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ARTIFICIAL INTELLIGENCE (AI), OPERATIONS RESEARCH (OR),
AND DECISION SUPPORT SYSTEMS (DSS): A CONCEPTUAL FRAMEWORK

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ABSTRACT

In recent years there has been increasing interest in applying the computer-based problem-solving techniques of Artificial Intelligence (AI), Operations Research (OR), and Decision Support Systems (DSS) to analyze extremely complex problems. The purpose of this paper is to develop a conceptual framework for successfully integrating these three techniques. First, the fields of AI, OR, and DSS are defined and the relationships among the three fields are explored. Next, a comprehensive adaptive design methodology for AI and OR modeling within the context of a DSS is described. The paper concludes with four major observations: (1) The solution of extremely complex knowledge problems with ill-defined, changing requirements can benefit greatly from the use of the adaptive design process, (2) the field of DSS provides the focus on the decision making process essential for tailoring solutions to these complex problems, (3) the characteristics of AI, OR, and DSS tools appears to be converging rapidly, (4) there is a growing need for an interdisciplinary AI/OR/DSS education.

INTRODUCTION

In recent years there has been increasing interest in applying the computer-based problem-solving techniques of Artificial Intelligence (AI), Operations Research (OR), and Decision Support Systems (DSS) to analyze extremely complex problems. The purpose of this paper is to develop a conceptual framework for successfully integrating these three techniques. First, the fields of AI, OR, and DSS are defined and the relationships among the three fields are explored. Next, a comprehensive adaptive design methodology for AI and OR modeling

within the context of a DSS is described. Finally, the paper presents four major observations about the use of AI, OR, and DSS techniques to analyze the increasingly complex problems of the future.

AI, OR, AND DSS

This section briefly characterizes the fields of AI, OR, and DSS and examines their fundamental similarities and differences.

AI can be defined as "the study of ideas which enable computers to do things that make people seem intelligent." [1] AI means different things to different people. Natural language processing, robotics, and expert systems are the three major areas of AI. For the kinds of problems addressed in this paper expert systems (ES) are most applicable. An expert system is "an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution." [2]

Expert systems attempt to capture highly specialized human expertise in limited problem domains. Unlike conventional computer programs, ES separate the deduction mechanism (inference engine) from the knowledge base, which contains both the facts and rules. ES also provide a friendly user interface as well as the capability to explain their reasoning and recommendations. ES can be viewed as a special class of models which assist with a variety of tasks including interpretation, prediction, diagnosis, design, planning, monitoring, debugging, repair, instruction, and control. [3]

OR can be defined as "the application of the methods of science to complex

problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, overnment, and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurement of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls." [4]

Operations research analysts traditionally use a wide range of mathematical models to help solve problems including mathematical programming, stochastic, simulation, and network models. For large problems the analyst traditionally works with a model providing input to the model and analyzing the resulting output.

DSS can be viewed as a evolutionary advancement beyond Electronic Data Processing (EDP) and Management Information Systems (MIS). EDP focuses on the generation, storage, processing, and flow of data at the operational level within the organization. MIS places its emphasis on the information flow of middle management. The key idea behind DSSs is their focus on supporting the decision process. The DSS builder views a DSS as consisting of three major components--a data base, a model base and a dialogue component which integrates the other two components and the user.

COMPARISON OF COMPUTER-BASED PROBLEM SOLVING APPROACHES

This section compares the relationship of the various computer-based problem solving approaches with the decision maker (summarized in Figure 1).

	DECISION-MAKER'S RELATIONSHIP				
	VALUES	FOCUS	SYSTEM INTERFACE	HUMAN INTERFACE	DEVELOPMENT APPROACH
ELECTRONIC DATA PROCESSING (EDP)	Clear	Efficiency	Least	Programmer	Traditional
MANAGEMENT INFORMATION SYSTEMS (MIS)	Clear	Efficiency	- Information Summaries - Decision Queries	Systems	Traditional
OPERATIONS RESEARCH/ MANAGEMENT SCIENCE (OR/MS)	Credibly Model	Efficiency Insight	Summary Briefings	OR/MS Analyst	Modeling
DECISION SUPPORT SYSTEM (DSS)	Can Not Credibly Model	Effectiveness	Interactive - Information - Analysis Models	DSS Designer	Adaptive Design
EXPERT SYSTEM (ES)	Clear	Efficiency Effectiveness	Interactive - Recommendations - Explanations	Knowledge Engineer	Rapid Prototyping

Figure 1 Summary Comparison of Computer-based Problem Solving Approaches

Unlike the other approaches, DSS is usually applied to relatively unstructured or underspecified problems where it is not easy to directly model the values of the decision maker using an objective or value function. Instead, the decision maker's values are incorporated into the problem solution through the choices that the decision maker selects during operation of the

DSS. Therefore, in the early stages of a DSS evolution, the system will likely take on a strong data base orientation.

EDP and MIS focus on efficiency, that is, accomplishing a specific task, such as processing a financial transaction, with a minimum amount of resources. Efficiency is an input-output measure. OR has a dual focus--allocating scarce resources efficiently and providing insight to the decision maker. DSS and ES provide the decision maker with new capabilities. The novice can use an ES to extend his capabilities. Experience has shown that because of the flexibility of a DSS a user often discovers that he can solve problems that he had never considered before or that could not be solved using other solution techniques.

The newer DSS and ES technologies allow the decision maker to interact directly with the system rather than relying on intermediaries such as a programmer or an operations research analyst. Particularly noteworthy is the capability of ES to make recommendations as well as furnish the decision maker with logical explanations to support these recommendations. This unique capability increases the credibility of the solutions generated.

The development approach taken by DSS and ES is significantly different from those of EDP, MIS, and OR. Both the adaptive design and rapid prototyping approaches involve initially selecting a small but significant problem. The design, development, and test phases are compressed into a few weeks and performed iteratively for a few months until a relatively stable system has emerged. Experience has shown that user requirements constantly change and, in reality, the system continues evolving until its retirement. The DSS adaptive design approach assumes that there exists an organizational commitment to field the system whereas it is not unusual to develop a 'throwaway' ES to demonstrate the feasibility of an ES technology.

ADAPTIVE DESIGN METHODOLOGY FOR AI AND OR MODELING IN DSS

This section describes our adaptive design methodology for AI and OR modeling in DSS. As mentioned earlier, a DSS has three components: the models, the data, and the dialogue (i.e., man machine interface). The three components can best be thought of as the three legs of a stool. Like the stool, the DSS can not withstand an ineffective leg.

The interrelationships of the three DSS components are shown in Figure 2. The role of OR/MS in DSS is well understood; however, the AI aspects require additional explanation. First, AI emphasizes new types of data (i.e., knowledge) and offers new knowledge representation approaches, e.g., semantic nets, frames, scripts, and rules. Second, AI offers new type of models, e.g., the cognitive models of human thought operationalized in an inference engine, for reasoning with the knowledge representation schemes. Third, AI shells and programming environments provide models for knowledge representation and MMI facilities.

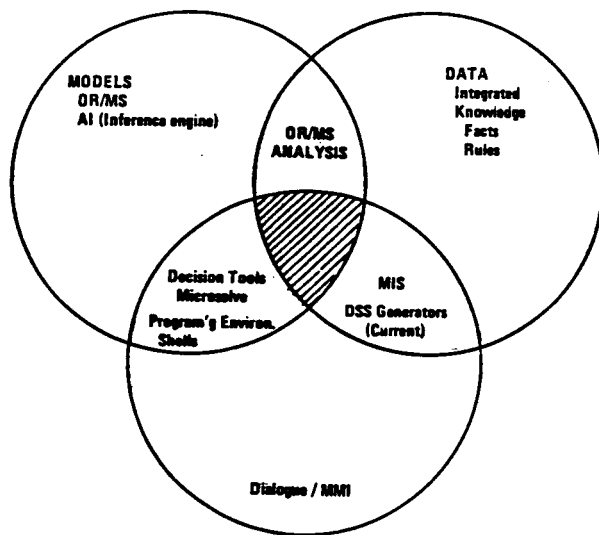


Figure 2. Decision Support System Components

Not all problems require a computer-based DSS using AI and OR techniques. Our experience has shown that the types of problem domains that require our approach (the cross-hatched area in the center of Figure 2) are complex, dynamic problem domains where specialized (procedural or heuristic) knowledge significantly improves the quality of recurring decisions. In these domains there may be many decision-makers.

The steps in our adaptive design methodology are summarized in Figure 3. These concepts have been developed and used by over 15 of our thesis students at AFIT over the past two years. We will focus on the first five steps,

since these are unique to our approach. It is important to understand that our methodology is highly iterative; the results of any step may require redoing portions of one or more of the previous steps.

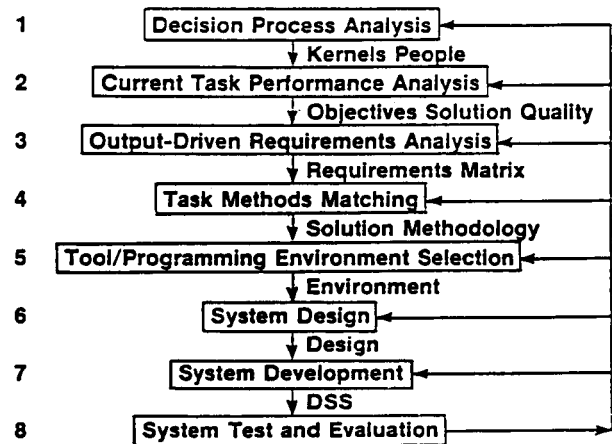


Figure 3. Adaptive Design Methodology for AI and OR Modeling in DSS

The first step in the process is the analysis of the decision process. This step is the most crucial in the entire methodology; fundamental errors in understanding of the decision process can easily result in solving the wrong problem. The most useful concepts have come from the DSS literature.

The major objective of the decision process analysis step is the identification of the kernel problems. We recommend focusing on the user's perspective and performing a technologically-unconstrained analysis of the decision process. A very useful technique is the concept map: a free-wheeling network, similar to a semantic net, that aids the analyst in capturing the major concepts and the cognitive processes of key decision-makers [5]. As an example, Figure 4 provides a concept map for determining the intent of an ICBM attack on the US [6]. Two additional components, the feature chart [7] and storyboarding [8], have also been used to capture the user's requirements using state-of-the-art graphics packages. This step concludes with the selection of the kernel problems in the decision process. The five kernels identified in Figure 4 are diplomatic, political, indications & warning, military, and economic.

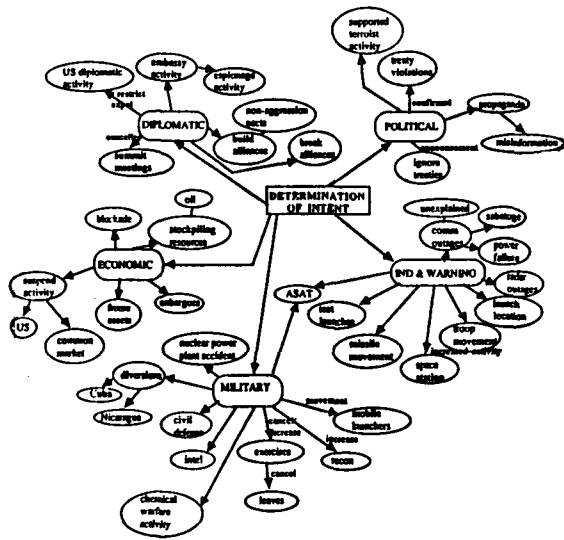


Figure 4. Concept Map

The second step in the methodology is the analysis of the current task performance for each of the kernel problems. We focus on the individuals involved, the objectives of each individual, and the desired quality of the solution. Figure 5 displays a matrix framework we have found useful. Tasks requiring an optimal solution suggest an OR model. Tasks where specialized knowledge is useful and a satisfactory solution is acceptable are candidates for AI techniques. Unstructured tasks with dynamic objectives are candidates for conventional data base query techniques. Finally, tasks with no feasible solutions are candidates for an OR analysis.

MAJOR TASK	EXPERT(S)		USER		MANAGER(S)		SENIOR DECISION MAKER	
	MIN COST		MIN COST		UNSPECIFIED		MIN COST	
TASK 1	S		F					
TASK 2	F		NF					
TASK 3					S			O
TASK 4								NF

- O: optimal solution
- S: satisfactory solution ⇒ specialized knowledge ⇒ AI
- F: feasible solution ⇒ DSS candidate
- NF: no feasible solution ⇒ OR analysis candidate

Figure 5. STEP 2: Current Task Performance Analysis

The third step in our adaptive design methodology is an output driven requirements analysis. The development of information systems requirements has been a major problem for MIS and DSS designers [9]. Users are unable to initially specify a complete set of the system requirements. Knowledge engineering focuses on capturing the knowledge of the experts but does not offer fundamentally new techniques for capturing system requirements. Like DSS, knowledge engineering makes extensive use of prototype knowledge systems to demonstrate the usefulness of AI in a problem domain. Our adaptive design approach synergistically combines AI and DSS concepts to use prototyping to capture the critical system requirements and provide a framework for the management of the adaptive design effort by focusing the prototype designer's efforts on the system requirements of the operational DSS.

Figure 6 provides our framework for recording DSS system requirements. This framework is used throughout the adaptive design effort. The current method column comes from the previous step. The second column identifies the requirements that the current prototype can successfully accomplish. The third column is only used when the goal of the design effort is to develop a prototype to establish the feasibility of an operational DSS. The fourth column identifies the desired requirements for an operational system. For the reasons discussed above, all four columns are iteratively developed during the adaptive design process.

	Current Method(s)	Prototype Status	Prototype Goal	Operational System
OUTPUTS				
Displays				
Graphics				
Knowledge				
Data Models				
ACTIONS				
Recommendations				
Explanations				
PROCESSES				
Tasks				
INPUTS				
Static Inputs				
- DB				
- KB				
Dynamic Inputs				

Figure 6. STEP 3: Desired Output Driven Requirements Analysis

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The left hand side of the matrix in Figure 6 identifies the types of knowledge or data the user would like displayed. We have found it useful to use storyboards to capture the users output requirements for each task. Many times we want our AI models to provide recommendations and explanations based on specialized knowledge in the DSS. The processes are the tasks analyzed in the previous step. In order for the processes to result in the desired outputs, static and dynamic inputs are required. The static inputs are the data and knowledge resident in the DSS. The dynamic inputs are provided interactively by the user or automatically by interfacing systems while the DSS is in use. Several AFIT thesis have successfully used this framework [10,11].

Step 4 in our methodology is the task/methods matching. Figure 7 provides an example of adaptive design step for a three task scheduling problem. Seven possible solution methodologies (paths) are identified. Three are pure paths: path 1 is knowledge engineering, path 3 is OR, and path 6 is data base browsing. The other four are mixed methodologies.

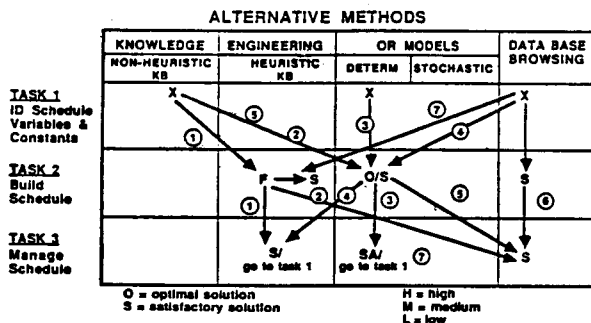


Figure 7. STEP 4: Task/Methods Matching

Step 5 is the analysis of the prototype tool/programming environments. Figure 8 provides a conceptual example for path 4 of the problem described in the previous paragraph. Three alternative approaches are identified. Again, each of these approaches can be evaluated against specific criteria and the selected approach can be implemented by the DSS designer. Two important trends are worth noting in this step. First, many AI tools increasingly allow the programmer to interface with database programs and conventional languages. Second, many conventional hardware and software vendors are seeking ways to incorporate AI programs.

TASK METHOD		TOOLS/ENVIRONMENT DESIGN				
		DSS GENERATORS	AI PROG. ENVIR.	AI TOOLS	OR PACKAGES	CONV LANGUAGE
1	4	DB	A	DB	B	
2	4				GP	FORTRAN
3	4			RULES IE		

* EE TOOLS ARE INCORPORATING DATABASES & IMPROVED MAN TOOL/ENVIRONMENT TRADE-OFF

PERFORMANCES	A	B
	Current Requirements Future Modifications	
Cost		
Schedule		
Availability Risk		

Figure 8. STEP 5: Prototype Tool/Programming Environment Selection

Once these steps are completed Step 6 (system design) and Step 7 (system development) proceed as in the normal development of a conventional DSS. If AI techniques have been used, Step 8 (system test and evaluation) may require AI test and evaluation techniques, e.g., the cases method.

OBSERVATIONS

Finally, we make four observations about the use of AI, OR and DSS techniques to analyze complex decision problems. First, most complex, dynamic problem domains require the adaptive design process to capture the system requirements and demonstrate the usefulness of a computer-based decision aid. Second, DSS provides the most useful techniques for the crucial decision process analysis step in our adaptive design process. Third, AI/OR/DSS tools appear to be converging. Finally, the effective use of the adaptive design process described requires an interdisciplinary education in AI, OR, and DSS.

SUMMARY

This paper developed a conceptual framework for integrating AI, OR, and DSS techniques. First, the fields of AI, OR, and DSS were defined and compared. Next, a comprehensive adaptive design methodology for AI and OR modeling within the context of a DSS was described. Finally, the paper presented four major observations about the use of AI, OR, and DSS techniques to analyze the increasingly complex problems of the future.

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