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Expert System Prototype Developments For Nasa-KSC Business And Engineering Applications

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ABSTRACT

Artificial Intelligence (AI) technology, and in particular expert systems -- a subset of AI which shows the strongest applicability to a wide variety of environments, has recently emerged from the realm of basic research into that of real-world applications. To further these advances, NASA-Kennedy Space Center (KSC) provided funding and other critical resources to the University of Central Florida (UCF) in support of instruction of expert systems technology. During the Fall 1987 semester, UCF's Colleges of Business and Engineering concurrently offered courses in response to the increased interest in expert system applications and to satisfy the intent of this grant. This paper describes the prototype expert systems which evolved from this sponsorship and the development methods used.

INTRODUCTION

The NASA-Kennedy Space Center (KSC) Technology Projects Office provided a grant (NAG10-0043) and access to experts in specific work environments at the center to the University of Central Florida (UCF) in support of student instruction. Computer hardware and software were purchased with these funds for student and faculty use. During the Fall 1987 semester, the Colleges of Business and Engineering offered graduate and undergraduate courses at their Orlando and Brevard campuses to advance this technology in response to the increased interest in Artificial Intelligence-related applications and to satisfy the intent of this grant. The authors of this paper taught the courses offered by their respective colleges. As a result, students greatly benefited from their involvement in the KSC work environment, KSC domain experts were exposed to expert systems technology, and prototype project results for future NASA use were achieved.

In general, the state-of-the-art of building application expert systems is in its relative infancy. Many potential environments exist for applications, and the NASA-KSC domain is one. Thus, the basic idea and central objective of the student projects are that they be designed to validate the prototype through interactions with the NASA expert(s) and to test the feasibility of the prototype development to the selected application.

EXPERT SYSTEMS DEFINED

Briefly, a general definition of an expert system is that they are computer systems that can perform in ways that we normally associate with a human expert. A more practical definition would be that expert systems are computer programs that help people diagnose problems and then indicate appropriate actions. Usually expert systems are knowledge and rule based, capturing the essence of the experiences and rules-of-thumb (hueristics) of an expert in any particular field of specialized knowledge. In practice the components of an expert system consist of a knowledge base, an inference engine, and a user interface. According to Mishkoff (1985), the knowledge base usually contains both declarative knowledge (facts about objects, events, and situations) and procedural knowledge (information about courses of action). Inference engines are control structures or rule interpreters. These software devices decide which search techniques should be used to determine how the rules in the knowledge base are to be applied to the problem. The user interface is the visual display and computer keyboard capabilities which allow the eventual user to communicate with the system itself.

The following are seven criteria that two authors indicate are important requirements for acceptance of an expert system by intended users. Buchanan and Shortliffe (1984) believe that the system should be useful, usable, educational when appropriate, explain its advice, be responsive to simple questions, be able to learn new knowledge, and the program's knowledge base should be easily modified. The end result of this technology according to Waterman (1986) is a system, unlike human expertise, which is permanent, easy to transfer and document, consistent, and affordable. Silverman (1987) suggests criteria for evaluating whether a potential expert system topic is appropriate for development. These criteria help to determine if an expert system approach is relevant, feasible, optimal, and success-oriented. All of these criteria and goals, in one form or another, were used by students to design and assess their projects.

GENERAL APPROACH

It was intended that students in each course would develop projects which would represent feasibility or prototype demonstrations of the technology and the application. It was envisioned that applications which showed promise, would receive additional funding by NASA-KSC for in-house or external future expansion and development into operational expert systems. Several projects and domain experts were identified and pre-selected by the instructors working with NASA management. This was necessary because of the importance of these project applications to NASA and the shortness of the semester (fifteen weeks). In the building portions of project activities, students were responsible for exploring alternative methods of representing the experts' knowledge and inference processes and to test the feasibility of the resultant expert system.

Project Teams

Students in each class were divided into project teams consisting of between two and four members. Each business team consisted of a project manager, a knowledge engineer, and a software shell specialist. However, each student was required to become familiar with all aspects of small-scale expert system project development. Engineering teams were unstructured to provide maximum working freedom. In both classes, project submissions were a group development effort with all team members sharing frustrations and rewards (grades) equally.

Scope

From the beginning it was expected that each project would demonstrate depth and breath for each application. However, it was realized by the university and NASA that an operational system could not be developed in one semester in a course which introduced new expert system technology for the first time. It was also envisioned that a minimum of fifty rules would be developed for each prototype project in business and fifty rules per team member for the engineering applications. However, all team members were instructed to identify as many rules as were feasible and appropriate in the time available.

Hardware and Software

Computer hardware and software were purchased with $31,025 in grant funding. Hardware consisted of several IBM-compatible computers, supporting equipment, and Kodak DataShow classroom computer projection equipment. A university-wide site license for Texas Instruments' Personal Consultant Plus, Personal Consultant Easy, and PC Scheme (a version of the LISP language) expert systems software allowed students personal access to these tools. In addition, Ashton-Tate's dBase III+ database and Dr. Halo graphics software by Media Cybernetics, Inc. were acquired.

Project Reports

Teams were required to prepare a typewritten project report which included copies of the developed software knowledge base(s). Copies of the reports and software knowledge bases were also provided to the NASA sponsor. Project reports were expected to be of high quality with quality being more importance than quantity. The reports consisted of two parts: an executive summary (three to five pages), and the full report with the executive summary excluded. Project team system demonstrations (from forty-five to sixty minutes) were required. Reviews by NASA project participants, as well as the instructor's critique, were given to each team at the end of the semester.

Project Schedules

Project teams were identified early in the course -- within the first three weeks of classes. It was expected there would be no less than three meetings between team members and the NASA-KSC domain experts during the semester. These knowledge acquisition sessions were scheduled to be complete before the midpoint of the course. Project reports were due before the end of the semester.

GRANT OBJECTIVES

The primary objective of this joint endeavor was to provide students with practical and effective applications in the area of knowledge-based systems. Specific benefits of this instruction and the approach taken were to: (1) provide opportunities for students to become familiar with expert systems technology via mutually agreed upon business and engineering project applications; (2) enhance student professional growth opportunities through exposure to a relevant public sector work environment, actual problems, and practicing professionals; and (3) provide NASA-KSC with student project prototype results.

PROJECT RESULTS

NASA-KSC project applications consisted of five business and two engineering topics. The following is a summary of project results achieved.

<u>Business #1:</u> Launch Vehicle Processing Simulation Assistant Expert System

Project Description

The Launch Vehicle Processing Simulation Assistant (LVPSA) is a decision support tool designed to identify ground operation costs for a variety of future NASA launch vehicle configurations. LVPSA is a rule-based expert system that derives processing, integration and recovery costs for user defined launch vehicle configurations and allows real-time changes in any of the configuration parameters. This is an enhancement to an existing Lotus 1-2-3 ground operations cost model. Based on the Texas Instruments' expert system shell Personal Consultant Easy, LVPSA is a menu driven system which prompts the user through the construction of a launch vehicle configuration and determines ground operating costs in both man-shifts and dollars. Currently, LVPSA contains 71 rules with 149 elements.

Organizational Domain

The NASA-KSC Comptroller's Office Requirements Branch is responsible for developing launch vehicle operations cost estimates. Financial analysts within the branch are given launch vehicle configurations by NASA-KSC engineers and outside contractors. The analysts then develop cost estimates for ground operations based on standard processing times derived from historical data. Dan C. Stout, a financial analyst within the Requirements Branch, served as the KSC domain expert.

Expert System Solution

LVPSA provides the user with a transferable means of developing timely, accurate, and consistent processing cost estimates; and offers: (1) menu-driven inputs, (2) parameter editing, and (3) cost traceability that results in an efficient cost estimating tool. The LVPSA queries the user through a series of prompts about the configuration of the launch vehicle under evaluation. Each element of the vehicle: core, orbiter, and booster and its technology complexity is thus defined. Technology in this instance is a variable cost factor established by the knowledge (domain) expert corresponding to the effect of technology on processing time. Labor rate is another user-assigned parameter that is used to determine project costs at various locations and time periods.

Once the launch vehicle configuration has been determined, LVPSA proceeds to calculate and display the estimated processing costs for that vehicle. Costs are displayed in terms of both dollars and man-shifts and are presented on the user screen with the vehicle configuration. On-line "what ifs" can be performed using the edit function of the system, and with this function all vehicle configuration parameters are displayed and can be modified. After change, LVPSA is used to recalculate and display the new estimated processing costs.

Project Assessment

The LVPSA is a valid application of expert system technology for two reasons. First, it allows the user to trace processing costs and the rules associated with the costs of each vehicle element. Secondly, it allows rapid configuration editing not currently available in the present ground operations cost model. The project was considered relevant by NASA-KSC in that it provides an enhanced capability, was feasible as was proven by the LVPSA system, and the outcome was a success from the user standpoint.

Business #2: Automated Data Processing Equipment Acquisition Plan Advisor

Project Description

The Automated Data Processing Equipment (ADPE) Acquisition Plan Advisor is a rule-based expert system designed to aid NASA personnel in the procurement of automated data processing equipment and software. The purpose of this application was to determine if a prototype expert system could be constructed which would assist NASA employees in determining if procurement rules governing such purchases have been followed; and if the analysis of the need and proposed solution had been properly planned, reviewed, and validated.

Organizational Domain

NASA-KSC like any other large organization needs various types of automated data processing equipment and software for a variety of operational and administrative purposes. Before actual procurement, an acquisition plan must be prepared before submission of a purchase requisition. Usually the preparation of this plan is a one-time occurrence by an individual or is done infrequently. The process can be time-consuming and frustrating because of the complexities and dynamic nature of government procurement regulations. If done improperly, the average correction turnaround time is six to eight weeks due to the number of reviews and additional information which may be needed.

Expert System Solution

After various interviews with the domain expert, knowledge was structured and coded. Melvin T. Hefter of NASA-KSC, normally responsible for advisement and review of requisitions for all ADPE purchases (large and small), served as the domain expert. The project team used Texas Instruments' Personal Consultant Easy for prototype development. In operation the system produces a two page check list for a person preparing an acquisition plan. The check list is specific to their particular need as delineated in Government Services Administration regulations and other rules. The ADPE Advisor prototype now contains forty-nine rules and many rule elements.

Project Assessment

The developed prototype is a valid application of expert system technology for several reasons. The problem takes from a few minutes to a few hours to solve, there is no controversy about the domain, an expert is available, and the knowledge can be represented as parameters and rules. The resultant prototype is a diagnostic system which can be used to analyze the contents of an acquisition plan for government procurement. However, application to other domains is anticipated.

Business #3: NASA Retirement Expert System

Project Description

A project team has worked in conjunction with NASA-KSC's Personnel Management Assistance Branch to develop an expert system prototype which attempts to capture specialized knowledge concerning various aspects of NASA's employee retirement programs. The NASA retirement domain has recently been in a transitional from the Civil Service Retirement System (CSRS) to the Federal Employee Retirement System (FERS). In addition, there is a third retirement plan, called "CSRS Offset," which applies in certain cases. The primary objectives of the prototype system were to determine which of the three plans is applicable to any given NASA employee and the impact of certain legislated retirement provisions on these employees.

Organizational Domain

The expected users of this system were defined to be specialists within the assistance branch who work with individual employees. This personnel group is a division of the Personnel Office that plans, organizes, and administers human resources programs for KSC's civil service employees. These employees consist of approximately twenty-six hundred professional, scientific, technical, clerical, and administrative people. Presently the FERS retirement plan provides benefits from three sources: a Basic Benefit Plan, Social Security, and a Thrift Savings Plan. Even if an employee leaves civil service before retiring, Social Security and Thrift Savings continue to work for the employee.

Expert System Solution

After study of the domain documentation and interviews with NASA domain experts, the extracted knowledge was organized using decision trees and backward chaining narratives for each of the provisions affecting retirement. Three domain experts participated during project development. The reason for multiple experts was that no single individual possessed all the specialized knowledge needed because of recent changes in the system. As a result of meetings with the experts, it was decided that the system should be diagnostic in nature and would identify the applicable retirement plan and examine legislation impacts on an employee's retirement. Prototype development was accomplished using Texas Instruments' expert system shell -- Personal Consultant Easy.

The final system classifies an employee under a retirement program, and then evaluate the impact of three major legislations on the employee's retirement options. The finished prototype consisted of four knowledge bases: (1) RPD, the retirement plan determinator module; (2) CATCH 62, which identifies an employee's options regarding creditable military service; (3) WINDFALL, which determines the affect of windfall elimination on an employee's Social Security; and (4) GPO, which determines the Social Security reduction resulting from government pension offset legislation.

Project Assessment

The developed prototype evolved into a fairly complete and successful expert system. Future development goals should include additional verification to evaluate the current system and efforts to unify the individual knowledge bases into a "personnel assistant" which takes full advantage of this technology. The resulting expert system could be a "fail-safe" personnel advisor which could be modified to allow an employee to "what if" various retirement options. This would require the employee to state some expectations of future economic conditions and for the personnel office to establish some heuristics for processing these expectations.

<u>Business #4:</u> Customer Requirements Identification System Expert System

Project Description

A prototype Customer Requirements Identification System (CRIS) expert system has been developed to demonstrate the feasibility of providing computer-based assistance for NASA-KSC payload ground operations processing personnel and customers planning to fly experiments and other payloads aboard the Space Shuttle. The concept behind CRIS is that a strawman requirements set can be generated based on the acquired past knowledge and hueristics possessed by KSC processing experts. The resultant requirement set would then evolve and become complete through the subsequent exchange of information between NASA-KSC processing personnel and experimenters. CRIS is designed to use "if-then" rules, and based on a small number of input responses from customers, a set of needed facilities, equipment, supplies, special requirements, and special services is generated by the system.

Organizational Domain

The domain for this project is KSC and all the facilities, services, and organizational support available for pre and post-launch payload processing. Joint KSC and customer information exchange meetings are normally held over an extended period on-site at KSC and at off-site customer locations worldwide. This process normally takes in excess of two years to complete for each Shuttle mission. Requirements generation will satisfy experimenter needs during all phases of payload processing while at KSC.

Expert System Solution

The breath of CRIS is presently limited to the discipline of life sciences animal research. Within this category, the requirements for primate experiments which fly in the Space Shuttle's Spacelab are used to demonstrate the depth of the system. Based on knowledge extraction interviews conducted with NASA-KSC domain experts, the requirements CRIS address include: test and checkout, test support, facilities, equipment, supplies, and special requirements and services.

The CRIS prototype operates a series of forward chained rules that are organized into groups based on the class of the requirements being tested. Presently there are seven rule groups, approximately ninety-five rules, and numerous rule elements. The system writes the requirements to a data base record as it determines them. The expert system shell software used for CRIS is Personal Consultant Easy by Texas Instruments, along with dBASE III by Ashton-Tate, and a Microsoft C program.

Project Assessment

This new system has the potential of providing the following benefits for this time consuming process: (1) the time required to determine the requirements for a particular experiment will be reduced significantly; and (2) CRIS can be sent to customer locations for preliminary requirements identification thus reducing various expenses. With the installation of a CRIS-like system, a potential exists for a significant reduction in this timeframe. In addition, it is felt that a number of other product and service domains can benefit from this concept and technology.

Business #5: Financial Accrual Data Expert System

Project Description

The Financial Accrual Data System (FADS) is a prototype rule-based expert system designed for use by NASA-KSC specialists to perform variance analysis of contractor financial reports. FADS was developed to determine if an automated system can provide time saving benefits and to determine if expert system technology is an appropriate technique for such an application.

Organizational Domain

The Resources Management Office (the domain organization) is under the control of the NASA-KSC Comptroller. Working in conjunction with budget and operational elements, its primary purpose is to manage financial resources by monitoring and controlling the monies contracted to various companies which support KSC operations. McDonnell Douglas Astronautics payload ground operations processing financial data were used for this prototype.

Expert System Solution

The final FADS prototype consists of twenty-seven rules in four rule groups. The system starts by asking the user which variance is to be calculated. The user is then prompted to enter planned and actual amounts from the contractor's Form 533 reports. Dollar and percentage variances are calculated if they exist. After determining the variance and deciding acceptability, the system displays its conclusions. FADS was developed using Texas Instruments' expert systems shell -- Personal Consultant Easy.

Project Assessment

An automated system for evaluating contractor reports would provide several benefits. It would greatly reduce the number of manhours spent evaluating the reports, and would ensure that the report is being evaluated completely each month. In addition, increased accuracy and consistency would be anticipated. Beyond the FADS prototype would be the incorporation of an automated interface with contractor submitted data using PC-based spreadsheet software such as Lotus 1-2-3 (assuming future contractor data is submitted in this format as is planned), and a data-based management system such as dBase III+ which could be used to process mathematical functions and to store data.

Engineering #1: LOX & GOX Ignition Source Expert System

Project Description

This prototype expert system was designed to detect potential ignition sources in liquid oxygen (LOX) and gaseous oxygen (GOX) transportation systems at KSC. It is a rule-based expert system developed on Texas Instruments' Personal Consultant Plus software. The system was created to be used as an expert consultant for a designer of oxygen transport systems. In use, the designer can consult the system to determine whether an ignition source is present. These sources may be due to component design or the material(s) of which the component is comprised. Sources that may be detected are: (1) heat of compression, (2) mechanical impact, (3) friction, (4) particle impact, and (5) resonance. The designer can also use the system to verify proper usage of materials within the component. A material can be inappropriate due to system parameters or because it is not on the Material Selections List (MSL). This system was not designed to be the last word on ignition sources. It informs the user that there may be a potential problem and a need to re-evaluate the component design or material usage.

Organizational Domain

Materials used at KSC must be acceptable for use in hazardous environments. The Materials Application Advisory Board provides a MSL to identify acceptable materials to be used with any hazardous materials such as oxygen. If the material is on the list it is tested according to NASA Handbook 8060 specifications. If it does not pass these tests it is sent to the materials centers representative for more extensive testing. These limits and specifications for a certain hazardous material are clear to those who test the material. However, this information is not made available to the designer until the component has failed under test. The ignition source expert system would allow the designer as well as others involved in the implementation and testing to see possible hazards of a design, and specifically to facilitate system and materials approval for the designer.

Expert System Solution

The knowledge base contains 175 rules within 8 frames and is currently structured to examine four different components. These components are (1) valves, (2) piping, (3) regulators, and (4) filters. The system gathers information on the chosen component(s) to determine the possible ignition sources and verify materials usage. The user has the option of examining one or more components for potential ignition sources.

If none of the components is chosen, the system can still reach a set of results. These conclusions are based on the state of the oxygen, maximum pressure and maximum temperature of the system, and represent the most probable ignition sources based on past expert experience. The system may also derive no conclusions, if all of the confidence factors are between -20 and +20 percent. This is a valid result for the designed system. In this case it is important to pay attention to any system messages that are printed during the consultation. These statements are flags to the user that there is a problem with the design or material used.

Project Assessment

This domain represents a good application for expert systems. It provides two of the necessary ingredients needed to build a successful expert system: suitability of application and availability of resources. The benefits include reduced cost and delays due to improper design and material usage. Further expansion of the knowledge base is possible. For example, the number of components could be increased to include pumps, hoses, dewars, and storage tanks. In addition, the sources of ignition could be extended to accommodate these component additions and the scope of hazardous material could also be increased to include all those handled at KSC.

<u>Engineering #2:</u> Hazardous Gas Expert System

Project Description

The Hazardous Gas Expert System (HGES) is designed to assist operators of KSC's Hazardous Gas Detection System (HGDS). The main portion of this existing system, located inside the Launch Control Center at KSC, is used for monitoring levels of gases (hydrogen, helium, oxygen, and argon) from areas around the Shuttle and launch pad. The HGDS is composed of primary and a backup systems. The HGES was developed to assist operators in diagnosing problems within the primary system, and provides support in interpreting the data read from the HGDS during various cryogenic setup and loading operations. Problems diagnosed within the primary system may require use of the backup system.

Organizational Domain

Operators of the HGDS are responsible for interpreting the data read from the system during cryogenic operations and determining if the gas conditions during all stages of this preparatory period are satisfactory for launch. Cryogenic loading begins at T-minus 6 hours and 30 minutes and is divided into different stages. These stages include chill-down, loading, stabilization, replenishment (refilling), and the time period of 9 minutes before launch. Different procedures occur for each of these stages to prepare a Shuttle for a launch. The gases monitored by the HGDS must stay within certain ranges depending on the present stage. Gary N. McKinney of Lockheed is an operator of the HGDS and provided the expertise that was necessary to develop the HGES.

Expert System Solution

The HGES was developed using Texas Instruments' Personal Consultant Plus software running on PC compatible machines. The system is made up of 150 rules that are divided into 5 rule groups. The knowledge base of this expert system is composed of two major areas. The first involves the diagnostics of the primary system to determine whether or not the operator should switch control to the backup. The second group is used for the interpretation the data read during cryogenic loading and to determine if the conditions during all stages of this preparatory period are satisfactory for launch.

User friendliness was incorporated into this expert system by the use of menus to relieve the user from excessive typing of data. Also, the knowledge concerning diagnostics was partitioned into three frames, which depending on previous user input, will direct further questioning to the most likely problem area. This eliminates unnecessary or redundant questions. The user may investigate more than one problem area by using respective confidence factors upon entry of the diagnostics section. Due to limited development time, the expert system was designed to handle those problems that are most likely to occur during cryogenic loading and runs diagnostics only on the primary system.

Project Assessment

The HGDS is a valid application for building an expert system because the problem involves an input/output type of knowledge that makes extensive use of data. It is recommended that the future expert system should be developed to only handle the diagnostics areas in both the primary and the backup system. Since speed is very crucial to this kind of problems, the expert system should be an "on-line" diagnoser. In this manner the operator can fully concentrate their attention to interpreting the incoming data during cryogenic operations while the on-line expert system is continuously checking the health of the primary and backup systems. One of the advantages of having an on-line diagnoser is its ability to detect any little change in the status of the health flags of the system. This is a real advantage since the expert is not continuously checking the screen and a flag might come on and off without ever having been noticed.

SUMMARY

This paper addressed and reported results of NASA-KSC and UCF mutually agreed upon student projects which were directed toward application problems in a variety of business/management and engineering domains at KSC. The primary objectives of this endeavor were to: (1) acquaint students with expert systems technology, (2) provide worthwhile learning experiences from actual work environment situations, and (3) to develop meaningful project results for NASA. The first objective was satisfied by traditional classroom lectures, readings, and testing. The other objectives were a more difficult challenge. Toward these latter goals, a number of successful expert systems business and engineering-related prototype applications projects were developed for NASA-KSC by UCF student project teams working with KSC domain experts and others.

This synergistic and mutually beneficial approach was made possible by the sponsoring grant provided by NASA. Future application development is now possible for those projects which demonstrate necessary technical and economic advantage over existing methods. For NASA and the various students involved in these projects this is a beginning, rather than an end, to a longer process.

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Launch Vehicle Processing Simulation Assistant Expert System

Developers: David M. Cheney and Walter P. Haverstein
Expert: Dan C. Stout.

Automated Data Processing Equipment Acquisition Plan Advisor

Developers: Richard A. Caliari, Martin L. Fillingim Jr., Hugh Morris, and Ramona L. Woods
Expert: Melvin T. Hefter

NASA Retirement Expert System

Developers: R. Alan Collicott, C. Edwin Weatherford, and Gina C. Wilson
Experts: Craig Whittaker, Madeline S. Kennedy, and Frederick N. Bailey

Customer Requirements Identification System Expert System

Developers: Michael P. Aldrich, Heidi R. Hollowell, K. Peter Schmid, and Michael A. Vine
Experts: Dr. Alan E. Drysdale, William R. Munsey, David E. Headly, and Bruce D. Yost

Financial Accrual Data Expert System

Developers: Cathy Kahn Hasselberger, Martin Grimes, and Barbara Quaintance
Experts: Brenda B. Brooks, Robert M. Hebeler, and James L. Jennings

LOX & GOX Ignition Source Expert System

Developers: Frederic D. McKenzie and Jenifer M. Sargeant
Experts: Cole J. Bryan and Floyd E. Lundy

Hazardous Gas Expert System

Developers: Cheryl E. Bagshaw and Taha A. Sidani
Expert: Gary N. McKinney

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