Offshore Engineering Applications Potential for Knowledge-Based Expert Systems

by

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ABSTRACT

Computer application using expert systems has recently become of interest to researchers in many fields of science and engineering. Discussed in this report are current uses, collected through literature research and interviews with individuals using this technology. Also, viable alternatives for future engineering applications are reported.

By generalizing the characteristics of engineering problems, application techniques for expert systems were developed contrasting those currently considered by the computer science community. A variety of "front-end expert advisors are suggested to enhance existing traditional computer programs in engineering. The creation of these hybrid programs hopes to create a "better" engineering computer program. Some problems with expert system tools and development methods are also discussed.

* Reference style according to American Society of Civil Engineers

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DEDICATION

To my father who was originally and continues to be my inspiration for this work.

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1.0 INTRODUCTION

Contemporary expert system technology developed as a result of artificial intelligence (AI) research. Although considered a modern concept, the origins of the basic framework of AI can be traced back beyond the invention of electronic devices to the early philosophers and mathematicians who were captivated by the workings of the human brain. The modern day development of AI perhaps began sometime around the 1930's and 1940's when Alan Turing postulated his theoretical abstract of the universal "Turing" machine. He believed, that given enough time, this computer could solve any problem that could be solved by a human being. By the 1940's, electro-mechanical computers had been developed and at the same time research into the workings of the human brain was taking place. Discoveries about neurological networks in the brain led to research into constructing electronic networks that could mimic the brain. As the complexity of the brain's neurology was discovered, this idea was abandoned.

It was not until 1956 with the development of the first symbolic computer language, IPL by Newell and Simon (CMU) and the coining of the term "Artificial Intelligence" by John McCarthy (Dartmouth), that AI really began to take hold. 1956 was also the year of the "Dartmouth Conference", organized by McCarthy and his friend Marvin Minsky (MIT). McCarthy proposed that,

> "a two month, ten man study of artificial intelligence be carried out during the summer of 1956 at Dartmouth College in Hanover, New Hampshire. The study is to proceed on the basis of conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it."(Charniak, 1985)

Using IPL as a basis, McCarthy developed LISP (List Processing) Language. LISP, by its symbolic, not numeric, nature, allowed researchers to delve into simulating human cognitive abilities. Herein lies the power of AI. While traditional computers solve problems using logical, sequential, repetitive computations, symbolic processing and AI try to imitate human thought procedures by collecting large stores of information, arranging them into categories and using them to make analogies and generalizations. "To make computers more useful . . . and to understand the principles that make intelligence possible," are the goals proposed by Winston (1984) that serve to identify the thrust of virtually all artificial intelligence research that is taking place today.

Contemporary research in artificial intelligence techniques can be grouped into basically four categories: natural language processing, computer vision, general problem solving, and expert systems. Expert systems is perhaps the most successful offspring of the AI technology. It is considered to have widely commercial applications potential. In recent years, expert systems have become a topic of interest to Civil and Ocean Engineers in academia and industry. Particularly at Carnegie Mellon University and Massachusetts Institute of Technology, large research programs have been implemented to determine the effective use of expert systems for problems in Civil Engineering. The potential of expert systems technology and its application to problems in Ocean and Civil Engineering constitutes the main thrust of this report.

2.0 LITERATURE REVIEW

2.1 An Overview of Expert Systems

Since expert systems is a relatively new topic to most people, it is appropriate to include a short introduction for them. Expert systems grew out of the fervor to formulate commercially useful applications from artificial intelligence techniques. Early systems developed from attempts to draw and store inferences from information. The earliest expert systems, which incidentally are still being used today, were MACSYMA, for analytical solution of mathematical problems, and DENDRAL, for identifying molecular structure from mass spectrograms. Since the success of these early programs, numerous other systems have been built with application areas as diverse as Computer Configuration (R1) and Medicine (MYCIN).

By definition, an expert system is " a computer program, based on artificial intelligence techniques, designed to reach the level of performance of a human expert in some specialized problem solving domain" (Hendrickson, 1985). While they both use symbolic representation, symbolic inference, and heuristic search, expert systems differ from other artificial intelligence problem-solving programs in several respects. First, they solve difficult, ill-structured problems to the level of performance of an expert. Second they are very domain specific in their problem-solving strategies. Third, they are able to provide reasoning for their conclusions reached and give a degree of certainty for their answers.

An expert system can typically be described as containing four components: a knowledge base, an inference engine, a working memory, and a user interface. Considered to be the strength of the expert system, the knowledge base contains the domain specific information necessary to solve the problem. This information consists of facts which are pertinent to the solution of the problem, and heuristics or "rules of thumb" which are identified by the domain expert. According to Waterman (1986), "The accumulation and codification of knowledge is one of the most important aspects of expert systems." The inference engine or control structure is employed as the administrator of the problem solution. It is responsible for organizing and controlling the steps taken to solve the problem. Several control strategies exist and are chosen according to the characteristics of your problem. The global database or context as it is sometimes called, is responsible for keeping track of the status of the problem solution during the program's execution. It acts like a bulletin board where the user can enter facts and the system posts the progress of the solution. Although not considered an essential part of an expert system, the user interface can allow easier system implementation and utilization. Suggested user interface components include an explanation module, that informs the user of the line of reasoning for a particular solution strategy, a knowledge acquisition module, that would allow the expert to input his expertise without the aid of a "knowledge" engineer , and a variety of graphics and natural language capabilities to provide a more user "friendly" environment.

2.2 Current Expert System Applications in Engineering

Presented here are selected examples of projects that have been successful in implementing expert systems. This provides only a sampling of the systems developed for Ocean and Civil Engineering. There exists many more documented examples in open literature, with undoubtedly more in proprietary and classified literature.

2.2.1 Expert Systems in Civil Engineering Education

Educators have always dreamed of making teaching and the learning experience more automated. Computers have been used for many years in teaching. Software has been developed to drill students on the solution of problems. Although practicing solving problems is useful, this software is not capable of pointing out the error in a student's method. Athena CATS (Computer-Aided Teaching of Structures) is a program being developed that will attempt to correct this inadequacy.

Using a large grant from initially supported by IBM and Digital Corporation, Professor John Slater and others in the Civil Engineering Department at MIT have targeted the areas of Statics, Structural Analysis, and Solid Mechanics for applying this research. The aim of the CATS system is to help students understand fundamental concepts and methods, develop an intuition for the subject's behavior, and learn the problem-solving strategy. The programs being developed utilize expert systems technology to accomplish this. Athena CATS seeks to fulfill three main objectives: creating an advisor, a tutor, and an integrated structural design and analysis package.

The advisor program is simply called Program Expert. It is a rule-based system which employs a tree-searching inference engine to drive the problem execution. Its purpose is simply to act as a consultant for structural problems.

Program FatCat, perhaps the most successful of the three, performs as a tutor. It can operate in three teaching modes: (1) the computer generates and solves problems, (2) the student generates and the computer solves the problems, and (3) the student solves problems while the computer coaches. The structure of the tutor contains five distinct modules: the example problem generator, a beam grader which checks solutions, a beam expert which demonstrates the solution, a beam tutor which explains a student's errors, and a calculator which is simply part of the computer's toolkit. This program is currently being tested and evaluated for its teaching effectiveness.

Program Growl Tiger has been developed to provide integrated capabilities for structural engineering analysis and design. The program is designed to enable analysis of 3-D structures, graphical display of deformation and moments, and design of components.

Although these programs may not replace conventional teaching methods, they have the potential to perform a valuable service. Students with problems in areas where these systems are available will have a patient tutor always ready to help them. Depending on the effectiveness of these programs, a student's efficiency can be greatly enhanced.

2.2.2 Expert Systems for Underwater Robots

As man ventures deeper into the sea, human risk in the activities performed there becomes more apparent. It is therefore reasonable that robotic systems would be developed to replace man in this high risk environment. Research is currently underway to identify the role of expert systems in extending the use of unmanned submersibles and robotics in the ocean. Both commercial and military interests are pursuing expanded use of marine robotics.

The Naval Ocean Systems Center (NOSC) in San Diego is the leader in underwater robotic research for military uses. Scott Harmon (Liebholz, 1983) of NOSC describes three types of submersibles that are being developed for implementation within the next ten years. Named for the type of task they will perform, they are the octupus, crab, and shark. The octupus will be a multi-armed manipulator primarily designed for inspection, repair, and retrieval. The crab's functions lie mainly on the sea floor where it will be responsible for construction and repair of sea floor structures. The shark is a mid-water high speed submersible which will have surveying, mapping, search and surveillance capabilities. All of these vehicles are being designed as autonomous robot submersibles and an aggressive program in expert systems research is being undertaken in order to accomplish this.

Commercial systems are being developed by several universities and private firms. Areas of interest range from mineral and raw material mining to robots for scientific exploration and research. Submersibles of this type could become replacements for the manned deep sea research submarines which are very risky and expensive to operate. Perceptronics, Incorporated is involved in the development of an intelligent interface for remote supervision and control of underwater manipulation. A prototype system, TOSC (Task-Oriented Supervision System) has been developed that acts as a "link between AI and a mechanical underwater manipulator" (Madni, 1983). Built as a procedural network supervisory system, TOSC has been tested under a variety of conditions and has been proven to enhance performance and reduce errors especially for complex manipulation tasks.

The Marine Systems Engineering Laboratory at the University of New Hampshire is currently researching the development of an expert system that performs as an expert pilot for an autonomous vehicle. The system being developed would have a parallel architecture where under normal operation, programmed algorithmic instructions act as the real time autopilot. At the same time the expert pilot monitors the vehicles operation taking control when decision-making is necessary, always keeping in mind the mission and final goal of the vehicle.

2.2.3 Expert Systems in Structural Design

Carnegie Mellon University (CMU) has been particularly ambitious towards using expert systems in Civil Engineering. Dr. Mary Lou Maher has been working on the application of artificial intelligence to engineering and architecture for several years now. Of special interest to her has been the use of expert systems in structural design.

The nature of problem-solving spans a range of problems from those which are derivation in nature to those of formation where smaller pieces are assembled. In engineering design, primarily a formation process, the techniques are available, yet good computer tools to aid in the design are not. Dr. Maher describes three major steps in structural design and points out where expert systems may be valuable. The first phase is preliminary design. The tasks of an expert system for this stage would include, recognizing structurally feasible systems, determining applicable constraints, and the interative process of approximating design parameters, checking the constraints and redesigning. Next comes an analysis phase where physical systems are converted to mathematical and computer models. Finite element programs are an example of a computer model that could be used here. However, it can take up to two years to learn to use models such as these effectively. She proposes using expert systems to more freely automate these exisiting programs. Finally comes the detailed design where expert systems could be used to locate and evaluate the many constraints mandated by design specifications or by the contracting firm itself.

Researchers at Carnegie Mellon have developed a series of programs that provide information for detailed structural analysis of a building. Named HIRISE and LOWRISE, for the types of buildings they are to work with, they require a 3-D grid of the space configurations for input. Another program, FLODER has been developed that generates the 3-D space configuration grid from architect's plans. It also has the capability of modifying architectural constraints in order to produce a better structure. Plans for the future include the development of an integrated structural design system. The program named DESTINY will contain levels of knowledge including a general strategy level, a specialist level that would use programs such as HIRISE and LOWRISE, and a resource level. Problems encountered in its development lie mainly with the formalization of expertise.

3.0 DISCUSSION OF RESEARCH

3.1 Engineering Problems in General

3.1.1 Introduction to the Field of Engineering

The formal definition for engineering according to the Accredidation Board for Engineering and Technology is,

> "The profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgement to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind."(Duderstadt, 1982)

Although not as formal, the most useful definition of an engineer is simply as a problem solver. Engineering is a challenging profession that combines science and creativity to solve the complex problems of the modern world.

As species were forced to adapt in order to survive the human species was given an intellect that allowed him to adapt the environment to his needs. In early times, engineering evolved alongside medicine and teaching. This early form of engineering however was different from what we recognize as modern day engineering. Early engineers designed bridges, ships, aqueducts and other massive projects, yet did this without knowledge of the scientific principles which govern these designs. Their designs were based on a common sense know-how coupled with experience and creativity. An engineer's training consisted of a period of aprenticeship where a novice accumulated experience under the guidance of an expert.

Engineering remained essentially in this form until after the invention of the steam engine. Only within the last century-and-a-half has science accumulated the vast wealth of information that embodies man's understanding of physical principles. Engineers recognized early on the advantages that could be gained by use of this knowledge in their design procedure. It was by this acknowledgement of scientific principles that classical engineering evolved into its modern form. These two quotes perhaps describe best modern engineering and its relationship to science.

"They do what they must; use science when applicable, intuition when useful, and trial and error when necessary." Charles L. Best (Krick, 1965)

"Scientists explore what is and engineers create what has never been." Theodore Von Karman (Krick, 1965)

3.1.2 Engineering Problem-Solving

From the point of view of engineering problems in general, a characteristic procedure can be defined that consists of several well-defined aspects. They can be listed as,

Problem Statement

Problem Analysis

Solution Technique Search

Development of Solution

Evolution

The problem statement begins with the recognition of a problem that needs to be addressed. Originally it is stated in either verbal or mathematical terms. At this point it is the responsibility of the engineer to decide specifically what the problem is and to restate it in those terms. The analysis phase is where the problem is defined in detail. The input and output variables must be determined as well as the variables leading to the solution, boundary conditions, and other criteria which might be important. Next the different techniques that are available for use in solving the problem are investigated. This involves both investigation of previous solutions and of those that might have occurred along the way. Often, genuine restrictions of the problems, an individual's own limited knowledge, and fictitious restrictions that unintentionally cause possible solution strategies to be rules out, narrows the available solutions. Finally comes the development of the solution. This is primarily a decision-making process where the solution strategy to be used, is determined from those enumerated in the previous phase. The evolution stage consists of specification of the problem solution. This will oftentimes, in modern engineering, involve the creation and documentation of a traditional computer solution. By traditional it is meant programs which, unlike those in artificial intelligence, are largely numeric in nature. Here also, modification and generalization of the solution techniques may occur.

Computers have been in common use by engineers for several decades now. It is unfortunate to note that their power is only utilized in the final stages of engineering problem-solving. The addition of expert systems to each of these different aspects could greatly enhance the engineering design process.

Perhaps more basic to engineering than those phases of problem solving listed above are engineering assumptions. Rarely will an engineer solve a problem in its most complicated form. Rather, the problem is reduced to a more simplified form where it can be easily handled by computational methods and available theories.

Assumptions can be thought of as being implicit and explicit. By stating that a cable can be thought of as a flexible structural member some of the problem characteristics are implied. It is implicitly assumed from this that the cable element has only strength in tension. Explicit assumptions are those that are stated expressly, such as the material weight of a cable is considered uniform over the length of the cable. Besides these assumptions, numerical techniques used involve approximations. Moreover, the accuracy (ie. truncation error) of coding used in developing computer models can result in superficial numerical results

3.2 A Sample Problem

It was apparent from the literature research that the best way to learn about expert systems was to attempt to build our own. In order to apply this technology, it was important to determine what characteristics a good candidate problem for expert system application possessed. This, however, was very difficult to ascertain since the literature review had uncovered numerous applications that spanned the entire spectrum of problem-solving. According to Waterman (1986), who writes in a popular guide on expert systems, you should "consider expert systems only if expert system development is possible. justified, and appropriate." These guidelines are somewhat nebulous and the text, whose purpose was to clarify this statement, did not provide much enlightenment for narrowing down possible choices for choosing a sample problem.

This perhaps was not the proper way to determine the engineering potential for expert system applications after all. It is possibly more constructive to choose a characteristic engineering problem and attempt to build an expert system to solve it. The problem chosen is one that has interested the Navy for many years. As illustrated in Figure 3.1 it involves determining the configuration of a long, flexible, structural member being towed by a vessel in a uniform stream. The configuration of the member is governed by the following differential equations.

$$\frac{dT}{ds} - w\sin\phi + f_\tau = 0 \qquad \frac{dx}{ds} = \cos\phi$$

$$\frac{Td\phi}{ds} - w\cos\phi + f_n = 0 \qquad \frac{dy}{ds} = \sin\phi$$

The problem is to position the end of the drillstring, point A, over a target on the seafloor, point B. The relative velocity acting on the cable, produces forces which are both normal and tangential to the cable.

The solution of this problem dates back to the 60's when tables

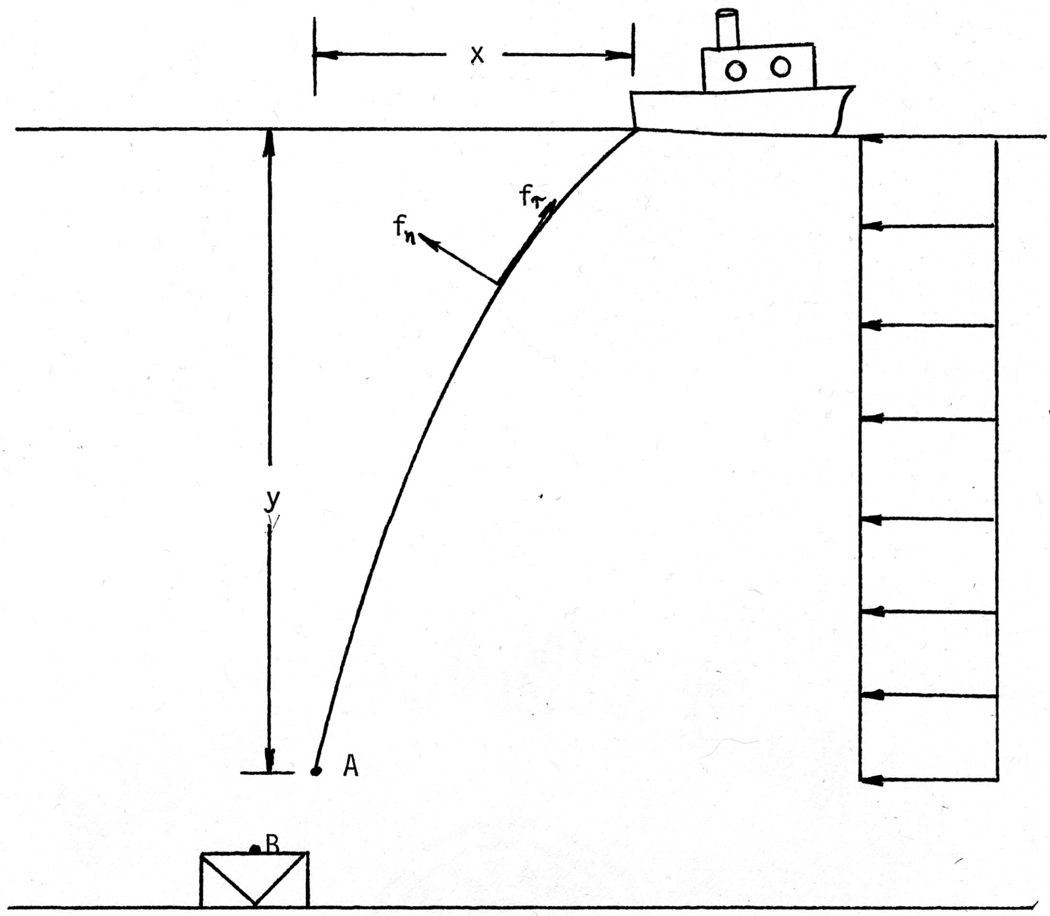

Fig. 3.1 Illustration of Sample Problem

were developed to determine the horizontal and vertical coordinates of cables at points along its length. Eventually, a program written in Fortran was developed at David W. Taylor Naval Ship Research and Development Center. Most recently, the program was updated in a dissertation by Young-Il Choo while at Catholic University in 1970. Using these programs as a basis, a Fortran program was developed. It was the goal of the research to create an expert system that would extend the use of this conventional program to position the end of the cable over the target.

SUMMARY AND CONCLUSIONS

The complete development of an expert system was not possible due to delays in receiving both software and hardware. However, much of the preliminary work was accomplished along with the development of other important ideas. The criteria that distinguishes the engineering viewpoint on expert systems versus the computer science one was successfully developed. A FORTRAN program was written to act as a test program for mating expert systems with traditional engineering programs. Also, individuals in a variety of fields in industry and academia were contacted to determine general views on the potential of expert systems. In addition, an overview of existing languages and tools for building expert systems was completed.

While engineering problems appear to be ideally suited to expert systems, considering the experience and heuristics that are normally involved in solving these problems, they are also numerically intensive. Strong numeric capabilities are not available in currently exisiting expert system tools or artificial intelligence techniques.

This then leads to the question of which approach is best; a numeric or symbolic one? From an engineer's point of view they may argue for the numeric approach. After all, large libraries of FORTRAN programs currently exist that would be irreplaceable by expert systems. However, it is worthwhile to suggest a compromise where expert systems are devised that act as an assistant to a traditional program.

Returning again to our sample problem for an example, the FORTRAN program that exists for the solution of the cable configuration is limited by a number of implicit and explicit assumptions. The cable is described as a long, flexible, structural member and the approach taken to solve for the configuration of it takes the implicit assumptions made here into account. Although specifically created for cables, this program could be used for an entire category of problems described as long, flexible, structural members, with some reservations. Considering Fig. 3.2, illustrated here is how the use of this program, originally developed for cables, can be extended to drillstrings, risers, etc. For each subcategory, within the category of long, flexible, structural members, the program has a range of validity. An expert "assistant" could be devised to act as a "front-end" to the original program that would check the validity of the program for your particular problem.

Other ways expert assistants might be used is in entering data to a program or in explaining the execution of the program to a novice. In this way the level of understanding involved in using a program and the methods implied there can be greatly enhanced. Referring to Fig. 3.3, what is suggested is the creation of technology which utilizes

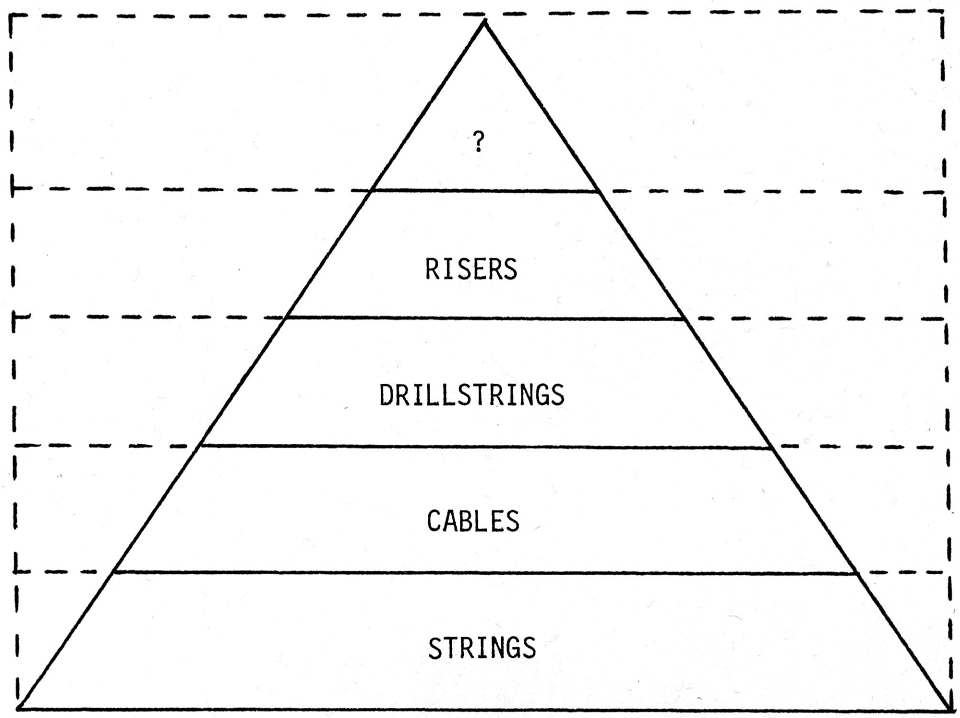

Fig. 3.2 Extending the use of Traditional Programs to a category of Problems

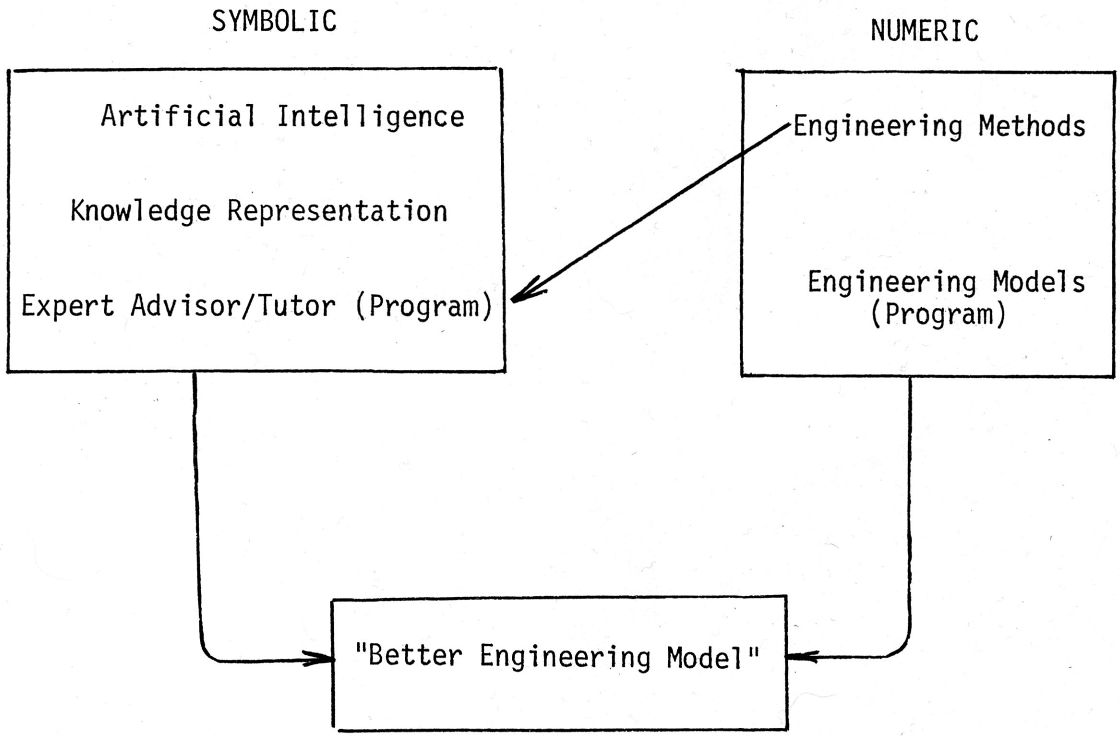

Fig. 3.3 Developing a Better Engineering Model

both symbolic and numeric programming to their respective advantages. From these ideas, perhaps it is viable to create a "better" engineering model.

In conclusion, there are a number of important issues that need to be addressed. First of all, at present, one of the most significant advantages to applying artificial intelligence techniques is the formalization of knowledge that must take place in order to do so. Never before have the fundamentals of these problem solutions been so heavily scrutinized and the solution procedures and alternatives so clearly identified. The little intricacies that previously were unknown about these problems have now been identified. The learning that can be accomplished from using one of these systems is likened to that which may be obtained from working with an expert in the field. Setting aside these exhuberant remarks, expert systems are however not a panacea. Actual "learning" by these systems has yet to be realized. Also, many problems exist with the languages and tools, software and hardware, available for building these systems. The popularity of expert systems in past years has led to a proliferance of expert system building software. It is difficult to ascertain which of these "tools" is appropriate for your needs. Many languages exist that may be used as well as many types of hardware. Each has its own advantages and disadvantages for its use.

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