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Toward an Expert Project Management System

by

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1.0) Introduction and Overview

The purpose of the research effort presented here is to prescribe a generic reusable shell that any project office can install and customize for the purposes of advising, guiding, and supporting project managers in that office. The prescribed shell is intended to provide both: (1) a component that generates prescriptive guidance for project planning and monitoring activities, and (2) an analogy (intuition) component that generates descriptive insights of previous experience of successful project managers. The latter component is especially significant in that it has the potential to: (a) retrieve insights, not just data, and (b) provide a vehicle for expert PMs to easily transcribe their current experiences in the course of each new project they manage (i.e. to act as the Corporate Memory).

For the past several years the principal author has conducted psychological, behavioral, and cognitive studies of expert project managers' thought processes for the purposes of deriving a model suitable for translation into an expert system. The model is based on the process of diagnosis and analogical reasoning as described above and in sections of this paper. This model is based on the study of 21 employees of NASA, numerous employees of the U.S. military, historical case studies from the Space station and Space Telescope Programs and papers of 16 famous inventors (e.g., Ben Franklin's diaries, to mention one) as documented in earlier reports. It is expected that the successful implementation of the model and the integration of the analytical and analogical components will result in many new innovations including special-purpose expert system generators, which would represent a new phase in the maturation of Expert Systems technology for project management applications.

1.1) Technical Objectives

The focus of this paper will be to report on the preparation, conduct and results of an experiment to prove/disprove the premise that an expert project management system can be configured that will improve/expand the ability of a manager to perform project planning and monitoring. This experiment has been designed with the intention of accomplishing the following three objectives:

- (1) Construction of a Simplified Prototype containing a Project Management (PM) Subsystem, an analogical reasoning inferencing mechanism and the associated knowledge bases.
- (2) Exploration of Eleven Key Research Questions relating to the nature of an expert project management system (EPMS) environment.
- (3) Evaluation of the Prototype and Recommendation of Design Guidelines for EPMS Version 1.

The evaluation of the prototype will consist of a system performance evaluation based on snapshots and backtracing of actual EPMS runs, and on comments/suggestions by 17 experts presented with three exemplary EPMS user sessions. The insights obtained from these evaluations will be used to formulate design guidelines for a working Version 1 system, which is expected to perform beyond the current limits of expert system shells, and exhibit the characteristics of an expert system kernel or generator.

1.2) Report Organization

This report will present in succession, the framework and results of the activities aimed at the accomplishment of the three technical objectives. The next section deals with the knowledge elicitation process and the resulting framework for the EPMS generator. Section 3 contains a top-level description of the prototype, and the evaluation of the prototype will be presented in section 4. The last section presents the conclusions reached and outlines of planned future developments.

2.0) PM Knowledge Elicitation

This section describes the concept of EPMS that evolved over dozens of knowledge collection sessions. In each session, feedback from domain experts was solicited by giving demonstrations and/or functional descriptions of EPMS: i.e. its goals, its conceptual design, and the types of sessions a user would encounter.

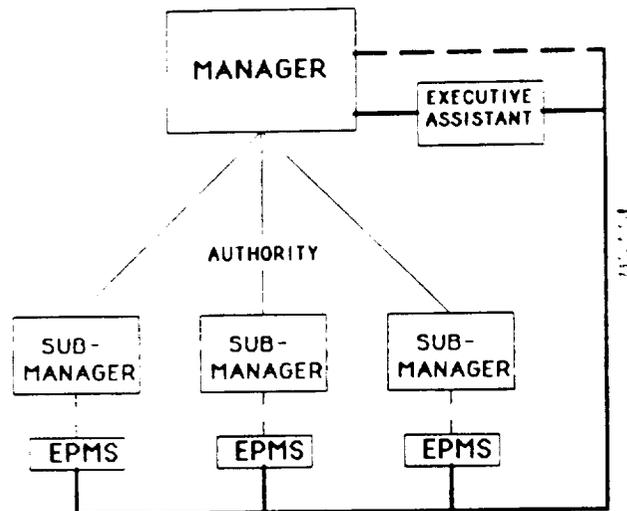
A common observation among the experts was the need to implement EPMS within any given two-level hierarchy, in order to be compatible and supportive of existing organizational boundaries and lines of communication (see Figure 1). Figure 1 also reflects the perception that the manager probably will not be the principal user of EPMS and that is more realistic to expect an Executive Assistant to assume the user role, and to expect the manager and submanagers to use EPMS either indirectly through the Assistant or occasionally themselves.

A significant observation made during the knowledge elicitation sessions was the presence of a wide diversity of needs for stand-alone expert system-based project management support tools. One of the managers interviewed presented a list of some of the possible areas for ES support (see table 1) and indicated that this list was by no means exhaustive. Furthermore, there was found to be an overwhelming preponderance of existing subsystems, data bases, MIS, DSS, etc. which would require direct interfacing to an integrated EPMS Kernel, or would

Table 1: Summary of Possible Stand-alone PM Expert Systems

Estimating	Cost and Time Control	Site Planning and Management
<ul style="list-style-type: none"> Project Selection Conceptual Estimating Parameter Estimating Life Cycle Costing Value Engineering Integration with CAD Historical Cost Data Management Collection Maintenance Tailoring Check List Contract Document Site Inspection Start Procedures Manuals Quantity Survey Pricing Securing Material and Subcontractor Prices Project Conceptual Planning Equipment Analysis Crew Analysis Cash Flow Analysis Bid Preparation Sub Bid Analysis Sub Bid Scratch Estimates Material Price Analysis Markup Analysis Bid Adjustments Change Order Estimating Impact Analysis Change Condition Pricing General Conditions Development Item Selection Pricing Insurance Analysis 	<ul style="list-style-type: none"> Planning Activity Breakdown Logic Definition Duration Analysis Contingency analysis Input Data Collections Checking Activity and Project Status Analysis Overrun Projections Problem Flagging Problem Diagnosis Remedy Recommendations Changed Condition Identification Impact Evaluation Recommendations for Execution Notifications of all Parties Involved Productivity Analysis Progress Payment Application Preparation Invoice Checking Material Tracking Penalty/Liquidated Damages Evaluation 	<ul style="list-style-type: none"> Site Layout Materials Handling Temporary Facility Requirements Site Management Staffing Access and Traffic Control Security Systems Safety Systems <u>Project Closeout:</u> Retention Reduction and Final Payment Resource Reduction Closeout Documentation Checklist Subcontract Closeout Lien Release Project Debriefing Historic Cost Acquisition Productivity Analysis Learning from the Project

Figure 1 : EPMS Two-Tier Hierarchy



require data/knowledge transfer in the case of a stand-alone EPMS. In either situation, compatibility with existing resources emerged as an important criterion that places unique flexibility demands on the expert system "shell".

In response to the need for this adaptability a concept for an EPMS generator having a four-ringed architecture was adopted (see Figure 2).

2.1) Ring Four: Site Specific Elements

The outermost ring is representative of a gateway to the manager's external information environment. Most of the managers interviewed indicated a strong dependence on the availability of reference information, historical data and other large data base management and information retrieval requirements. Access to the external environment is accomplished in many different ways including person-to-person communications, on-line retrieval via a computer terminal, customized research conducted by a services firm, or physically locating the information in a library or other repository. Most of the groups indicated that for an EPMS generator to be effective, this vast array of information resources had to be taken into account, either by direct interface (in the case of computer data bases) or at a minimum, by identifying the source, point of contact, and location where supplementary information can be obtained. In essence, the outer ring represents the various "hooks" of the EPMS generator to the outside world, including intelligent information retrieval, organizational knowledge, generation of copies/sessions for use on proliferated stand-alone machines, and numerous other extension utilities.

2.2) Ring Three: The PM Kernel

The next ring represents the next "layer" of project management activity that emerged as a result of the experts' discussions. PM activity was found to have two main modes: 1) planning, where specifications, budgets, milestones, etc. for a new project are formulated, and 2) monitoring, where the execution of the plans developed in (1) are carried out. Most participants indicated that, after they had researched and obtained the necessary (or at least the most available) reference and background material regarding a problem or decision, the next step involved a series of processes where the information was sorted, ordered, analyzed and presented. Performance of this type of activity was the basis for the design of the planning mode of the EPMS generator. This generator consists of a project management subsystem that contains heuristics and analytical techniques used by project managers in analyzing information, assessing problem situations and generating proposed responses. For the monitoring mode, it was necessary to make available a subsystem of customizing utilities, whereby a project manager could specify and create an "automated layer of information filtering" including parameter and alarm thresholds, milestones, quick-look summaries etc. Finally, a user interface subsystem that makes use of human factors and computer visual engineering (CVE) principles was identified as a requirement for both modes. The interface design feature most requested by the experts was the ability to choose from a list of presentational formats, depictions, or other customized user-generated displays.

2.3) Rings Two and One: Analogical Reasoning Applied

The analytical filtering and processing specified for Ring Three is intended to result in the generation and display of key indicators, barometers and other parameters that are important to project management decision making. Most managers agreed that it was at this point in the thought process that analogical reasoning was most frequently applied. This was evident in most manager's comments, which stated that comparisons with past similar experiences were keyed

Figure 2. Rings of the EPMS Generator

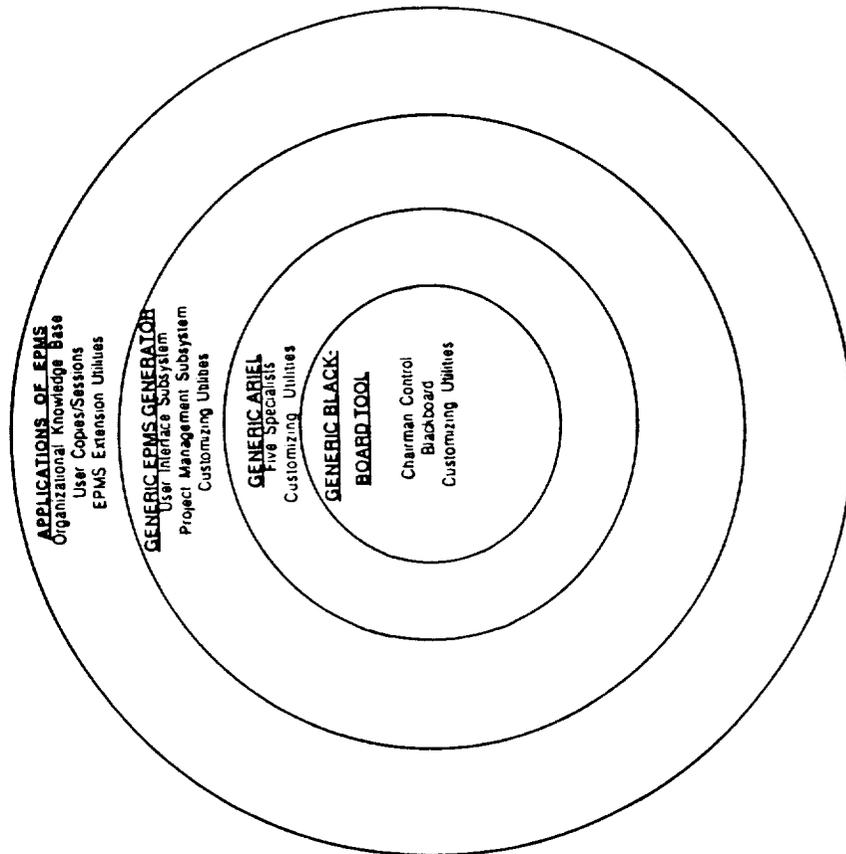
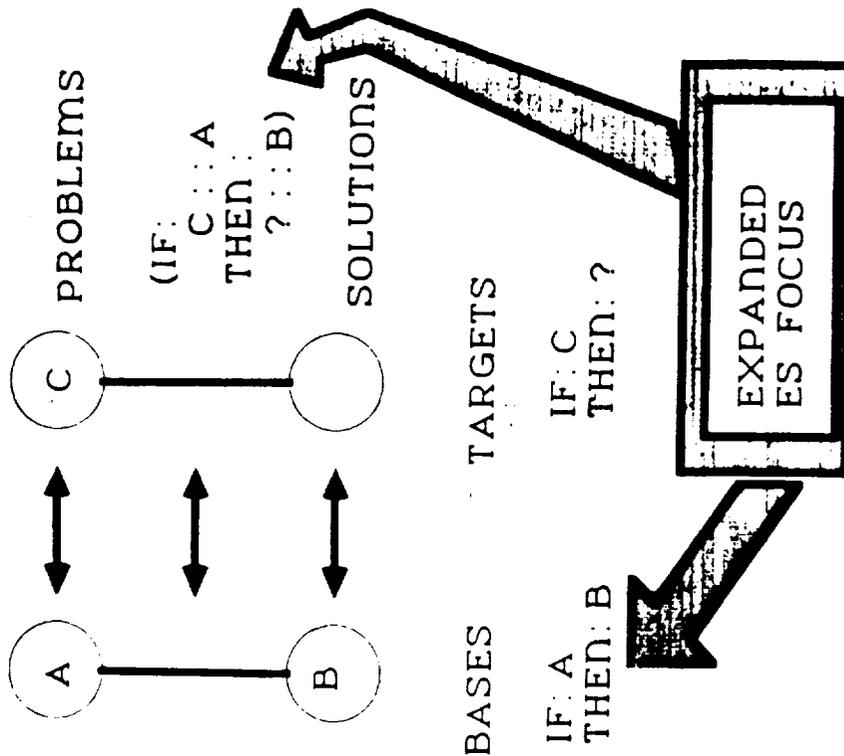


Figure 3. Contribution of ARIEL



on parameters resulting after extensive analysis of the data had been performed (ring three) rather than on the raw data elements themselves (ring four).

The process of analogical reasoning is best understood by referring to the classical analogy test question which is invariably written in the form: "some known problem, A, is to some known solution, B, as a new problem, C, is to which of several possible options (X,Y, or Z)"? Or more tersely, this can be written as $A:B::C:(X,Y,Z)$? This is depicted in Figure 3, where A and B are the Base problem-solution pair (or pairs if more than one possible analog exists) and where C is the target problem statement. X,Y, or Z are the unknown target solution shown in Figure 3 as an empty circle.

A traditional stand-alone expert system operates on target problem-solution pairs generally via a series of productions of the form:

IF: C
THEN:?

That is, the traditional expert system isolates the conditions of the target problem space and attempts to directly infer the solution to be one of X,Y,or Z.

In order to make effective use of analogy, particularly in an automated analogical reasoning support environment, studies of the knowledge elicitation sessions showed the need to extend a traditional expert system in two principal ways: (1) facilitate identification of the target problem, C, by looking for similar problem statements in the set of bases, A, and (2) to help flush out the target solution space by suggesting past solutions from B that in part or in whole appear helpful and by assisting in adapting those solutions to the current problem (minimizing tendencies to rely too heavily on the past -- i.e., the "anchoring and adjustment" bias). This capability is illustrated as the "extended expert system focus" shown in Figure 3. Furthermore, this expanded focus must support situations in which the target problem, C, is initially ill-defined, rather than known a priori, as is the case with more conventional analogy programs. The same uncertainty must be manageable in determining analogous problem-solution pairs (A and B)s. For this reason, a major goal of this development effort was to gain the ability to scan a large set of possibilities and to generate and test ideas, with the best ideas being examined for merging, manipulation, transformation, and other disanalogy elimination heuristics.

3.0) EPMS Prototype

Figure 4 provides an overview of the portions of EPMS that were experimented with in the prototype. There are three major parts to Figure 4 -- the longer term aids, the core of EPMS, and the customizing utilities and user support functions. The prototype was an experiment upon the latter two parts which involved building just enough of each part to glean insights useful for next step development. The first part identifies the long term aids that are foreseen in order to integrate EPMS into an existing support structure, which would complete the kernel concept by bridging together the EPMS core with external data bases, tools, algorithms, sources of knowledge, workstations, personal computers, and other hardware.

The customizing utilities identified on the right-hand side of Figure 4 are geared toward making the EPMS kernel attractive to a wide variety of potential users. Hence the utilities support the tailoring of each and every knowledge base, analog, object, and PM subsystem module to the specific application of the individual user. Although the customizing utilities were not developed for the prototype, their design and scope was a major focus of the experiment. High level designs for many

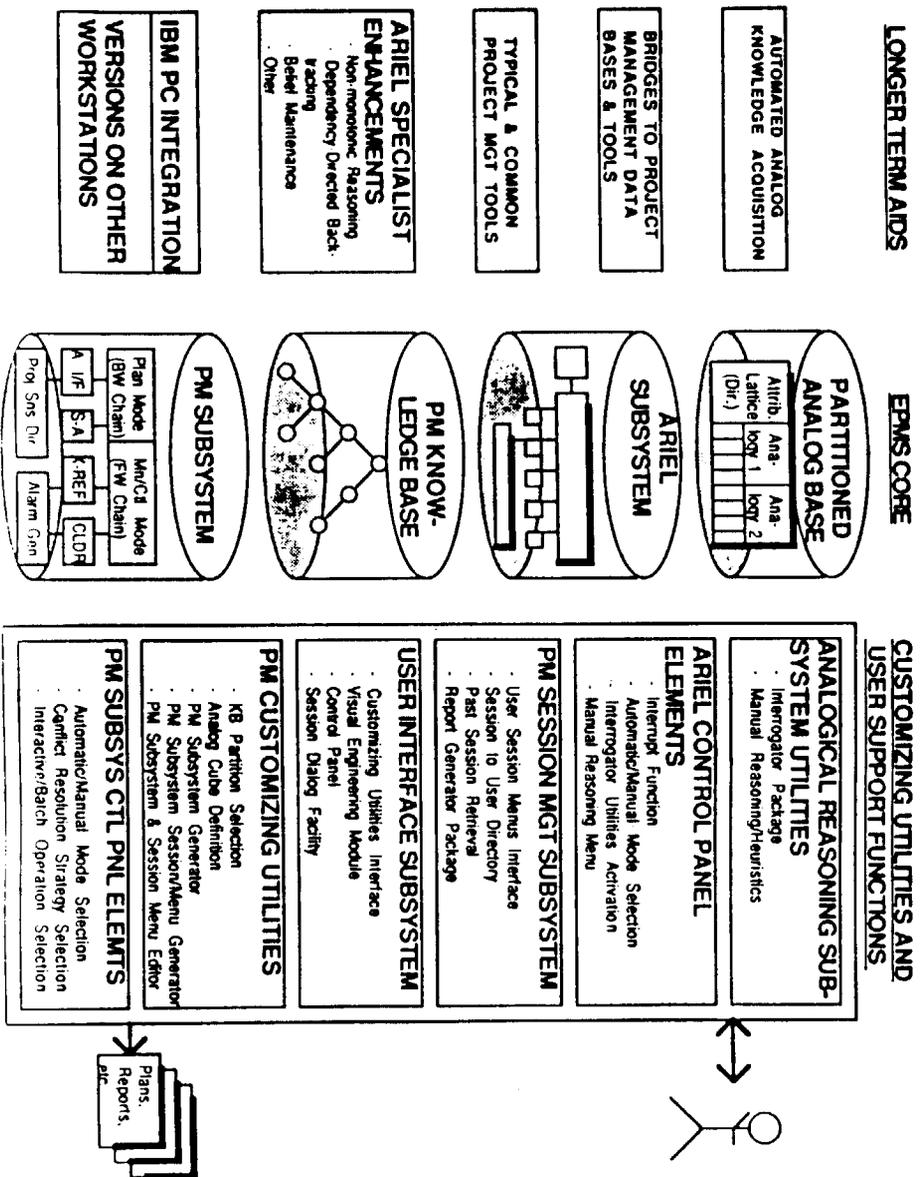


Figure 5. Project Management Subsystem Overview

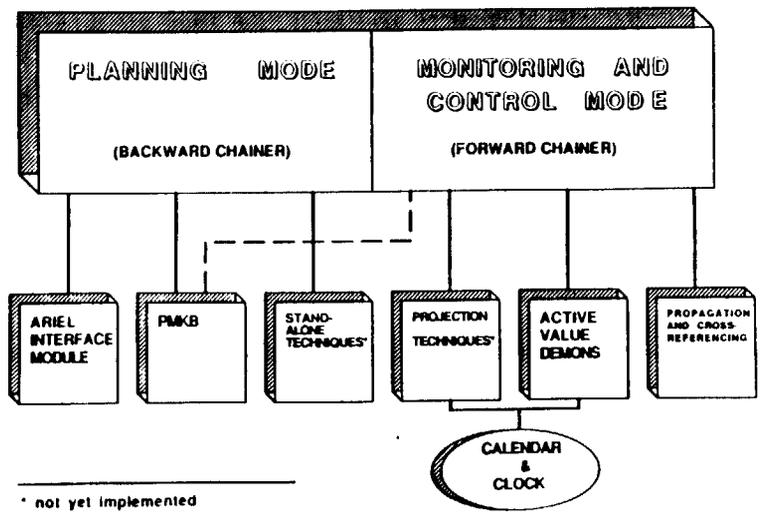


Figure 6 An Intelligent Subsystem Milestone-Aspect Object of the PMKB

[Subsystem-Milestone-Aspect Name:

- Definition:
- Comment:
- Objects Depended On:
- Objects Affectable:
- Techniques To Use For Inferring The Plan:
- Plan Value:
- Comment on Value:
- Technique Used:
- Date By Which Plan Value Is Due:
- Techniques For Determining Actual Value:
- Techniques For Projecting Actuals:
- Actual Value (Current Date):
- Actual Value (Projected To Due Date):
- Caution Threshold Level:
- Object Status (one of Completed, On Track, Caution, Emergency):
- Actual Value Comment:]

ORIGINAL PART IS OF POOR QUALITY

of these utilities were created and user evaluations of and reactions to these designs were elicited.

The remainder of this section will be devoted to providing descriptions of the four main components of the EPMS core, along with a discussion of the three exemplary user sessions that were run during the course of the experiment.

3.1) PM Subsystem

An overview of the PM subsystem is shown in Figure 5, which further illustrates the two-mode concept of operation. In the planning mode, a self-contained PM Knowledge Base (PMKB) works with a stand-alone backward-chaining inference engine to assist the user in planning all aspects of a new project. The inference engine "knows" how to draw on the ARIEL subsystem for assistance if its stand-alone techniques are unable to estimate a value required by the plan or if a search across a wider range of candidate analogs is required. That is, it chains through each subsystem, milestone, and aspect of the new plan for a new project. The aspects elicited include planned levels of manpower, dollars, etc. per time period and work package.

In the monitoring and control mode, a forward chaining inferencing technique is used in conjunction with active value "demons" to constantly monitor and test the deviations of actual values from planned values for the various subsystem-milestone-aspect objects. When cautionary (or emergency) alerts are detected, all related objects within the knowledge base are tagged with an alarm message, which allows the user to determine the source and the nature of any deviation that may affect overall project performance. This cross-referencing feature was cited as a major requirement currently lacking in most project monitoring systems. This mode was also equipped with a clock and calendar, in response to concerns expressed regarding the lack of the ability of current expert systems to adequately account for the effects of the passage of time on any given situation. As a result, all activities in EPMS are time-tagged in a Julian date format, as a means of keeping a record of the time of occurrence and duration of important events. The operation of each subsystem component including the control panel will be illustrated further in the description of the user sessions.

3.2) Project Management Knowledge Base (PMKB)

The EPMS PM Subsystem seeks to establish a new project plan and to monitor its progress. This is done cooperatively and interactively with a human participant, and a completed project plan ultimately becomes one more analog in the Analog Knowledge Base (AKB). The PMKB is thus a set of rules and objects designed to capture and hold the subsystem-milestones-aspect knowledge for the "target". Since this knowledge is unknown initially, the PMKB must hold both the expected or planned value for each subsystem-milestone-aspect and how that value was obtained.

The data structure for such a subsystem-milestone-aspect is shown illustratively in Figure 6. The slots for holding the important pieces of information are shown, however, the methods and other intelligence features are only implied by this Figure. The prototype EPMS implemented and tested most of these features with the exception of the projection capability.

3.3) Partitioned Analog Knowledge Base (AKB)

In order to facilitate search and to improve execution time the analogs are stored in a structure (Figure 7A) that defines two important characteristics: (1) the typology classification scheme, and (2) the progressive deepening levels. The typology classification scheme captures the sorting process that PMs use to classify

projects. For example, the statement "this project is a Class X, Type Y" is often encountered in analogical reasoning (see Silverman 1983, 1984, 1985, 1986). Hence the knowledge base offers a "typology plane" or surface. This classification scheme can be pursued at multiple levels of problem solving depending how deeply involved the problem solver is. Thus a progressive deepening scheme is also offered wherein the EPMS user could enter at the level at which he wishes to work (only three example levels are shown in Figure 7 A, more are possible).

Within each partition of Figure 7 A, are the analogs that correspond to that class-type of problem. Each analog is itself multi-dimensional as portrayed illustratively in Figure 7 B. The three dimensions shown are of variable length and capture the fact that most projects involve multiple subsystems each marching along a set of prescribed milestones. Attached to each milestone are each of the aspects listed vertically in Figure 7 B. The actual knowledge about each subsystem-milestone-aspect is stored in any of a number of possible representations (e.g., map, icon, graph, table, list, rule, etc.). Also stored with each subsystem-milestone-aspect are any relevant advice lessons learned, etc. for selected class-types of problems encountered. The prototype EPMS includes a 270 node object lattice of attributes associated with Figure 7 A and three analogs corresponding to Figure 7 B. The three analogs are the LANDSAT, SPACE TELESCOPE, and NIMBUS-G projects. In this lattice, each node represents a specific activity, system element, or organizational element of a given project and is organized in hierarchies and grouped into specialized project domain areas, so that the further the lattice is traversed, the more detailed the information about a specific project domain becomes. In this way, the lattice can be used for two purposes within the project management domain: (1) as a guide for selecting attributes to characterize new analogs being entered into the AKB, and (2) as a means of entering a description of the target problem/project to be planned/analyzed.

3.4) ARIEL Subsystem

The ARIEL subsystem physically implements the 5-part analogical reasoning process described in Silverman (1985) & Silverman & Moustakis (1986) within five specialists and a blackboard (see Figure 8). Each specialist consists of a short-term memory, local knowledge bases, and an interface to the main blackboard, which is the shared memory used by the other specialists. The local knowledge bases store the knowledge regarding the specialist's particular area of expertise, as well as knowledge related to planning and control. The local knowledge bases are used to formulate an approach by the specialist on the main blackboard. The local control knowledge base controls the flow of information between the specialist and the main blackboard, making sure that only relevant data/information is exchanged.

3.4.1) The CHAIRMAN

The main blackboard is interfaced with a CHAIRMAN that controls the information flow among the five specialists. The CHAIRMAN has the same basic structure as a specialist. The primary purpose of the CHAIRMAN is to monitor the operation of the five specialists and to maintain an orderly flow of information to and from the blackboard. The CHAIRMAN also handles all inputs and requests from the user. The situation can best be compared to an individual (the user) presenting a problem to another individual (the CHAIRMAN). The CHAIRMAN then convenes a meeting of five specialists each of which is an expert in a particular aspect of the application of analogical reasoning to problem solving in general. These experts are sitting at a conference table (the Blackboard) and the input problem/request from the user is placed on the table by the CHAIRMAN. The CHAIRMAN directs each specialist to look at the information on the table. Each specialist is asked by the CHAIRMAN to prepare and submit a plan to solve or to help solve the problem, based on its own local knowledge about problem solving. The CHAIRMAN then

Figure 8. ARIEL ARCHITECTURE

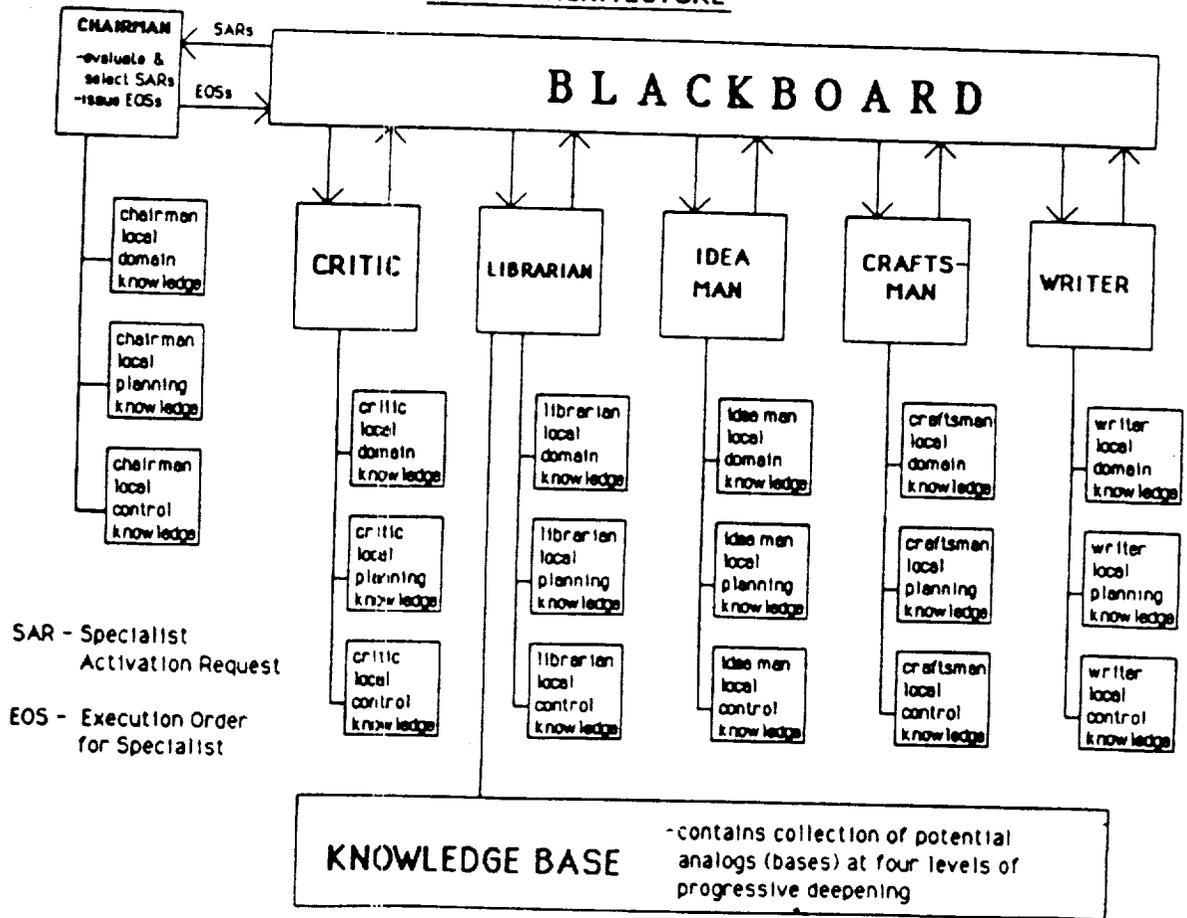


Table 2: Functions Supported a. . Current Status of EPMS Panel Elements

		PROJECT MANAGEMENT FUNCTIONS SUPPORTED & STATUS							
		KNOWLEDGE ACQUISITION	PLANNING & DEFINITION	PLANNING ASSESSMENT	PERFORMANCE MONITORING	PERFORMANCE ASSESSMENT	COLLATERAL USES	IMPLEMENTED IN PROTOTYPE	APPEARS INACTIVE ON PROTOTYPE SCREEN
EPMS CONTROL PANEL ELEMENT	ARIEL ACTIVE IMAGES								
	ARIEL INTERROGATOR								
	CALENDAR								
	CLOCK								
	V E SCREENS								
	TEXTUAL ADVICE								
	TOP-LEVEL TYPESCRIPT WINDOW								
	ARIEL QUERY/RESPONSE								
	USER QUERY/RESPONSE								
	ARIEL UTILITIES								
	MODE SELECT SWITCH								

CURRENTLY IMPLEMENTED VIA PROMPT WINDOW
 CURRENTLY IMPLEMENTED IN TYPESCRIPT WINDOW & VISUAL ENGINEERING MODULE

evaluates each plan and decides which plans are to be activated. The activation of one or more plans will result in new information being presented to the blackboard, which could conceivably affect the planning processes and results of the other specialists. The CHAIRMAN's main purpose, therefore, is to decide which specialists should be permitted to proceed and in what sequence in order to maintain an optimal and orderly progression toward the goal (target solution). For the purposes of EPMS, a plan submitted by a specialist to the CHAIRMAN is called a SAR (Specialist Activation Request), and the order issued by the CHAIRMAN to a specialist to proceed with that plan is called an Execution Order for Specialist (EOS). The SAR is similar (analogous) in nature to the KSAR employed in HEARSAY-II. (Erman, et.al 1980).

3.4.2) The Five Specialists

Each specialist is a self-contained expert system that opportunistically examines the contents of the blackboard and proposes an analogical reasoning related process or function (e.g., diagnose, classify, evaluate, scan, assimilate, etc.) to the CHAIRMAN as a means of contributing to the progression of the problem toward a final solution. The five specialists support the problem identification (PI), Knowledge Acquisition (KA), Analog Transfer (AT), Knowledge Transformation (KT), and Introduction into Use (I) steps outlined in earlier articles, and are called the CRITIC, LIBRARIAN, IDEAMAN, CRAFTSMAN and WRITER, respectively.

The main function of the CRITIC is to aid in the process of problem identification, problem formulation and requirements definition. To this end the CRITIC monitors the contents of the target problem definition space and determines what methods are to be employed in order to expand or refine the target problem definition. These methods usually entail the selection of an appropriate problem definition aid being presented to the user (via the Writer). The CRITIC is also charged with the overall responsibility of monitoring the target solution generation process as a whole. These tasks range from seeking additional information from the user or LIBRARIAN to invoking a "stopping rule" when either an optimal solution has been achieved or when successive iterations would produce little or no change in the entropy of the target solution. The purpose of the LIBRARIAN is to ensure that all possible building blocks within a certain threshold that could be used in constructing a target solution to the problem are being considered. In order to accomplish this, the LIBRARIAN conducts a search of the AKB by taking each attribute contained in the target problem definition space, searching for each new occurrence of that attribute, and returning to the blackboard all previously unconsidered bases exhibiting that particular attribute. Another major task of the LIBRARIAN is to ensure that the AKB is properly updated with new information generated either by the user or by the ARIEL system itself. Currently the LIBRARIAN is configured only to assimilate final results as a new base (analog) to be considered for subsequent problem solving sessions. In later versions of ARIEL it is planned to also incorporate intermediate results, including erroneous paths, etc., in order to increase the overall intelligence of the system and to promote maximum reuse of lessons learned during the problem solving session.

The primary responsibility of the IDEA MAN is to evaluate each candidate analog based on the value of the similarity metric [Silverman 1986] for that particular analog and the corresponding attributes contained in the target problem definition. Weighing factors to be used in calculating the similarity rating are provided by the user at the request of the IDEA MAN via the WRITER. The candidate analogs are ranked starting with the analog having the highest similarity rating, along with the value of the rating. This output represents a prioritized and valuated space of potential solutions for use by the CRAFTSMAN in generating a composite target solution.

The CRAFTSMAN has as its goal a means ends analysis that leads to the construction of an optimal solution to the target problem using to the greatest extent possible the existing analogs contained in the knowledge base and provided by the user. At this point in the process, all relevant analogs that have been identified have been evaluated and ranked. In constructing the target solution, the CRAFTSMAN starts with the highest ranked analog and checks for a similarly value of 1.0, in which case that analog becomes the final solution and the stopping rule is invoked by the CRITIC. If the similarity rating is less than 1.0, the CRAFTSMAN takes the analog with the next highest rating, and constructs a temporary target solution by combining it with the highest-ranked analog. At this point a new similarity rating is calculated and compared with the rating of the highest-ranked analog. If the new rating is lower the second-highest candidate is dropped from consideration and the third highest candidate is considered in a similar fashion. If the new rating is higher the temporary target solution now becomes the new basis for comparison and the process continues.

The WRITER is the only element through which ARIEL can send messages to the user. For this reason, most of the functions that are assigned to the WRITER involve the generation of prompts aimed at soliciting user input. The core structures of these prompts reside in the ARIEL knowledge base and are accessible via the LIBRARIAN. Once accessed, the WRITER fills in any additional information germane to the problem being worked, and outputs the resulting prompt directly to the user via the screen. These prompts contain hooks to specific data structures (lists) on the blackboard, and these lists are automatically updated as the user responds to the prompt. The other main function of the WRITER is to document ARIEL results and problem solving activity in a manner acceptable for inclusion by the LIBRARIAN into the AKB.

3.4.3) The Blackboard Problem-Solving Framework

The blackboard configuration provides an opportunistic search framework that is used to support an orderly progression from initial problem definition to final target solution formulation (see Figure 9). ARIEL differs from most conventional blackboards in that the user, at his option, can override the actions of any specialist at any stage in the problem solving process. This was considered necessary in order for ARIEL to truly function as an "extension" of the human analogical reasoning process. The arrows in Figure 9, which indicate lateral, forward or backward level transitions, show the user as being totally unconstrained. The CRITIC has the next greatest influence on effecting changes in the direction of the problem -to-solution progression. Note also that this process is iterative, and can be influenced by the activity of the other specialists.

3.5) User Session

The current prototype has the capability to run three exemplary user sessions that were developed with the intention of soliciting feedback from potential users and providing additional insights into the design of the overall system. In particular, the sessions were intended to address some of the EPMS Research Questions, especially with regard to the use of analogy, and the determination of what analytical techniques should be directly incorporated into EPMS. The three prototype sessions and the objectives of each are delineated as follows:

- 1) Session 1, to demonstrate the project requirements definition function and the use of the analogical reasoning extension.
- 2) Session 2, to demonstrate the budget planning function as supported by analytical techniques.

3) Session 3, to demonstrate the project monitoring function as supported by analytical techniques, including the cross referencing capability of the EPMS knowledge base.

A step by step summary of each of the sessions is provided in Table 2.

3.5.1) EPMS Control Panel

The purpose of the EPMS Control Panel is to provide a total multi-screen environment in a combination desk-top/pilots' console configuration from which the user can access any and all functions during an EPMS session. The control panel must also facilitate smooth-flowing user-machine dialogs. Use of the mouse/cursor is favored over the keyboard whenever feasible. Although the control panel is ultimately intended to be "tamper-proof", locking out all unauthorized access to the EPMS executive or resident software, the prototype version allows this access because of the developmental nature of the system.

The EPMS control panel is displayed in Figure 10. Some of the features were fully implemented in the prototype, others appear on the screen but are currently inactive (specifically the calendar, CVE screens and manual mode).

4.0) EPMS Prototype Evaluation

The purpose of this section is to document the results of the EPMS prototype evaluation sessions. Following a sequence of software IV & V (Initial Validation and Verification) tests, a series of expert evaluation sessions were conducted in which potential users were given the opportunity to run exemplary sessions and to provide reactions/comments on the overall system design and user interface. The comments were then used to create a composite summary of desired enhancements/improvements to be incorporated in EPMS Version 1.0, and to generate a list of 11 research questions mandating continued further exploration.

4.1) Expert Evaluation

This section describes the results of six separate knowledge collection sessions in which domain experts were given demonstrations and/or functional descriptions of EPMS: i.e., its goals, its conceptual design, and the types of sessions a user would encounter. The domain experts, in turn, each offered several types of feedback that are documented here including:

- 1) Evaluation of EPMS in terms of its goals, design and sessions. This feedback included suggestions for altering and improving EPMS.
- 2) "Deep Knowledge" was offered for EPM's knowledge banks. That is numerous ways for EPMS to utilize and/or "plug in" to existing handbooks, data bases, and other procedural aids was offered.
- 3) Heuristic Knowledge and rules of thumb used in project management were elaborated that could and should be incorporated into the EPMS knowledge base.

These three types of feedback--evaluation, deep knowledge, and heuristic knowledge are popularly thought to be collected in distinct sessions: a knowledge elicitation session with domain experts and an expert system evaluation session by potential users. While textbook descriptions of knowledge engineering invariably separate evaluation from elicitation, the fact is that both forms often are intermingled in any one interview session, particularly so during the conceptual

design period, as was the case here. A summary of the types of sessions and the experts participating in each is provided in Table 3.

4.1.1) Overview of 17 Experts' Comments

Table 4 provides a comprehensive summary of the major comments/suggestions received during the 6 sessions, and indicates whether the suggestion influenced the design of the prototype, the user sessions (interface), the planned version 1 system, or long-term enhancements. Not surprisingly, the three unanimous reactions favored: 1) the need for an environment to support and extend the human expert analogical reasoning process; 2) the need to structure domain-related knowledge in a 3-dimensional format that supports traversal across various functional characteristics and down various levels of granularity (progressive deepening); 3) the need to capture "lessons learned" and incorporate this knowledge in a manageable automated "Corporate Memory" structure, that could be called on to produce advice when a set of similar conditions are detected in real-time. It should also be noted that with the exception of the executive assistant concept arrived at in session #2, and the need for a separate AKB and PMKB from session #3, no other comments were unique to only one session. In fact, each session generated an average of about seven comments that were either actually incorporated in the prototype, or were entered as planned enhancements for either Version 1 or other long-term developments

4.2) Insights for an EPMS Generator

At the beginning of the EPMS prototype effort the investigators formulated 11 questions to be researched as stated in technical objectives of this report. The purpose of this section is to delineate the 11 research questions (see Table 5) and to discuss the answers arrived at during the course of the study. The first three answers indicate that there is a strong-felt need for analogical support; maintaining that support should not require much time or effort of the project team members, a dedicated assistant should be responsible for interfacing to EPMS (it may not be his only responsibility). The next two answers repeat the fact that there are an innumerable number of PM subsystems possible, most of which should be relegated to the longer term development period or to user development activity.

In terms of the Physical Model, answers to questions 6 through 8 were explored in describing the design of the Control Panel and sample user sessions and are summarized in Table 5, primarily in terms of utilities and packages needed to effect the desired results. These are not final answers but rather may be viewed as good starting points for future refinement. The answer to question 9 extends the scope of the utilities needed for effective user interrelation with EPMS. Finally the answer to question 10 points toward utility packages that help EPMS achieve flexibility and generality.

The very last question deals with what machine, environment and language to develop EPMS in. This is the same question numerous software vendors have yet to find the optimal answer to. The only solution seems to be to develop the product generically as possible on one machine and then gradually port it to other machines as time and funds permit.

5.0) Next Steps

Given the work done to date, the lessons learned, (partial) answers to the research questions, and the user interests and attitudes, a number of next steps are immediately obvious. These include:

- 1) Proceed With ARIEL Subsystem -- The ARIEL Subsystem should be flushed out as soon as possible and as originally designed and conceived. No user reactions indicated any concerns about ARIEL's design or heuristics. On the contrary, users

Table 4: Experts' Comments Summary

SESSION #						SUGGESTION	IMPACT					
							DESIGN			SESSION		
							Proto-Type	Version 1.0	Long-Term	Proto-Type	Version 1.0	Long-Term
1	2	3	4	5	6	Analogical Reasoning Extension to Support Stand-Alone EPMS		X				
X	X	X	X	X	X	Integration of EPMS to existing DBMS/MIS/DSB Resources				X		
X	X					2-Tier Management Support Structure	X					
	X					Executive Assistant Concept (Recall Figure 3B)		X				
	X	X		X		KB Generation Aid				X		
	X					AKB Separate from PMKB	X			X		
	X		X	X		Separate Planning and Monitoring Modes	X			X		
X	X	X	X	X	X	Progressive Deepening and Typology Strategy	X			X		
		X		X	X	Alarm Condition Propagation and Cross-Referencing	X			X		
X	X	X	X	X	X	Management of "Lessons Learned" Knowledge to Support Advice Generation				X		X
		X		X		Schedule/Calendar Module			X		X	
		X		X	X	Projection Algorithms				X		X
			X	X		Computer Visual Engineering	X			X		

Table 3. Expert Knowledge Collection/System Evaluation Sessions Summary

SESSION #	EXPERT #	RANK/TITLE	ORGANIZATION	SESSION TYPE			
				KNOWLEDGE ELICITATION		SYSTEM & USER LIFE EVALUATION	
				CONCEPT WORKSHOP	DESIGN BRIEFING	SESSION BRIEFING	SESSION DEMO
1	1	Division Manager	Godard Space Flight Center (GSFC)		X	X	
2	2,3	Technical Manager	Jet Propulsion Laboratory (JPL)		X	X	
3	4-6	Project Manager	(JPL)	X			
4	7	Project Manager	Department of Energy (DOE)	X			
5	8-12	Deputy Under Secretary's Staff	Department of Defense (DUSD&E)		X		X
6	13	Lieutenant Colonel, US Army	Chief of Staff, US Army		X		X
	14	Procurement Officer	US Army		X		X
	15	Professor	University of Oregon		X		X
	16	Major, US Air Force	Defense Systems Management College		X		X
	17	Captain, US Navy	Defense Systems Management College		X		X

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TABLE 5: EPMS Research Questions

Answers

Logical Model

- (1) Q. Is analogy truly important to project managers and if so what is its most important purpose? Is there a hierarchy of purposes and uses?
- (2) Q. Given the rapid pace of most projects and the already heavy staff workloads, how should analogy information be collected for use in EPMS?
- (3) Q. Given that a project is a team of people should there be a single principal user of EPMS or should EPMS simultaneously support a number of members of the team?
- (4) Q. How exactly will these different users utilize EPMS? The analogical information? What types of sessions will they want to have?
- (5) Q. Analogical reasoning is only one technique of project personnel. Which closely related techniques should be directly incorporated into EPMS vs. which should be relegated to user integration efforts?

Physical Model

- (6) Q. A great many heuristics (i.e., computerized functions) appear necessary so that non-programmers can effectively retrieve and manipulate analogy and project data. Which of these are most important? In what order should they be developed?
- (7) Q. Man machine interfaces can make a large difference in the success of a software package. How should the user interface be designed? What parts of the EPMS should the user see on the screen and how should user access be effected?
- (8) Q. Along the same lines, how should the user interface be designed from a knowledge representation and display perspective?
- (9) Q. What is needed to assist nonprogrammers in customizing EPMS to their site? What can be expected to be generic vs. what is site specific in the knowledge bases and ARIEL subsystems? What customizing/extending utilities are needed and in what order should they be developed?
- (10) Q. What degree of effort needs to be expended to develop the project A. management subsystem? Will users generally have their own stand alone aids that they want to connect EPMS to or will they want EPMS to provide this capability? What is the essential kernel of this subsystem that many types of potential users will find most effective? What customizing utilities will be needed to

Actual Computer Implementation

- (11) Q. Ideally, the EPMS generator should be readily available to users who own a variety of vendor workstations and computers. Given that the prototype is being developed on a Ierax LISP machine is it reasonable to make maximum use of COMMON LISP and of IBM PC interfacing software or is some other language and environment (e.g., C on the SUN) more nearly optimal?

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want lots of simple heuristics, progressive deepening, typology and level selection, etc.

2) Flush Out Manual and Interrogator Mode Utilities -- These utilities have been defined and should now be built to permit users to both inspect all aspects of ARIEL reasoning chains and to permit advanced users to manually reason by analogy on the KB elements.

3) Develop Customizing Utilities -- Requirements for generality and flexibility can be satisfied with the development of numerous, relatively small utilities. Each utility can perform a single adaptation function (e.g., support individual analog feature generation tasks) that permits EPMS to be molded to the user's specific PM subsystem needs.

4) Select Field Test Site(s) -- Until users begin to actually try and apply EPMS to their site and to use it on a regular basis, there will be no way to accurately evaluate its man machine interface. For that purpose, one or more test sites should be selected as soon as possible and EPMS should be installed and adapted to their problem(s). It is most desirable to select a test site that either already has an existing stand alone PM subsystem or that does not want a very strong PM subsystem capability. These sites would provide useful MMI insights with a minimum of tangential PM subsystem development activity. A longer term goal will be to select sites with needs for greater PM subsystem help so as to focus in more clearly on what the customizing utilities and kernel elements should entail.

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