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Methodology for Development of Expert Systems: Quality Assurance in Construction

by

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Within the U.S. Army Corps of Engineers (USACE) military construction program, a limited number of quality assurance (QA) personnel are responsible for a large and increasing work load involving many more complex practices than are found in traditional construction. To ensure the continued quality of military construction, several approaches are being considered, including automation. Expert systems technology in particular shows great promise in creating tools to assist quality assurance/quality control (QA/QC) personnel.

Developing expert systems for applications in facilities involves the task of diagnosing failures in existing facilities and equipment. However, developing expert systems for quality assurance in construction operations requires an approach different from that of failure diagnosis. By applying the concept of real-time process control to quality assurance in construction, a system can be developed that allows inspectors to obtain advice before, during, and after construction.

This report describes a methodology to develop expert systems for quality assurance in construction. This methodology was used to create a prototype expert system for quality assurance in construction.

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FOREWORD

This investigation was performed for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162731AT41, "Military Facilities Engineering Technology," Work Unit BO-042, "Advanced Technology Applications for Quality Assurance." HQUSACE Technical Monitors were Robert Chesi and Richard Carr, CEMP-CE.

This work was performed by the Engineering and Materials Division (EM) of the U.S. Army Construction Engineering Research Laboratory (USACERL). Dr. Robert Quattrone is Chief of USACERL-EM.

LTC E.J. Grabert, Jr. is Commander of USACERL and Dr. L. R. Shaffer is the Director.

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METHODOLOGY FOR DEVELOPMENT OF EXPERT SYSTEMS: QUALITY ASSURANCE IN CONSTRUCTION

1 INTRODUCTION

Background

The state of the economy has forced the construction industry to optimize its operations where possible. The U.S. Army Corps of Engineers (USACE) military construction program, too, is facing this challenge in that defense spending cuts are likely to continue. The economic situation is aggravated by advances in technology that have brought about increased construction rates and more complex construction practices. The impact of these conditions on military construction quality has been accentuated by a decline in the number of quality assurance (QA) staff. As a result, many emerging computer technologies that might enhance the capabilities and improve the productivity of QA personnel are being investigated.

One approach, the expert system, looks very promising because it allows ready access to the kinds of detailed information used by QA representatives. The knowledge base of an expert system contains both published information (specifications, etc.) and heuristic knowledge (e.g., rules of thumb for solving specific problems) supplied by an expert in the field. An expert system suitable for QA construction would allow user access in three modes: (1) during construction, to advise the QA representative concerning inspection procedures and to provide expert evaluation of given situations; (2) after inspection, to confirm the inspector's conclusion that a correction is necessary; and (3) at any time, to tutor the QA representative in inspection procedures and problem-solving techniques. To provide these modes of access the QA expert system must be usable as inspections are occurring during the construction process itself, providing real-time assistance for quality assurance procedures in construction operations.

Objective

The objective of this study was to develop a methodology for creating expert systems with real-time applications for quality assurance inspection of military construction.

Approach

The literature was surveyed to assess the current status of expert systems applications related to construction inspection. Expert systems used in manufacturing that feature real-time process and production control were also included. Next, applicable concepts were identified and used to develop a new methodology. Finally, the methodology was implemented in a prototype system for quality assurance in built-up roof construction.

Scope

This work is aimed at identifying a method of developing expert systems for use by construction QA representatives. A field evaluation of the prototype system will be conducted at a later date and is beyond

the scope of the report. This study is not intended as an introduction to expert systems, nor does it attempt to identify a methodology that will be a general solution for all construction applications.

Also note that many of the authors cited do not use the terms "quality assurance" and "quality control" according to the Corps of Engineers' standard definitions. Awareness of this fact should help the reader avoid misinterpretation.

Mode of Technology Transfer

Information in this report will be used in developing knowledge engineering tools and expert systems for use by QA personnel in military construction. When these expert systems have been completed and successfully tested, they will be transferred to the field through on-site training, tutorials, and hands-on experience. In addition, they may be transferred to industry through mechanisms such as Cooperative Research and Development Agreements.

2 EXPERT SYSTEMS

Technology

An expert system is a computer program that simulates an expert's thinking to solve a particular problem. It is based on the principles of artificial intelligence, and its reasoning processes are similar to normal human thinking. One of the leading researchers in the field, Edward Feigenbaum, has defined an expert system as:

...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. Knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field. The knowledge of an expert system consists of facts and heuristics. The "facts" constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The "heuristics" are mostly private, little-discussed rules of good judgment (rules of plausible reasoning, rules of good guessing) that characterize expert-level decision making in the field. The performance level of an expert system is primarily a function of the size and the quality of a knowledge base it possesses.¹

The quality of an expert system is reflected in its ability both to make proper decisions and to explain them sufficiently for the user.²

Expert systems are distinguished from other types of software by their structure and the way information is presented to the user. An expert system consists of a knowledge base, which contains encoded knowledge, and an inference engine, which uses the knowledge base in reasoning about a particular problem. Expert systems are different from traditional software for two reasons: the knowledge is separate from the inference mechanism, and expert systems are able to explain their reasoning.

Packages are available, referred to as "shell" systems, that provide the inference engine and allow the programmer to "plug in" a knowledge base for a particular application. These systems reduce the time required for system development, but they limit the programmer's flexibility and options. Shell systems are based largely on production rules, which take the form

IF (condition) THEN (action)

where the condition itself may be expanded to include logical conditions and implications. The IF (condition) THEN (action) statement is the primary rule of inference from which production rules are derived, and it is known as *modus ponens*.³

In addition to the inference engine, most shells have an editor function that allows easy modification and expansion of the knowledge base. The syntax for each shell is unique and may offer special features that allow optional types of control. Thus, the shell syntax allows the programmer some flexibility in

¹ Cited in P. Harmon and D. King, *Expert Systems* (John Wiley and Sons, 1985).

² E. H. Shortcliffe, *Computer Based Medical Consultations: MYCIN* (North-Holland, 1976).

³ B. G. Buchanan and R. D. Duda, *Principles of Rule-Based Expert Systems*, Stanford University Heuristic Programming Project Report No. HPP-82-14 (Stanford University, August 1982).

tailoring the system for the user. All shells offer the basic capability of representing rules, and second generation shells have increasingly improved their explanatory capabilities.

Applications

General applications for expert systems are listed below:

- Interpretation: inferring situation descriptions from sensor data
- Prediction: inferring likely consequences of given situations
- Design: configuring objects under constraints
- Planning: designing actions
- Monitoring: comparing observations to plan vulnerabilities
- Debugging: prescribing remedies for malfunctions
- Repair: executing a plan to administer a prescribed remedy
- Instruction: imparting specific information
- Control: interpreting, predicting, repairing, and monitoring system behaviors.⁴

The following are applications for expert systems in civil engineering and architecture:

- Welding
- Structural analysis
- Code checking
- Structural design and planning
- Geotechnical engineering
- Construction engineering
- Construction management
- Maintenance

⁴ F. Hayes-Roth and D. A. Waterman, *Building Expert Systems* (Addison-Wesley, 1983).

- Environmental engineering
- Transportation engineering.⁵

Several prototype expert systems have been developed, and many systems are currently under development in these areas. Examples of application prototypes in construction engineering are listed below:

- SOILCON (Soil Exploration Consultant)
- CRANES (Crane Resource and Evaluation System)
- SIGHTPLAN (Layout of Temporary Construction Facilities)
- RODEOS (Road Curve Design and Setting Out)
- Real-Time Optimization of Earthmoving Equipment.⁶

The literature search revealed no prototype or operational systems relating to quality assurance in construction engineering. However, quality assurance applications found in expert systems used for production process monitoring and control in manufacturing can also be used in construction. This is because construction operations are production processes, although they are much less structured than manufacturing production processes. Modern construction production processes are similar to factories of the past, where the tasks were largely unstructured and craft oriented.

Introducing expert systems to improve quality in the production process for both construction and manufacturing has great potential. According to Ballard:

The application of expert systems fits into quality management primarily because it is now widely accepted that maintaining quality in an organization is the responsibility of all employees and hence knowledge about quality needs to be easily and quickly accessible. Also, knowledge about quality often appears, on the surface, to be imprecise and is largely based on expertise built up from experience of operating a particular organization or manufacturing a particular product. These factors, and others, point to a vast range of possibilities for expert system applications in quality management.⁷

Expert systems in manufacturing are seen as a necessary step toward the intelligent factory of the future.⁸ One application is the "smart foreman," which embodies a wide range of knowledge including quality control.⁹ Other related systems in manufacturing, known as Knowledge Based Process

⁵ M. L. Maher, *Expert Systems for Civil Engineers: Technology and Application* (American Society of Civil Engineers, 1987).

⁶ M. L. Maher.

⁷ R. Ballard, "Prospects for Expert Systems in Quality Management," *CME* (January 1987).

⁸ D. Hughs and A. Smith, "Intelligent Systems for Intelligent Factories," in *Proceedings of the AI Europa Conference, Weisbaden, Germany* (TCM Expositions, Ltd., September 1986).

⁹ M. E. McDonald, "The Smart Foreman--Expert Systems for Manufacturing," in *Proceedings of the Society of Manufacturing Engineers: 1985 Autofact Conference* (Society of Manufacturing Engineers, 1985).

Management systems (KBPM),¹⁰ are applications of real-time problem solving in a manufacturing environment, situation assessment, real-time signal interpretation, autonomous vehicle control, provision of timely advice based on time varying data bases, and sensor interpretation and management.¹¹

One of the immediate factors making expert systems development and implementation economically feasible is the use of microcomputers. With the increased speed and power of microcomputers, the differences between microcomputer, minicomputer, and mainframe have become less distinct. In addition, the costs of processing power have steadily declined as microcomputers have become powerful and inexpensive. Many development environments are now available, and run-time systems are common on microcomputers.

¹⁰ M. R. Fehling, "Performance Requirements for Knowledge-Based Process Management Systems," in *Proceedings ISA-86* (Instrument Society of America, 1986).

¹¹ B. D. D'Ambrosio, "Knowledge-Based Process Management: The Road Ahead," in M. D. Oliff (Ed.), *Expert Systems and Intelligent Manufacturing* (North-Holland, 1988).

3 REAL-TIME MODELING FOR CONSTRUCTION INSPECTION

Process Analysis

Construction Process

A recent survey by the Building Research Establishment revealed that 50 percent of deficiencies in construction are caused by design errors, 40 percent are due to construction errors, and 10 percent are due to materials deficiencies.¹² All deficiencies identifiable during construction fall into these three categories. Corrections are directly related to the deficiency's category.

If a design deficiency is detected during construction by the QA representative, he or she notifies Corp designers or the resident engineer. A contractor is obliged to perform construction according to specifications unless obvious errors are present. A contractor can legally correct a design deficiency only after receiving a change order, and this process often involves major expense to the Army. Using an expert system to check for errors at the design stage should be cost effective--it should keep errors out of the contractual documents and prevent them from slipping through undetected until the more costly construction stage of the process.

When the QA representative detects construction errors or defective materials, they notify the contractor's QC representative, who initiates action to correct the condition. If the QA representative determines that the problem is not being corrected, it may be necessary to take more decisive action.

Implementing quality assurance in construction requires knowledge of inspection procedures and how to carry them out, knowledge of materials and construction processes, ability to recognize deficient conditions, and awareness of the actions necessary to correct the deficiencies.

Manufacturing Process

In manufacturing, product quality is monitored by inspecting the completed product and inspection during the process of production.¹³ In addition, monitoring of quality control procedures themselves, or quality assurance, can be used to monitor quality.

When completed products are inspected, the possible corrective actions involve several inadequacies:

1. Quality issues are solved when the product or service is already completed.
2. Quality is obtained at high cost and loss of productivity.
3. A "firefighting" approach to quality control is adopted, which results in short-term solutions to immediate problems at the expense of long-term improvement.¹⁴

¹² I. T. Clark, "The Introduction of Quality Assurance to the Building Services Industry," *Quality Assurance*, Vol 12, No. 1 (1986).

¹³ D. G. Hall and D. P. A. Martin, "Integrated Inspection and Assembly," *Quality Assurance*, Vol 13, No. 1 (1987).

¹⁴ R. D. Moen and T. W. Nolan, "Process Improvement--A Step-by-Step Approach to Analyzing and Improving a Process," *Quality Progress* (September 1987).

Higher quality can be obtained at lower costs through process improvement. One rule of thumb states, "Don't pass anything on to the next operation unless you know it's good."¹⁵ (This refers to inspection during production processes.) Process control, rather than final product inspection, has been identified as a critical element in quality manufacturing. "Time, materials and money can be saved by detecting and rejecting faults immediately, and with good design, comprehensive checks can be made after (and often during) every phase in the process."¹⁶ The basic principle is that "if the manufacturing process is understood and controlled, the product will come out all right."¹⁷ In the machine environment of the manufacturing facility, control is often accomplished by integrating intelligence directly into the machine controller, so decisions can be made according to sensed conditions in real time. With construction automation looking more promising in the future, integrated machine intelligence will play a major part in obtaining quality construction.

Modeling the Manufacturing Process

The first step in modeling real-time process control is identifying the manufacturing process and then dividing it into identifiable groups or subtasks.¹⁸ The subtasks are then divided into their constituent operations. The next step is to understand how the production process is organized, that is, "the set of operations together with their casual relationships that must be executed to reach the aim of the organization."¹⁹ The model of any process must contain the precedence information about basic operations and their conditions. "Process" can be defined as "a set of causes and conditions that repeatedly come together to transform inputs into outcomes. . . There can be several stages to the process, or each stage could be viewed as a process."²⁰

Modeling quality assurance in construction processes requires the same steps as modeling any manufacturing process. It involves identifying the subtasks that constitute (1) a specific construction operation and (2) the monitoring process, or procedures, necessary for quality assurance in construction.

¹⁵ R. D. Moen and T. W. Nolan.

¹⁶ R. D. Moen and T. W. Nolan.

¹⁷ J. R. Tunner, "Total Manufacturing Process Control--The High Road to Product Control," *Quality Progress* (October 1987).

¹⁸ R. L. Moore, "Expert Systems in Process Control: Applications Experience," in *Applications of Artificial Intelligence in Engineering Problems* (Springer-Verlag, 1986).

¹⁹ A. Dileva and A. Gidito, "Data Models and Process Models for Computer Integrated Manufacturing Systems," in *Applications of Artificial Intelligence in Engineering Problems* (Springer-Verlag, 1986).

²⁰ R. D. Moen and T. W. Nolan.

4 DEVELOPING A PROTOTYPE EXPERT SYSTEM FOR QUALITY ASSURANCE IN CONSTRUCTION

Knowledge Acquisition

The knowledge base for an expert system is constructed by a knowledge engineer, who obtains information about the domain and structures the information to be formatted into a knowledge base. The knowledge base must be syntactically correct according to the rules for a particular expert system shell.

Knowledge concerning a particular domain can be gathered in many different ways:

- Interviews
- Analogies
- Examples
- Observation, discovery, and experimentation
- Reasoning from deep structure
- Published information.²¹

At USACERL, different approaches to improve the efficiency of knowledge acquisition have been tried.²² Currently, the Metallurgy and Quality Assurance team is using a prototyping approach that has been quite successful in the development of other expert systems. This approach consists of searching published information for knowledge pertaining to the domain and prototyping an initial system without using heuristic information from experts. This is advantageous in several ways. First, in prototyping a system with "book" knowledge the engineer becomes familiar with the domain and thus competent to discuss the domain with experts. No time is wasted having the expert explain rudimentary domain knowledge to the knowledge engineer. Second, the prototype provides a mechanism which the expert can quickly (and quite willingly) criticize. The expert is better able to assess the logic and substance of a prototype expert system than to organize his or her expertise for a knowledge engineer who may have little domain knowledge.

This approach has reduced the time necessary for interviews, improved the exchange of information during interview and review sessions, and improved the overall efficiency of the knowledge engineer. USACERL is currently researching an Interactive Domain Model (IDM), a computer program that will allow an expert to build an abstract domain model of a physical system. The system queries the expert for domain information, which is used automatically to generate a knowledge base that the expert can inspect and modify as needed.

²¹ R. H. Michaelsen, D. Michie, and A. Boulanger, "The Technology of Expert Systems," *BYTE* (April 1985), pp 303-312.

²² R. Lange, "The Use of Knowledge Engineering Teams as a Method for the Development of Expert Systems," in *Applications of Artificial Intelligence in Engineering Problems* (Springer-Verlag, 1986).

Domain Modeling

A method of modeling and monitoring the construction process in real time, as discussed in chapter 3, was used. This allowed use of the system in three modes:

1. During actual construction, to advise the QA representative of inspection procedures and expected results to ensure that all possible deficiencies have been considered.
2. After inspections have been performed, to confirm the QA representative's conclusion or "gut feeling" that something is not correct.
3. At any time, to tutor the QA representative about inspection procedures and conditions.

A specific area of construction was needed as the domain of the prototype. Due to the many problems with built-up roofs in military construction, quality assurance in built-up roof construction was selected. A time sequence of the construction operations for built-up roof was used to model the construction process. This information was a result of both research and interviews with experts. The basic construction inspections involved in a built-up roof are shown in Figure 1.

The quality assurance inspections follow the construction operations sequence shown in Figure 1. This allows modular expert system development, that is, each module identifies a specific phase of construction and allows real-time inspection recommendations to occur during that phase.

Once built-up roof construction is divided into modules that allow real-time monitoring, construction of the knowledge base can begin.

Expert System Development

A manufacturing process modeling methodology was used to develop a prototype expert system for quality assurance in built-up roof construction. The prototype was developed in an IBM PC environment on the expert shell CRITIC,²³ which was developed at USACERL. CRITIC allows the use of production rules in either forward or backward chaining mode. It also allows graphic representation of decisions and explanatory information.

During conversion of information obtained during knowledge acquisition, it became evident that some explanations were difficult to understand using text alone. For this reason, CRITIC was modified so graphics could be presented to the user to explain a particular fact or technique. Thus, pictures from Army technical manuals could be included in the expert system to improve communication.

A prototype was developed incorporating "book" knowledge but without any heuristic input from experts. This prototype was taken to an expert for critical review. During review, the system's strengths and weaknesses became apparent. The prototype's understanding of the domain was inadequate, and it lacked problem-solving information. However, the system occasionally included details in explaining a conclusion that the expert had forgotten. This factor highlighted a significant problem of construction inspection addressed by expert systems: QA involves many more details than the QA representative will be able to remember.

²³ Lange, R., "Exception Hierarchies as a Knowledge Representation for Expert Systems," in *Proceedings of the 2nd International Conference on Applications of Artificial Intelligence in Engineering Problems* (Springer-Verlag, 1987).

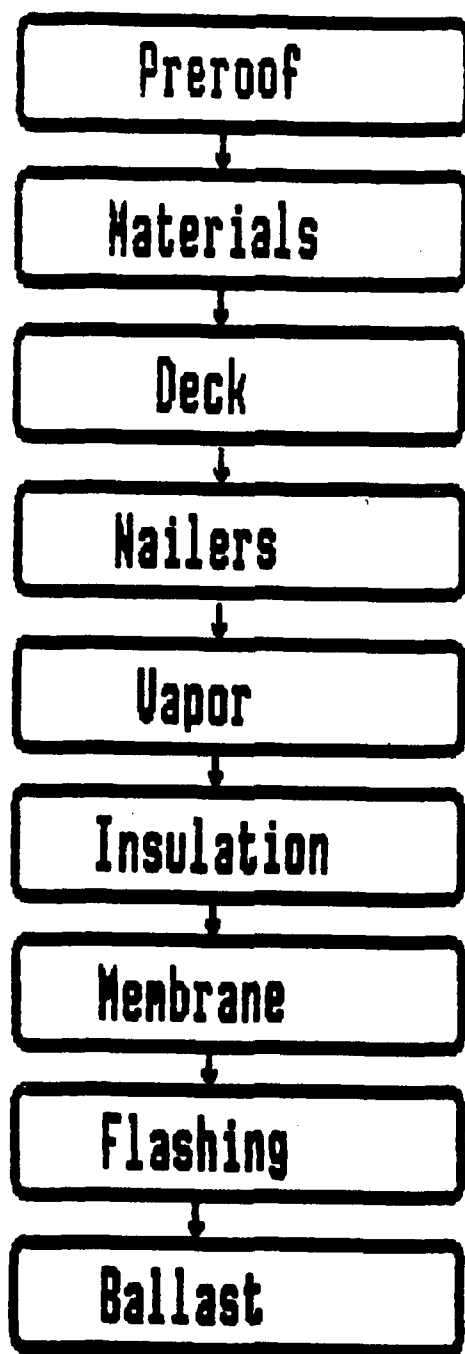


Figure 1. Construction sequence for built-up roofs.

5 PROJECT STATUS AND FUTURE WORK

Present Status

The prototype built-up roof construction expert system is being refined with feedback from experts. Field testing began in the summer of 1989. Attempts are being made to improve the graphic interface by adding interactive video, which will allow video presentation of actual construction sequences of built-up roofs. Video display of actual construction at critical times could significantly improve a QA representative's understanding of the conditions necessary for quality construction. Further, employing an expert system that uses interactive video as part of a training system could greatly contribute to the knowledge level of QA representatives.

Summary of Benefits

The following benefits have been identified in using an expert system for QA:

1. An expert system can include all the detail necessary for adequate performance of QA inspections in real time during construction.
2. Expert systems can incorporate the specifications of new construction technologies as they are introduced, thus supplementing formal training of QA representatives.
3. Expert systems can be used to create an institutional memory of the knowledge of the best experts in a field.
4. The tutorial function of expert systems allows inspectors to review existing technologies and learn new technologies quickly and efficiently. This function can utilize training materials being developed at U.S Army Corps of Engineers Huntsville Division.
5. Expert systems can aid contractors in quality control of construction processes and materials.
6. Use of expert systems by QA representatives should contribute to a higher quality of military construction.

CITED REFERENCES

- Ballard, R., "Prospects for Expert Systems in Quality Management," *CME* (January 1987).
- Buchanan, B. G., and R. O. Duda, *Principles of Rule-Based Expert Systems*, Stanford University Heuristic Programming Project Report No. HPP-82-14 (Stanford University, August 1982).
- Clark, I. T., "The Introduction of Quality Assurance to the Building Services Industry," *Quality Assurance*, Vol 12, No. 1 (1986).
- D'Ambrosio, B. D., "Knowledge-Based Process Management: The Road Ahead," in M. D. Oliff (Ed.), *Expert Systems and Intelligent Manufacturing* (North-Holland, 1988).
- DiLeva, A., and P. Giolito, "Data Models and Process Models for Computer Integrated Manufacturing Systems," in *Applications of Artificial Intelligence in Engineering Problems* (Springer-Verlag, 1986).
- Fehling, M. R., "Performance Requirements for Knowledge-Based Process Management Systems," in *Proceedings ISA-86* (Instrument Society of America, 1986).
- Hall, D. G., and D. P. A. Martin, "Integrated Inspection and Assembly," *Quality Assurance*, Vol 13, No. 1 (1987).
- Harmon, P., and D. King, *Expert Systems* (John Wiley & Sons, 1985).
- Hayes-Roth, F., and D. A. Waterman, *Building Expert Systems* (Addison-Wesley, 1983).
- Hughes, D., and A. Smith, "Intelligent Systems for Intelligent Factories," in *Proceedings of the AI Europa Conference, Weisbaden, Germany, September 1986* (TCM Expositions Ltd., 1986).
- Lange, R., "The Use of Knowledge Engineering Teams as a Method for Development of Expert Systems," in *Application of Artificial Intelligence in Engineering Problems* (Springer-Verlag, 1986).
- Lange, R., "Exception Hierarchies as a Knowledge Representation for Expert Systems," in *Proceedings of the 2nd International Conference on Applications of Artificial Intelligence in Engineering Problems* (Springer-Verlag, 1987).
- Maher, M. L., *Expert Systems for Civil Engineers: Technology and Application* (American Society of Civil Engineers, 1987).
- McDonald, M. E., "The Smart Foreman--Expert Systems for Manufacturing," in *Proceedings 1985 Autofact Conference, Detroit, MI, November 1985* (Society of Manufacturing Engineers, 1985).
- Michaelson, R. H., D. Michie, and A. Boulanger, "The Technology of Expert Systems," *BYTE* (April 1985), pp. 303-312.
- Moen, R. D., and T. W. Nolan, "Process Improvement--A Step-by-Step Approach to Analyzing and Improving a Process," in *Quality Progress* (September 1987).

Moore, R. L., "Expert Systems in Process Control: Applications Experience," in *Applications of Artificial Intelligence in Engineering Problems* (Springer-Verlag, 1986).

Shortcliffe, E. H., *Computer Based Medical Consultations: MYCIN* (North-Holland, 1976).

Tunner, J. R., "Total Manufacturing Process Control--The High Road to Product Control," in *Quality Progress* (October, 1987).

UNCITED REFERENCES

Barr, A., and E. A. Feigenbaum, *The Handbook of Artificial Intelligence*, Vol I-III (HeurisTech Press, 1981).

Berry, D. C., and D. E. Broadbent, "Expert Systems and the Man-Machine Interface," *Expert Systems* (October 1986).

Buchanan, B. G., "Expert Systems: Working Systems and the Research Literature," *Expert Systems* (January 1986).

Clancey, W. J., "The Epistemology of a Rule-Based Expert System--Framework for Explanation," *Artificial Intelligence*, Vol 20 (1983).

Stefik, M., et al., "The Organization of Expert Systems, A Tutorial," *Artificial Intelligence*, Vol 18 (1982).

Tello, E., "Raw Power For Problem Solving," *PC Magazine* (April 16, 1985), pp 131-137.

Winston, P. H., and B. K. Horn, *Lisp* (Addison Wesley, 1984).

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