraft, releasing seats on a C-130, and releasing seats on "all other" types of aircraft. Using the last number in each aircraft's designator and the number 9 for "all other" aircraft, a random number generator was used to select one of the four categories. Then, using one knowledge set after another, all possible rules were generated for the selected category. The result was three complete sets of rules--each set derived from a different acquisition technique. As the rules were formulated, the number of inferences required to complete a rule were noted.

The procedures for measuring the number of rules generated from each of the knowledge acquisition techniques are illustrated in Figure 4. The results of these measures are presented in Table 3.

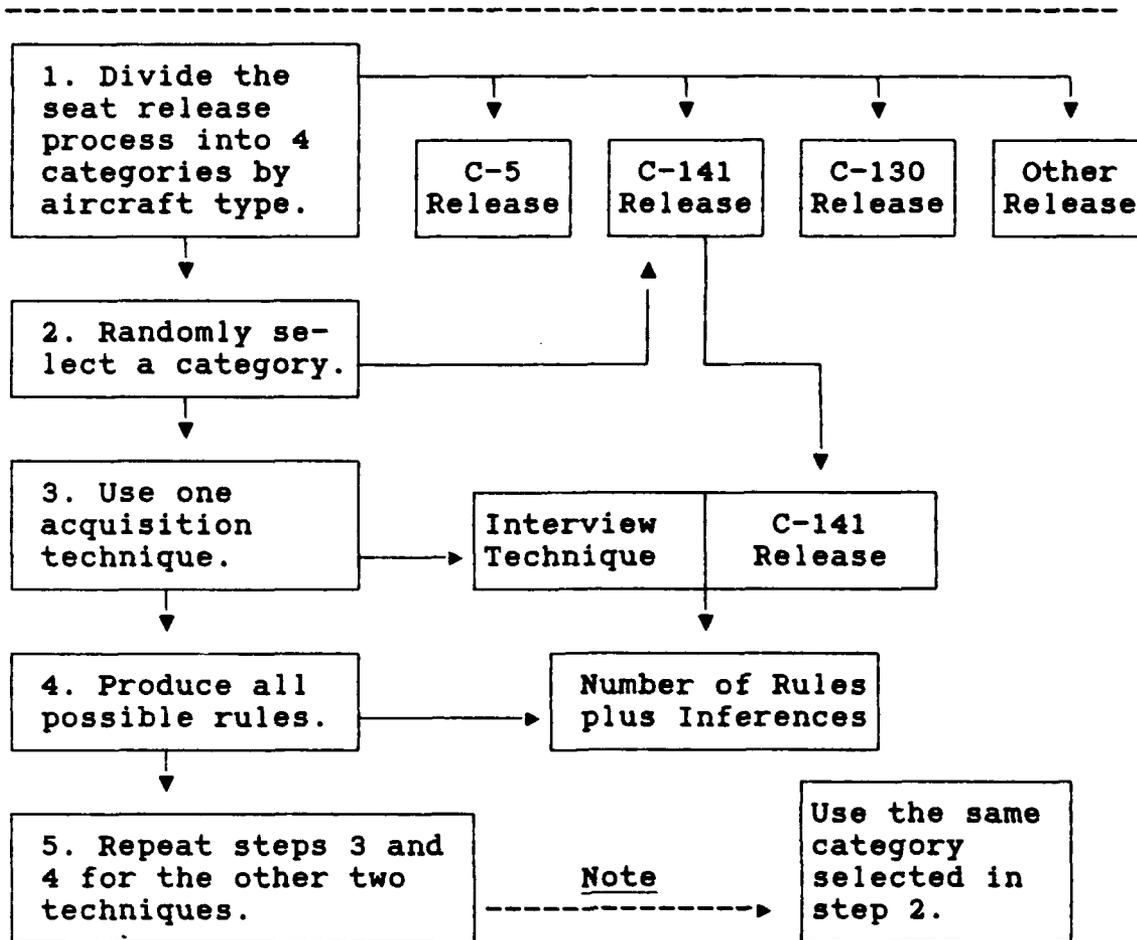


Figure 4. Procedure for Measuring Number of Rules Formulated and Inferences Required.

Table 3  
Number of Rules Formulated  
and Inferences Required to Formulate Rules

|                      | Interview | Concept Mapping | Task Observation |
|----------------------|-----------|-----------------|------------------|
| Number of Rules      | 16        | 18              | 11               |
| Number of Inferences | 4         | 2               | 7                |

Concept mapping provided two more rules than the interview technique and seven more rules than the task observation technique. The information in the concept map which generated the additional rules was missing from the transcripts of the interview and the task observations. Although additional interviews or more time spent in the observation of tasks might have supplied this missing information, given the fixed, and somewhat limited time allotted for each technique, concept mapping was more useful for rule generation, both in the larger number of rules it supported and the smaller number of inferences required in the rules.

Concept mapping also required the fewest inferences to complete its set of rules. Task observation required the greatest number of inferences because the researcher had to assume the rationale for many of the actions the expert took in performing his tasks. An explanation was provided for the actions that the expert took only when the researcher clearly did not understand the action being observed and asked for clarification. As a consequence, the knowledge gained by this technique was inferred from the expert's actions rather than verbally explained. The results from this test reflect the fact that the knowledge engineer made assumptions about rules for instances when he did not ask the expert the exact reason for the expert's action.

Gaps in the Knowledge Base. Gaps in the knowledge base were areas identified in the transcripts of the interviews

and task observations or in the concept map where the information needed to produce expert system rules was missing. The number of gaps in a knowledge base is an indicator of the incompleteness of that knowledge base.

For this test, a general diagram of the seat release procedure was developed using the knowledge collected during the course of all knowledge acquisition sessions. This diagram was not based on the knowledge collected from any one technique, but represented the combined knowledge acquired by the researcher using all three acquisition techniques during the course of this study.

Next, the knowledge collected from each of the three acquisition techniques used in this research was compared to this diagram. If a particular step in the seat release procedure was missing from the knowledge data set obtained with a particular technique, then an 'x' was placed next to this step in the diagram under the column of the applicable knowledge acquisition technique. This 'x' represented a gap in the knowledge collected by that particular technique. The general diagram of the seat release process is presented in Figure 5. The total number of gaps found for each technique is located at the bottom of the last diagram on page 44.

The results indicate that the concept mapping technique made the greatest contribution to the total knowledge base since there was only one area of knowledge that it did not capture from the expert.

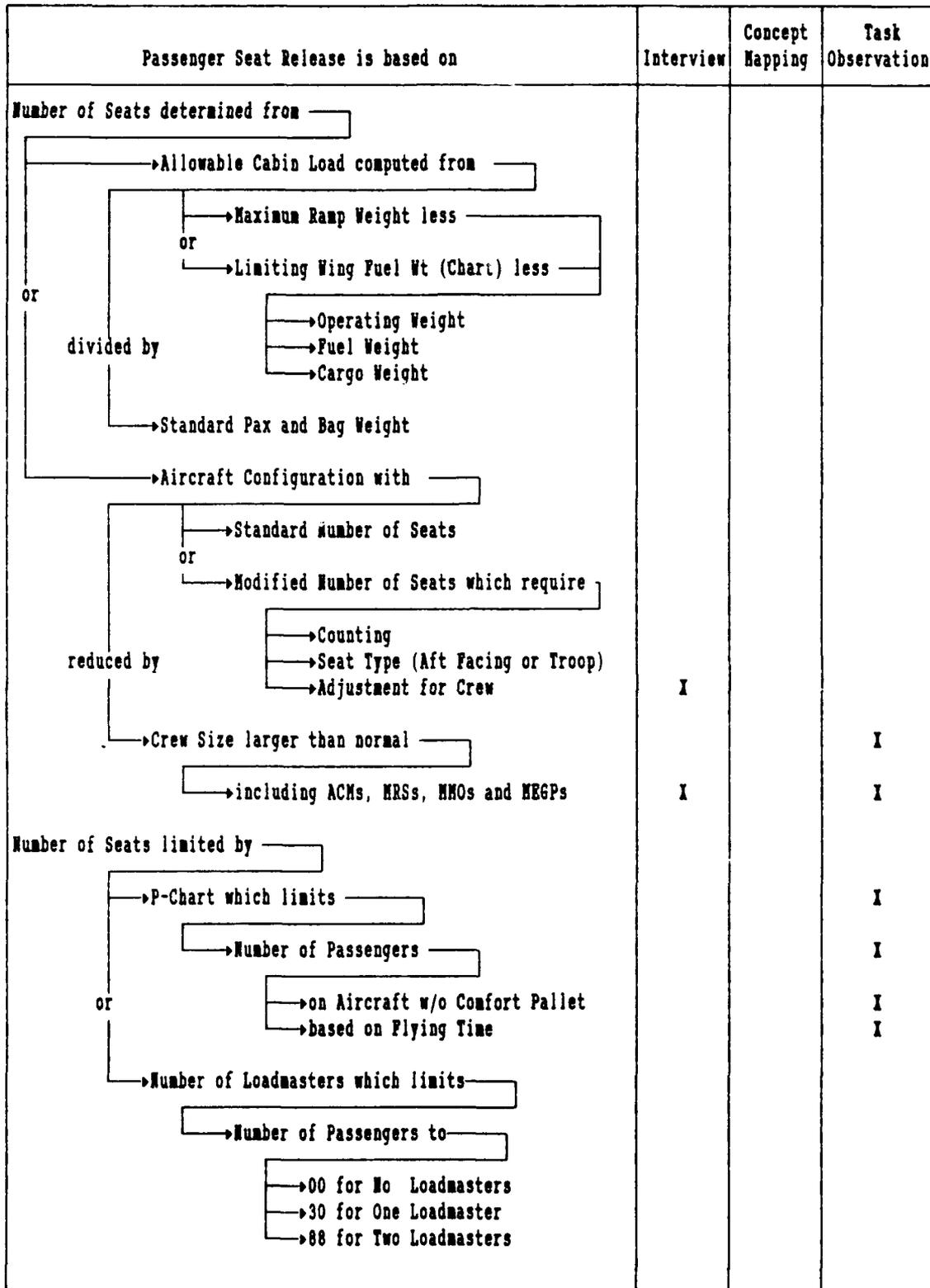


Figure 5. General Diagram of the Seat Release Process Indicating Gaps in Knowledge (continues)

| Passenger Seat Release is based on   | Interview | Concept Mapping | Task Observation           |
|--|-----------|-----------------|----------------------------|
| <p>Number of Seats limited by _____</p> <ul style="list-style-type: none"> <li>→ Availability of Life Support Equipment limits _____ <ul style="list-style-type: none"> <li>→ Number of Infants to Seven</li> <li>→ Number of Inlaps to Four _____ <ul style="list-style-type: none"> <li>→ on C5</li> </ul> </li> </ul> </li> </ul> <p>Number of Seats dictated by _____</p> <ul style="list-style-type: none"> <li>→ Aircrew on _____ <ul style="list-style-type: none"> <li>→ KC10</li> <li>→ KC135</li> <li>→ DC9 (Air Medical)</li> </ul> </li> </ul> <p>Passenger Restrictions due to _____</p> <ul style="list-style-type: none"> <li>→ Mission Requirements such as _____ <ul style="list-style-type: none"> <li>→ Training</li> <li>→ Special Assignment Airlift</li> <li>→ Enroute Requirements</li> </ul> </li> <li>or</li> <li>→ Maintenance Problems</li> <li>or</li> <li>→ Destinations which have _____ <ul style="list-style-type: none"> <li>→ No Service Facilities</li> <li>→ No Customs Officials check _____</li> <li>→ Entry Restrictions check _____ <ul style="list-style-type: none"> <li>→ Foreign Clearance Guide</li> </ul> </li> </ul> </li> <li>or</li> <li>→ Hazardous Cargo that is _____ <ul style="list-style-type: none"> <li>→ Passenger Prohibitive and not waived by _____ <ul style="list-style-type: none"> <li>→ Major Air Command</li> <li>→ Numbered Air Force</li> <li>→ Airlift Division</li> </ul> </li> </ul> </li> </ul> | <p>I</p>  | <p>I</p>        | <p>I</p> <p>I</p> <p>I</p> |

Figure 5 (continued). General Diagram of the Seat Release Process Indicating Gaps in Knowledge (continues)



The steps involved in preparing an expert system rule from the interview consisted of transcribing the information contained on audiotape to writing, producing a production rule from the written text, and then formulating expert system rules in the syntax required by the development shell, VP Expert.

The first transformation required with concept mapping was to redraw, reorganize, and integrate the rough concept maps produced in each individual session and produce one complete concept map of the entire seat release process. Because the graphical representation of knowledge in the concept map provided clear and concise relationships among the data, expert system rules were formulated directly from the concept map, eliminating the step needed for the development of production rules.

Task observation involved the same steps as the interview. Information was transcribed from audiotape and integrated with notes to produce a written text. Production rules were produced from the written text and then transformed into expert system rules.

Summary of Rule Production. Concept mapping produced more rules, in less time, and with fewer inferences than the interview or task observation techniques. Concept mapping also produced the most complete knowledge base. The interview was the simplest technique to implement in the researcher's judgement, while the concept map presented the knowledge in a form which was the easiest for the researcher

to use when formulating rules. As a result, the concept map took one less transformation than the interview or task observation techniques to arrive at an expert system rule.

### Qualitative Judgements

The quantitative measurements of the three knowledge acquisition techniques do not reflect all the relevant information with regard to using each of the techniques. There are a couple of qualitative judgements which should be considered. They are the ease with which each technique was implemented and the ease in transforming the knowledge into production and expert system rules.

Ease of Technique Implementation. This researcher felt that the interviewing technique was the easiest method to use during the knowledge acquisition sessions. The question and answer format for knowledge transfer was easily understood by both the researcher and the expert. The interview required little preparation time, and it was relatively easy to transcribe the audiotapes of the interviews to writing.

Ease of Knowledge Transformation. Once the knowledge had been acquired, the graphical representation of knowledge as provided by the concept mapping technique proved the easiest to use when producing expert system rules. Not only were the relationships clear and concise, but a concept map required the least amount of time to search and find all of the pertinent relationships. Both the interview and the

task observation methods were difficult to work with when it came to sifting through the pages of written transcripts for the purpose of producing production rules.

The most difficult knowledge to work with was that collected by task observation. This data was loosely structured and incomplete. Because all of the possible situations that could have an effect on a seat release did not occur during the time allotted to make observations, large gaps were present in the knowledge base.

#### Expert System Development and Validation.

This part of the analysis pertains to the selection and further evaluation of the concept mapping technique which was used to build a prototype expert system for determining passenger seat releases.

Technique Selection. In terms of the time required to implement each of the knowledge acquisition techniques, the interview was more useful among the three techniques compared in this study. However, in terms of the completeness of the knowledge base and the ability to produce more rules, in less time, and with fewer inferences, concept mapping was the most useful technique. Because the time had already been invested in implementing all three techniques, it was not a factor in the selection of a technique to use for further expert system development. Therefore, base on its ability to produce rules, concept mapping was selected as the technique to use to develop a

prototype seat release expert system. The complete concept map used to program the expert system can be found at Appendix E.

Expert System Development. The coding of the expert system was accomplished by the researcher using the text editor provided with the VP Expert Shell. The completed prototype expert system contained 1443 lines of code and 123 rules. An example of the program is provided at Appendix F. The complete program is contained on a 5.25 inch diskette which can be obtained from AFIT/LSC, Wright-Patterson AFB, Ohio 45431.

Expert System Validation. The expert system was validated in a field test according to the procedures identified in the methodology chapter. The purpose of this validation was twofold. First, the purpose was to determine if the knowledge base of the expert system was complete in the judgement of the expert who contributed to it through the concept mapping technique. Second, the purpose was to determine if the results produced by the expert system matched the results produced by all three experts.

For the first part of the validation, the contributing expert worked through several of his own seat release scenarios using the expert system. In each case he found that the expert system produced the same solution that he would have arrived at had he determined the seat release manually. In his judgement the knowledge base contained in the expert system was complete and accurate.

For the second part of the validation, three non-experts were asked to solve six seat release scenarios according to the instructions provided with the scenarios (see Appendix C). The three experts used in this study were asked to solve the same six scenarios using manual methods. The manual solutions provided by the experts for each scenario were then compared to solutions found by non-experts using the expert system. In all cases, the solutions arrived at by the non-experts matched those of the experts and were, in fact, the correct solutions. Additionally, it took less time to solve the scenarios using the expert system than it did using manual methods. The times required to solve each scenario is presented Table 5.

Table 5  
Seat Release Scenario Solution Times  
(Time in Minutes)

| Scenario     | Manual Solution Times |     |     | Expert System Solution Times |     |     |
|--------------|-----------------------|-----|-----|------------------------------|-----|-----|
|              | 1                     | 2   | 3   | 1                            | 2   | 3   |
| 1            | 3.7                   | 4.6 | 4.0 | 2.6                          | 3.2 | 2.7 |
| 2            | 1.9                   | 1.4 | 1.8 | 1.4                          | 1.0 | 0.8 |
| 3            | 3.5                   | 4.0 | 3.7 | 2.2                          | 2.4 | 1.7 |
| 4            | 3.8                   | 3.6 | 4.3 | 2.5                          | 2.9 | 2.1 |
| 5            | 4.1                   | 4.2 | 3.6 | 2.0                          | 2.3 | 1.8 |
| 6            | 1.2                   | 0.9 | 0.9 | 1.3                          | 0.8 | 0.7 |
| Average Time | 3.0                   | 3.1 | 3.0 | 2.0                          | 2.1 | 1.6 |

The results of this field test support the validity of the expert system and the completeness of the knowledge base it contains. Additionally, the field test shows the advantage of using an expert system in terms of time taken to arrive at a seat release.

#### Summary

Chapter IV presented the results of the comparative study of the three knowledge acquisition techniques. The interview technique proved more useful when the time required to obtain a transcript of the knowledge was of primary concern to the knowledge engineer. However, concept mapping was more useful in producing more rules in less time than the other two techniques. Concept mapping was also easier to use when transforming the acquired knowledge into expert system rules. The ability of the concept mapping technique to produce a complete and correct knowledge base for an expert system was validated in a field test of the expert system.

## V. Summary, Conclusions, and Recommendations

### Overview

The purpose of this chapter is to review the research effort, present the conclusions drawn from the analysis, and suggest recommendations for future research.

### Summary of the Research Effort

Despite continued advances in expert system technology, the process of acquiring the expert knowledge that will make up the most important component of an expert system--the knowledge base--had not been comparatively studied. It is a problem that most limits the application of expert system technology. Many acquisition techniques have been identified in the literature, but very little data is available on which technique, or combination of techniques, may be more useful in different situations.

This research effort compared three knowledge acquisition techniques--interviewing, concept mapping, and task observation--used to gather knowledge from an Air Terminal Operation Center. The objective was to determine which of these three techniques was more useful in acquiring the knowledge needed to develop an expert system. This expert system was designed to determine the number of seats to release to the passenger terminal for use by space available passengers. The comparison was based on the ease with which each technique was implemented, the ability of

each technique to produce a complete and accurate knowledge base, and the ability of each technique to produce knowledge in a form that simplified the programming effort.

Concept mapping proved to be the more useful technique based on its ability to produce more rules, in less time, and with fewer inferences. It also produced the knowledge in a form that required one less conversion prior to the encoding process. As further support of its usefulness, a prototype expert system was developed using the concept map. This system was then validated in a field test.

### Conclusions

This section provides the answers and conclusions to the research questions presented in Chapter I.

Conclusion to Research Question 1. The first research question asked what are the current and most widely recognized techniques used to acquire knowledge from experts. A review of the literature on expert system technology and knowledge acquisition revealed that there are several methods of knowledge acquisition. These methods can be classified into two categories: those that attempt to acquire knowledge that can be explicitly stated or observed and those that attempt to acquire knowledge that must be inferred by indirect methods.

Of the techniques that focus on explicit knowledge, the interview is, by far, the most common and widely used of these knowledge acquisition techniques. Some other

techniques in this category that are discussed frequently in the literature on knowledge acquisition are task observation, questionnaires, and protocol analysis. Also mentioned, but much less frequently, are interruption analysis, inferential flow analysis and drawing closed curves.

The most common and widely recognized technique used to acquire knowledge by inference is repertory grid analysis. The literature also discusses concept mapping, multidimensional scaling, hierarchical clustering, and general weighted networks as methods that can be used to get at the knowledge that experts cannot easily verbalize.

Conclusion to Research Question 2. The second research question asked what current Air Force issue in the ATOC was appropriate for building a prototype expert system and what software development tool could be used to build it. For this research effort, passenger operations was selected as the problem area to address with a prototype expert system. VP Expert, an expert system shell from Paperback Software International, was selected as the expert system development tool.

Within the area of passenger operations, the process of determining the number of seats to release for use by space available travelers was appropriate for an expert system application. Air Force managers have a high degree of interest in this process because space available travel is publicized as a "service benefit" for recruiting and

retention purposes. However, the procedures for determining seat releases are unstructured and require the consideration of a number of different variables. Further, personnel qualified and experienced with the procedures are frequently lost due to assignment changes, separation and retirement. In fact, of the three experts used in this study, one will retire in December of 1990, and another will be moving to another base in September 1990.

A prototype expert system was successfully developed using VP Expert. The software is able to run on all hardware available in the Wright Patterson AFB ATOC. Most important, three non-experts, using the expert system, were able to determine correctly the seat release in a field test of six seat release scenarios in less time than it took the experts to determine the releases manually.

Conclusion to Research Question 3. The third question asked which extraction technique among three evaluated in the research was more effective in producing the knowledge that would be programmed into the prototype expert system. The answer to this question is that it depends on the situation facing the knowledge engineer. As a result, a format very similar to the production rules presented in Chapter III is used to present the conclusions to this research question.

If it is not possible to observe all possible events in a problem area being considered for an expert system application, then the task observation method of knowledge

acquisition is not an effective method. In this study, task observation proved to be very ineffective, because many potential situations involving seat release procedures did not occur.

If time available to spend with the expert is limited and is the most important factor to the knowledge engineer about to begin an expert system project and if the knowledge engineer has little or no prior experience with concept mapping or if the expert feels uncomfortable with concept mapping, then interviewing would be the more useful technique. The data in this study show that the interview took less time to use than the other two techniques. However, it should be noted that this researcher lacked experience with using concept mapping, a fact which contributed to the higher implementation time recorded in this study. A knowledge engineer, experienced with using concept mapping might find it takes less time to use than the other techniques.

If the time required to transform raw knowledge into properly syntaxed expert system rules is the primary consideration, then concept mapping would be the more useful technique. In this study, it took less time to develop rules from the concept map than it did from the transcripts of the interviews and task observations. Additionally, the prototype expert system was programmed directly from the concept map. This eliminated the additional step of

formulating production rules which was required with the interview and task observation transcripts.

If the completeness of the knowledge base is of primary concern to the knowledge engineer, then a combination of interviewing and concept mapping would be the most effective knowledge acquisition method. An incomplete knowledge base could invalidate the expert system. In this study, there were gaps in the knowledge data sets of all three techniques; however, the combination of the data from the interview and the concept map produced a complete knowledge base.

Conclusion to Research Question 4. The fourth and final research question asked whether the knowledge base that was used to build the expert system was complete and expert system valid. The knowledge base used in the prototype expert system developed in this research effort was valid. In a field test of six seat release scenarios it produced the same correct solutions as those produced by the experts. Additionally, the content of the knowledge base was reviewed by the expert who had contributed to the concept map that was used to develop the expert system. He found the knowledge base to be complete.

#### Recommendations for Future Research

This thesis examined only three of many recognized knowledge acquisition methods. Further research in this area would be useful in providing additional information on the effectiveness of other knowledge acquisition methods

used for developing experts systems. This research could take many different directions. One possibility would be to select three different techniques for comparison. Another possibility would be to compare one or more techniques in combination with other techniques. For example, the interview technique combined with task observation could be compared to the interview combined with concept mapping. Still another possibility would be to compare the three techniques used in this research using a different problem situation and a different development tool. It is obvious that the possible combinations of study are numerous. The important point is that continued research in this area will provide additional information in an area where information is hard to find.

Another important recommendation for further research is in the application of expert system technology in the Air Terminal Operations Center (ATOC). The expert system developed for this thesis was a by-product of the comparative study of knowledge acquisition methods and was small by comparison to any expert system that might have been developed had that been the topic of this thesis. However, the system did prove successful in providing an expert solution to a problem in less time than the manual methods used by the real experts. The Air Force would benefit from a research effort that applied expert system technology to the ATOC environment or similar transportation activities.

## Appendix A:

### Definitions of Terms used in the Report and the Expert System

Additional Crew Member (ACM) - An individual with valid aeronautical orders who is required to perform inflight duties and is assigned in addition to or authorized to accompany the normal aircrew compliment required for a mission. (12:5)

Aerial Port - An airfield which has been designated for sustained air movement of traffic and to serve as an authorized port of entrance or departure to or from the country in which located. (12:5)

Allowable Cabin Load - The total load an aircraft can transport over a given distance taking into account weight and volume. (12:5)

Artificial Intelligence - The branch of computer science devoted to the study of how computers can be used to simulate and duplicate the process by which humans solve problems. (21:1)

Comfort Pallet - A self contained unit having two lavatories and a galley for storing and preparing inflight meals which can be loaded on aircraft to support additional passengers. (12:7)

Conclusion - The "THEN" part, or consequent, of a rule in VP Expert. (30:2-4)

Domain - The application area for which an expert system is being developed. (21:8)

Goal - The results or achievement toward which effort is directed. In VP Expert, a goal is an expression for which a value is being sought. (30:2-2)

Hazardous Cargo - Any material which (by virtue of its properties) is flammable, corrosive, an oxidizing agent, explosive, compressed gas, poisonous, an irritating agent, radioactive, magnetic, and items not otherwise specified. (12:11)

Inlap - Infants less than two years old who may travel in the lap of an adult sponsor at no charge. (12:11)

Knowledge Engineer - The individual who is responsible for knowledge acquisition, representation, and programming phases of developing an expert system. (1:20)

Limiting Wing Fuel Weight - That weight expressed in pounds where an addition to the aircraft gross weight can be made only by adding fuel in the wing tanks. Value is also referred to as the Zero Fuel Weight. (12:12)

Loadmaster - An aircrew member who accomplishes loading and offloading aircraft functions, insures the safety and security of cargo and baggage in flight, and provides for the safety and comfort of passengers in flight. (12:12)

MAC Mission Observer (MMO) - Personnel who have been invited by the Commander-in-Chief Military Airlift Command (CINCMAC) to accompany MAC aircrews on MAC military aircraft. (12:12)

Maximum Takeoff Weight - Stated allowable upper limit, in pounds, for a particular aircraft while at take off. (12:13)

Maximum Ramp Weight - Stated allowable upper limit, in pounds, for a particular aircraft while sitting on the airfield. (12:13)

Mission Essential Ground Personnel (MEGP) - Individuals who perform unique support duties directly related and essential to a particular aircraft, aircrew or numbered mission. (12:13)

Operating Weight - Basic aircraft weight plus the weight of crew members, crew baggage, oil, emergency equipment, stewards equipment, and extra equipment. (12:14)

Premise - The "IF" part, or antecedent, of an rule in VP Expert. (30:2-3)

Rule - A regulation or statement defining a particular conduct, habit or behavior. In an expert system, the rule states that if a given premise is true, then a specific action should be taken. (30:2-3)

## Appendix B:

### Description of Knowledge Acquisition Techniques

#### Interviewing

The most common method of knowledge acquisition is the face-to-face interview. Through conversation, experts are asked to verbalize how they go about solving a problem (25:153). In its simplest form the interviewer asks questions to which the interviewee responds with answers. The answers are collected, most often with the aid of a tape recorder, and subsequently transcribed, analyzed, and coded (31:31).

The interview can be structured or unstructured. In a structured interview, the same questions are asked in the same order with the same words for each interview. The questions are usually closed, in that the expected responses will be short and to the point. The structured interview is useful when specific material is required and the responses can be anticipated. The unstructured interview allows the interviewees to cover topics in their own way, usually in response to an opening question followed by additional probing questions or prompts. The unstructured interview is useful when greater understanding of the structure of the problem is required before more structured questions can be asked (10:107-116).

AI researchers have found that the interview is one of the most important tools for facilitating the transfer of

human knowledge (10:107-108; 31:31). Most knowledge engineering sessions begin with at least an initial interview to get acquainted with the expert and to get a feel for the basic structure of the problem domain (5:229). It is taken as a starting point for considering more formal techniques to use in later knowledge acquisition sessions.

The single biggest advantage of using the interviewing technique is that it is a natural process, which is easily understood by both the knowledge engineer and the expert (5:229; 25:153). However, interviewing is often more than just simply sitting down and talking with an expert. The interview relies on the expert's ability to articulate the information used to work through a task. Unfortunately, experts often have a difficult time verbalizing how they go about solving problems (31:31). As a result, the interview is not always a reliable way to obtain complete, objective, or well-organized descriptions of complex cognitive processes.

Table 6 offers some general suggestions for the interviewer to follow during the interview process.

#### Task Observation

Task observation involves observing experts work at a real problem to determine how they make a decision (25:153). Through the direct observation of the expert working a problem, the knowledge engineer has the opportunity to

Table 6  
General Suggestions for the Interviewer (29:204)

---

1. Do not allow the interview to remain at the general or abstract level for too long. Get to specifics in order to general useful information.
  2. Do not ask the experts to represent their thinking in ways that are not familiar to them.
  3. Do not interrupt the expert's train of thought. Be patient and do not rush the expert, even though the expert seems to ramble on.
  4. Record information carefully. Using a tape recorder is highly recommended.
  5. Be attuned to the way in which experts apply their knowledge. The explicit content of the interview may mask other important information that is implicit and less obvious.
  6. Remain flexible. Avoid drawing conclusions too early and do not be disappointed if a favorite theory is proven incorrect.
- 

discover the objects, relationships and the inferences that the expert uses when solving problems (15:21). In task observation, the observer will watch the behavior or activities of the expert as they proceed naturally, and then ask questions. Observers often notice things that the experts take for granted or are unaware of (15:21). Like the interview, task observations can be structured or unstructured, though here structure is in the decisions regarding what to look for, instead of what to ask (15:21). Like most other acquisition methods, task observation is not suited to achieving all knowledge acquisition goals, and there are limitations to the method (25:155). Access to the

people and places to be observed is foremost among the problems (15:21). The problem may also take a considerable amount of time to solve. The task observation method is not the method designed to probe issues deeply, but rather to let the situation speak for itself (15:22; 25:55).

### Concept Mapping

Concept mapping gives the expert the opportunity to visualize real problems in terms of individual objects in a problem area (20:276; 25:159). It helps the expert depict "relationships between concepts in the form of propositions" (23:15). Gowin and Novak define propositions as "two or more concept labels linked by words in a semantic unit" (23:15). A simple example of a concept map forming a valid proposition would be "sky is blue" with "sky" and "blue" as the concepts and "is" the link between them (23:15). This is drawn as:

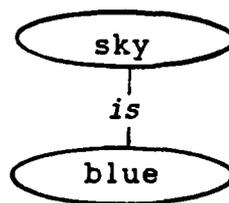


Figure 6 gives a larger example of a concept map for living things and closely related concepts.

Although infrequently listed in the knowledge acquisition literature as a technique, concept mapping may

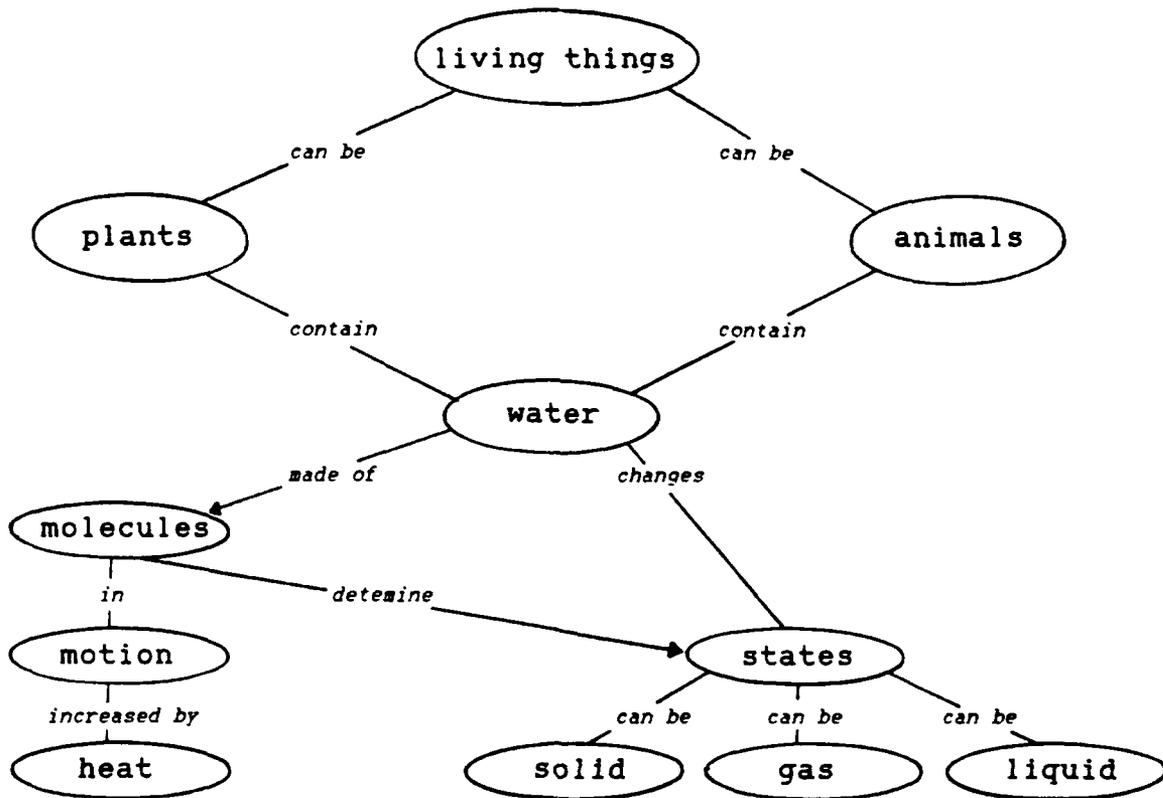


Figure 6. Concept Map for Living Things (23:16)

prove to be particularly useful in that the process itself establishes limits on a problem space and defines the problem explicitly. Concept maps provide structure to an unstructured situation.

## Appendix C:

### Passenger Seat Release Scenarios used in System Validation

#### General Instructions

1. Insert the 5.25 inch disk, labeled "ATOC Advisor" in Drive A. At the A> prompt type: "RUN".
2. In a few moments (required to load the VP Expert Program) you will see a short introductory screen. Press any key to proceed with the consultation.
3. A simulated schedule of missions will then be displayed on the screen. It will ask you to select one of the missions on the schedule or to enter "NEW" for any mission not on the schedule. Select the mission number corresponding to the mission identified in Seat Release Scenario #1.
4. From this point on the system will ask you a series of questions about the selected mission. Use the scenario narrative to answer each of these questions. If at any point, the answer is not provided in the narrative, enter "?" for unknown. If you are unable to proceed through the consultation for lack of information, consult with the Knowledge Engineer. [See Knowledge Engineer's notes at the end of this appendix.]

#### Seat Release Scenarios

##### SEAT RELEASE SCENARIO # 1:

This aircraft is a C-141, flying mission number AQB0707A0065. The estimated flying time is 4 hours. The aircraft is configured CP-3. The crew consists of 7 basic crew members, 4 ACMs and 4 MEGPs. This crew compliment includes 2 loadmasters. The operating weight of the aircraft is 153,630 pounds. The planned fuel load is 135,000 pounds. The planned cargo load is 14,600 pounds of cargo, of which 1,620 pounds is hazardous. Some of the hazardous material is "passenger prohibitive." There are no human remains.

SEAT RELEASE SCENARIO # 2:

This aircraft is a C-5, flying mission number ABA02F200065. The estimated flying time is 8 hours. The aircraft is configured CP-3. The crew consists of 12 basic crew members and 1 MMO. This crew compliment includes 3 loadmasters. The operating weight of the aircraft is 374,558 pounds. The planned fuel load is 172,000 pounds. The plan cargo load is 68,452 pounds of cargo, none of which is hazardous. This cargo load includes 1232 pounds for two human remains.

SEAT RELEASE SCENARIO # 3:

This aircraft is a C-141, flying mission number ABR04F200065. The estimated flying time is 6 hours. The aircraft configuration is modified with a comfort pallet and 51 aft facing seats. The crew consists of 6 basic crew members including 2 loadmasters. The operating weight of the aircraft is 152,385 pounds. The planned fuel load is 138,000 pounds. The planned cargo load is 100,000 pounds of cargo none of which is hazardous. There are no human remains.

SEAT RELEASE SCENARIO # 4:

This aircraft is a C-130E, flying mission number ABA09C901065. The estimated flying time is 2 hours. The aircraft is configured CP-5. The crew consists of 5 basic crew members and 4 MEGPs. This crew compliment includes 2 loadmasters. The operating weight of the aircraft is 83,546 pounds. The planned fuel load is 43,400 pounds. There is 2000 pounds of cargo planned for this mission including one human remains weighing 542 pounds. There is no hazardous cargo.

SEAT RELEASE SCENARIO # 5:

This aircraft is a C-141, flying mission number ABA04330A065. The estimated flying time is 8 hours. The aircraft configuration is modified with 50 troop seats and no comfort pallet. The crew consists of 7 basic crew members and 2 ACMs. This crew compliment includes 2 loadmasters. The operating weight of the aircraft is 151,250 pounds. The planned fuel load is 148,000 pounds. The planned cargo load is 13,364 pounds of cargo. There are no human remains.

SEAT RELEASE SCENARIO # 6:

This is a new mission, a C-12, mission number SWIFT 21. The estimated flying time is 2 hours. The schedule indicates that there are 2 space required passengers getting on this station and each is authorized 40 pounds of excess baggage for a total of 80 pounds.

Knowledge Engineer's Notes (not provided to the user)

1. For seat release scenario #1, the user should look for a "pax pro" waiver number. The knowledge engineer, playing the role of 21AF, will provide waiver number 21AF001 to the user when asked.
2. For seat release scenario #3, there is a error concerning the cargo weight. The cargo weight should be 10,000 pounds, not 100,000 pounds.
3. For seat release scenario #5, there is not information in the narrative about the presence of hazardous cargo in the planned aircraft load. The knowledge engineer, playing the role of the load planner, will apologize for forgetting to pass this information along and inform the user that there is 450 pounds of hazardous cargo, but no passenger prohibitive cargo.

## Appendix D:

### Partial Transcript of an Interview

To illustrate the interview method of knowledge acquisition, a partial transcript of a sample discussion with the expert is presented below. This transcript describes the interaction between the knowledge engineer (KE) and the expert concerning seat release procedures for aircraft other than the C-141, C-5, and C-130.

**KE:** On what types of aircraft do you determine a seat release for use by space available passengers?

**EXPERT:** Here at Wright Patterson one of the most common aircraft we deal with is the C-21 aircraft, a small aircraft, where the seat releases a based on six passengers on an airplane. We get a schedule from MAC which comes out daily with the names on it and the itineraries, call signs for the airplanes, the times and everything. We type the manifest up from the message we get from MAC, we post the times, and what ever is left over we open up seats. If we have six passengers we say no seats. If we have five passengers we put down one seat on the board and go from there. On the larger airplanes, we have four types of team travel. We have the 135 aircraft which come in from Offutt. They carry 89 passengers. Then we have the boxer call sign which are stationed at Andrews, run by the Air National Guard. They have 727s and they have 89 seats. Then we have the Bobcat missions which are run out of Buckley. They're the T-43's run by the Air National Guard and they have 64 seats. They all also come out on a schedule, on a team travel schedule. So we all know what the seat capacities are for the airplanes. For example, this morning we had this boxer come in and I knew it had 89 seats on the airplane and the schedule said it had 15 people getting off here. So automatically we would release 15 seats out to the next stop. Then based on the schedule we know how many people are getting on and off at the next stop and the stop after that and so we can release more seats depending on what the schedule is.

**KE:** So, it's a matter of taking the number of seats available on the aircraft and then subtracting the number of schedule passengers to arrive at a seat release for space available passengers?

**EXPERT:** No, not always. If we have two people trying to go for one seat and depending on what type of plane it is, say if it's a C-12, we'll really go after that and try to get

another seat because C-12s have a jump seat and can really take seven passengers if they need to. When the plane comes in, we'll check with the crew and ask how many seats we can get out. We'll look at the schedule and he may say, "well I'm picking up five people and I'll give you one seat" or "I'll go ahead and give you two seats". It depends on where there going. And then the weather, you know. If it's weather then sometimes they'll only give you three seats even though you know the plane is leaving here with no scheduled passengers. It's because they're putting extra gas on. Then we look out for excess baggage. A lot of times the schedule will have the name and next to it will say how much baggage is excess, because on the C-12 and the C-21 the baggage is normally 30 pounds and they know that and that's all they usually bring. So we look at that, and see how many bags they are authorized extra. Like the couriers a lot of times are authorized a lot. Sometimes they'll come with 200 or 300 pound boxes. So if there is any excess we always take a seat away, maybe two, it depends on the weight and the types of bags. Usually if it's less than 80 pounds we'll take one seat away and if it's more than 80 pounds we'll take two seats away, but again it all depends on the type and size of the excess baggage also.

**KE:** Are you saying there is no established procedure for reducing seats because of excess baggage?

**EXPERT:** Yes, it's kind of something you learn with experience. You have to look at the bags or the boxes in addition to weighing them to get an idea of how many seats they'll take up on the airplane. And its not only true for the C-12s and the C-21s. Its also true in a way for the 727's. Normally a passenger is allowed to carry 66 pounds of baggage, but on the 727 it's 45 pounds when you use all the seats. That's because if all 89 people took 66 pounds the aircraft would be too heavy. But that doesn't usually happen hear so we don't worry about it too much, but it is something you have to think about.

**KE:** Would you once again run down the list of aircraft you deal with most often and the number of seats each offer?

**EXPERT:** Okay, we start off with the C-21 and the C-12. The capacity of both airplanes is six seats. We run daily flights of those aircraft and those are run by MAC. We also have the T-43, C-22, and the C-135 and those are all MAC team travel airplanes. Now, the 135 is a 74 seat airplane, the C-22 is an 89 seat airplane, the T-43 is a 64 seat airplane.

**KE:** And excess baggage applies only to the smaller C-12 and C-21?

**EXPERT:** Yes, unless it's the C-22, that's the 727, is going to be full of 89 passengers. The C-22, the T-43, and the C-135 all have areas on the airplane to stow baggage, so excess baggage is not really a problem.

**KE:** Are there any other aircraft that you work with?

**EXPERT:** Yes. There is the medivac C-9 which we get three to four days a week. Here the seats are released by the crew about 30 minutes prior to leaving and they're based on mission availability. We also get some SAC aircraft like the KC-10 and KC-135. But there again the seats are released by the crew and we don't have to much to say about them.

**KE:** When you say "released by the crew", is there a particular crew member who has the authority to release seats?

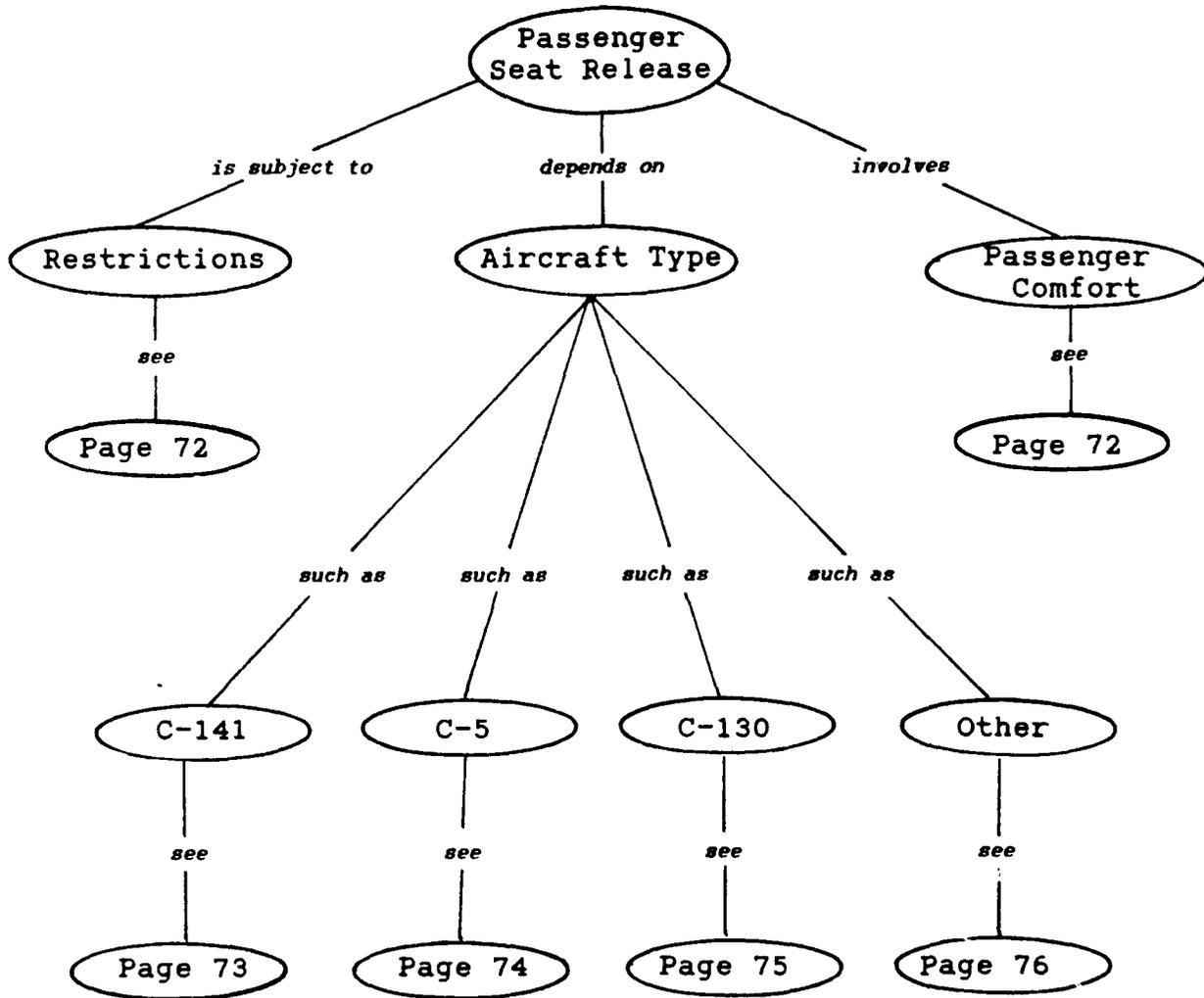
**EXPERT:** Kind of. For the C-9 we get the seats from the medical attendant and for the KC-10 and KC-135 we talk to one of the boom operators.

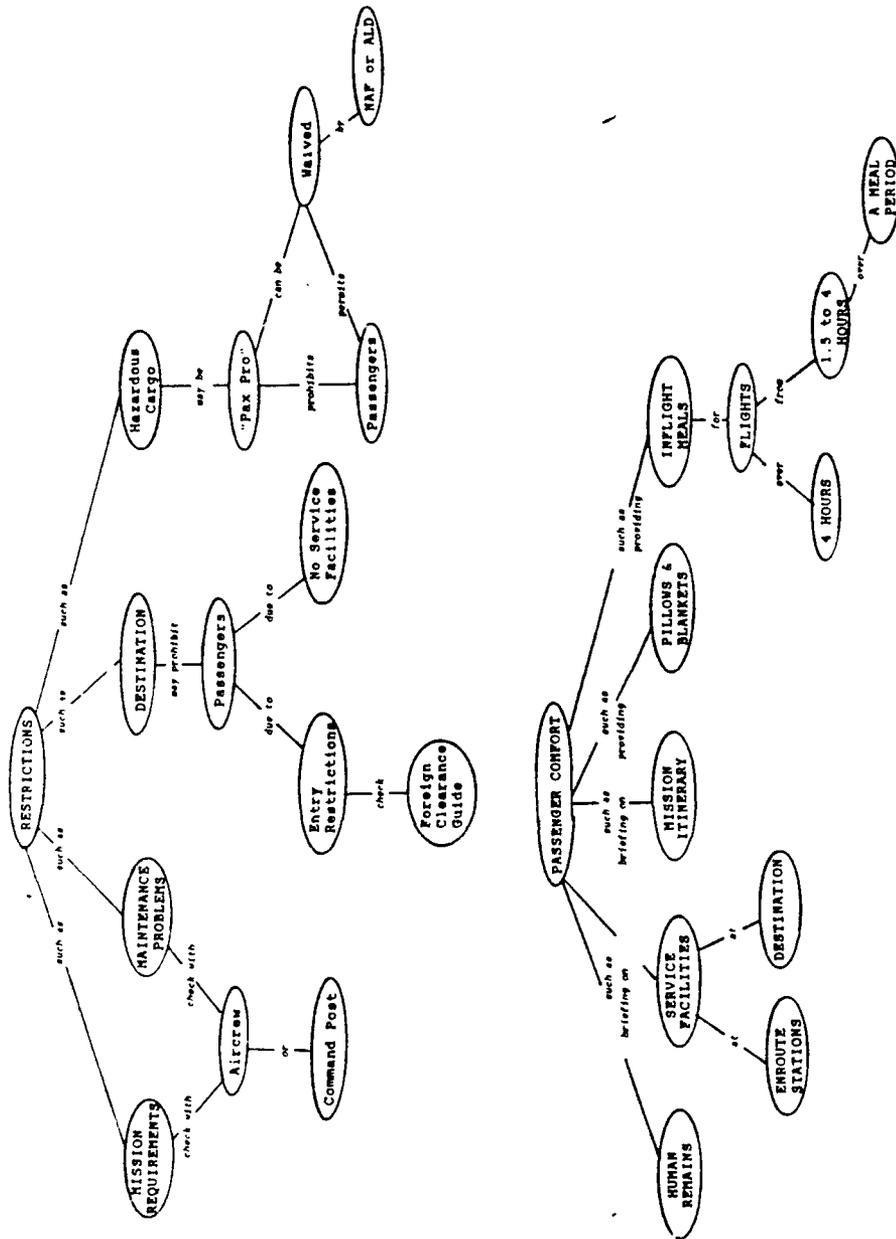
**KE:** Okay, how about the aircraft I see parked on the other side of the flightline? I see a couple of the old A model C-141s and the EC-135. Do you ever get seats on those aircraft?

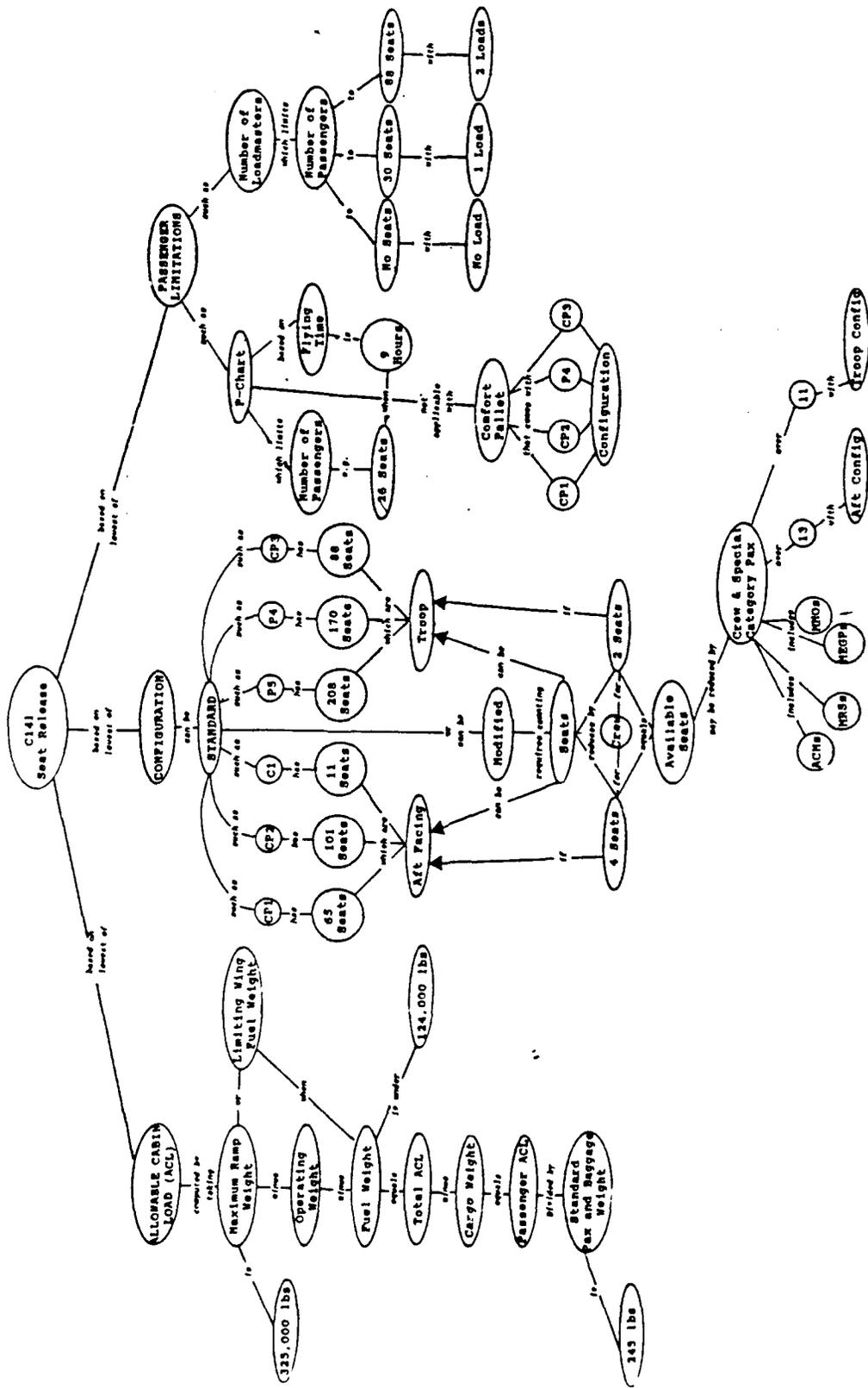
**EXPERT:** Seldom. That's the 4950th stuff. They pretty much handle things for themselves and they call us. We never call them.

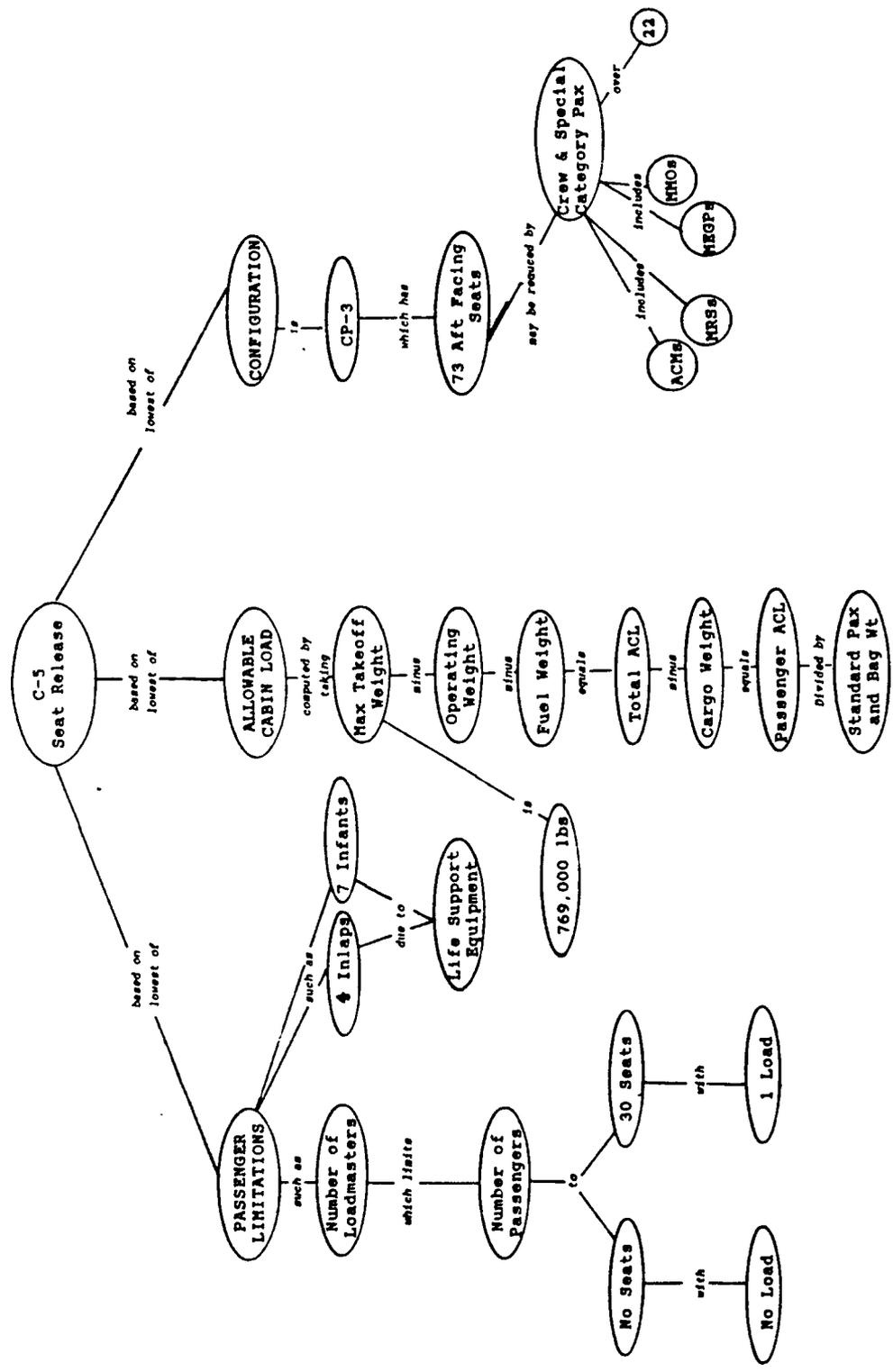
Appendix E:

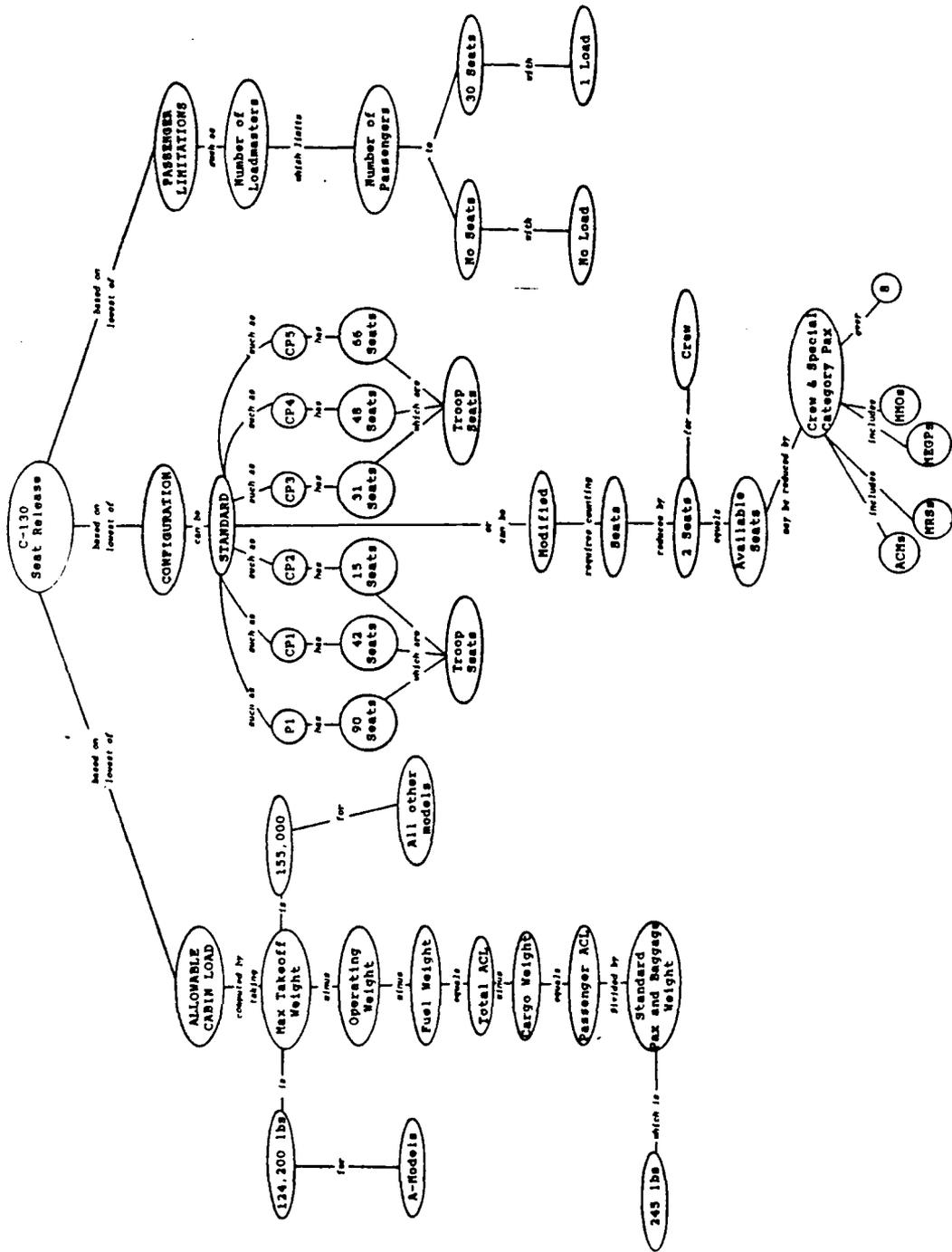
Concept Map of the Passenger Seat Release Process

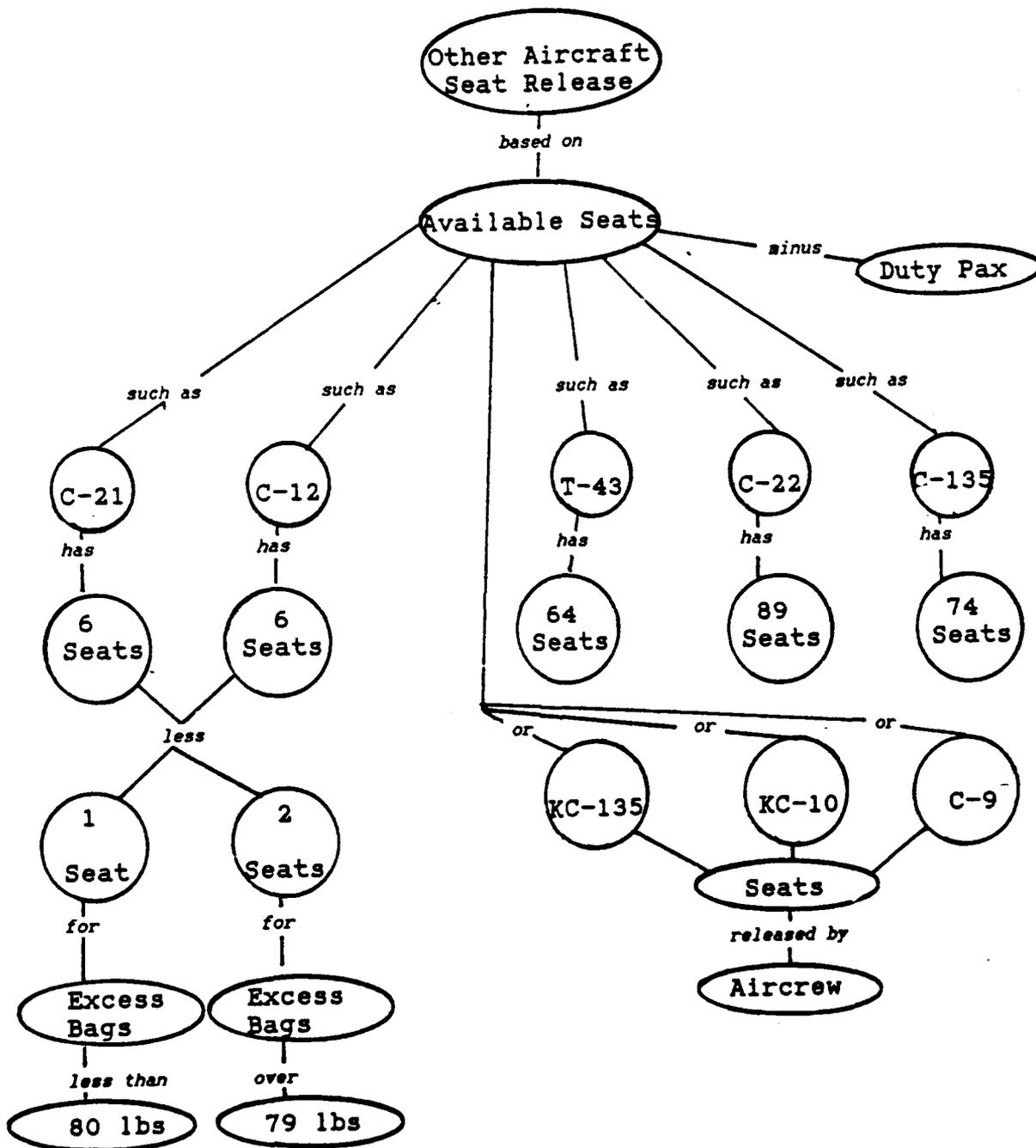












## Appendix F:

### Example of Expert System Program

Following is an example of the expert system program. It contains approximately one fourth of the total program code that was developed during this study. This particular part of the program determines the number of passenger seats that can be released on a C141 aircraft.

```
EXECUTE;  
ENDOFF;  
RUNTIME;  
BKCOLOR = 3;
```

```
ACTIONS  
LOADFACTS Factfile  
CLS  
WOPEN 1,1,1,20,77,3  
ACTIVE 1  
DISPLAY
```

```
"          PASSENGER SEAT RELEASE RECORD
```

```
-----  
MISSION NUMBER:{16Mission}    ACFT TYPE:{6Acft}
```

```
FLYING TIME: {3FlyTime}
```

```
CONFIGURATION:{6Config}    CREW SIZE:{4Crew}
```

```
NUMBER OF LOADMASTERS:{3Loadmaster}
```

```
OPERATING WEIGHT:{8Op_Wt}    FUEL WEIGHT:{8Fuel_Wt}
```

```
ACL:{8Acl}
```

```
CARGO WEIGHT:{7Cargo_Wt}    HAZARDOUS:{4Hazard}
```

```
PAX PRO:{4PaxPro}    WAIVER NUMBER:{8Waiver}
```

```
SEAT RELEASE:
```

```
REMARKS:"
```

```
WOPEN 2,16,2,4,75,7
```

```
ACTIVE 2
```

```
FIND Mission
```

```
FIND FlyTime
```

```
RESET Release
```

```
FIND Release
```

```
CLS
```

```
FORMAT Release,3.0
```

```
DISPLAY " You can release{3release} seats."
```

```
DISPLAY " "
```

```
DISPLAY "                               Press any key to continue...~"
CLS
WCLOSE 1
WCLOSE 2
FIND ModConfig
WOPEN 1,1,1,20,77,3
ACTIVE 1
DISPLAY
"
```

PASSENGER SEAT RELEASE RECORD

```
-----
MISSION NUMBER:{16Mission}    ACFT TYPE:{6Acft}

FLYING TIME: {3FlyTime}

CONFIGURATION: {Config}{Mod} CREW SIZE:{4Crew}

NUMBER OF LOADMASTERS:{3Loadmaster}

OPERATING WEIGHT:{8Op_Wt}    FUEL WEIGHT:{8Fuel_Wt}

ACL:{8Acl}

CARGO WEIGHT:{7Cargo_Wt}    HAZARDOUS:{4Hazard}

PAX PRO:{4PaxPro}    WAIVER NUMBER:{8Waiver}

SEAT RELEASE:{4Release}
```

```
REMARKS:"
WOPEN 3,15,2,5,75,7
ACTIVE 3
CLS
FIND HRRemark
RESET Continue
FIND Continue
CLS;
```

! Rules Block

```
RULE 1
IF      Config = C1
THEN    Seat_Type = AftFacing
        CP = No
        Seat_Count=11;
```

```
RULE 2
IF      Config = CP1
THEN    Seat_Type = AftFacing
        CP = Yes
        Seat_Count=65;
```

```

RULE 3
IF      Config = CP2
THEN    Seat_Type = AftFacing
        CP = Yes
        Seat_Count= 101;

RULE 4
IF      Config = CP3
THEN    Seat_Type = Troop
        CP = Yes
        Seat_Count=88;

RULE 5
IF      Config = P4
THEN    Seat_Type = Troop
        CP = Yes
        Seat_Count=170;

RULE 6
IF      Config = P5
THEN    Seat_Type = Troop
        CP = No
        Seat_Count=208;

RULE 7
IF      Config = Unknown AND
        Seats > 0 AND
        Seat_Type = Troop
THEN    Seat_Count = ((Seats)-2)
        Mod = Modified
        Find CP;

RULE 8
IF      Config = Unknown AND
        Seats > 0 AND
        Seat_Type = AftFacing
THEN    Seat_Count = ((Seats)-4)
        Mod = Modified
        Find CP;

RULE 9
IF      Seat_Count = 0
THEN    Release = NO
        CLS;

RULE 10
IF      Seat_Type = AftFacing
        AND Crew > 13
        AND Seat_Count < ((Crew)-(Seat_Count))
THEN    Release = NO
        CLS;

```

```

RULE 11
IF      Seat_Type = Troop
        AND Crew > 11
        AND Seat_Count < ((Crew)-(Seat_Count))
THEN    Release = NO
        CLS;

RULE 12
IF      Loadmaster = 0
THEN    Release = NO
        CLS;

RULE 13
IF      Seat_Count > 0
        AND Op_Wt > 0
        AND Fuel_Wt > 0
        AND Cargo_Wt <= 100000
THEN    Acl = (325000-(Op_Wt)-(Fuel_Wt)-(Cargo_Wt))
        FIND HR
        CLS;

RULE 14
IF      Acl < 0
THEN    Release = NO
        CLS
        WOPEN 4,16,2,4,75,4
        ACTIVE 4
        DISPLAY "WARNING! You have overloaded this
aircraft. Look at reducing fuel or cargo weight.
                Press any key to continue . . .~"
        CLS
        ACTIVE 2
        RESET Acl
        RESET Cargo_Wt
        RESET Fuel_Wt
        RESET Release
        FIND Fuel_Wt
        FIND Cargo_Wt
        FIND Acl
        FIND Release;

RULE 15
IF      Cargo_Wt > 0
        AND Hazard = Yes
        AND PaxPro = Yes
        AND Waiver = NA
        OR Waiver = UNKNOWN
THEN    Release = NO
        CLS
        WOPEN 4,16,2,4,75,4
        ACTIVE 4
        DISPLAY "WARNING! - Some of the hazardous cargo you
are planning for this mission is, as you indicated,

```

passenger prohibitive. You must obtain a waiver from the NAF before you can release seats. <Press any key to continue>~"

```
CLS
ACTIVE 2
Reset Release
Reset Waiver
Find Release;
```

RULE 16

```
IF      Cargo_Wt > 0
      AND Hazard = UNKNOWN
```

```
THEN   Release = NO
```

```
CLS
WOPEN 3,16,2,4,75,4
ACTIVE 3
```

DISPLAY "WARNING! - Some categories of hazardous cargo prohibit the carrying of passengers. You must know about any hazardous cargo to move passengers. Recheck your load information and try again. <Press any key to continue>~"

```
CLS
ACTIVE 2
Reset Hazard
Reset Release
Find Release;
```

RULE 17

```
IF      Cargo_Wt > 0
      AND Hazard = yes
      AND PaxPro = UNKNOWN
```

```
THEN   Release = NO
```

```
CLS
WOPEN 3,16,2,4,75,4
ACTIVE 3
```

DISPLAY "WARNING! - Some categories of hazardous cargo prohibit the carrying of passengers. You must know about the type of hazard to move passengers. Recheck your load information and try again. <Press any key to continue>~"

```
CLS
ACTIVE 2
Reset PaxPro
Reset Release
Find Release;
```

RULE 18

```
IF      Acl <= 244
THEN   Release = NO;
```

```

RULE 19
IF      Acl > 244
THEN    Weight_Seat = ((Acl)/245);

RULE 20
IF      Seat_Type = AftFacing
        AND Crew > 13
THEN    Seat_Crew = ((Seat_Count)-((Crew)-13));

RULE 21
IF      Seat_Type = Troop
        AND Crew > 11
THEN    Seat_Crew = ((Seat_Count)-((Crew)-11));

RULE 22
IF      Seat_Type = Troop
        AND Crew <= 11
THEN    Seat_Crew = (Seat_Count);

RULE 23
IF      Seat_Type = AftFacing
        AND Crew <=13
THEN    Seat_Crew = (Seat_Count);

RULE 24
IF      CP = No AND
        PLimit < (Seat_Count) AND
        Weight_Seat > (PLimit) AND
        Seat_Crew > (PLimit)
THEN    Release = (PLimit);

RULE 25
IF      Loadmaster = 1 AND
        Seat_Count > 30 AND
        Weight_Seat > 30 AND
        Seat_Crew > 30 AND
        PLimit > 30
THEN    Release = 30;

RULE 26
IF      Loadmaster = 2 AND
        Seat_Count > 88 AND
        Weight_Seat > 88 AND
        Seat_Crew > 88 AND
        PLimit > 88
THEN    Release = 88;

RULE 27
IF      FLYTIME=1
THEN    PLIMIT=(162-(crew));

```

RULE 28  
IF FLYTIME=1.500000  
THEN PLIMIT=(162-(crew));

RULE 29  
IF FLYTIME=2  
THEN PLIMIT=(162-(crew));

RULE 30  
IF FLYTIME=2.500000  
THEN PLIMIT=(110-(crew));

RULE 31  
IF FLYTIME=3  
THEN PLIMIT=(108-(crew));

RULE 32  
IF FLYTIME=3.500000  
THEN PLIMIT=(84-(crew));

RULE 33  
IF FLYTIME=4  
THEN PLIMIT=(63-(crew));

RULE 34  
IF FLYTIME=4.500000  
THEN PLIMIT=(56-(crew));

RULE 35  
IF FLYTIME=5  
THEN PLIMIT=(51-(crew));

RULE 36  
IF FLYTIME=5.500000  
THEN PLIMIT=(47-(crew));

RULE 37  
IF FLYTIME=6  
THEN PLIMIT=(44-(crew));

RULE 38  
IF FLYTIME=6.500000  
THEN PLIMIT=(41-(crew));

RULE 39  
IF FLYTIME=7  
THEN PLIMIT=(38-(crew));

RULE 40  
IF FLYTIME=7.500000  
THEN PLIMIT=(36-(crew));

```

RULE 41
IF      FLYTIME=8
THEN    PLIMIT=(34-(crew));

RULE 42
IF      FLYTIME=8.500000
THEN    PLIMIT=(31-(crew));

RULE 43
IF      FLYTIME=9
THEN    PLIMIT=(31-(crew));

RULE 44
IF      FLYTIME=9.500000
THEN    PLIMIT=(31-(crew));

RULE 45
IF      FLYTIME=10
THEN    PLIMIT=(31-(crew));

RULE 46
IF      Seat_Type = Troop AND
        Weight_Seat > (Seat_Count) AND
        Crew > 11
THEN    Release = ((Seat_Count)-((Crew)-11));

RULE 47
IF      Seat_Type = AftFacing AND
        Weight_Seat > (Seat_Count) AND
        Crew > 13
THEN    Release = ((Seat_Count)-((Crew)-13));

RULE 48
IF      Weight_Seat > (Seat_Count) AND
        Crew <= 11 AND
        Seat_Type = Troop
THEN    Release = (Seat_Count);

RULE 49
IF      Weight_Seat > (Seat_Count) AND
        Crew <= 13 AND
        Seat_Type = AftFacing
THEN    Release = (Seat_Count);

RULE 50
IF      Weight_Seat < (Seat_Count)
THEN    Release = (Weight_Seat);

```

```

RULE 51
IF      HR = Yes
THEN    HRRemark = Yes
        DISPLAY
"Human remains (HRs) are scheduled for this mission.  If you
release seats you must brief potential passengers that there
will be HRs on the aircraft and that the transfer case(s)
may be close to where they may sit.
        <Press any key to see next remark>~"
CLS;

WHENEVER 1
IF      Continue = Yes
THEN    CLS
        WCLOSE 1
        WCLOSE 2
        CHAIN Missions
ELSE    CLS
        DISPLAY
"Consultation Ended.  I hope you found this program helpful.
Any suggestions that you may have to improve the program
would be greatly appreciated.  Thank You.
        Press any key to exit . . .~";

! Statements Block

ASK Crew: "How many members are there in the aircrew to
include ACMs, MRSSs, MEGPs, and MMOs? ";
RANGE Crew: 5,30;
ASK Seats: "How many seats are on the aircraft? ";
RANGE Seats: 0,208;
ASK Loadmaster: "How many loadmasters are in the crew? ";
RANGE Loadmaster: 0,5;
ASK Op_Wt: "What is the operating weight of the aircraft? ";
RANGE Op_Wt: 130000,165000;
ASK Fuel_Wt: "How much fuel will be taken? ";
RANGE Fuel_Wt: 75000,160000;
ASK Cargo_Wt: "How much cargo (in pounds) are you putting on
the aircraft? ";
RANGE Cargo_Wt: 0,100000;
ASK Hazard. "Is any of this cargo hazardous? (enter '?' if
unknown) ";
CHOICES Hazard: Yes,No;
ASK PaxPro: "Is the hazardous cargo 'passenger prohibitive'?
(enter '?' if unknown) ";
CHOICES PaxPro: Yes,No;
ASK Waiver: "What is the PAX PRO Waiver Number?
(Enter 'NA' if not required or '?' if unknown.)";

```

WD-A229 252

A COMPARISON OF KNOWLEDGE ACQUISITION TECHNIQUES USED  
IN THE DEVELOPMENT O. (U) AIR FORCE INST OF TECH  
WRIGHT-PATTERSON AFB OH SCHOOL OF SVST.

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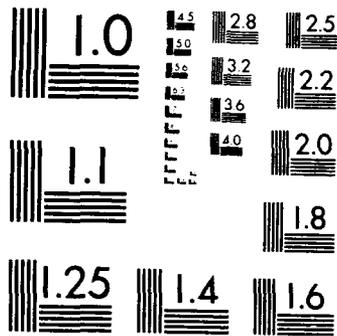
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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

ASK Continue: "Would you like to determine another seat  
release?";  
CHOICES Continue: Yes,No;  
ASK ConFig: "How is the aircraft configured? (Enter '?' if  
Modified)";  
CHOICES ConFig: CP1,CP2,C1,CP3,P5,P4;  
ASK Seat\_Type: "What type seats are installed on the  
aircraft?";  
CHOICES Seat\_Type: AftFacing,Troop;  
Ask CP: "Is there a comfort pallet installed?";  
CHOICES CP: Yes,No;  
ASK FlyTime: "What will be the duration of the flight (in  
hours)?";  
ASK Mission: "For what mission do you want to determine a  
seat release?";  
ASK HR: "Does this cargo include any human remains (HRs)?";  
CHOICES HR: Yes,No;

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### VITA

Captain James R. Heatherton was born 31 May 1953 in Cincinnati, Ohio. He graduated from high school in 1971 and attend Miami University of Ohio for a year and a half before enlisting in the Air Force in 1973. He continued his undergraduate studies during his off duty time and graduated from Park College with a Bachelor of Arts Degree in Management in September 1982. Captain Heatherton was distinguished graduate of the Officer Training School, where he received his commission in the United States Air Force in January 1983. His first assignment as an officer was Pease AFB, New Hampshire, where he was the Vehicle Operations Officer, Traffic Management Officer, and Plans and Programs Officer. In January 1986, he was assigned to Rhein Main AB, West Germany, where he was an Air Terminal Operations Center Duty Officer. He attend Squadron Officer School in March 1988. In May 1990, Captain Heatherton was assigned to the Air Force Institute of Technology. His next assignment is Headquarters, Air Force Logistics Command at Wright-Patterson AFB, Ohio.

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| <b>13. ABSTRACT (Maximum 200 words)</b> The primary objective of this thesis was to compare three knowledge acquisition techniques used to gather knowledge for the development of an expert system. The goal was to determine which technique produced knowledge in a form most suitable for incorporation into an expert system. The three acquisition techniques compared were interviewing, task observation, and concept mapping. Three experts were selected and randomly paired with a technique. Knowledge acquisition sessions were then conducted with each expert using the technique assigned to that expert. The knowledge extracted from these acquisition sessions was then compared. Overall, concept mapping produced more rules, in less time, and with fewer inferences than the interview or task observation techniques. Additionally, the knowledge base acquired through the concept mapping technique was more complete. Finally, concept mapping required one less translation of the knowledge to arrive at a form necessary for programming the expert system. An expert system was developed using the concept mapping technique and was validated in a field test. Results showed that the solutions provided by the expert system matched those provided by the human experts. |   |  |  |  |
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