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MATERIEL COMMAND

ARTIFICIAL INTELLIGENCE

CONCEPTS AND APPLICATIONS

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The scope of this study is focused on the manufacturing applications of Artificial Intelligence as it relates to potential applications in Army or contractor manufacturing facilities.

The specific study objectives were to:

- perform a literature review and summarize relevant articles and books on the subject so that general concepts can be understood
- perform a survey of actual installations and summarize important applications for the Army.

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ARTIFICIAL INTELLIGENCE - CONCEPTS AND APPLICATIONS

EXECUTIVE SUMMARY

This report considers Artificial Intelligence as it is and may be applied to manufacturing. The first portion of this report is based on a literature review. AI is defined and various potential applications considered. This review includes summaries of twenty publications as well as recommendations for a library in manufacturing.

Artificial Intelligence technology in DoD has taken on a great deal of importance as evidenced by the Army AI Center established at Army Headquarters to prepare the Army for AI in the 1900s; the Navy Center for Applied Research in AI at the Naval Research Laboratory in Washington, D.C.; and the Air Force AI Center currently being established in Dayton, Ohio. These AI organizations are being formed to centralize and facilitate coordination and sharing of information, issues, and concepts about AI within the DoD branches.

Applications - in various stages of research, development and implementation - range from strategic systems for management decision-making to tactical systems such as smart missiles, terrain analysis, and reconfigurable flight controls to logistics applications related to design, manufacture, diagnostics and repair of defense equipment. In this category, applications relating to diagnostics appear to be the most mature and those related to manufacturing the least. AI was often found to be a future planned enhancement of CIM systems already in production or currently being implemented.

While few AI systems have been in implementation long enough for measurable track records to be documented, preliminary estimates show the potential for Artificial Intelligence to provide tremendous savings in weapons systems logistics. Most systems are application specific with few generic parts that can be directly applied to other problems. The real significance to the projects in the survey are that the concepts are transferable, they prove that it can be done, they provide lessons learned in how to do it, and they demonstrate the potential for tremendous savings.

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FOREWORD

This report presents the results of a study that investigated Artificial Intelligence (AI) as it relates to manufacturing. The report was prepared by the Manufacturing Technology Information Analysis Center (MTIAC) under Contract DLA 900-84-C-1508 for the Department of Defense.

OBJECTIVE AND SCOPE

The objective of this study was to provide the U.S. Army Materiel Command (Alexandria, Virginia) with summarized, state-of-the-art information on the concepts and applications of Artificial Intelligence in manufacturing.

The scope of this study is focused on the manufacturing applications of Artificial Intelligence as it relates to potential applications in Army or contractor manufacturing facilities.

The specific study objectives were to:

- perform a literature review and summarize relevant articles and books on the subject so that general concepts can be understood

- perform a survey of actual installations and summarize important applications for the Army

STUDY PARTICIPANTS

The **Manufacturing Technology Information Analysis Center (MTIAC)** is a Department of Defense Information Analysis Center. Established in 1984, MTIAC serves as a central source for currently available information concerning manufacturing technology. The primary focus of the Center is to collect, analyze, and disseminate manufacturing technology for the production of defense materials and systems.

Cresap, McCormick & Paget, the prime contractor for MTIAC, is a management consulting firm that has operated the Center since its inception in June 1984. Cresap, McCormick & Paget is a division of Towers, Perrin, Forster & Crosby. The Cresap staff numbers over 1800 with offices located in 33 cities around the world. Cresap has provided management consulting services to private, government and not-for-profit enterprises since 1946.

IIT Research Institute (IITRI) performed the bibliographic literature review for this study. IITRI, the principal subcontractor for MTIAC, is a multidisciplinary, not-for-profit organization. Established in 1936, IITRI has provided applied research and development to industry and government. IITRI is one of the four largest contract research organizations in the United States employing a staff of over 1800 in four divisions--Chicago, East (Lanham, Maryland and Rome, New York), Annapolis (Maryland), and Bartlesville (Oklahoma).

Wizdom Systems, Inc. performed the survey of AI installations for this study. Wizdom Systems, Inc., also a subcontractor for MTIAC, is a consulting firm established in 1986 by Mr. Dennis Wisnosky that specializes in CIM, manufacturing automation and information automation. Mr. Wisnosky is an expert in CIM and has extensive experience with CIM in the Department of Defense through his involvement with the Air Force's ICAM program.

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INTRODUCTION

The purpose of this review is to consider artificial intelligence (AI) as it relates to manufacturing - past, present, and future. Manufacturing is considered here in its broadest concept as the entire enterprise associated with manufacturing products. Within this concept of manufacturing, the potential applications of AI are virtually unlimited.

The meaning of AI is discussed in greater detail in the following section. As will be noted, AI is a moving target - what is considered as AI today may be integrated with commercial products tomorrow. Many technologies presently used in manufacturing such as the computer concepts that led to word processing, spread sheets, and data base searches were originally considered within the realm of AI. Once these concepts became commercialized, they were no longer considered as AI.

AI was for many years far removed from mainstream technology - it was the realm of computer experts primarily in the academic world. This was an elitist group numbering somewhere between 100 and 200 AI experts in the United States and perhaps as many other AI experts worldwide. AI had little meaning outside of this select group.

In the early 1980s this suddenly changed. AI became a common subject in the popular and technical press. Venture capital supported AI start-up companies. Many of those who were computer literate became AI experts and many computer techniques that were being used and/or developed suddenly became tagged as AI.

The above is not intended to downplay the contribution or potential of AI, but it is important to recognize that AI is simply a continuum of the computer revolution that has been underway for several decades. Computers have become all pervasive within manufacturing (and in the world in general). AI offers the potential of vastly extending the impact of computers by giving them greater "intelligence".

In a subsequent section some of the applications of AI to manufacturing are presented. Some of the various books and papers describing the role of AI within manufacturing will be considered. To give some indication of the range of these potential applications the following table is excerpted from Iwata and Moriwaki (1984).

TABLE 1. Applications and Subjects of Knowledge Engineering in Manufacturing

Field of application	Subject of application
General	1. Knowledge base system
	2. Manufactoring system simulation
	3. Decision-making system for manufacturing
	4. Evaluation system for CAD/CAM
	5. (3 + T) dimensional CAD/CAM system
	6. Enterprise automation
Design	1. Understanding of required functions
	2. Preparation and confirmation of specifications
	3. Recognition and understanding of specifications
	4. Examination and determination of basic concept of design
	5. Formation of product concept
	6. Formation of model
	7. Formation of computational and experimental procedures
	8. Determination of structure
	9. Inspection of drawing
	10. Modification of drawing
Production (software)	1. Understanding of required functions for production
	2. Formation of production model
	3. Process planning
	4. Operation planning
	5. Intelligent NC programming
	6 Robot programming
	7. Software system for assembly
	8. Software system for inspection
	9. Software system for diagnosis
	10. Software system for maintenance
Management	1. Production planning
	2. Load planning
	3. Scheduling
	4. Progress management
	5. Quality control
	6. Factory management
	7. Layout of plant facilities
	8. Project management
	9. Estimation management
	10. Modelling of management
	11. Understanding of management requiring function
Intelligent machine	1. High intelligence FMS
	2. Intelligence control machine and equipment
	3. Learning control machine and equipment
	4. Adaptive control machine and equipment
	5. Intelligent robot
	6. Precision and ultra-precision machining system
	7. Intelligent machine for specific purpose

Perhaps this table does not include every aspect of manufacturing, but it certainly comes close and anything missing is simply an oversight. AI is and will be all pervasive within the manufacturing enterprise. The challenge facing manufacturing managers, along with those supplying equipment and services for manufacturing, is to accept the potential contribution of AI to manufacturing and take action to make certain that these are introduced.

WHAT IS ARTIFICIAL INTELLIGENCE?

This section is based on a chapter under this title in an earlier MTIAC study by Cook (1985). The possibility of thinking machines has been a subject of debate since Charles Babbage was designing his "analytical engine" around 1833. Kurzweil (1985) provides a very interesting account of the roots of the discipline development, tracing a path that touches philosophers and mathematicians such as Bertrand Russell and Allen Turing and ends with today's computer scientists such as Herbert Simon and Allen Newell.

Other accounts also make reference to the roots of AI going back more than a century, but the coining of the term "artificial intelligence" is usually credited to John McCarthy's use of it in a grant application for a conference he was organizing in 1956. This conference, held at Dartmouth College, brought together researchers in different fields whose common concern was the study of human and machine cognition.

The popularity of AI has caused the definition of the discipline to become vague. This has probably been exacerbated by the origins of AI being interdisciplinary, with no single fundamental concept clearly setting the initial limits. One definition that appears often is that AI technology is anything that deals in making a machine (computer or a robot) behave in a way that if done by a human would be considered intelligent. Of course one of the problems with this definition is that it requires a further definition of what is meant by "intelligent". Another definition is that AI is any technology that enables a computer or computer based machine to respond to situations that were not anticipated by the computer programmer.

Kurzweil defines AI by discussing several assertions about what AI is and what it isn't. He makes the point that an individual concept of intelligence as an attribute is dependent upon the degree of a personal comprehension. Thus, if a computer is observed responding correctly in a situation and that person is unable to understand how it could have done so, it might be considered to be exhibiting intelligence. If one later comprehends how it was done, it would likely be classified as just a rote technique rather than a manifestation of some innate intelligence. Winston (1984) has pointed out: "...one of the few requisites of thinking something is intelligent is that you really don't understand it very well."

Winston and Kurweil both echo a sentiment that AI should be defined as those computer science problems currently at the state of the art. Today this includes search-oriented automatic problem-solving and planning techniques, knowledge representation, computational logic, knowledge engineering and expert systems, computer vision, natural language processing, speech recognition, and parallel processing.

Considering AI as state of the art is not a bad way to look at the field. AI is very dynamic, and things that are considered part of it today may not be in a few years. A lighthearted suggestion has been made that the abbreviation "AI" should represent "anything interesting" instead of "artificial intelligence". As mentioned above, when somenthing is understood, it is no longer interesting and cannot qualify as AI.

There is a concept which seems to be a moderately consistent common denominator in spite of the proliferation of technologies in the AI family. This concept is the reliance on very efficient forms of search to find solutions from the space of all possible solutions. This stands in sharp contrast to the classical approach to problem solution in which a detailed algorithm is derived from first principles which guarantees a solution when all input parameters are established. When AI is defined as that programming which enables the item being programmed to adapt to conditions not specifically anticipated by the programmer, this enabling may be considered a manifestation of the concept of search.

Gevarter (1984) contains several reports prepared for the National Aeronautics and Space Administration (NASA) and the National Bureau of Standards (NBS) which provide good overviews of AI. Gevarter (1985) provides an overview and update of these reports. He summarizes the discussion defining AI as: "... Unlike conventional computer programming, it is knowledge based, almost invariably involves search, and uses heuristics to guide the solution process."

"Thus AI can be considered to be built on the following:

- Knowledge of the domain of interest.
- Methods for operating on the knowledge.

- Control structures for choosing the appropriate methods and modifying the data base (system status) as required. This contrasts with conventional computer programs, which utilize known algorithms for solution, are primarily numeric (number crunching) in nature rather than symbolic manipulation, and in general do not require knowledge to guide the solution."

Winston (1984) classic text on AI contains a variety of views on AI. "The perspective of Artificial Intelligence complements the traditional persepctives of psychology, linguistics, and philoshopy. Here are some reasons why:

- Computer metaphors aid thinking. Work with computers has led to a rich new language for talking about how to do things and how to describe things. Metaphorical and analogical use of the concepts involved enables more powerful thinking about thinking.

- Computer models force precision. Implementing a theory uncovers conceptual mistakes and oversights that ordinarily escape even the most meticulous researchers. Major roadblocks often appear that were not recognized as problems at all before beginning the cycle of thinking and experimenting.

- Computer implementations quantify task requirements. Once a program performs a task, upper-bound statements can be made about how much information processing the task requires.

- Computer programs exhibit unlimited patience, they require no feeding and they do not bite. Moreover, it is usually simple to deprive a computer program of some piece of knowledge in order to test how important that piece really is. It is impossible to work with animal brains with the same precision."

"Note that wanting to make computers be intelligent is not the same as wanting to make computers simulate intelligence. Artificial Intelligence excites people who want to uncover principles that all intelligent information processors must exploit, not just those made of wet neural tissue instead of dry electronics. Consequently, there is neither an obsession with mimicking human intelligence nor a prejudice against using methods that seem involved in human intelligence. Instead, there is a new point of view that brings along a new methodology and leads to new theories."

"One result of this new point of view may be new ideas about how to help people become more intelligent. Just as psychological knowledge about human information processing can help make computers intelligent, theories derived purely with computers in mind often suggest possibilities about methods to educate people better. Said another way, the methodology involved in making smart programs may transfer to making smart people."

"Do we really need to make our computers smarter? It seems so. As the world grows more complex, we must use our energy, food, and human resources wisely, and we must have high-quality help from computers to do it. Computers must help not only by doing ordinary computing, but also by doing computing that exhibits intelligence."

"It is easy to think of amazing applications for intelligent computers, many of which seem like science fiction by yesterday's standards. Here are a few:

- In business, computers should suggest financial strategies and give marketing advice. Moreover, computers should schedule people and groups, refer problems to the right people, summarize news, and polish draft documents, freeing them of grammatical errors.

- In engineering, computers should check design rules, recall relevant precedent designs, offer suggestions, and otherwise help create new products.

- In manufacturing, computers should do the dangerous and boring assembly, inspection, and maintenance jobs.

- In farming, computers should control pests, prune trees, and selectively harvest mixed crops.

- In mining, computers should work where the conditions are too dangerous for people, and they should recover the manganese nodules from the bottom of the sea.

- In schools, computers should understand their students' mistakes, not just react to them. Computers should act as superbooks in which microprocessors display orbiting planets and play musical scores.

- In hospitals, computers should help with diagnosis, monitor patients' conditions, manage treatment, and make beds.

- In households, computers should give advice on cooking and shopping, clean the floors, mow the lawn, do the laundry, and deal with maintenance."

"Some of these things are being done now. Others are close. Still others will require a lot more work. All are possible."

Gevarter (1985) and Winston (1984) are both suggested as introductory texts relating to AI, its applications, and its potential.

For the purpose of this report AI is considered to encompass anything utilizing the current state of the art technologies within computer science which are involved with machine intelligence. There is a thread of continuity in these areas, brought about by the common goal of producing some degree of intelligence in machines.

The references mentioned thus far are only a few among many. Publications relating to AI have proliferated along with interest in the subject. Shapiro (1987) edited a two-volume encyclopedia (1219 pages) on artificial intelligence which covers a wide range of AI related subjects and contains detailed references for all of them. There are various other books relating to AI including coverage of such specialized subjects as: "Expert Systems" by Waterman (1986); "AI and Instruction" edited by Kearsley (1987); "Manufacturing" edited by Krakauer (1987); and "CIM" edited by Kusiak (1988). Information on AI abounds in publications and with conferences.

AI FOR MANUFACTURING

It was noted in the first section and illustrated by Table 1 that AI is all pervasive in manufacturing - effectively all aspects of AI have potential applications for manufacturing. On the other hand, every element of manufacturing contains problems amenable to AI type solutions. The preview of AI and the preview of manufacturing are both broad and there is no basis for limiting either.

Two of the early references, i.e, Cook (1985) and Krakauer (1987) focused on manufacturing in general. Kusiak (1988) specifically considered AI and CIM. Miller (1985) presented a workman-like review of AI in manufacturing and is worth inclusion in a focused library on the subject. Wright and Bourne's (1988) book on Manufacturing Intelligence is recommended for AI and CIM experts, but not for a general introduction. There certainly is no shortage of publications relating to AI and manufacturing - there are a great many proceedings, papers, and books available. The challenge in fact is to select the "wheat from the chaff". Much of the published material is superficial, repetitive, or overly specific. The reader that is looking to understand the interaction between AI and manufacturing must start with general publications.

Schaffer (1986) presented a general overview for the readers in "American Machinist" that provides a good introduction and is recommended for a library. Cook and Emrich (1987) presented a review of the literature relating to AI in manufacturing. They considered the state of the art computer science technologies that involve machine intelligence and they suggest the following.

> "Search Oriented Automated Problem-Solving and Planning Techniques: The concept of search permeates many AI technologies, and a rich repertoire of search techniques has evolved. For very simple problems, blind search - the random trial of all conceivable possibilties - might be used. However, for any real world problem the large number of possibilities creates what is referred to as the combinatorial explosion; the number of possibilities to be searched is too large for a blind search.
>
> Overcoming the combinatorial explosion through the development of efficient search methods is one of the central issues of auomated problem solving and planning. Problem solving approaches have been developed

involving terminology such as backward chaining, problem reduction, and hierarchical planning and repair, for example. Since search techniques alone will work only on simple, well-structured problems, most research is now being focused toward using additional information, i.e, "knowledge". Knowledge helps pick the most efficient search techniques and guide the search.

Knowledge Representation: The evolving use of knowledge to direct the search has created a need to efficiently store, modify, and retrieve large quantities of knowledge. A considerable technology is developing in this area involving knowledge representation concepts such as semantic networks, frames, scripts, and production systems.

Computational Logic: A given knowledge base will directly provide certain information and implicitly represent additional information. The methods of computational logic, including resolution and nonresolution theorem proving, logic programming, fuzzy logic are being applied to facilitate access to this implicit information.

Knowledge Engineering and Expert Systems: The addition of knowledge representation and computational logic techniques to search oriented automated problem-solving and planning has recently found successful appliation to some real-world problems. The discipline formed around the application of these combined technologies has been named knowledge engineering. Its main products are called expert systems.

Computer Vision, Natural Language Understanding, and Speech Recognition: The environment in which a machine resides provides a large knowledge base, which must be made available to resolve certain problems. These three technologies play a vital role in the perception of this environment by the machine and thus belong in the AI family of technologies.

Parallel Processing: Despite recent developments in VLSI, orders-of-magnitude-faster processing speeds are needed before reasonable AI systems become available. While it is true that some successes are reported using current processing speeds, these are generally in nonreal-time or contrived environments. Since the processing speed is limited by the speed of light traveling across the processor, improvements must come by making smaller processors or using more processors working in parallel. Making smaller processors has been the approach for over 10 years, and will continue to be for several more years. However, some fundamental limits in fabrication technology and heat dissipation are anticipated as the circuit elements approach molecular sizes. Taking a cue from nature, research is under way to utilize the parallel approach. Some experts feel AI will not really arrive until parallel processing does."

The range of AI/manufacturing interfaces is illustrated by authors Cook and Emrich with tables on AI applications profiles: part design (Table 2); process planning and scheduling (Table 3); and assembly and process control (Table 4).

TABLE 2. AI Applications Profile: Part Design

AI technology	Manufacturing subarea	Status	Reference
ES[a]	Part design	In use	O'Connor (1984). Discusses DEC EXCON ES for configuring Vax 11 systems
ES	Part design	In use	Swift, et al. (1984). Describes ES to help an engineer design components for efficient automatic handling
ES	Part design	In use	Palmer and Machin (1984). Describes several ES for aiding designers of cables and connectors
AI techniques	Part design	In use	Swift (1983). Describes consultation program that helps the designer design easily assembled products
AI techniques	Part design	Being developed	Bohachevsky, et al. (1984). Discusses the development of computer programs for designing image forming optical systems
ES	Part design	Being developed	Matthews and Swift (1983). Discusses ES that assists designers in the specification and selection of surface coatings
ES	Part design	Being discussed	Dyer and Flowers (1984). Considers potential ES creativity with respect to the design process

TABLE 3 (continued)

AI technology	Manufacturing subarea	Status	Reference
ES	Process planning	Being developed	Cotter (1984). Describes an ES for automatic generation of NC programs starting with a solid product model
ES	Process planning	Being developed	Latombe and Dunn (1984). Describes process planning ES
ES	Process design	Being developed	Nasr (1985). Describes ES for the selection of material handling equipment
ES	Process design	Being developed	Ingrand and Latombe (1984). Describes ES for automatic fixture design
AI techniques	Scheduling	Being discussed	Szenes (1982). Discusses production scheduling using T.PROLOG
ES	Process planning	Being discussed	Nof (1984). Discusses using ES for facility planning
ES	Process planning	Being discussed	Nau and Chang (1983). Discusses using ES for process planning
ES	Process planning	Being discussed	Hall and Putnam (1984). Discusses using ES for process determination, sequencing, and scheduling
ES	Process planning	Being discussed	Allen (1984). Discusses using ES for process planning
ES	Process planning	Being discussed	Elwell and Jardine (1984). Discusses using ES to develop machinability models in the manufacturing planning process
AI techniques	Process design	Being discussed	Walter (1984). Discusses use of AI techniques in automatic control
AI techniques	Process design	Being discussed	Henkel (1983). Suggests use of AI programs for developing floor layouts when using robots

TABLE 4. AI Application Profile: Assembly and Processing Control

AI technology	Manufacturing subarea	Status	Reference
Machine vision	Assembly	In use	Bevan (1984). Discusses machine vision system used for inspection
Machine vision	Assembly	In use	Anon. (1984). Discusses machine vision system used for assembly assistance

TABLE 4. (continued)

AI technology	Manufacturing subarea	Status	Reference
Machine vision	Assembly	In use	Baird (1983). Discusses machine vision system used for inspection
Machine vision	Process control	In use	Lapidus (1984). Discusses machine vision system used for inspection
ES	Process control	In use	Hakaml and Newborn (1983). Discusses using ES to help operate a steel rolling mill
ES	Process control	In use	Moore, et al. (1984). Discusses using ES to assist in the process control of a refinery
ES	Process control	In use	Moore (1984). Discusses using ES to assist in the process control of a refinery
ES	Assembly	In use	Gliviak, et al. (1984). Discusses using ES to supervise a manufacturing cell
AI techniques	Assembly	In use	Anon. (1983a). Discusses robotic system for electronic component insertion
AI techniques	Assembly	In use	Anon. (1983b). Discusses robot used for assembly work
ES	Process control	Being developed	Sakaguchi and Matsumoto (1983). Discusses using ES for power system restoration assistance
Machine vision	Assembly	Being discussed	Villers (1984). Discusses robotic applications for machine vision
Machine vision	Assembly	Being discussed	Atkinson (1983). Discusses the impact of intelligent sensors on the scope of manufacturing processes
Machine vision	Assembly	Being discussed	Okhotsimsky, et al. (1984). Discusses the automation of industrial assembly processes with robots plus simple sensors plus machine vision
Machine vision	Assembly	Being discussed	Horn and Ikeuchi (1983). Discusses machine vision as applied to the bin picking problem
Machine vision	Assembly	Being discussed	Ejiri (1983). Reviews applications of vision technology in industry
Machine vision	Assembly	Being discussed	Wagner (1984). Provides a general discussion of machine vision capabilities
Machine vision	Assembly	Being discussed	Branaman (1983). Discusses the possible applications of machine vision

TABLE 4. (continued)

AI technology	Manufacturing subarea	Status	Reference
Machine vision	Assembly	Being discussed	Hall and McPherson (1983). Reviews 3-D perception techniques for machine vision
AI techniques	Assembly	Being discussed	Bellmann, et al. (1984). Discusses use of AI for monitoring equipment
AI techniques	Assembly	Being discussed	Dodds (1984). Discusses use of AI for robot planning
AI techniques	Assembly	Being discussed	Pinto (1983). Discusses practical application of AI in Robotics and Process Control
AI techniques	Assembly	Being discussed	O'Shima (1983). Discusses computer automation of plant operation
AI techniques	Assembly	Being discussed	Albus, et al. (1982). Discusses AI techniques for providing control systems with sensory capabilities
AI techniques	Assembly	Being discussed	Novak (1984). Discusses the use of AI in machine tool control

These three tables indicate the variety of activities that are underway relating to manufacturing. It is interesting and important to note that those in use are substantially fewer than those being discussed. These tables are based on a 1985 review - since then more approaches are being discussed and a few more are being used. This is a highly fluid technology and there are many suggestions and research efforts for each approach that is actually used.

Another example of the range of applications, shown in Table 5 taken from Meyer (1987), indicates the expert systems available for manufacturing applications. The subdivisions here are different than those considered above, but still cover the full range of manufacturing activities. This list of expert systems is incomplete and not all of those listed are commercial - the point is that there are many and they offer a wide range of potential applications. As an indication of the complexity of developing expert systems, Table 6 from Meyer (1987) is also included. Some of the complexity and costs involved in developing an expert system are pointed out. Many of the "interesting" applications for expert systems in manufacturing are large or extra large. Clearly with the current state of the art expert systems they are not suitable for every application. As AI technologies evolve the complexity and costs of developing expert systems will be reduced.

TABLE 5. Expert Systems
Manufacturing Applications

System	Developer	Application
Engineering Design		
XCON	DEC	Configures all DEC VAX computer systems
Hiclass	Hughes	Knowledge base implementation for producibility aspects of small fabricated mechanical part design
Vulcan	United Technologies Corp.	Automated design of intermediate manufacturing shapes for a class of axisymmetric forged parts
Cell Design Aid	Arthur Andersen and Co.	Use for group technology flexible manufacturing cells/systems design
Cadhelp	DEC	CAD subsystem for assisting in the design of digital logic circuits
Knowledge System	Boeing	Integrated computation programs for vehicle designers that integrates heterogeneous software for aerospace vehicle design
Excabl	Rockwell International	Configures control cabling for space shuttle payloads and experiments
Intelligent Optical Design Program	Los Alamos National Laboratory	Designs image-forming optical systems
Manufacturing Planning		
Hiclass	Hughes	Generates process plans and manufacturing work instructions
Cuttech	Metcut	Generates process plans for machining operations
Automated CNC Milling	Ben Gurion University (Israel)	Generates CNC part programs for CNC milling
XPSE-E	CAM-I	Generates process plans for part fabrication
Manufacturing Control		
IMACS	DEC	Generates detailed build plans from customer orders for computer hardware fabrication and assembly
ISIS	Westinghouse	Develops factory job shop schedules for detailed parts fabrication
PTRANS	DEC	Controls manufacture and distribution of DEC computer systems
ISA	DEC	Assists production control analysts in scheduling factory orders
IFES	Hughes	Models the dynamic flow of factory information
Factory Automation		
Move	Industrial Technology Institute	Planning assistant for material handling
Dispatcher	Carnegie Group, Inc.	Controls and monitors automated material handling systems
GMR Experimental Flexible Assembly Cell	General Motors Research Laboratory	Flexible automation assembly system programmed via graphical language
Virec	University of Florida	Knowledge-based system for automated visual recognition of industrial parts
FMS/CML	Westinghouse, North Carolina State University	Computer simulation tool for FMS design, planning, and control
Hiclass	Hughes	Interprets design engineering notes via natural language processing and communicates producibility information to both assembly workers and design engineers
FMS Simulator	Arizona State University	Constructs FMS design models for system verification via simulation

TABLE 6. Expert Systems Development Resources

Considerations	Small	System Type Large	Very Large
Rules	50-350	500-3000	10,000
Tool Available	Probably	Probably	Maybe
Person-Years To Develop	1/4-1/2	1-2	3-5
Project Cost	$40,000-60,000	$500,000-1 Million	$2-5 Million

NOTE: Included in costs — design, development, knowledge engineers, computing, and overhead
Excluded from costs — company expert, travel, fielding, and transition

SUMMARY

The material presented above clearly demonstrates a significant interaction between manufacturing and AI.

Manufacturing managers should understand that AI is an important technology that cannot be ignored. AI will have a significant impact on manufacturing. On the other hand, expectations for AI should be constrained based on the developmental nature of much of the ongoing work relating to manufacturing.Interest and involvement in artificial intelligence should be broadbased.

The challenge facing manufacturing management is to understand and accept that AI is evolving. They must strive to understand and support AI - accepting that the contribution of AI is ill-defined and will require substantial development. Manufacturing management should accept and support AI, understanding that major developments will be introduced through commercial offerings.

CLOSURE

Following is a list of the references used in this review as well as a listing of those publications suggested for inclusion in the AI library. Attached is an appendix of one-page write-ups of the books and papers selected for this AI review.

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ARTIFICIAL INTELLIGENCE & ROBOTICS: FIVE OVERVIEWS
VOLUMES 1 THROUGH 5C

by

William B. Gevarter

Manufacturing Productivity Center
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616
1984
618 pages (Vol. 1 - 90 pp; Vol. 2 - 64 pp; Vol. 3 - 150 pp; Vol. 4 - 44 pp; Vol. 5A - 66 pp; Vol. 5B - 108 pp; Vol. 5C - 46 pp)

This publication contains seven volumes that were originally published separately.

Robotics: An Overview (Volume 1)
Expert Systems: An Overview (Volume 2)
Computer Vision: An Overview (Volume 3)
Computer-Based Natural Language Processing: An Overview (Volume 4)
Artificial Intelligence: An Overview (Volume 5A - The Core Ingredients)
Artificial Intelligence: An Overview (Volume 5B - Fundamental Application Areas)
Artificial Intelligence: An Overview (Volume 5C - Basic Topics)

This series of reports collected in this volume were prepared by Dr. Gevarter, Manager of Automation Research & Technology, Office of Aeronautics and Space Technology, National Aeronautics and Space Administration. The series was prepared by the National Bureau of Standards (NBS) in conjunction with NASA.

This series dealt with the interrelated fields of robotics, artificial intelligence, expert systems, and computer-based national language processing. This publication, to a significant extent, took AI from a research area into mainstream technology. This book represented a significant contribution with definitions, and references. Obviously more recent work is not included, so this publication is not up to date.

Portions of this publication are contained in Artificial Ingelligence; Expert Systems, Computer Vision and Natural Language Process by William B. Gevarter, Noyes Publications, 1984.

MANUFACTURING INTELLIGENCE

by

Paul Kenneth Wright and David Alan Bourne

Addison-Wesley Publishing Company, Inc.
Reading, Massachusetts, etc.
1988
352 pages

This book is divided into four parts.

Part 1 reviews the economic and social influences on the manufacturing industry that are changing its focus from mass production to batch production. In batch production, considerable effort from human craftsmen is still needed to nurture the machines through setup procedures because of the limitations of current machine tools, robots, and sensors. Also, process parameters are set conservatively to make batch runs more predictable. For these reasons, and others, hardware and software that mimic the skills and decision-making process of the manufacturing craftsman must be developed.

Part 2 develops general principles for building intelligent machines. To accomplish this, it considers anthropomorphic systems (i.e., brain, eye, and hand) that must be built in order to physically replace the human craftsman. Each chapter attempts to provide practical design guides that can be used to construct these manufacturing systems. A special effort is made to outline important research problems that remain open.

Part 3 continues the theme of modeling the manufacturing craftsman with a case study of an intelligent machine tool. Initially, the skills exhibited by the human machinist are described, together with details of knowledge engineering experiments. This is followed by a review of the flexible fixtures and cutting sensors that are being developed to relieve human machinists of their loading and monitoring duties.

Part 4 predicts the manufacturing achievements of the next thirty years by looking at the long-term goals of current research. These predictions take the form of a dialogue between a mechanical engineer and a computer scientist, with the hope of stimulating and provoking similar or divergent research ideas.

This book is less practical than one might hope, but it does introduce a variety of subjects relating to the general theme. It represents current thinking over a variety of interacting technologies and interests.

DESIGN OF AN INTELLIGENCE SCHEDULING SYSTEM

by

D. R. Hughes and A. W. Smith

Proceedings - 2nd International Conference on
Machine Intelligence
IFS (Publications) Ltd.
35-39 High Street
Kempston, Bedford MK42 7BT
United Kingdom
1985
9 pages (p. 77-85)

The paper proposes a methodology for the design of an intelligent scheduling system. A start is made by recognizing the need to redistribute activities and intelligence between man, machine and computer in computer integrated manufacturing (CIM) systems. The implications of such a redistribution are explored focusing on the scheduling of CIM systems which poses a particular problem. Next the limitations of traditional approaches to scheduling are described concluding that an intelligent scheduling system (ISS) is required to alleviate the problems identified. A design methodology for an ISS is proposed which uses a combination of interviewing and structured systems analysis techniques. The paper concludes with a case study describing the use of the approach in collaboration with an industrial partner.

It must be emphasized that the approach is still being developed and considerable work remains to be done. Future plans include the identification of further criteria on which to base the selection of expert system shells for specific applications and the launch of a major research project to translate IDEF diagrams into production rules.

OPPORTUNTIES FOR EXPERT SYSTEMS IN A CIM ENVIRONMENT

by

L. Mannis and J. Morris

Advanced Manufacturing Systems
Proceedings of the AMS '86 Conference
IFS (Publications) Ltd.
35-39 High Street
Kempston, Bedford MK42 7BT
United Kingdom
1986
15 pages (p. 813-827)

The promise of CIM is that the control system complexity can be hidden in computers with simple human interfaces. Realizing that promise has proven challenging, to say the least.

The challenge has not come so much from programming the controls for an individual robot or NC machine. Classical information technology suffices. The real difficulty has come in linking these various automation technologies the so-called "Islands of Automation". Solving linkage problems requires help from an information technology just now gaining momentum -- Expert Systems (ES) Technology.

This paper considers how:

1. To introduce the essence of Expert System Technology, and
2. To provide a framework for evaluating the opportunties and imperatives for Expert Systems at your company and encourage you to do so.

The steps used were:

1. Introduce the value chain model of using information technology to gain competitive advantage and relate it to CIM, thereby uncovering the need for ES Technology.
2. Describe Expert Systems and how they can create value within the value chain system.
3. Identify potential areas for ES application in a CIM environment and provide guidance for prioritizing these opportunities from a strategic perspective.
4. Explain how to develop Expert Systems.
5. Address the problem of controlling Expert Systems.

This paper provides a view of the interactions between CIM and Expert Systems. Expert systems are an important element of artificial intelligence; this paper gives important insight on these interactions.

MANUFACTURING INFORMATION FLOW EXPERT SYSTEM

by

Carlene M. Nightingale

Ultratech Conference Proceedings
Society of Manufacturing Engineers
One SME Drive
P.O. Box 930
Dearborn, Michigan 48121
1986
11 pages (p. 2-165 to 2-175)

Information representation in a computer-integrated manufacturing environment represents a challenge that existing manual and computer documentation tools are unable to meet. An information flow expert system (IFES) was developed to address these needs. In order to support and control the dynamic need on the factory floor, artificial intelligence techniques create a "living" document that can model the complex movement of information and automate decision making. On-line graphical display of information paths and an interactive interface attract user interest, which, in turn, ensures that the information knowledge base is up to date and accurate. The ability to associate attributes, such as frequency and volume, with each exchange of information, aids in determining the best areas for improvements through networking and automation projects. It serves as a tool in predicting the results and in quantifying the improvement.

Existing computer and manual systems do not provide analysis tools that handle data in a way that is natural to the way people think. Our ability to manage information relies on how we represent it. Artificial intelligence techniques provide the means to allow people to change the representation of data to suit their own views and needs. Information flow is just that, fluid movement of data from one person to another. In order to predict the impact of automation and integration on information systems, a tool is required that can provide dynamic simulation of information flow.

The heart of CIM is the management of information. A thorough understanding of existing information systems is an essential baseline for CIM development, yet not much work has been done in this area. The Information Flow Expert System (IFES) is a tool for modeling information flow in a modern factory. Interactive graphical display portrays information clearly. Artificial intelligence techniques provide the key to creating a helpful user interface and providing the tools required for analyzing information flow and automating the decision-making process.

This paper interrelates CIM and Expert Systems so is particularly relevant for this review.

ARTIFICIAL INTELLIGENCE
EXPERT SYSTEMS, COMPUTER VISION AND NATURAL LANGUAGE PROCESSING

by

William B. Gevarter

Noyes Publications
Mill Road
Park Ridge, New Jersey 07656
1984
222 pages

This book is based on studies done by the author for NASA and NBS. This is a subset of the more extensive publication by the author. This work represents a general overview of artificial intelligence which helps to move AI from research to a commercial technology.

This book is divided into three parts.

PART A - Artificial Intelligence - The Core Ingredients

I. Artificial Intelligence - What it is
II. The Rise, Fall and Rebirth of AI
III. Basic Elements of AI
IV. Applications
V. The Principal Participants
VI. State-of-the-Art
VII. Towards the Future

PART B - Applications - Expert Systems, Computer Vision, Natural Language Processing, Etc.

I. Expert Systems
II. Computer Vision
III. Natural Language Processing (NLP)
IV. Speech Recognition and Speech Understanding
V. Speech Synthesis
VI. Problem Solving and Planning

PART C - Basic AI Topics - Automation, Search-Oriented Problem Solving, Knowledge Representation, Computational Logic

I. Artificial Intelligence and Automation
II. Search-Oriented Automated Problem Solving and Planning Techniques
III. Knowledge Representation
IV. Computational Logic

This book was published in 1984 and provides a good review of AI up to 1983. There has been considerable development and as a result the contents of this book are somewhat outdated.

ARTIFICIAL INTELLIGENCE IMPLICATIONS FOR CIM

edited by

A. Kusiak

IFS (Publications) Ltd.
35-39 High Street
Kempston, Bedford MK42 7BT
United Kingdom
1988
527 pages

This book is the first in a series, "Artificial Intelligence in Industry". This first volume has been divided into 14 chapters, each including one to four papers. Each paper has been written by one or more authors according to an outline prepared by the editor. The result of this approach is a series of papers which blend into a valuable and readable book.

The chapters are:

1. Introduction
2. Technological Components of CIM Systems
3. Sensors and Artificial Intelligence
4. Expert Systems in Manufacturing
5. Factory Communication Systems
6. Distributed Artificial Intelligence
7. CIM Databases
8. Process Planning and Part Programming
9. Production Planning and Control Systems
10. Scheduling
11. Managerial Expert Systems
12. Expert Support Systems
13. Simulation and Control Systems
14. Applications

The focus on AI's implications for CIM make it particularly relevant for these reviews. It does not contain everything that is known about CIM or AI, but does introduce both subjects and notes some of the potential interactions.

This book is current, with recent references. For this reason and because of the contents, it represents a good introductory and reference book.

A GUIDE TO EXPERT SYSTEMS

by

Donald A. Waterman

Addison-Wesley Publishing Company
Reading, Massachusetts, Menlo Park, California, et al.
1986
419 pages

This is the second in the "Teknowledge Series in Knowledge Engineering" with Frederick Hayes-Roth as Managing Editor. The first in the series was "Building Expert Systems" by Haynes-Roth, Waterman, and Lenat (1983). Expert Systems (ES) are one of the most visible elements of AI since ES are independent systems. This book is the definitive book on ES although the coverage of manufacturing is limited

The book is organized into 30 chapters in six sections:

Section One - Introduction to Expert Systems

Section Two - Expert System Tools

Section Three - Building an Expert System

Section Four - Difficulties with Expert System Development

Section Five - Expert Systems in the Marketplace

20. Where is Expert System Work Being Done?
21. How are Expert Systems Faring in the Commercial Marketplace?
22. What's Next for Expert Systems?
23. Sources of Additional Information about Expert Systems

Section Six - Expert Systems and Tools

24. Index for Expert Systems
25. Catalog of Expert Systems
26. Bibliography of Expert Systems
27. Index for Expert System Tools
28. Catalog of Expert System Tools
29. Bibliography of Expert System Tools
30. Companies Engaged in Expert System Work

Disappointing is the coverage of manufacturing. In Chapter 26 on bibliography of expert systems there is a section on manufacturing. It includes six items under references and two items under additional reading. All are dated 1984 or earlier. This is neither an up-to-date or complete listing.

This book is the "definite" work on Expert Systems but is of marginal value for those interested in manufacturing and CIM.

ARTIFICIAL INTELLIGENCE & INSTRUCTION APPLICATIONS AND METHODS

edited by

Greg P. Kearsley

Addison-Wesley Publishing Company
Reading, Massachusetts, Menlo Park, California, et al
1987
351 pages

Intelligent computer-assisted instruction (ICAI) built upon computer-assisted instruction (CAI) which has long been available. AI offers the potential for vastly expanding CAI.

This book is divided into five parts and 13 chapters:

Part 1 - Introduction
1. Overview
2. Intelligent CAI: Old Wine in New Bottles, or a New Vintage?

Part 2 - Artificial Intelligence in Education
3. PROUST: An Automatic Debugger for Pascal Programs
4. Micro-SEARCH: A "Shell" for Building Systems to Help Students Solve Nondeterministic Tasks
5. Mathematical Microworlds and Intelligent Computer-Assisted Instruction

Part 3 - Artificial Intelligence in Training
6. STEAMER: An Interactive, Inspectable, Simulation-Based Training System
7. Artificial Intelligence Applications to Maintenance Training
8. Intelligent Job Aids: How AI will Change Training in the Next Five Years

Part 4 - Building Intelligent Tutors
9. Methodology for Building an Intelligent Tutoring System
10. Theoretical Frontiers in Building a Machine Tutor
11. The TEACHER'S APPRENTICE: Designing an Intelligent Authoring System for High School Mathematics

Part 5 - Implementing ICAI Systems
12. Development Strategies for ICAI on Small Computers
13. Authoring Systems for ICAI

This book does not focus on Manufacturing or CIM, but it does present an excellent introduction to ICAI. ICAI will become a very important aspect of manufacturing in the future and this book provides excellent coverage. There are many books on AI, ES, etc., but this is the only one found on ICAI.

ARTIFICIAL INTELLIGENCE

by

Patrick Henry Winston

Addison-Wesley Publishing Company
Reading, Massachusetts, Menlo Park, California, etc.
Second Edition
1984
524 pages

This is the second edition of a classic publication that was first published in 1981. It was and remains a key publication on this subject. The author's approach is logical and readable by individuals who are not AI experts. For that reason it is recommended as the best introductory AI book.

This book is divided into 14 chapters:

1. The Intelligent Computer
2. Description Matching and Goal Reduction
3. Exploiting Natural Constraints
4. Exploring Alternatives
5. Control Metaphors
6. Problem-Solving Paradigms
7. Logic and Theorem Proving
8. Representing Commonsense Knowledge
9. Language Understanding
10. Image Understanding
11. Learning Class Descriptions from Samples
12. Learning Rules from Experience
13. Exercises
14. Bibliography

The chapters are organized with summaries and references at the end of each. There are 48 pages of exercises at the end of the book. Finally, there is an overall bibliography that is definitely up to date on publications.

This book was prepared and intended to be used as a textbook. It is sufficiently well written so that it could be used for self study. It is also organized and written so that it can be used to find information on specific subjects.

An excellent introductory book for reading and for use as a reference.

ARTIFICIAL INTELLIGENCE IN MANUFACTURING

by

James H. Cook and Mary Emrich

Manufacturing High Technology Handbook
Marcel Dekker, Inc.
270 Madison Avenue
New York, New York 10016
1987
24 pages (p 741-764)

Artificial Intelligence (AI) is one of the most complex, ill-defined, and far-reaching technologies. There are those who refer to AI as a science, while others question its classification as a technology. It will take time to establish an accepted practice--at least with regard to manufacturing. Despite its early stage of development, its rate of progress is accelerating.

The availability and application to manufacturing operations of computers of ever-increasing power make knowledge of AI a requirement as preparation for the industrial high technology of the future.

This paper summarizes some of the available information and considers the role of AI in manufacturing with emphasis on the future. This article contains an extensive list of references and bibliographies. The authors also provide a listing of resources for further information. Also included is a listing of commercial expert system development tools and a listing of AI companies with addresses and telephone numbers.

This paper provides an interesting overview and introduction to applications of AI that are and will impact manufacturing.

"Artificial Intelligence Applications in Manufacturing" by James Cook is used extensively in this article.

MANUFACTURING HIGH TECHNOLOGY HANDBOOK

edited by

Donatas Tijunelis and Keith E. McKee

Marcel Dekker, Inc.
270 Madison Avenue
New York, New York 10016
1987
773 pages

This handbook provides single-volume coverage of many of the advanced technologies associated with advanced manufacturing. The book is divided into nine parts with a total of 27 chapters prepared by individual experts.

Part I presents a general introduction to manufacturing technology.

Part II considers computer-integrated manufacturing with chapters on factory of the future, information resource management, group technology, and computer-integrated manufacturing.

Part III covers flexible manufacturing systems with chapters on flexible manufacturing, justification of flexible manufacturing systems, and flexible material handling.

Part IV on numerical control contains a chapter on that subject plus chapters on programmable control, and data communication.

Part V covers robotics with a chapter on that subject as well as chapters on robot selection process, robot peripherals, and end effectors.

Part VI considers material selection and processing with chapters on changes in traditional materials and processes, new materials, new process features for the traditional shop, and material removal innovations: nontraditional processes.

Part VII covers various aspects of quality with chapters on quality, quality control, and quality assurance concepts; procurement quality; in-process control for quality assurance; and design of interrelated manufacturing and quality systems.

Part VIII covers advanced manufacturing system design and management tools with chapters on computer-aided process modeling; manufacturing simulation; computer-aided decision support systems, and artificial intelligence in manufacturing.

Part IX is an epilogue review the approach.

This handbook is extensively referenced with bibliographical citations and contains over 400 illustrations. The individual chapters are stand-alone articles which can be useful references in their own right.

SMART MANUFACTURING WITH ARTIFICIAL INTELLIGENCE

edited by

Jake Krakauer

CASA/SME
One SME Drive
P.O. Box 930
Dearborn, Michigan 48121
1987
258 pages

This is one in the series of SME "Manufacturing Update Series". It is organized into eight parts which contain 23 articles. The book is organized as:

1. AI in Manufacturing
2. Expert Systems for Computer Aided Design
3. Computer Aided Process Planning
4. Robotics and Vision
5. Flexible Manufacturing Systems
6. Inspection
7. Process Control
8. Case Studies
   CATS: Precursor to Aerospace Expert Systems?
   DORIS - A Case Study in Expert System Shell Development
   Intelligent Management System in Manufacturing

This publication contains a variety of interesting papers relating to AI in manufacturing. Papers are selected from a variety of key publications and as a result this is a valuable collection of papers.

Artificial intelligence is the capturing of experience, knowledge, and information, filing it and arranging it for selective recall. The word artificial is a misnomer since the intelligence is not truly artificial, but based on human knowledge and experience. The comptuer does not actually "think," but instead executes instructions and manipulates data and "coded experience" to present conclusions based on human-supplied criteria. Computer-based AI is knowledge manipulation.

This new technology must prove itself in specific areas of design engineering, manufacturing engineering, and business management before it can significantly affect CIM system control. Initial AI activity centered around oil exploration, medical diagnosis, loan and insurance analysis, and maintenance management. Current applications also include engineering design and producibility, manufacturing scheduling and control, robot vision, and quality control.

ENCYCLOPEDIA OF ARTIFICIAL INTELLIGENCE
VOLUME 1 AND 2

edited by

Stuart C. Shapiro

Wiley-Interscience Publication
John Wiley & Sons
New York, New York
1987
1219 pages

The Encyclopedia of Artificial Intelligence defines the discipline of Artificial Intelligence (AI) by bringing together the core of knowledge from all its fields and related disciplines. The articles are written for the professional from another discipline who is seeking an understanding of AI, and also for the lay reader who wants an overview of the entire field or information on one specific aspect. The Encyclopedia clarifies and corrects misperceptions as well as provides a proper understanding of AI.

The object of research in AI is to discover how to program a computer to perform the remarkable functions that make up human intelligence. This work leads not only to increasingly useful computers, but also to an enhanced understanding of human cognitive processes of what it is that we mean by "intelligence" and what the mechanisms are that are required to produce it. AI is surely one of the most exciting scientific and commercial enterprises of our century.

The Encyclopedia has significant contributions to the AI literature, not only because it brings many disciplines into one comprehensive reference, but also because it contains many landmark articles, such as: Blackboard Systems; Computer Chess Methods; Cognitive Psychology; Grammar (Augmented Transition Network; Case; Definite-Clause; Generalized Phrase-Structure; Phrase-Structure; Semantic; and Transformational); Limits of AI; Lisp; Natural-Language (Generation; Interfaces; and Understanding); Path Planning and Obstacle Avoidance; Reasoning (Casual; Commonsense; Default; Nonmonotonic; Plausible; Resource-Limited; Spatial; and Temporal); Robotics; Search (Best-First; Bidirectional; Branch-and-Bound; and Depth-First); and Social Issues of AI. All of the material is specifically written for the Encyclopedia.

The Encyclopedia also has separate articles on various game-playing programs, vision, speech understanding, image understanding, matching, multisensor integration, and parsing, as well as many short articles.

The articles and the authors invited to write them were chosen with the cooperation of an editorial advisory board of distinguished authorities. The author of each article is a recognized research expert on the topic. The reader may start with almost any article and be led by cross-references to almost every other article in the Encyclopedia. There are more than 450 tables and figures. Stressing readability, accuracy, and completeness of facts as well as overall usefulness of material, this great work brings you the result of years of labor and experience.

ARTIFICIAL INTELLIGENCE: A TOOL FOR SMART MANUFACTURING

by

George H. Schaffer

American Machinist & Automated Manufacturing
McGraw Hill, Inc.
Volume 130, Number 8
1986
12 pages (p 83-94)

This is a special report published in American Machinist. This is a fairly general review of the subject which defines terms and discusses options. Expert systems are emphasized for the near term with AI in the broader sense considered for the longer haul.

Artificial intelligence may, in the long run, be the single most important and most pervasive ingredient for the realization of true computer-integrated manufacturing (CIM).

The reason for such promise is that the technique is applicable to the entire range of manufacturing activities. It also holds the key to sharing of information, or knowledge, among the many disparate elements of a typical CIM environment.

AI is quite benign and represents a natural evolution in the way computers are programmed and applied for the solution of relatively routine problems.

This is a relatively general article that lends considerable credibility to the application of AI in manufacturing. Artificial intelligence may be an unfortunate choice of name for an emerging technology, but, stripped of its popular hype, this may be the smartest thing that ever happened to manufacturing.

ARTIFICIAL INTELLIGENCE
APPLICATIONS FOR MANUFACTURING

by

Richard K. Miller

SEAI Technical Publications
P.O. Box 590
Madison, Georgia 30650
1984
202 pages

This report focuses on the areas of expert systems and natural language systems in manufacturing. Applications of expert systems developed by DEC and Carnegie-Mellon University are cited along with a system used by General Electric. A survey is made of the fields of intelligent robots, artificial vision and speech recognition. The 21 chapters are:

1. An Introduction to Artificial Intelligence
2. Expert Systems
3. Tools for Building Expert Systems
4. Expert Systems in Manufacturing: An Overview
5. Application of XCON (R1) at Digital
6. Industrial Expert Systems from Carnegie-Mellon University
7. Expert Systems for Quality Control
8. Expert Systems for Robotics
9. Expert Systems for CAD/CAM
10. Expert Systems for Maintenance
11. Artificial Intelligence Applications for Energy Management
12. Expert Systems for Process Control
13. Expert Systems for Simulation
14. Natural Language Understanding
15. Commercial Natural Language Software
16. Speech Recognition
17. Intelligent Robots
18. Artificial Vision
19. Artificial Touch Sensing
20. Computers for Artificial Intelligence Programming
21. AI on the Personal Computer

This report provides a readable review and state of development. It is obviously limited by the date of the publication, but is still a worthwhile resource.

ARTIFICIAL INTELLIGENCE & ROBOTICS

by

James H. Cook and John P. Lamoureux

AIRCON 2 Conference Proceedings
Manufacturing Productivity Center
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616
1985
475 pages

This proceedings contains a variety of papers relative to AI in manufacturing. The association with robots is more emotional than logical. The term robotics has become a euphemism for advanced manufacturing and there are those who expect all advances to be associated with robots. The robot industry has accepted this view itself and has, in many instances, taken the technical lead. Nevertheless the use of robotics in the title for this conference could well have been a mistake and has caused some confusion. The stated purpose of this conference was to encourage interaction amoung experts in artificial intelligence, robotics, and applications domains. Considerable work is being done to develop these technologies since they have a potential impact on many sectors of the economy. This two-day conference considered potential impacts, current status, and future potential of these technologies.

This conference proceedings contains 20 papers reviewing artificial intelligence as it relates to robotics and automated manufacturing in general. The papers are:

- Near-Term Military Application of Artificial Intelligence and Robotics
- Automating Reasoning: Rules We Can Live With
- Economic Impacts of Manufacturing Automation
- Recent Developments in Artificial Intelligence and Robotics in the UK
- Artificial Intelligence for Assembly Planning
- Problem of Transition
- Robotics Technology - A Current Overview
- The Robot Industry and Artificial Intelligence
- Research Directions in Artificial Intelligence and Robotics
- CAM-I Directions in Artificial Intelligence
- An Overview of Expert Computer Systems
- Industrial Applications: the Naturals
- Artificial Intelligence and Robotics Forecast
- Artificial Intelligence and Robotics in Automatic Wire Processing
- Overview of the Air Force Manufacturing Science Program
- Systems Architecture of AI-Embedded CIM
- Keynote Address: Artificial Intelligence and Robotics
- Future of Industrial Automation
- A Control System for An Automated Manufacturing Research Facility
- Artificial Intelligence and Robotics Forecast

ARTIFICIAL INTELLIGENCE AND ROBOTICS

by

Michael Brady

AIRCON 2 Conference Proceedings
Manufacturing Productivity Center
IIT Research Institute
Chicago, Illinois 60616
1985
44 pages (p 273-316)

Since Robotics is the field concerned with the connection of perception to action, Artificial Intelligence must have a central role in Robotics if the connection is to be intelligent. Artificial Intelligence addresses the crucial questions of: what knowledge is required in any aspect of thinking; how that knowledge should be represented; and how that knowledge should be used. Robotics challenges AI by forcing it to deal with real objects in the real world. Techniques and representations developed for purely cognitive problems, often in toy domains, do not necessarily extend to meet the challenge. Robots combine mechanical effectors, sensors, and computers. AI has made significant contributions to each component. We review AI contributions to perception and object-oriented reasoning. Object-oriented reasoning includes reasoning about space, path-planning, uncertainty, and compliance. We conclude with three examples that illustrate the kinds of reasoning or problem-solving abilities we would like to endow robots with and that we believe are worthy goals of both Robotics and Artificial Intelligence, being within reach of both.

Robotics is the intelligent connection of perception to action. The key words in that sentence are "intelligent" and concomitant "perception". Normally Robotics is thought of as simply the connection of sensing to action using computers. The typical sensing modalities of current robots include vision, force and tactile sensing, as well as proprioceptive sensing of the robot's internal state. The capacity for action is provided by arms, grippers, wheels and, occassionally, legs.

Insofar as Robotics is the intelligent connection of perception to action, Artificial Intelligence (AI) is the challenge for Robotics. On the other hand, however, we shall argue that Robotics severely challenges Artificial Intelligence (AI) by forcing it to deal with real objects in the real world. Techniques and representations developed for purely cognitive problems often do not extend to meet the challenge.

AI AND EXPERT SYSTEMS: IN PURSUIT OF CIM

by

Ronald J. Meyer

Carbide & Tool Journal
The Society of Carbide and Tool Engineers
ASM International
Rt. 87
Metals Park, Ohio 44073
Volume 19, Number 6
1987
4 pages (p 11-14)

This is a short article, but it emphasizes that AI/ES for CIM applications is important for this evaluation. The author is an authority on CIM so his views on the interactions with AI/ES are important. Emphasis in this article is on expert systems which are the element of AI that is most appropriate for direct applications. Other aspects of AI are and will have a very significant impact on manufacturing in general and on CIM in particular, but many of these AI applications will be embedded in equipment and systems. Expert systems are more or less stand-alone and can be introduced independently.

ES development resources are estimated: 1/4 to 1/2 person years to develop a small ES with 50-350 rules; 1-2 person years to develop a large ES with 500-3000 rules; and 3-5 person years to develop a very large ES with 10,000 or more rules. The author notes that the available tool may or may not be adequate for the very large systems.

A major portion of this paper is a table listing of expert systems for manufacturing applications. The author considers four categories:

Engineering Design	8 Systems
Manufacturing Planning	4 Systems
Manufacturing Controls	5 Systems
Factory Automation	7 Systems

This is a short article but worth reading.

ARTIFICIAL INTELLIGENCE APPLICATIONS IN MANUFACTURING

by

James H. Cook

MTIAC (TA-85-01)
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616
1985
47 pages

This publication is a technology assessment of the subject prepared and distributed by MTIAC. It is the result of an extensive literature search as well as interactions with experts in the field. There are tables listing AI applications for Part Design; Process Planning and Scheduling; and Assembly and Process Control. There are also tables listing Commercial Expert Systems Development Tools; Commercial Natural Language Understanding Systems; and AI Workstations. There is also a table listing expert system contacts; 23 references are included for further reading. Also included for further information is a list of professional organizations, conferences, as well as trade journals and newletters. U.S. programs relating to AI in manufacturing are reviewed along with a brief review of foreign programs.

This publication starts with a general introduction to AI along with a discussion of the role of AI in manufacturing. The tables described above are based on the author's profile.

This publication represents a short readable introduction to AI in manufacturing that is suitable for management or technical staff. It offers a reasonable summary through September 1985, when it was completed. It is still appropriate reading, but in a technology as dynamic as artificial intelligence, it should be understood that there have been significant developments since this study was completed. It forms a basis for understanding and a summary up to the date of publication. Since there is nothing more current it is valuable, but should be used with caution.

Substantial portions of this report are contained in "Artificial Intelligence in Manufacturing" by Cook and Emrich.

ARTIFICIAL INTELLIGENCE APPLICATIONS IN GOVERNMENT OPERATIONS

ARTIFICIAL INTELLIGENCE APPLICATIONS IN GOVERNMENT OPERATIONS

BACKGROUND

The emerging field of Artificial Intelligence (AI) has dramatically affected technology development in recent years. One of the most widely used applications of artificial intelligence is in expert systems which elicit knowledge and experience from recognized experts in a particular field and use this knowledge to solve complex problems with a degree of efficiency comparable to a human expert's. Artificial Intelligence and expert systems technology provide the potential for widespread applications in planning, designing, analyzing, tutoring, interpreting, diagnosing, and monitoring problems. These applications offer many opportunities to the Department of Defense (DoD) for increasing productivity and maximizing readiness capabilities in the production, repair and deployment of weapons systems.

While the potential benefits are great, AI has not yet been widely implemented in either private industry or government. New developments and the myriad of projects in various stages of research and development make it difficult if not impossible for the potential user to to know where to look for successful applications. The purpose of this survey is to assess and summarize applications of Artificial Intelligence within the Department of Defense to help potential users decide on the applicability of these projects to their own situations.

APPROACH

The approach taken was:

- to develop a survey questionnaire,
- to review various AI databases, directories, reports, and proceedings
- to develop a selection criteria for potential locations, and
- to conduct a telephone survey of those locations.

From the projects included in the survey, another screening was performed to select the most significant ones according to agreed upon criteria. This report contains a listing of those projects surveyed, including a summary of the application, cost, benefits, and person to contact for more information. Those projects selected from the second screening are described in more detail in the referenced abstracts. Selection criteria for the projects were as follows:

- Implementation oriented as opposed to pure R&D
- Significant level of funding
- Logistics oriented as opposed to Tactical and Strategic applications
- Engineering and Manufacturing oriented as opposed to information systems
- Significant benefits demonstrated or substantiated
- Applicable in concept to Army requirements

FINDINGS

Artificial Intelligence technology in DoD has taken on a great deal of importance as evidenced by the Army AI Center established at Army Headquarters to prepare the Army for AI in the 1990s; the Navy Center for Applied Research in AI at the Naval Research Laboratory in Washington, D.C.; and the Air Force AI Center currently being established in Dayton, Ohio. These AI organizations are being formed to centralize and facilitate coordination and sharing of information, issues, and concepts about AI within the DoD branches.

Artificial Intelligence technologies were found to be generally less mature than some of the other computer integrated manufacturing (CIM) technologies. Much is being done in basic research and development and much in applied research. The majority of projects are still in the prototype stage of funding and development.

Applications - in various stages of research, development and implementation - range from **strategic systems** for management decision-making to tactical systems such as smart missiles, terrain analysis, and reconfigurable flight controls to logistics applications related to design, manufacture, diagnostics and repair of defense equipment. In this category, applications relating to diagnostics appear to be the most mature and those related to manufacturing the least. AI was often found to be a future planned enhancement of CIM systems already in production or currently being implemented.

In some cases contracts have been awarded to several vendors who are taking different approaches to solving similar problems, each demonstrating particular strengths and weaknesses. Lessons are being learned, particular approaches are emerging as superior to other approaches - an initial step on the road to standardization. There appears to be considerable awareness within the AI community of what is going on in other projects and the AI centers will increase that awareness.

While few AI systems have been in implementation long enough for measurable track records to be documented, preliminary estimates show the potential for Artificial Intelligence to provide tremendous savings in weapons systems logistics. Most systems are application specific with few generic parts that can be directly applied to other problems. The real significance to the projects in the survey are that the concepts are transferable, they prove that it can be done, they provide lessons learned in how to do it, and they demonstrate the potential for tremendous savings.

SIGNIFICANT AI APPLICATIONS IN GOVERNMENT OPERATIONS

NO.	ABS-TRACT	RESPONSIBLE ORGANIZATION	PROJECT NAME	WHERE IMPLEMENTED	PROTOTYPE OR PRODUCTION	DOD BRANCH	CIM/ AI	APPLICATION	COST	BENEFITS	START TO FINISH	DOD CONTACT	VISIT SITE
AAI01	X	AMTL WATERTOWN,MA	QC/THERMOSET. RESINS	AMTL	PROTOTYPE	ARMY	AI	MATERIAL QC & SPECIFICATIONS	$100K 1 MAN YR.	FASTER MTRLS. QUALIFIC.	1987-1988	GARY HAGNAUER (617)923-5121	
AAI02	X	US ARMY AI CENTER WASHINGTON,DC	MULTIPLE	AI CENTER	PROTOTYPE & PRODUCTION	ARMY	AI	MGMNT. DECISION	N/A	PREPARE ARMY FOR AI IN 1990S	ON-GOING	DAVID TYE (202)694-6900	X
AAI03	X	LABCOM FT.MONMOUTH,NJ	DESIGN SYN.TOOL	LABCOM	PROTOTYPE	ARMY	AI	IC DESIGN	$1.4M	LOWER COST PARTS REPLACE.	1986-1991	CHARLES BOSCO (201)544-2283	
AAI04	X	AVSCOM FT.EUSTIS, VA	AVIATION SYS. FAULT ISOL.	HUGHES;BOEING MCDD HELICOPTER	PROTOTYPE	ARMY	AI	HELICOPTER FAULT ISOLATION	$153K	CORRECT 90%	1985-1988	B. THOMPSON 804-878-5305	
AAI05	X	NAVSEA WASHINGTON,DC	ADAPTIVE WELDING	GD LAND SYSTEMS	PRODUCTION 1987	NAVY	AI	WELDING M-1 TURRETS/HULLS	$5.5M	IMPROVED WELD QUALITY	1985-1987	ROBERT KING* (516)273-9700	
AAI06		TOBYHANNA ARMY DEPOT PA	ES FOR COST ESTIMATING	TOBYHANNA	PRODUCTION 1987	ARMY	AI	COST ESTIMATING	$25K	FASTER MORE ACCURATE ESTIMATING	1979-1989	FRANK ESTOCK (717)894-7089	
AAI07		USATPL FT.BELVOIR,VA	TERRAIN ANALYSIS	USATPL	PROTOTYPE	ARMY	AI	MINE FIELD DETECTION	$650K	FASTER TERRAIN ANALYSIS	ON-GOING	JOHN BENTON (703)355-2717	
AAI08		USATPL FT.BELVOIR,VA	AUTONOMOUS LAND VEHICLES	USATPL	PROTOTYPE	ARMY	AI	OPTIMAL ROUTE DETERMINATION	$100K	BATTLEFIELD PLANNING	ON-GOING	JOHN BENTON (703)355-2717	
AAI09		AMCCOM PICATINNY, NJ	AIDECS DIAX	IOWA ARMY AMMUN. PLANT	PRODUCTION PRODUCTION 1988	ARMY	AI	XRAY INSPECT.	$10M $1.5M	2-3/UNIT XRAY FILM COST	1979-1988 1984-1988	EMMETT BARNES ((201)724-4238	
AFAI01	X	AFSC/ASD WPAFB,OH	CITS CEPS	B-1 OPERATING BASES	PROTOTYPE	AF	AI	INTEGRATED TEST SYSTEM		REDUCED LIFE CYCLE COSTS	1985-1991	STEVE JENKINS (513)255-9552	

NO.	ABS-TRACT	RESPONSIBLE ORGANIZATION	PROJECT NAME	WHERE IMPLEMENTED	PROTOTYPE OR PRODUCTION	DOD BRANCH	CIM/ AI	APPLICATION	COST	BENEFITS	START TO FINISH	DOD CONTACT	VISIT SITE
AFAI02	X	AFHRL WPAFB, OH	MDAS	AFHRL WPAFB, OH	PROTOTYPE	AF	AI	MAINTENANCE DIAGNOSTICS	$750K	TREMENDOUS SAVINGS	1985-1988	ROBERT JOHNSON (513)255-3771	
AFAI03	X	AFATL ELGIN AFB,FL	EMMA	RAYTHEON BEDFORD,MA	PROTOTYPE	AF	AI	MISSILE FAULT ISOLATION	$998K	20% FASTER 30% MORE ACCUR.	1986-1989	MARK GERSH (904)882-2961	
AFAI04		AFWAL/MLTM WPAFB, OH	AUTOMATED AIRFRAME ASSY	NORTHROP	PRODUCTION 1992	AF	CIM/ AI	ABOVE-THE-FLOOR-COSTS	GOV.$15M NORTHROP $5M	TREMENDOUS SAVINGS	1988-1992	MICHAEL HITCHCOCK (513)255-7371	
AFAI05		AFLMC GUNTER AFS ALABAMA	COMPUTERIZED FAULT REPORTING	MCDD	OPERATIONAL PROTOTYPE	AF	AI	PILOT DEBRIEFING FAULT DIAG.	$152K + $400K (6 MAN/YRS.)	45% INCREASED ACCURACY	1986-1989	GARY GEMAS (205)279-4581	
AFAI06		AFHRL	IMIS	AFHRL WPAFB, OH	PROTOTYPE	AF	CIM/ AI	INTEG. MAINT. INFOR. SYSTEM	$3.5M	TREMENDOUS SAVINGS	1985-1991	ROBERT JOHNSON (513)255-3771	
AFAI07		AFLMC GUNTER AFS,AL	AFAMS	MYRTLE BEACH AFB	PRODUCTION 1985	AF	AI	AUTO FLYING & MAINT. SCHED.	$2M	75% LESS SCHED. DEVELOP. TIME	1981-1985	JOHN TURNER (205)279-4581	
AFAI08		AFLMC GUNTER AFS, AL	MUNITIONS PRODUCTION CAPAB. ASSESS.	COMMAND-WIDE	PRODUCTION 1985	AF	AI	MUNITIONS PROD. CAPAB. ASSESS.	$1M	INCREASED RELIABILITY	1983-1985	HUGH TAYLOR (205)279-4581	
NAAI01	X	NAVAIR	APOMS	ROBOTIC VISIONS SYSTEMS	PRODUCTION 1988	NAVY	AI	AUTO.PROPELLER MEASURING SYS.	$10M	IMPROVE QUAL./ACCURACY	1982-1986 1988	ROBERT KING* (516)273-9700	
NAAI02	X	NRL WASHINGTON,D.C.	FAULT ISOLATION CELL	FOUR NAVY TEST SITES	OPERATIONAL PROTOTYPE	NAVY	AI	ELECTRONICS FAULT DIAG.	$1.2M	25% REDUCTION ATE TEST TIME	1986-1988	RANDALL SHUMAKER (202)767-2884	
NAAI03		NPRDC SAN DIEGO, CA	CBAET	NPRDC SAN DIEGO, CA	PROTOTYPE	NAVY	AI	MAINTENANCE DIAGNOSTICS	$3.5M	TREMENDOUS SAVINGS	1986-1991	ROBERT SMILLIE (619)553-8015	
NAAI04		SPAWAR NOSC,SAN DIEGO	IFAHMM	TELEDYNE	PRODUCTION 1989	NAVY	CIM/ AI	AUTOM. HYBRID MANUFACTURING	$2.4M	RED.COST 25% IMP. YIELD 50%	1986-1989	RICHARD GAMBLE (619)553-3254	

NO. ABS-TRACT	RESPONSIBLE ORGANIZATION	PROJECT NAME	WHERE IMPLEMENTED	PROTOTYPE OR PRODUCTION	DOD BRANCH	CIM/ AI	APPLICATION	COST	BENEFITS	START TO FINISH	DOD CONTACT	VISIT SITE
DARPAI01	DARPA ARLINGTON,VA	ITA	HONEYWELL MARTIN MARIET.	PROTOTYPE PROTOTYPE	DARPA	AI	PROGRAM. ASSY. PROGRAM. INSP.	$7.6M $3.1M	MORE PRODUC-TIVE MFG.	1982-1988	ROBERT ROSENFELD (202)694-4001	
COAI01	BELL HELICOPTER	EXPERT MACHIN. KNOWLEDBE BASE	BELL HELICOPTER	PROTOTYPE	CON-TRACTOR	AI AI	RETAIN EXPERT. OF MACHINISTS	$25K	RETAIN EXPERTISE	1986-1988	JOHN MADDOX* (817)280-4817	

*Contractor

Abstract # AAI01

AN EXPERT (AI) SYSTEM FOR QC OF THERMOSETTING RESINS

DESCRIPTION

The primary objective of this project was to develop a prototype expert system to assist resin suppliers, manufacturers and specifications experts in selecting test methods and procedures for the quality control of thermoset resin prepreg materials. The expert system is essentially a computer program consisting of three main parts - a database of "rules" and "facts" which represent the reasoning of an expert in a particular knowledge domain, an inference engine to interpret the rules and facts, and a user interface to aid the user. The prototype expert system is a consultative system designed to recommend test methods and advise specialists on specific test procedures depending upon the type of material and its intended application. When completed,the system will guide users through schemata for the chemical, physical and mechanical characterization of materials and assist users in the interpretation of results.

The approach in the development of this system was to focus on using AI as a tool and to approach AI at the entry level with a minimum investment in equipment and personnel. It was decided to limit the problem domain and address only areas where there was a high level of technical expertise and a demonstrated need. A Tektronix 4404 Artificial Intelligence machine hosting a variety of computer languages (LISP, ProLOG, and Smalltalk) specifically designed for AI applications was purchased for $15,000. The Tektronix 4404 and an IBM PC/AT were used to train personnel in these AI languages and in the basic concepts of expert system design.

BENEFITS

Too few experts exist to meet increasing demands for knowledge in the area of qualifying new materials. The use of thermosetting resins is growing and being extended to new application areas in DoD and the private sector. Too much time is involved in qualifying new materials and developing appropriate test methodology. Rapid response is needed in evaluating materials to meet design and processing requirements. Materials selection is often haphazard and ill-advised. Materials selection and acceptance criteria need to be documented and utilized.

The payoff in this expert system will be in improved, more reliable, and lower cost materials and faster response times for materials qualification and application.

SIGNIFICANCE TO THE ARMY

It is anticipated that the expert system will be implemented in materials specifications and in the manufacture of a wide range of Army materiel. As such the system will impact directly on the application of both conventional and advanced materials for lightening the forces. Ultimately, this effort should result in special computer software adaptable not only for the developing and manufacturing of Army materiel, but also for use in the private sector.

Abstract # AAI02

U.S. ARMY HDQA AI CENTER

DESCRIPTION

The Army AI Center was started in October of 1985 with the goal of preparing the Army for AI in the 1990's. The AI Center has three goals:

1) To act as AI proponents for the Army Logistics community to assist in AI applications and to transfer AI technology;

2) To apply existing AI techniques to Army Corporate level decision processes; and

3) To keep track of the R&D community and identify those R&D projects that can be applied to manufacturing applications.

There are two groups within the center: 1) the Proponency Group charged with goals 1 and 3. This group keeps track across the Army as to what is going on in AI. They become facilitators for other groups; 2) the Knowledge Engineering Group - dedicated to goal number 2. One of the systems implemented by the AI Center is an AI system for improving the quality of decision-making at Army Headquarters.

BENEFITS

Artificial Intelligence and expert systems technology provide the potential for widespread benefits in planning, designing, analyzing, tutoring, interpreting, diagnosing, and monitoring problems. These applications offer many opportunities to the Department of Defense for increasing productivity and maximizing readiness capabilities in the production, repair and deployment of weapons systems.

SIGNIFICANCE TO THE ARMY

The Army AI Center is unique in its mission to institutionalize the Army AI Program. The Center is available as a resource to Army personnel (as well as Navy and AF) for assistance in specific AI applications. The Center has been so successful that the Air Force has designed a similar program and is currently implementing a counterpart facility in Dayton, Ohio. These centers are being formed to centralize and facilitate coordination and sharing of information, issues, and concepts about AI within the DoD branches. They are an important resource for anyone developing an AI application.

Abstract # AAI03

DESIGN SYNTHESIS TOOL

DESCRIPTION

The purpose of this project is to provide an advanced subsystem capability to CAD necessary for microcircuit prototyping technology. The Design Synthesis Tool for integrated circuit design uses the design description language to automatically synthesize a design from a functional description. It allows a designer to describe functionally what the IC must do and the design is then automatically generated. This tool allows the design to become contractor independent and technically independent. The same requirement can be used for today's technology and the same model 10 yrs. from now with new technologies. DoD can require ICs be specified in this language. The designer can take this function and have the computer go into its knowledge base and synthesize the design. Years later, when the part needs to be replaced, the design can be given to any vendor for manufacture of the replacement part. It would not be necessary to pay prohibitive prices to the original manufacturer or to scrap the part because of unavailability of the replacement part.

BENEFITS

The Design Synthesis Tool and the hardware descriptor language will allow documentation and storage of IC designs instead of spare parts. Because parts will be able to be reordered from the documentation, it will not be necessary to go back to the original manufacturer for replacement parts. This opportunity for getting competitive bids on replacement parts provides tremendous potential for payback.

The Design Synthesis Tool has the potential to save DoD billions of dollars. An example might be a radio with two small chips that are no longer operational. In a scenario where the company that made them had gone out of business, the radios would have to be rendered obsolete. The Design Synthesis Tool system would allow the design to be taken out of archive and brought to any manufacturer to fill the reorder. This scenario multiplied by hundreds of thousands of electronic components shows potential for tremendous savings. The goal of this project is to obtain a 10 to 50 times reduction in complex IC design time and cost by applying CAD tools and AI.

Additional benefits will be realized from junior engineers being able to produce very sophisticated designs automatically using the Design Synthesis Tool.

SIGNIFICANCE TO THE ARMY

This is a long-term project with a whole package of software tools that is expected to set an IEEE standard for a design descriptor language. A facility is now in place with the system running on a mainframe computer which will be opened up to government and industry in conjunction with the National Science Foundation. The system will be made available to anyone in industry with a need that is mutually beneficial.

Abstract # AAI04

ARTIFICIAL INTELLIGENCE (AI) APPLICATION TO ARMY AVIATION SYSTEMS FAULT ISOLATION

DESCRIPTION

The purpose of this project is to demonstrate various AI techniques applied to fault isolation for Army aviation systems, especially the AH-64 Apache Helicopter and the UH-60A Helicopter, and the Army Helicopter M65 Tow missile system. The goal is to reduce the time and accuracy in fault isolation. This project consists of three contract awards to McDonnell Douglas Helicopter Company, Hughes Helicopter, and Boeing Vertrol for the development of a prototype system using Artificial Intelligence technology for improving the ability to fault-isolate and repair Army aviation systems and subsystems. Each contractor developed its own diagnostic system and tested it on its own product. The project started in September of 1985. Hughes is finishing in February of 1988, McDonnell Douglas in March of 1988 and Boeing towards the end of 1988. Each contractor used different hardware and software and each has its own particular strengths.

A second part of the project, to install a modified standard off-the-shelf flight data recorder on board the aircraft to collect flight data, will be completed in November of 1988. The two parts of the project will show the ability of collecting data on board the aircraft, putting the data into a usable form, and using the data to aid in maintenance of the aircraft.

BENEFITS

Benefits include extension of time between overhauls, reduction in troubleshooting and maintenance time, lower skill level required of maintenance personnel, and improved accuracy of fault coding. When the systems were tested with intentional faults, the McDonnell Douglas system was accurate in finding the correct fault the first time 85% of the time; the Hughes system was correct 90% of the time.

SIGNIFICANCE TO THE ARMY

This project demonstrated that various AI techniques can be successfully applied to fault isolation for Army complex aviation systems including helicopter subsystems, weapons systems, and a cross section of various other systems. This is the first time solid state flight recorders have been used on Army helicopters and it has been shown that the flight data collected can be used for diagnostics and maintenance of the aircraft. As a result of this project, the Army has decided to put flight recorders on Blackhawk and Apache aircraft. Later, expert systems modules will be added to facilitate diagnostic information processing.

Abstract # AAI05

AUTOMATED WELDING SYSTEM FOR THE M-1 TANK

DESCRIPTION

The hull and turret of the M-1 tank are produced with the aid of an adaptive welding system integrated with a robotic vision system produced by Robotic Vision Systems, Inc. of Hauppauge, New York.

The first of four welding stations is being installed at the Lima Army Tank Plant in Lima, Ohio. Each station will employ dual rail-mounted robots which have combined 3D vision-sensors and effectors, such as preheat torches, electric arcs, and weldment extruders, mounted on the end of an articulated arm. The robot arm will be mounted on an elevator platform that runs on a set of rails alongside the workstations. In the hull welding station, positions are provided for two hulls to be processed at once. While one hull is being set up, the other is being worked on. When the latter is finished, the robot moves to the setup hull and begins to work. Concurrently, the latter hull is moved on to the next workstation and another hull is moved in for setup.

The operation of the system will proceed in four steps. First, the system will receive the basic configuration from the engineering computer system. The basic configuration includes the shape of the welding path and the specifications for the setup and fit between the pieces to be welded. Second, the vision system will inspect the area of the weld for proper setup, fit, and preparedness for welding. From this it will determine the total volume of the weldment necessary. Third, it will calculate the weld process parameters, such as the exact path to take, the amount of wire that will be needed to be extruded, and the rate at which the torch will move. Finally, it will perform the welding operation at speeds of up to 160" per minute.

The perceptual-processing and process-adaption algorithms were developed by the vendor to meet the needs presented by this system.

BENEFITS

The benefits of this system are an improved weld quality and reduced manufacturing costs due to a decrease in manual intervention.

SIGNIFICANCE

This system will be one of the first to perform real-time adaptation of the welding process-parameters in a production environment.

Abstract # AFAI01

CITS (CENTRAL INTEGRATED TEST SYSTEM) EXPERT PARAMETER SYSTEM (CEPS)

DESCRIPTION

CEPS is an expert system for maintaining the B-1 bomber. Data is gathered in-flight, then brought to the ground to be analyzed by the system. CEPS is in the third phase of a three-phase 6.4 program. Project development will be transitioned to the field at the end of phase three. CEPS consists of a maintenance advisor, including analysis tools and database for helping maintenance determine the source of problems. It helps at the flight line to determine which box to pull off the aircraft and in the base shops to determine which circuit board to pull.

Complex automated test equipment (ATE) currently runs test on the boxes that last from 20 minutes to 20 hours to determine which circuit is bad. The CEPS can drastically cut this time by telling where to start the test so that it becomes unnecessary to run the whole test. CEPS will receive flight data, give maintenance advice, send information to the Core Automated Maintenance System (CAMS) and generate trend analysis and historical reports.

BENEFITS

Quantified benefits include 30%-60% reduction in intermediate level ATE time; 30% reduction in "cannot duplicates" - identified failures on the plane which cannot be duplicated on the ground; and 30% reduction in "retest okays" - a box that is pulled into the shop, but at intermediate level test nothing can be found wrong.

Other benefits include very significant life cycle cost savings; training benefits inherent in the system; increase in aircraft availability directly related to required maintenance time; on-line information as to current configuration, including design properties; and the capability to be rapidly updated.

SIGNIFICANCE TO THE ARMY

CEPS is the first expert system ever to be applied to a problem this large. It is looking at doing diagnostics for an entire aircraft on one piece of hardware on the most complex aircraft ever built. If the application can be done for the B-1, it can be done for any other aircraft more easily.

CEPS is also significant in that its 6.4 funding means it will be put on an operational system at the end of the current phase (Phase 3). Completion is estimated to be late 1991. The system will be available for maintenance people on the flight line and base level shop at four main operating bases for the B-1 bomber and also at the Logistics Center an Oklahoma City. While very little of the system would be generic, the biggest benefit to other programs is a real-life example of what one might want to do for another venture and, most important, proof that it can be done.

Abstract # AFAI02

MAINTENANCE DIAGNOSTIC AIDING SYSTEM (MDAS)

DESCRIPTION

MDAS is a part of the Integrated Maintenance Information System (IMIS), which is an on-going R&D effort for integrated aircraft maintenance consisting of the following subsets: 1) Automated Technical Data; Training; Interface with other Ground Information Maintenance Systems; Physical Interface with the Airplane; and the MDAS Diagnostic System. MDAS is the heart of the IMIS project. The system pulls data from various sources and considers that data to give the technician the next best test and give him enough data to do the next best thing. The system steps him through and gives him instructions to correct the problem. Once the solution has been found, it is stored into the historical database.

The focus of MDAS is to take information from many sources, coordinate that information transparently to the user, and provide all the information needed by the technician through one hardware source. Of significance is that the one hardware source is a portable unit which will be used to perform the diagnostics at the flight line. The system will undergo field test on the F-16 aircraft in the fall of 1988.

BENEFITS

The cost savings that might be achieved from the MDAS project are estimated to be astounding. The portable unit used for diagnostics at the flight line will break the chain to the intermediate shop which hosts a massive amount of automated test equipment (ATE). Another significant savings will come from the reduction in mobility equipment. Currently, mobilization would require several aircraft loads to take ATE equipment to the battlefront. Other big savings would come from reduced stocking of spare parts. If the right component can be pulled on the flight line, the number of spares could be drastically reduced. Further savings will be the impact on time and skill level of maintenance personnel.

SIGNIFICANCE TO THE ARMY

While similar in concept to other fault code diagnostic systems outlined in this report, MDAS is significant in that it uses a portable unit, rendering it capable of doing diagnostics at the flight line, with the potential of eliminating a host of intermediate shop processes. While MDAS is significant of itself as an expert diagnostic system, it is also the heart of the IMIS project. IMIS in turn is a centerpiece project for DoD's Computer-Aided Logistic Support program whose purpose is to establish a unified interface with industry for the exchange of digital data. CALS's significance lies in the fact that DoD spends $5 billion annually to acquire and maintain weapons systems technical information, including manuals, engineering drawings, specifications, and other information essential to weapon system operation, maintenance, and procurement of spares. CALS will have great impact on this $5 billion as well as great impact on the way DoD conducts business.

Abstract # AFAI03

EXPERT MISSILE MAINTENANCE AID (EMMA)

DESCRIPTION

Work on this project is being carried out at a Raytheon Company plant in Bedford, Massachusetts. This facility is a government owned contractor operated facility. The objective of this project is to develop two "smart" missile Automatic Test Equipment (ATE) diagnostic systems (field level and depot level) for an in-house supported Air Force tactical missile guidance and control unit. The work is divided into two phases. Phase I is to apply knowledge engineering techniques to develop an expert system for use at an Equipment Maintenance Squadron (EMS). These techniques will include concepts of dynamic test sequencing and diagnoses explanation capability. Phase II will be enhancements to depot level of missile maintenance. This phase begins with development of a knowledge engineering plan and concludes with development of an expert system for use at the depot.

This project took 1-1/2 years for development of the prototype system requiring approximately 6 man years of effort at a total cost of just under $1,000,000. The prototype underwent extensive evaluation at Kimball Air Force Base. The system is directly interfaced to the automatic test equipment. It runs on a Symbolics 3675 using ART expert system shell and Common Lisp for the application code. Over 7000 lines of code were written with approximately 250 knowledge based rules. The system is currently being marketed and Raytheon is looking for someone to put it in the field. A videotape is available.

BENEFITS

Testing on the Sparrow missile showed that a novice using the expert system could diagnose a fault 30% more accurately and 20% faster than an expert not using the system. The system demonstrated super performance finding every fault that was inserted.

SIGNIFICANCE TO THE ARMY

This project is the first that demonstrates expert systems applied to missile testing. The quantified performance demonstrates the great improvement in diagnostic accuracy and speed that can be achieved through the application of expert systems.

Abstract # NAAI01

AUTOMATIC PROPELLER OPTICAL MEASUREMENT SYSTEM (APOMS)

DESCRIPTION

Robotic vision systems are one of the primary offshoots from research into Artificial Intelligence.

The Automatic Propeller Optical Measurement System (APOMS) is a 3-story high inspection robot with 3D vision-sensor utilizing laser-triangulation to provide accuracies to within .0025" locally. The APOMS will be matched with four Propeller Machining Systems (PROMS) within the Integrated Comprehensive Automatic Manufacturing of Propellers System (ICAMPS). The processing and control functions are distributed between two types of systems: an HP-1000 running the RTX operating system handles the real-time process-control, a Computervision workstation is executing the numerical calculations. The complete system is interconnected using the IEEE-488 communications interface.

The APOMS monitors the profile of the workpieces (propellers) as they are being machined. Due to the large size of the workpieces, as material is machined away, the propellers "spring" into new configurations as internal stresses are relieved. The APOMS reports on the current shape of the workpiece, and automatically adjusts the cutting programs to produce the optimal shape.

The primary vendor for APOMS, Robot Vision Systems, Inc. of Hauppauge, New York will integrate this system with the entire ICAMPS as it is produced. The software and mechanical technology derived from this project will appear in other robotic vision projects they partake in.

BENEFITS

One of the performance factors for undersea propulsion systems is "quietness". Precise machining produces a propeller which generates less noise as it moves through the water. Dynamic, manual intervention and reprogramming of the milling machines without this system would be prohibitively expensive in time and dollars.

With this system, quality of the machining process is not only higher, but more consistent, as well.

SIGNIFICANCE

Research in the field of Artificial Intelligence has been going on for nearly as long as there have been computers. Production application of this research and its offshoots, such as this project, are just now appearing.

Abstract # NAAI02

FAULT ISOLATION CELL

DESCRIPTION

The purpose of the fault isolation cell is to develop representative schemes and search methods for fault diagnostics of electronic systems. The project started in 1984 and will be complete in 1988, resulting in an operational prototype complete with documentation, manuals and implemented examples. The fault isolation cell demonstrates a way of modeling a system that allows automatic generation of search trees to optimize test programming and diagnostics of avionics equipment. Most of the information to build the model is available from CAD data and the system was designed to be incorporated into CAD systems.

The fault isolation cell consists of a shell and interface for test programmers, technicians, and automatic test equipment. It includes a data compiler which can take raw circuit data and put it into a format which is needed by the system. The prototype system is the result of ten man years of effort and $1.2 million in funding.

The system runs under Unix on a Sun workstation, on a Digital Equipment VAX or a Symbolics Lisp machine. The expert system shell was generated by the Navy and is called the Fault Isolation Shell (FIS). There are approximately 50,000 lines of applications code and 200-300 rules for a typical piece of avionics equipment. The system has been tested on the K-18 radar receiver exciter and displayed complete fault coverage to the module level, which is the level to which that piece of equipment is tested.

BENEFITS

Preliminary estimates show that the fault isolation cell can reduce test time in automated test equipment by 25% by generating optimal test trees and reduce procurement for test sets by 25% by automating fault tree generation for test program sets.

SIGNIFICANCE TO THE ARMY

The fault isolation cell is being offered by the Navy as public domain stand-alone software. The Naval research center is offering initial support and the system is available with a very simple licensing agreement, requesting user evaluation and copies of any reports issued as a result of its use. The system is potentially applicable to all facilities that do test and repair of avionics systems. This includes at least 50 naval sites and should also be of interest to the Army, the Air Force, and all avionics contractors. The system is currently being evaluated by Warner-Robbins AFB and has been requested by six electronics suppliers.