ABSTRACT

Uses and Applications of
Artificial Intelligence in Manufacturing

by

Manojkumar H. Desai

The purpose of the THESIS is to provide engineers and personnels with a overview of the concepts that underline Artificial Intelligence and Expert Systems. Artificial Intelligence is concerned with the developments of theories and techniques required to provide a computational engine with the abilities to perceive, think and act, in an intelligent manner in a complex environment.

Expert system is branch of Artificial Intelligence where the methods of reasoning emulate those of human experts. Artificial Intelligence derives it's power from its ability to represent complex forms of knowledge, some of it common sense, heuristic and symbolic, and the ability to apply the knowledge in searching for solutions.

The Thesis will review : The components of an intelligent system , The basics of knowledge representation , Search based problem solving methods , Expert system technologies , Uses and applications of AI in various manufacturing areas like Design , Process Planning , Production Management , Energy Management , Quality Assurance , Manufacturing Simulation, Robotics , Machine Vision etc.

Prime objectives of the Thesis are to understand the basic concepts underlying Artificial Intelligence and be able to identify where the technology may be applied in the field of Manufacturing Engineering.

USES AND APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN MANUFACTURING

by

Manojkumar H. Desai

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APPROVAL SHEET

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This thesis is
dedicated to my father
Shri. Hasmukhlal M. Desai

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CHAPTER 1

INTRODUCTION TO ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS

Integration has become one of the main issues in manufacturing today. Experts believe that progress in this area will mark a decisive step in to the future of production or with other words toward the factory of the future. Despite great there however still a considerable gap between the user requirements and performance of today's systems.

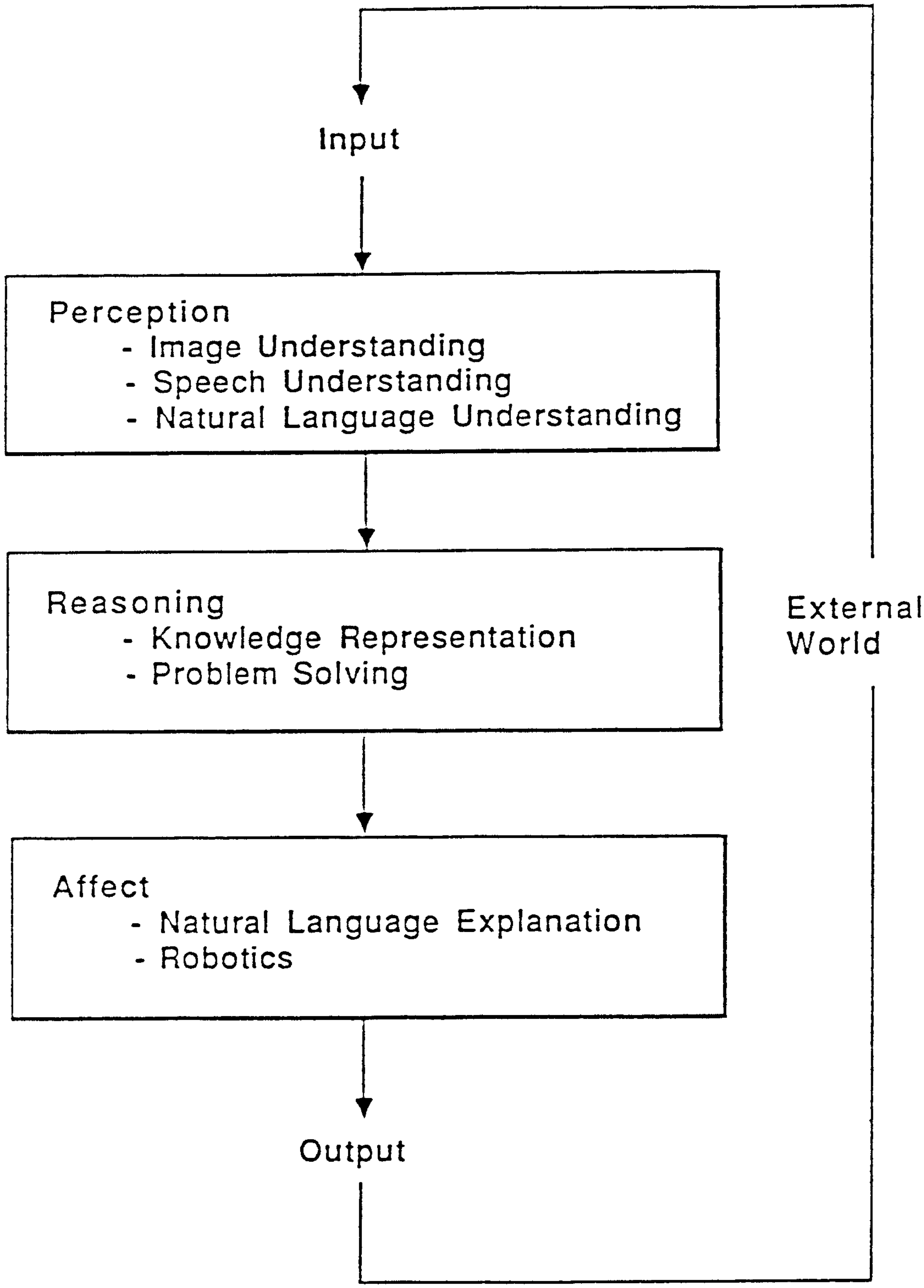
Taking a comprehensive view of manufacturing from product design, process design, production, distribution to field service and reclamation, complexity of the process and the multilayered interactions is an inherent quality. Experience a " rules of thumb " or " standards of good practice " used to be the approaches to these problems which often ill defined and under constrained. Conventional computing, however usually fails.

The aim of the THESIS is to bridge the gap between technical knowledge and the managerial and organizational questions regarding applicability and introduction of these systems. It seems reasonable to claim that a sound knowledge about the technical concepts and their potential will become increasingly important for all levels of management. Even small and medium size companies may fell an increasing pressure to adopt the new technologies since the large conglomerates will tend to integrate their subcontractors into an overall manufacturing concept.

Combinatorial complexity and non-linearity are the types of problems Artificial Intelligence attempts to solve. AI in the context of manufacturing as a three stages problem solving technique.

The first step is represented in the question: " What knowledge is

Fig 1. Components of an intelligent system



available to overcome the combinatorial explosion? " The second : " How can this knowledge be represented in the computer ? " and third : " How can this knowledge be utilized by computer ? ".

1.1 What is Artificial Intelligence

Artificial intelligence is the science concerned with the creation of machine intelligence which is able to perform tasks heretofore only performed by people. Much of this machine intelligence is symbolic and heuristic. Artificial Intelligence deviated from the juggernaut of computer research in the early 50s by exploring how computers can be used for more than just numeric processing. Back during the days when languages like COBOL and FORTRAN were being defined, people at Carnegie - Mellon University and MIT where investigating the simulation of human problem solving on a computer. Some of the first programmes at that time were being applied to solving logic problems as found in the book " Principle Mathematics " by Whitehead and Russel. Problems such as chess, checkers, image understanding etc... began to be investigated. As a matter of fact one interesting set of problems that people chose to demonstrate the AI techniques could solve problems at the same level that humans could, were chosen from the intelligence tests that we normally give to students to measure their IQ. It happens that computers are very good to solve them. The difficulty in the development of machine intelligence lies in programming computers to perform common sense reasoning, i.e reasoning about everyday occurrences which people find easy to do.

Thus the AI is " The development of theories and technique required to provide a computational engine the abilities to perceive , think and act in intelligent manner, in a complex environment."

Basic Theories

* Research.
* Knowledge Representation.

Basic Areas

* Problem solving , Expert systems.
* Learning.
* Natural Language.
* Perception: Speech, Vision.
* Effectors: Robotics, Mobility.
* Programming Environments: Lisp , Prolog

Knowledge Engineering Systems.

Applications

* Medical.
* Engineering / Manufacturing.
* Financial.
* Games.

Research

* Problem Solving (thinking) can be viewed as search through a state space.
* A state is a collection features (values) that define some situation.
* The application of an Operator transforms the current state in to a new state.
* Problem solving is finding a path from an initial state to a goal state.

Hierarchical search

We can reduce search complexity by focusing on the more salient aspects of the problem.

Example: Plan the major operations first.

Opportunistic Search

For complex , nonlinear problems more powerful search control is required; recognizing where in the problem space the next , most important decision is to be made.

1.2 Attributes of an AI and Expert Systems

Attributes of an AI systems

Insight: General Methods

* Adaptable
* Robust
* Reduced Error
* Performs sometimes
* Inefficient

Error: Weak methods

* Takes more times to solve problems.

Exprrt systems

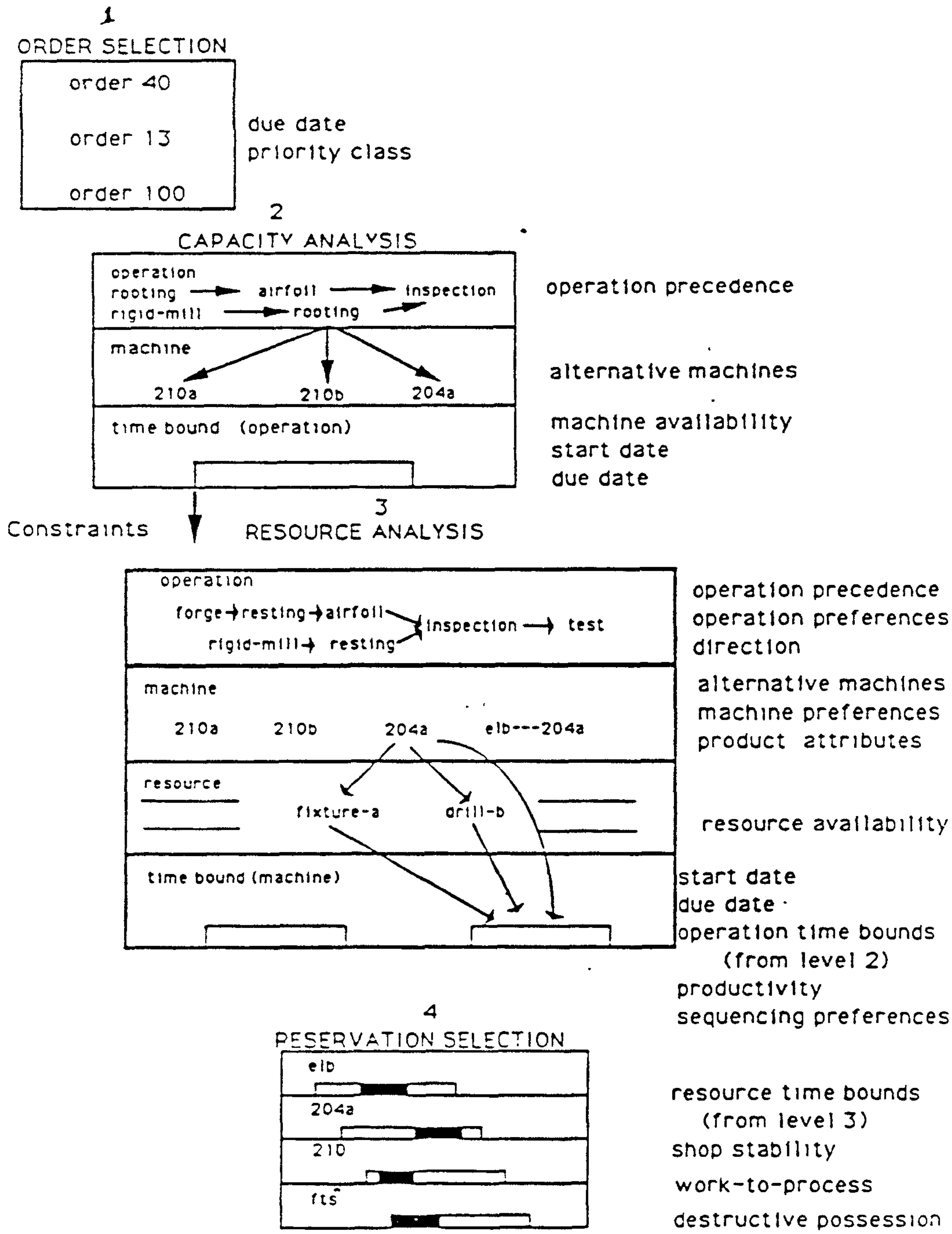
The power of an expert system derives from the knowledge it possesses and not from the particular formalisms or inferences schemes it deploys (Feignbaum, 1977).

Attributes of an Expert systems

Insight: Capture expertise

* High performance
* Efficient
* Reduced Error

Fig 2. A factory schedular (search hierarchy)



* Not adaptable

* Not robust

Error: Hacking expertise

What is an expert system?

* A measure of performance?

* A rule based program?

* An emulation of expert's problem solving behavior?

NO ! The expert system is:

- An extension of AI search where additional knowledge is used to guide the search process.

- Resulting search behavior emulates human expertise.

A fundamental law of AI

The law of knowledge - search Duality states:

* Search compensates for lack of knowledge

* Knowledge reduces uncertainty thereby reducing search

Expert system search techniques:

* Structured selection/ classification problem solving

* Pattern directed inference

Structured selection:

Problem Type:

Select from a few (< 100) alternative solutions for which analytic models do not exists, but heuristic casual relations do.

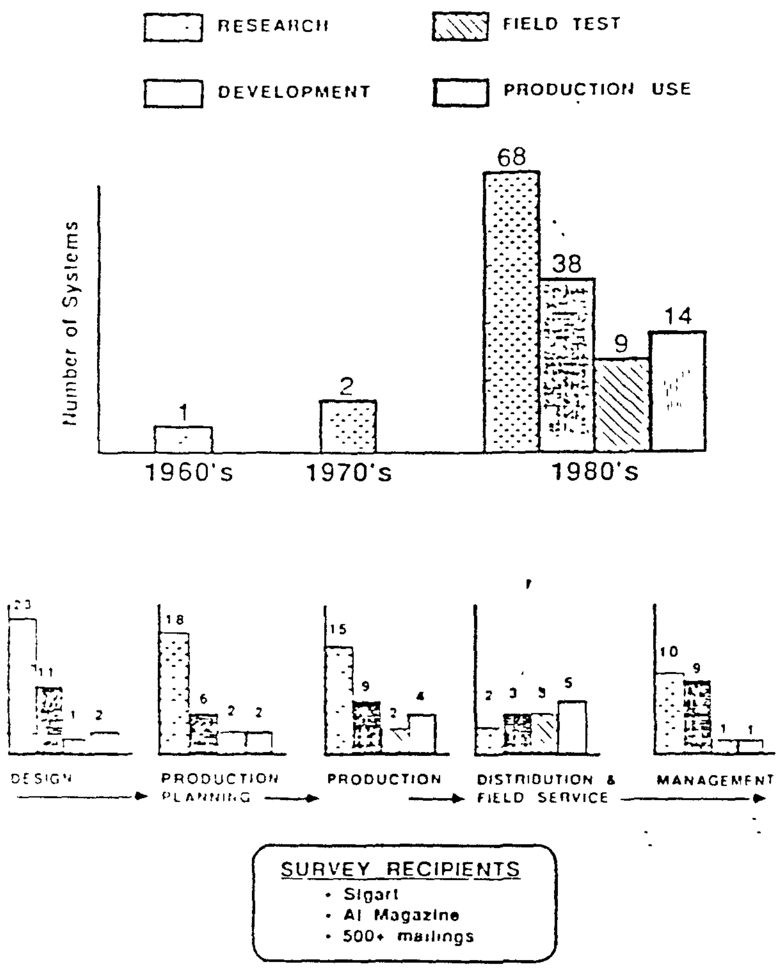
Technology:

* Use rules to represent the casualties of situations: link evidence to hypotheses

* Form networks transitive causality

Note: Rules are imprecise and require a calculous of uncertainty.

Fig 3. Survey of AI systems



UNCERTAINTY:

Not all rules are absolutely certain.

Techniques:

Associate with a each rule a measure of how certain the eduction is true:

* Bayes theorem.
* MYCIN certainty fectors.
* Prospector certainty factors.
* Dempester- Schaefer.

Pattern Directed Inference

Problem Type:

Large complex problems that exhibit a fair amount of sequential structure

Technology

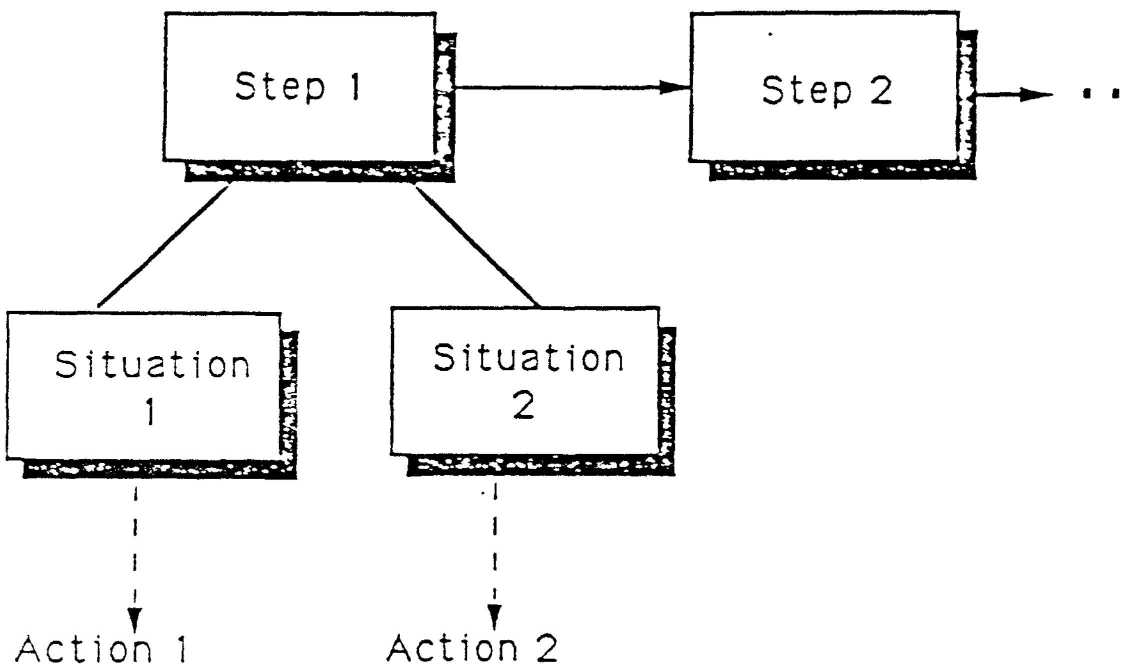
- The problem is decomposed in to subproblems,
- Subproblems are solved separately, hence reducing combinatorics,
- Each subproblem may be solved in one or more ways, and
- Constraints are propagated between subproblems to maintain consistency.

AN EXAMPLE

If: The current subtask is assigning devices to unibus modules
And there is an unassigned dual port disc drive
And the type controller it requires is known
And there are two such controllers neither of which has any devices assigned to it
And the number of devices which these controllers can support is known

Then: Assign the disc drive to each controller
And note that each controller supports one device

Fig 4. Pattern directed (forward) chaining



1.3 Knowledge Based Systems

The power of a knowledge based system derives from a combination of the knowledge it possesses and formalisms and inference schemes it deploys.

ATTRIBUTES OF A KBS

Insight: Knowledge and Methods.

* High performance---> High quality.
* Efficient / reduced cognitive load.
* Reduced Error.
* Adaptable.
* Robust.

MODEL BASED REASONING

For many complex systems heuristics do not suffice: Nuclear plants, complex continuous processes.

Example of Aluminum alloy design.

- Combines heuristics with analytical knowledge.
- Rules serve as the glue with calls on other types of knowledge.

Is there a representation problem ?

Consider the following database record:

OBJECT	COLOR
DRILLING MACHINE	GRAY

What does it mean?

* All drilling machines are gray?

* All drilling machines are gray unless specified otherwise?

* A particular drilling machine is gray?

* When choosing a color for a drilling machine, you should choose gray?

* What is drilling machine anyway?

What is the problem?

* The meaning of the contents of data structure cannot be interpreted unambiguously without referring to the programs that create and manipulate it.

* With the cost of codifying the data, information and knowledge so high, how are we do reuse/share knowledge among functions in the interpret it consistently?

What is knowledge representation

A set of syntactic conventions that specify the form of notation used to express descriptions, and a set of semantic conventions that specify how expressions in the notation correspond to things described.

Requirements of knowledge representation

* Epistemological Adequacy (Expressiveness):

The representation can be used practically to express the facts that one actually has about the aspect of the world (McCarthy & Hayes 1969)

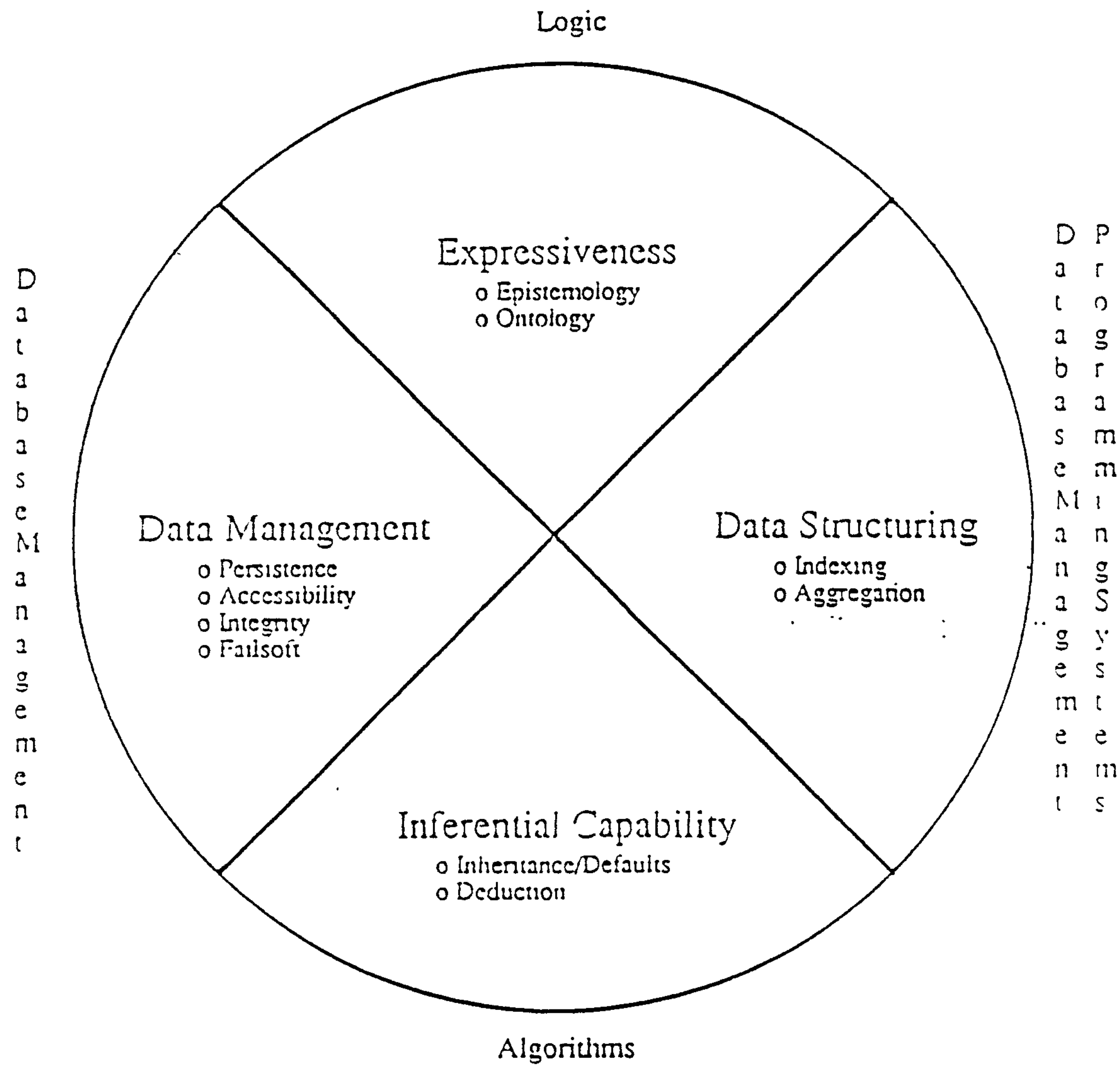
* Heuristic Adequacy (Inference):

The reasoning processes actually gone through in solving a problem are expressible in the language (McCarthy & Hayes, 1969)

* Dynamic Adequacy (Management):

The contents of the representation can be managed as it grows and chances over time.

5. Knowledge Representation



* Computational Adequacy (Complexity):

The complexity of solving a problem with a particular representation is acceptable for the particular domain.

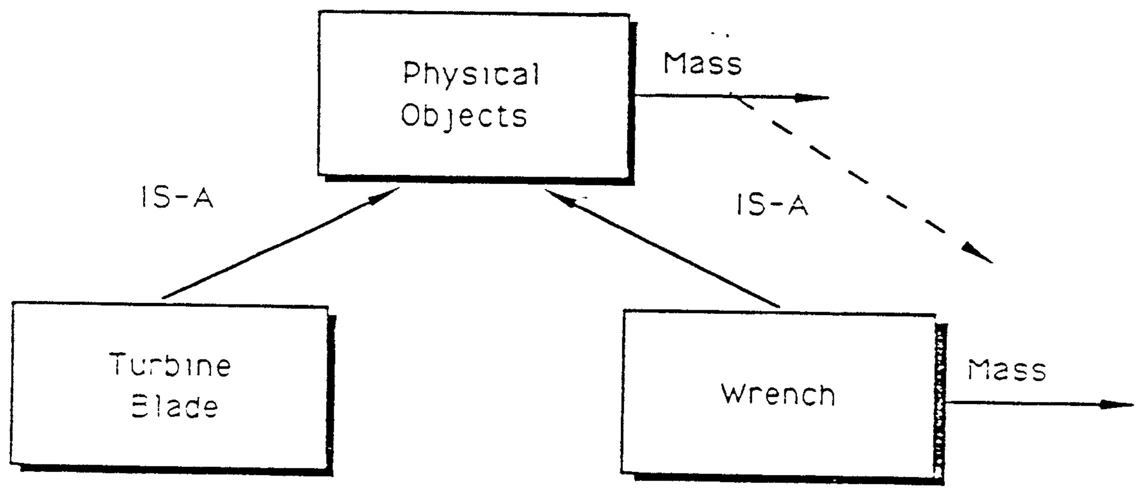
Though representations may have equivalent expressiveness, the may not be useable.

AN EXAMPLE

" The milling operation precedes the drilling operation. It is composed of two setups : Setup & Run. Setup takes one hour and run time 10 minutes. Two resources are required. A five pound wrench and a healthy operator. The wrench is only required during set up. The operation is performed in cost center 48."

Fig 6. Classes

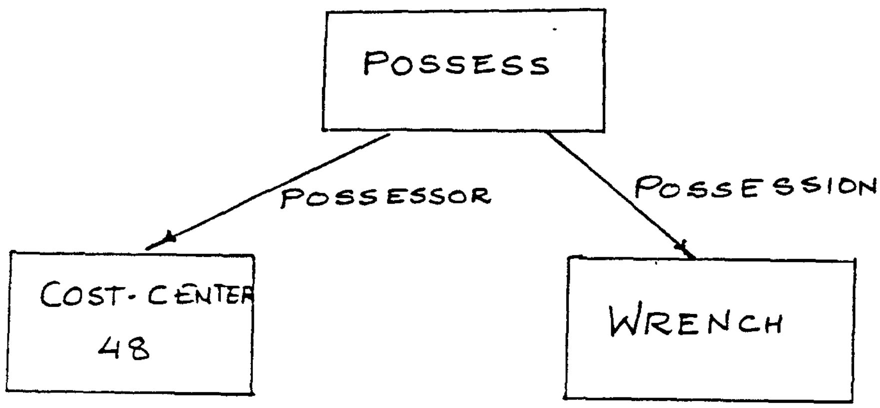
Objects may be structured in to classes or taxonomies via IS-A relations.



Sub classes inherit properties from super classes.

Fig 7. Possession

Someone possesses an object.



Activity

Activities transform states.

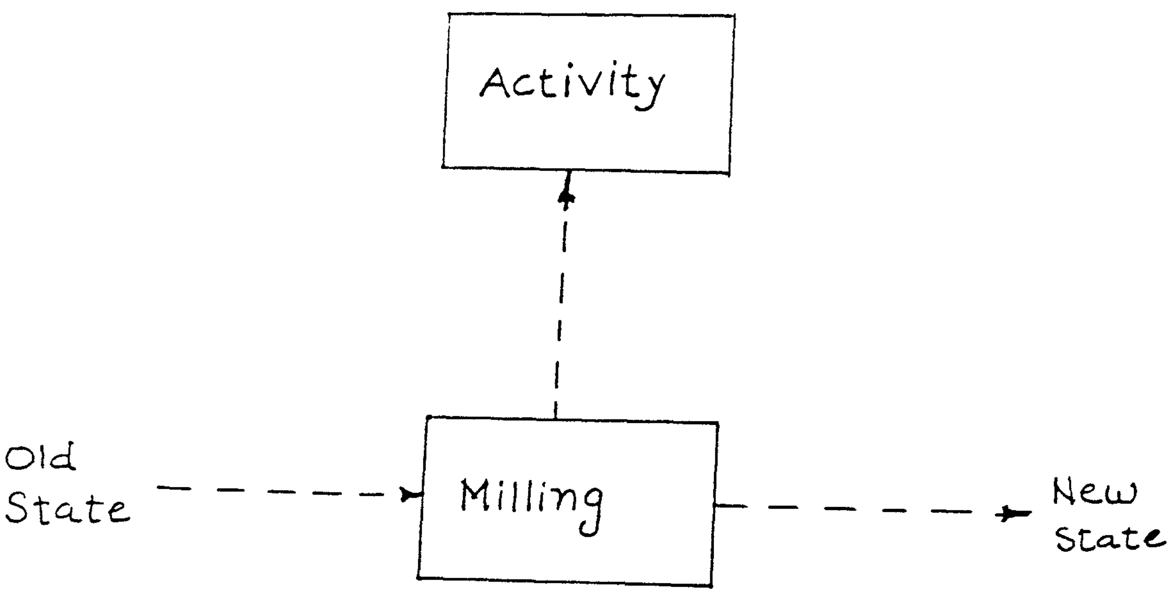


Fig 8. States

The world is modeled as a sequence of states over time.

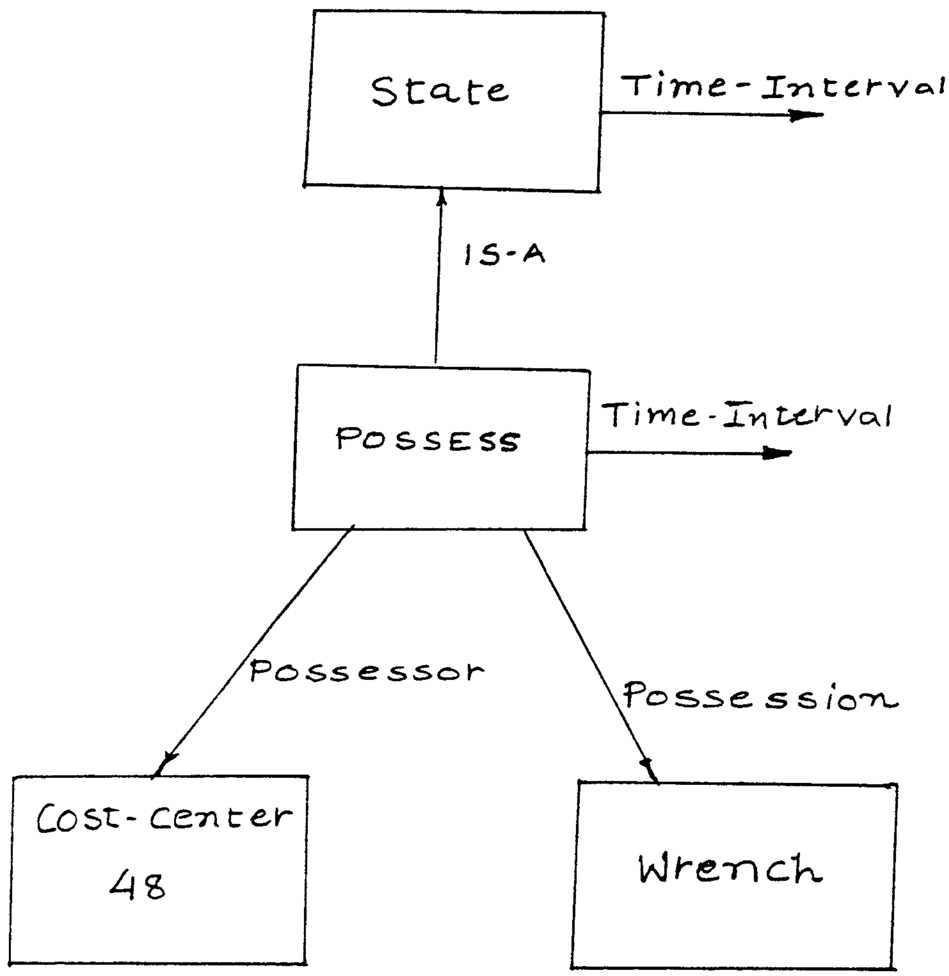


Fig 9. Composite states

A state may be composed of sub-states.

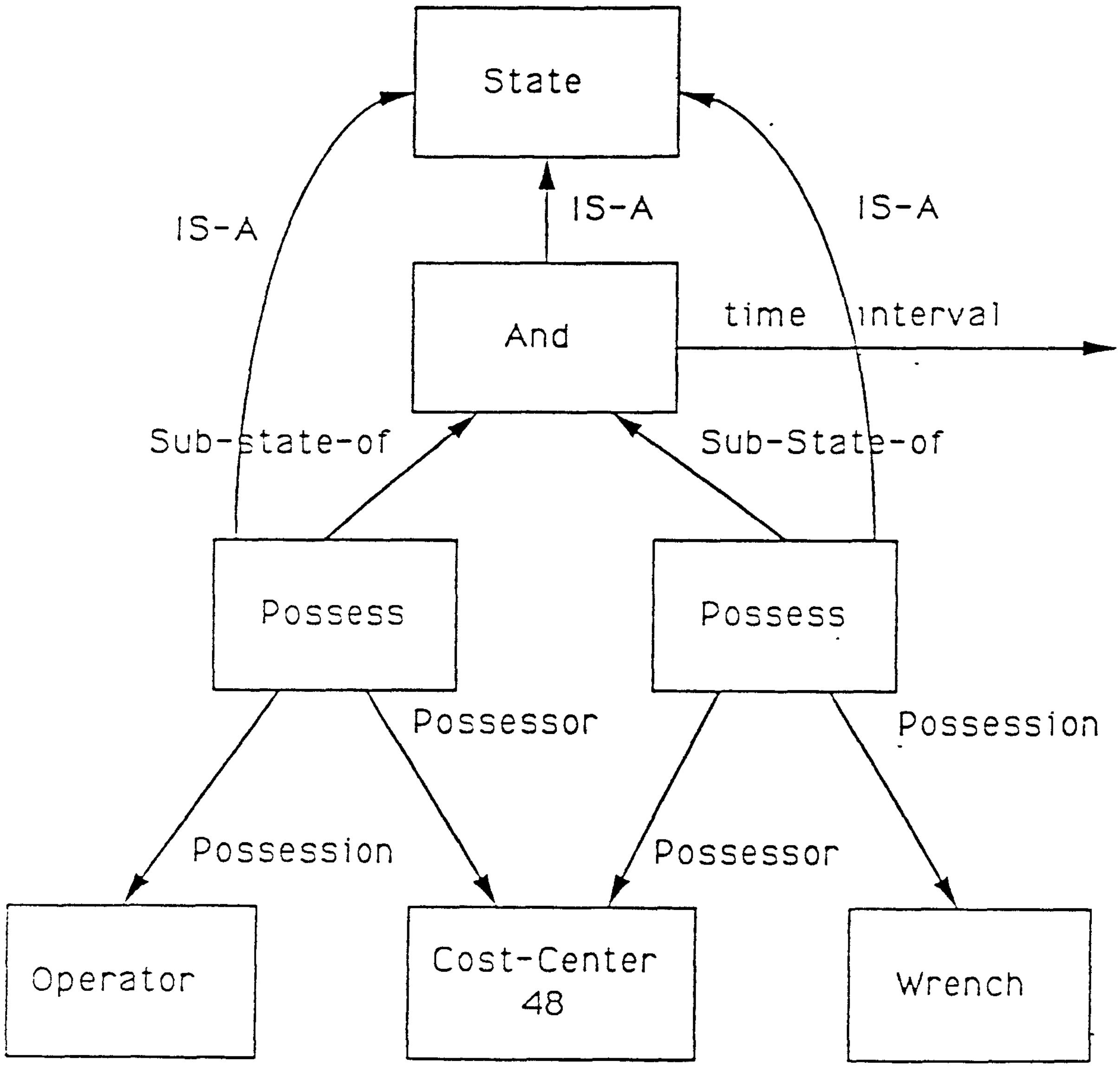


Fig 10. Abstraction

Activities may be composed of sub-activities.

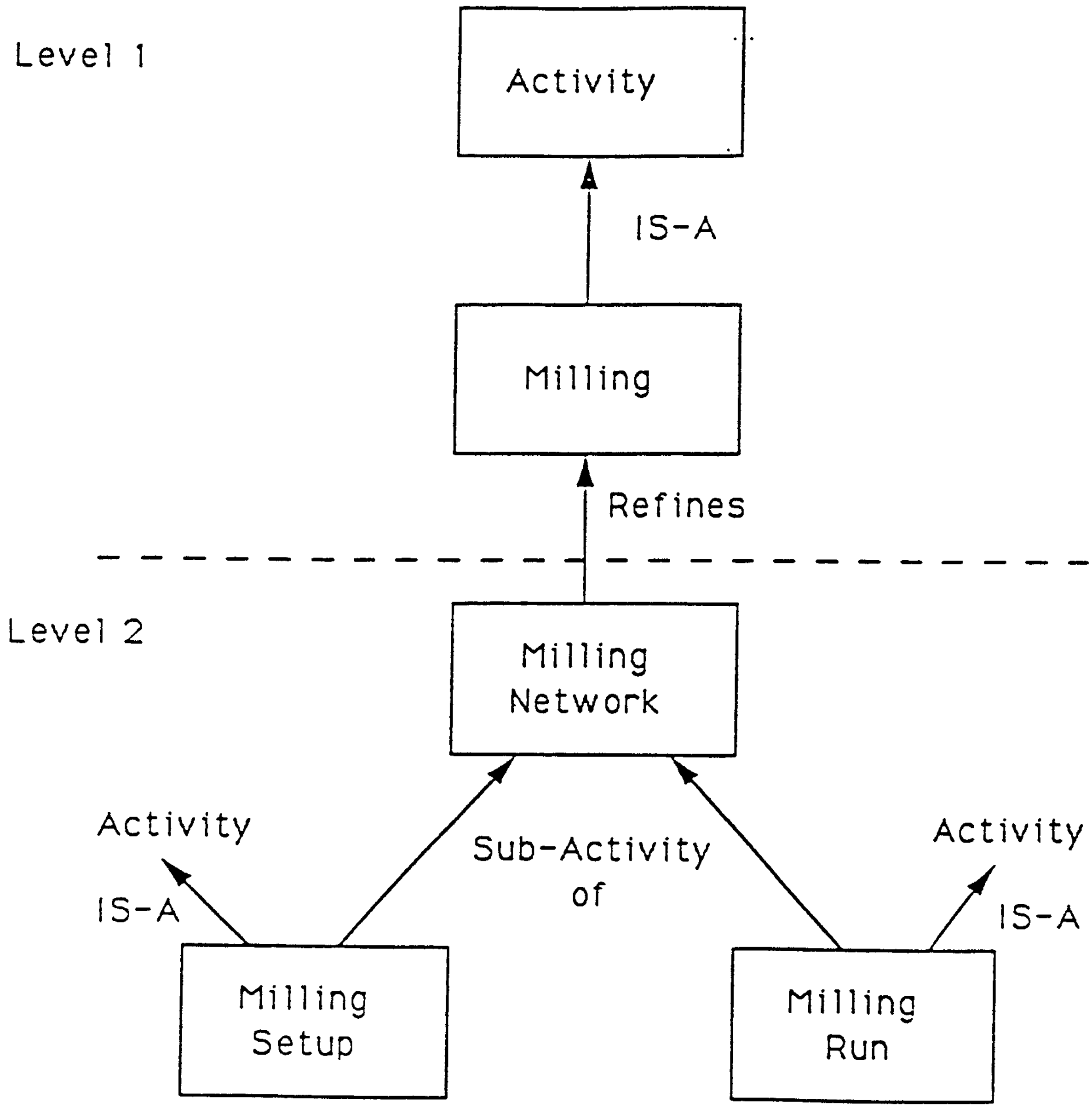


Fig 11. Casual relations

* Enablement - what must be true of the world in order for an activity be performed.
* Casualties - what new states are created by an activity.

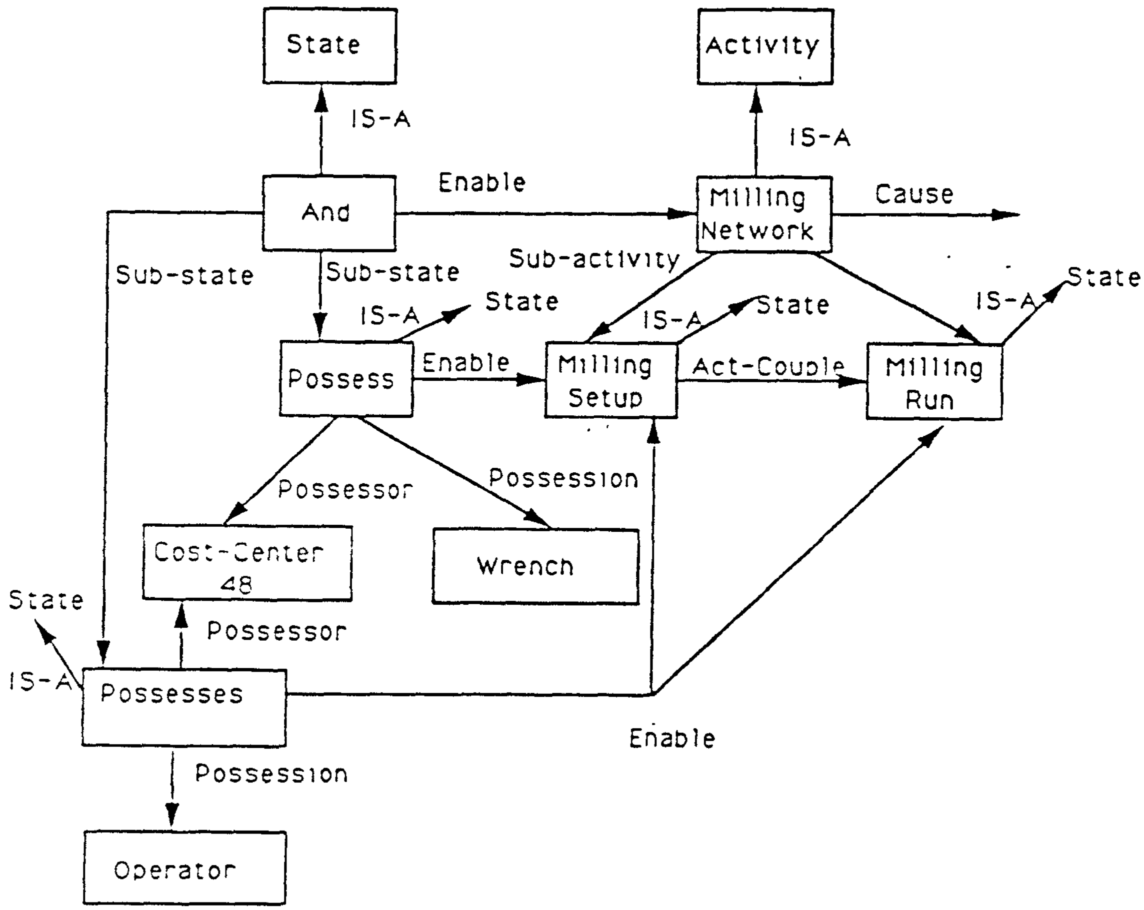
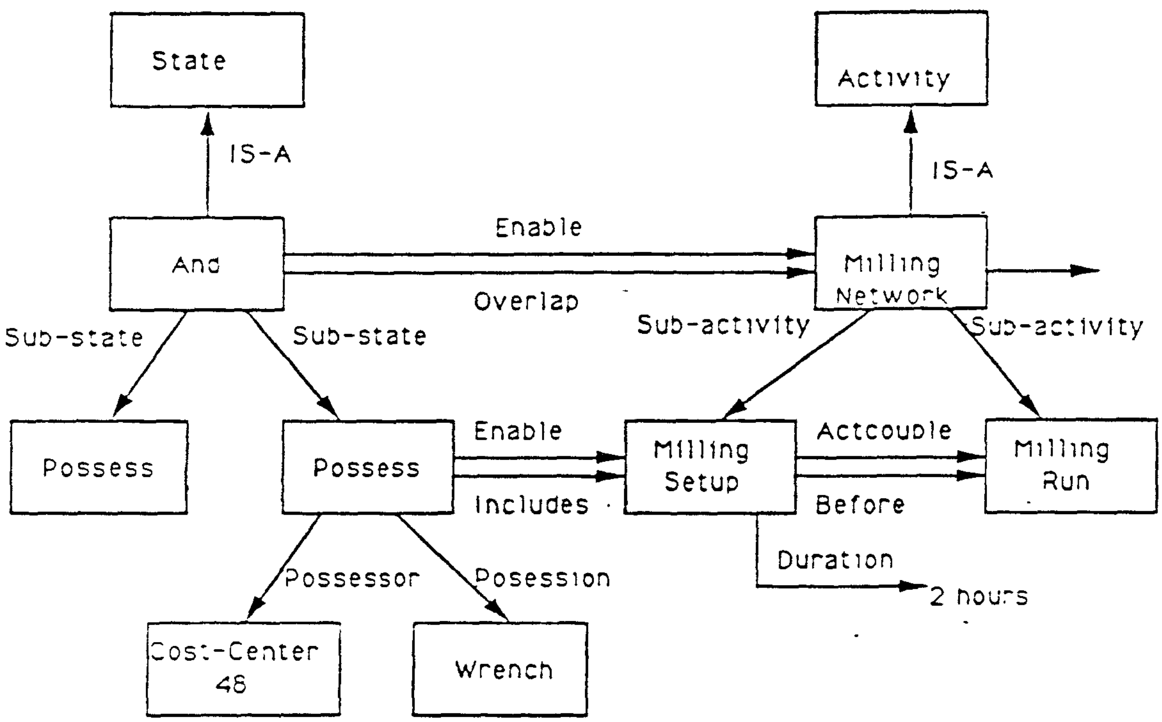


Fig 12. Time

When do states exist and when are activities performed ?



1.4 Role of AI

First realize that AI bridges the gap between what we are know how to solve algorithmically, and what we do not; problem that are complex, uncertain and ambiguous.

Almost all
Nonlinear
Models

AI		Conventional Programming
* symbolic * heuristic * separates control from knowledge * non- deterministic * satisfices	Linear Problems Complete Analytic Models Calculations	* numeric * algorithmic * integrates control and information * deterministic * optimizes

Incomplete Models

Uncertain Model

AI can be viewed as another programming technique in the software engineer's toolbox.

Choosing a problem

* Choose a problem that is important with measurable returns.
* Can the problem not be solved using another approach?

* Does an expert exist? Are they available? Are they interested?

* Is the input well defined? Output?

* Can it be solved using experience of from first principle?

* Is the customer part of team?

* Are expectations in line with deliverables?

* Do you have an experienced AI engineer?

A safe approach

1. Start small.

    * Choose an easy problem

    * Experiment

    * Use the best

    * Promise nothing

2. Educate yourself

    * Courses

    * Seminars

3. Link up with someone

    * University

    * Consultants

    * Industry

4 Acquire technology.

    * Knowledge engineering systems

5. Educate management

    * Understand the technology !

Based on the above discussion we can conclude that AI is the development technique required to provide a computational engine the abilities to perceive , think and act in intelligent manner , in a complex environment using theories with a number of applications in number of areas. Attributes discussion among AI , Expert systems , and knowledge based systems reveals comparison between them and leads to choose correct method or approach for solving the specified problem. Very few AI systems are in use today , most of under development , research or field testing. Mainly they are Design , Production Planning , and Management.

AI have a major applications in Medical , Engineering / Manufacturing , Financial Games etc. , with an emphasis in Manufacturing as it enjoys highest research , development and working systems. AI is exploring its new horizons of applications today in manufacturing. Manufacturing is the basic tool for integration and improvement. As a Graduate student in Manufacturing Engineering I realize that AI is a powerful tool for Manufacturing environment this fact tend me to pursue work in various applications of AI in manufacturing.

CHAPTER 2

2.1 Expert Systems Overview

What are expert and knowledge based systems?

Expert systems are currently the most emphasized area in the field of Artificial Intelligence and represent the leading edge of commercialization in computer science. It can be stated as " An intelligent computer program that uses knowledge and inference procedure to solve problems those are difficult enough to require significant human expertise for their solution. The knowledge necessary to perform at such a level plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field. "

The knowledge of an expert system consist of facts and heuristics. The facts constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The performance level of an expert system is primarily a function of the size and quality of the knowledge base that it possesses.

The potential use of expert system appear to be limitless. They can be use to diagnose , monitor , analyze , interpret , consult , plan , design , instruct , explain , learn , and conceptualize. Thus they are applicable to mission planning , monitoring , tracking and control , communication , signal analysis , command and control , intelligence analysis , targeting , construction and manufacturing (Design, planning , scheduling , control) , education , equipment (design , monitoring , diagnosis , maintenance , repair , operation , instruction), image analysis and interpretation , professions (law , medicine , engineering , accounting , law enforcement), consulting , instrumentation interpretation , analysis , software (specification , design , verification , maintenance , instruction) and weapon systems (target identification , electronic warfare , adaptive control).

An expert system consist of :

1. A knowledge base (or knowledge source) of domain facts and heuristics associated with the problem.

2. An inference procedure (or control structure) for utilizing the knowledge base in the solution of the problem , and

3. A working memory " global database" for keeping track of the problem status , the input data for the particular problem , and the relevant history of what has been done.

An expert system differs from more conventional computer programs in several important respects. Duda observes that in an expert system " there is a clear separation of general knowledge about the problem (the rules forming a knowledge base) and methods for applying the general knowledge to the problem (the rule interpreter)." In a conventional computer programme, knowledge pertinent to the problem and methods for utilizing the knowledge are all intermixed, making it difficult to change the program. In expert system , " the program itself is only an interpreter (or general reasoning mechanism) and ideally the system can be changed by simply adding or subtracting rules in the knowledge base."

What is knowledge engineering?

In simplest terms , it is the codification of a specific domain of knowledge in to a computer program that can solve problems in that domain. the task involves the cooperation of human experts in the domain working with the program designer and/or knowledge engineer to codify and make explicit the rules that a human expert uses to solve real problems. The expert often uses rules applied almost subconsciously , and the program usually develops in what may seem to be a hit - or - miss method. As the rules are refined by using the emerging program , the expertise of the system increases.

Major goals in the knowledge include the construction of programs that are modular in nature , so that additions and changes can be made to one module without affecting the working of other modules. A second major goal is the obtaining of a program that can explain why it did , when it did , what it did it.

Feigenbaum defines the activity of knowledge engineering as follows:

" *The knowledge engineer practices the art of bringing the principles and tools of AI research to bear on difficult application problems requiring expert's knowledge for their solution. The technical issues of acquiring this knowledge , representing it , and using it appropriately to construct and explain lines of - reasoning , are important problems in the design of knowledge based systems. the art of constructing intelligent agents is both part of and an extension of, the programming art. It is the art of building complex computer programs that represent and reason with knowledge of the world.*"

2.2 Artificial Intelligence & CIM Systems

Manufacturing at risk ?

"Japanese excellence in manufacturing originates with the Japanese belief that through continuous economic growth Japan will obtain " its proper place in the world, " the belief that manufacturing is the key to continuous economic growth , Japanese resolve to be first among world class manufacturing nations - as a matter of national priority , and the Japanese willingness to make the long term commitments necessary to achieve this goal. " *Findings of the US Department of Defence Technology Assessment Team on Japanese Manufacturing Technology , 1989.*

Computer Integrated Manufacturing
the key to American Manufacturing Competetiveness?

CIM : stage 1

Using computers to automate flexible labor.

* Computer controlled machines.
* Material handling systems.
* Cell controllers.

CIM : stage 2

Integrating islands of flexible automation.

* Databases.
* Networks: MAP.

CIM barrier

Stages 1 & 2 focused on the use of computers to implement decisions made by people , but problems still abound:

* Information complexity.
* Scarce expertise.
* Decision complexity.
* Decision timeliness.
* Coordination.

Need to focus on automating decision making!

CIM : stage 3

Using computers to automate indirect labor.

* Planning.
* Control.
* Troubleshooting.

CIM : stage 4

Broadening the application of computer integration to the product manufacturing life cycle:

* Design.
* Planning.
* Production.
* Distribution.
* Field Service.

CIM : stage 5

Integrating all facets of the firm:

* Sales.
* Marketing.
* Engineering.
* Manufacturing.
* Administration.

Key Technologies

How can be achieved stages 3 through 5 ?

* Databases.
* Networks.
* Interfaces.
* Intelligent Systems, Artificial Intelligence.

CHAPTER 3
AI IN MANUFACTURING

3.1 Artificial Intelligence in Design

General Discussion:

What does A.I have to offer designers and engineers?

* A new tool (like calculus or statistics)
* A new way of thinking about what they do

Where it is useful?

A few successful domain include:

* Structural design
* Construction planning
* VLSI design and process planning
* Design of mechanical assemblies
* Power plant configuration
* Design of injection molded components

In general , AI methods tend to be successful in design and planning problems for which:

* There is body of knowledge that can be organized and written down. (i.e., there are acknowledged experts);
* The knowledge is not so formal that tables or procedures would work as well;
* The knowledge is easy to articulate in the form of rules, constraints, etc. (e.g, not a "skill")

A.I In Design

Consider three basic types of design problems for which AI methods have been, or being, successfully applied:

1. Expert Advisors
2. Parametric Design
3. Configuration Design

1. Expert Advisors

Characteristics:

* Most established, most common, easiest to implement.
* Adapted from early successes in medicine, oil exploration, maintenance etc.
* Exploit standard expert- system shells.
* Applicable to most design domains -- Wherever advice, rules of thumb experience are useful.
* Numerous documented success stories.

Investment:

* A small one may take 3-12 man months including time to learn the expert system shell. A large one, involving extensive interviews with specialists , testing, etc., may take a few years before it is fine tuned.

Payoff:

* Faster designs (faster than applying handbooks or consulting with a group of different specialists).

* Better designs (more consistent, more assured, that all the checklist items have been throughtly addressed).

* Standardization (advice leads to more uniform approach).

* Better understanding of what your organization actually does.

Examples:

1. Assembly advisor (Saphire Inc)

   * Format: Expert system + Hypercard for convenient user interface

   * Input: Description of the components and how assembled.

   * Output: Estimate of assembly cost and suggestions to improve the assembly.

2. Injection molding advisor (Sekisui Industries)

   * Format: Expert system + Object oriented programming environment. Integrated with commercial CAD system and library of procedures.

   * Input: Surface shape of component , material , features , design , specifications.

   * Output: Preferred draft angles , parting lines , gate locations , etc . and CAD model of component.

Fig 13. Assembly advisor -- entering the assembly

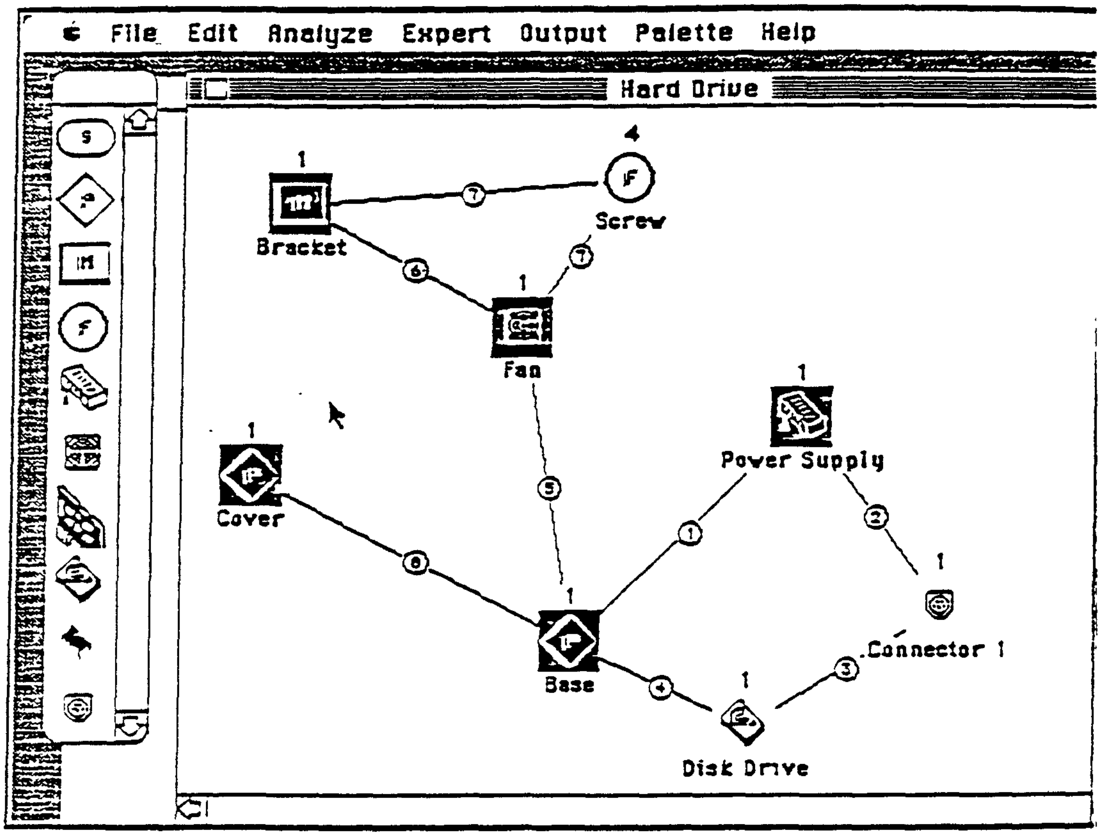


Fig 14. Assembly advisor -- basic structure of the expert system

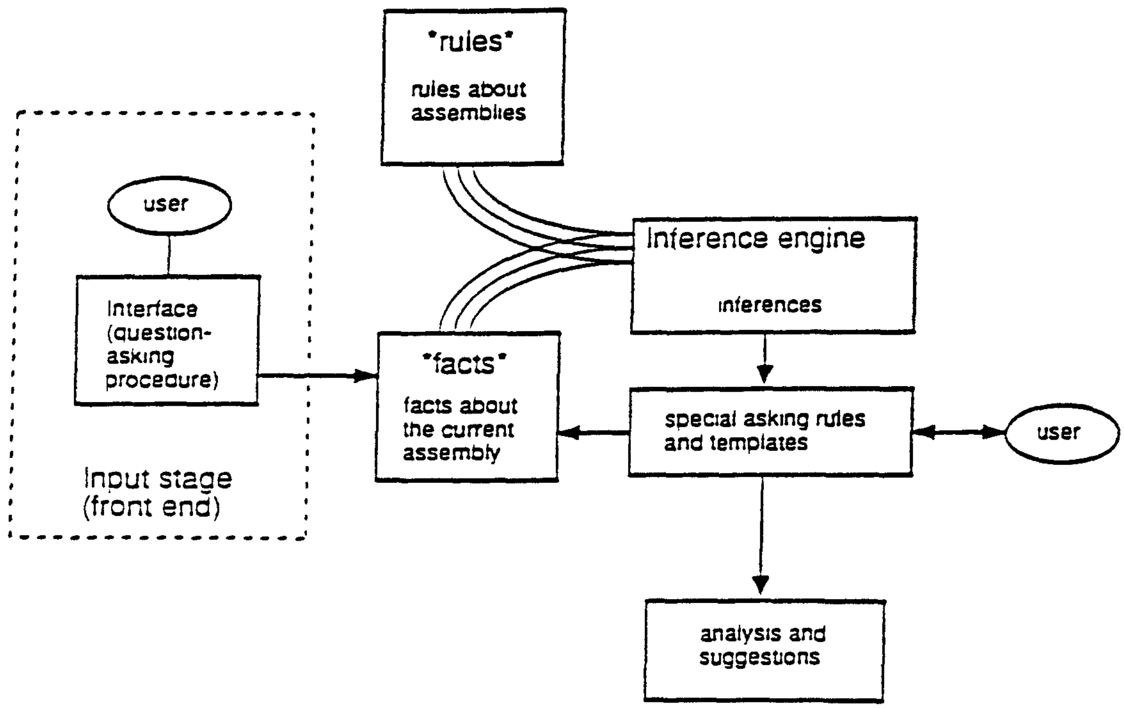


Fig 15. Assembly advisor -- responding to queries about the connections between components

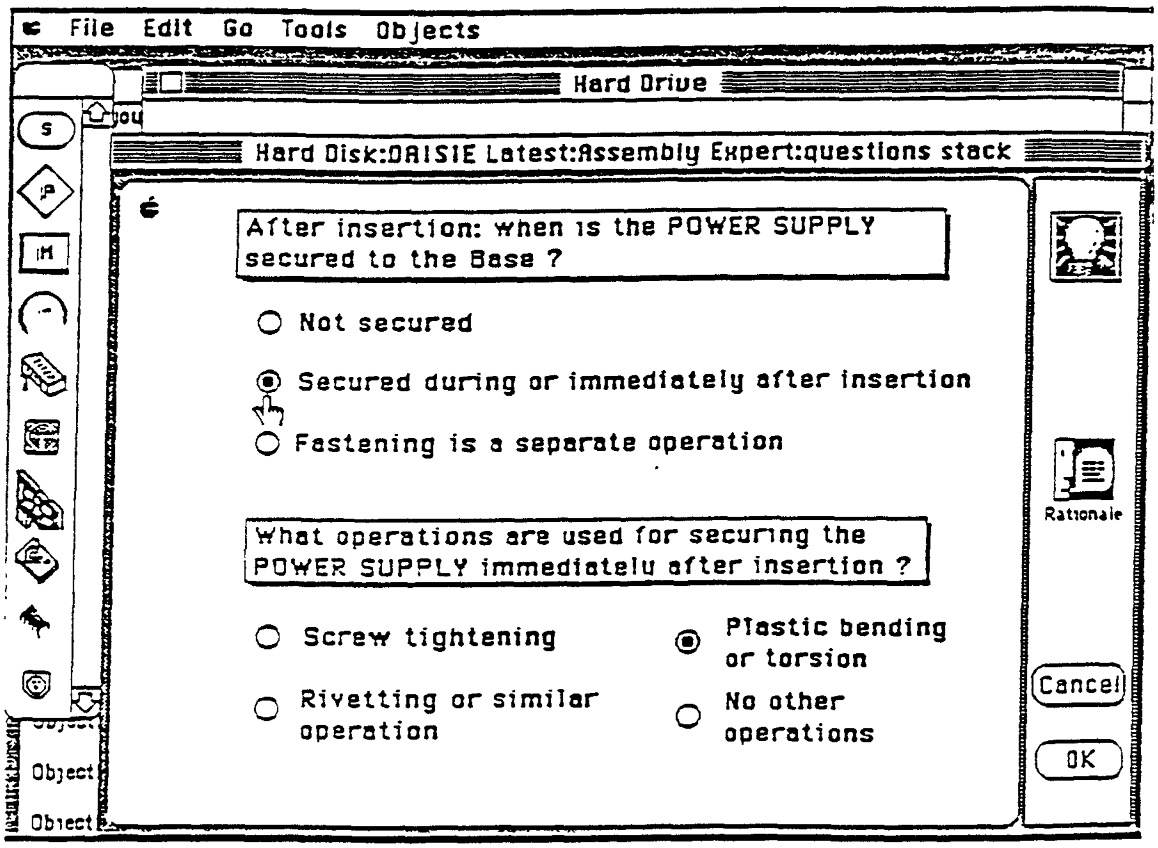
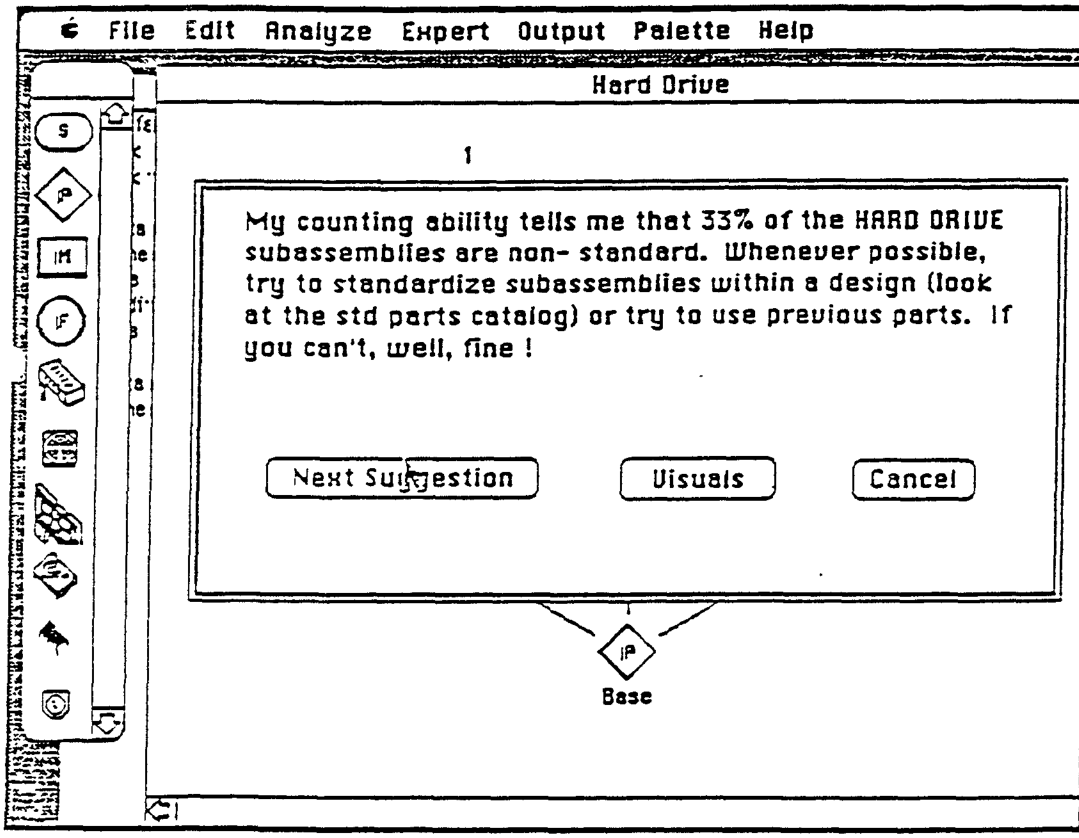


fig 16. Assembly advisor -- output suggestions and estimated costs



17. Structure of the injection molding advisor

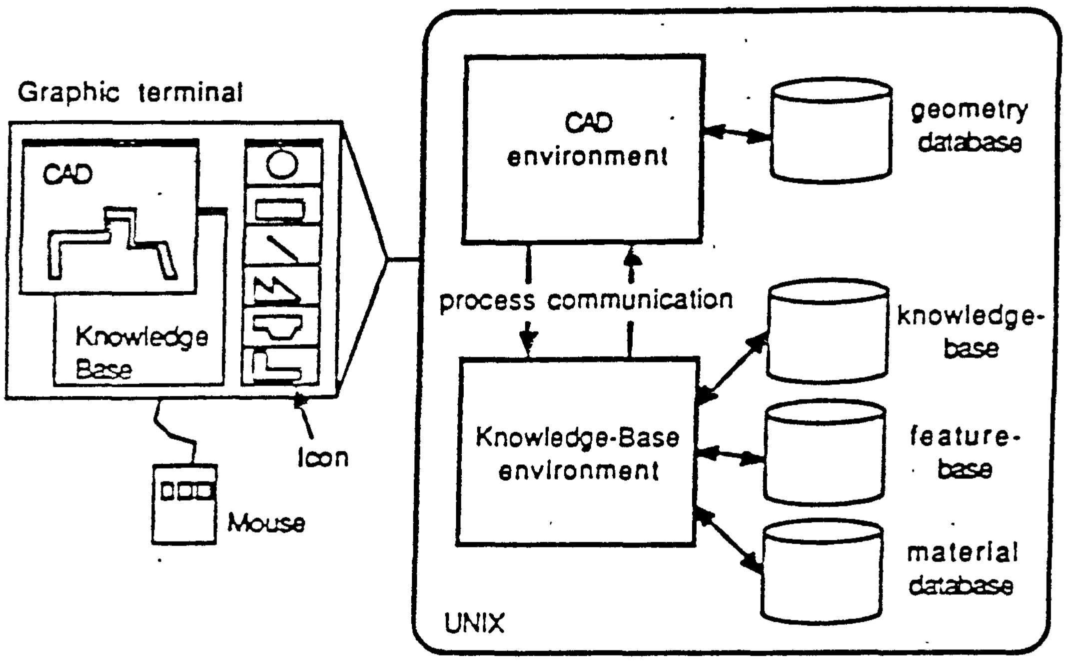
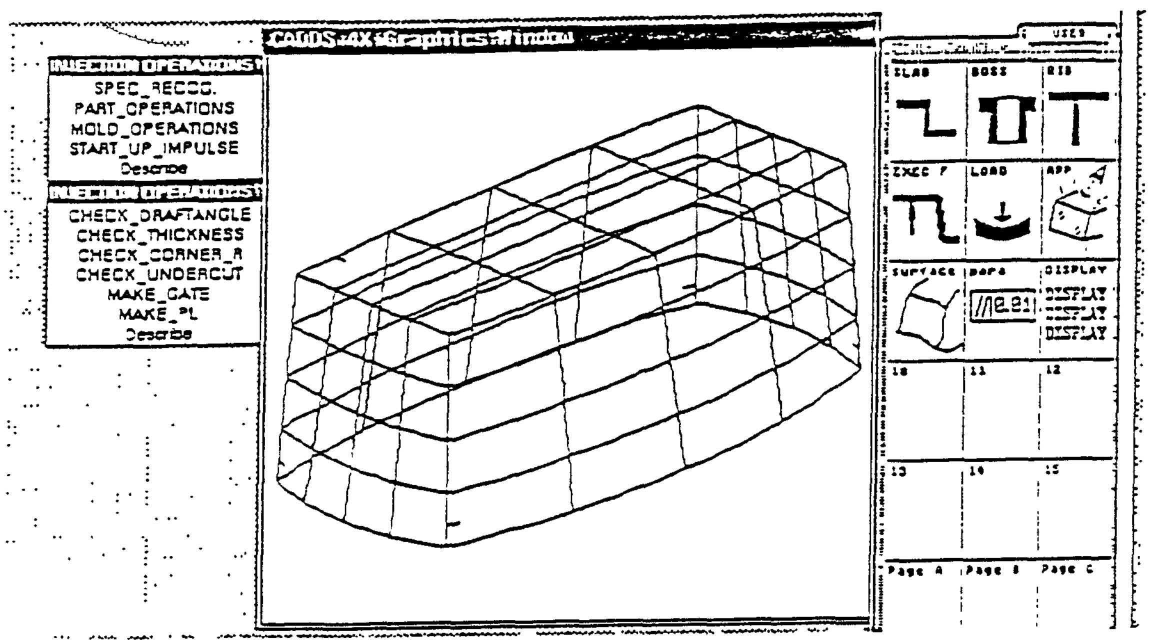


Fig 18. Injection molding advisor -- typical input screen



19 Injection molding advisor -- interactive feature identification and specification of part requirements

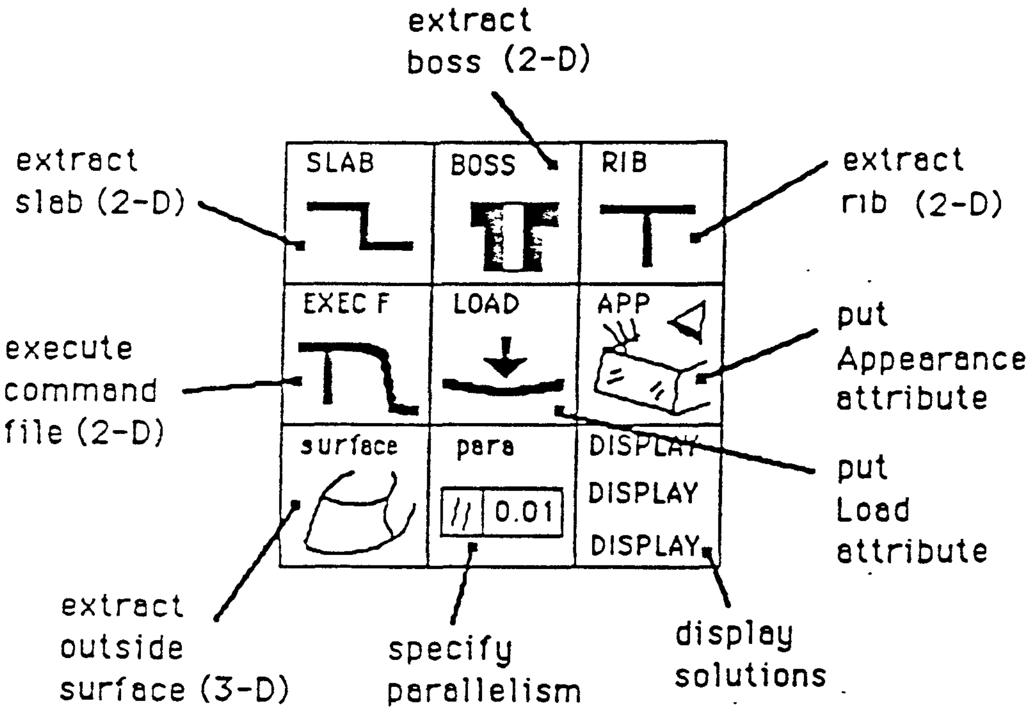
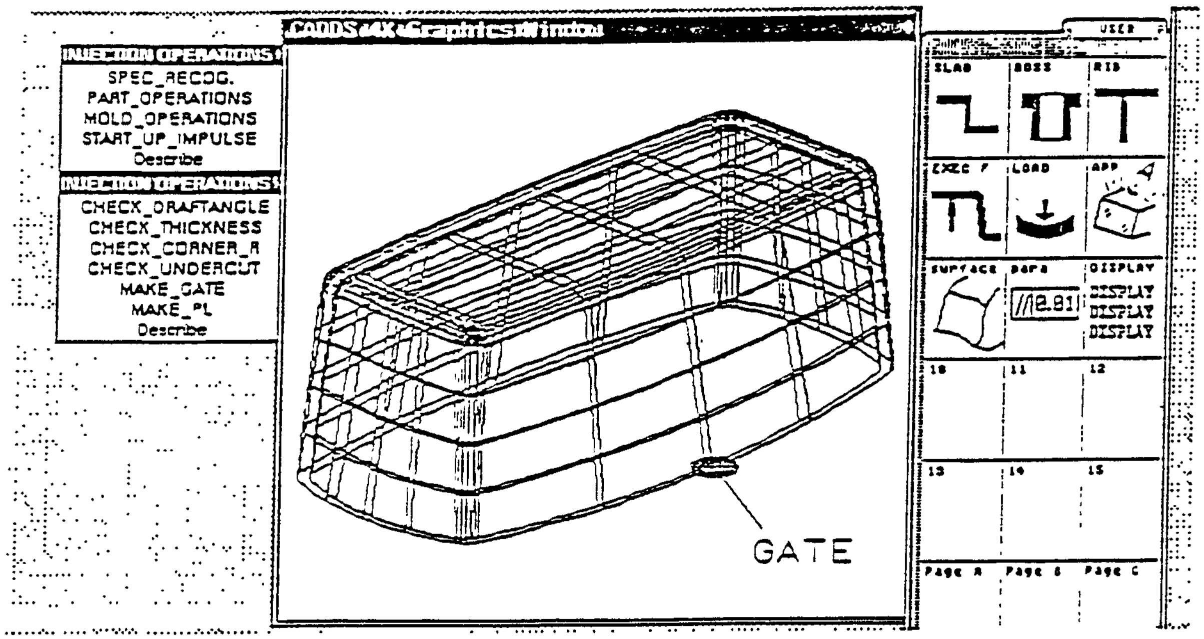
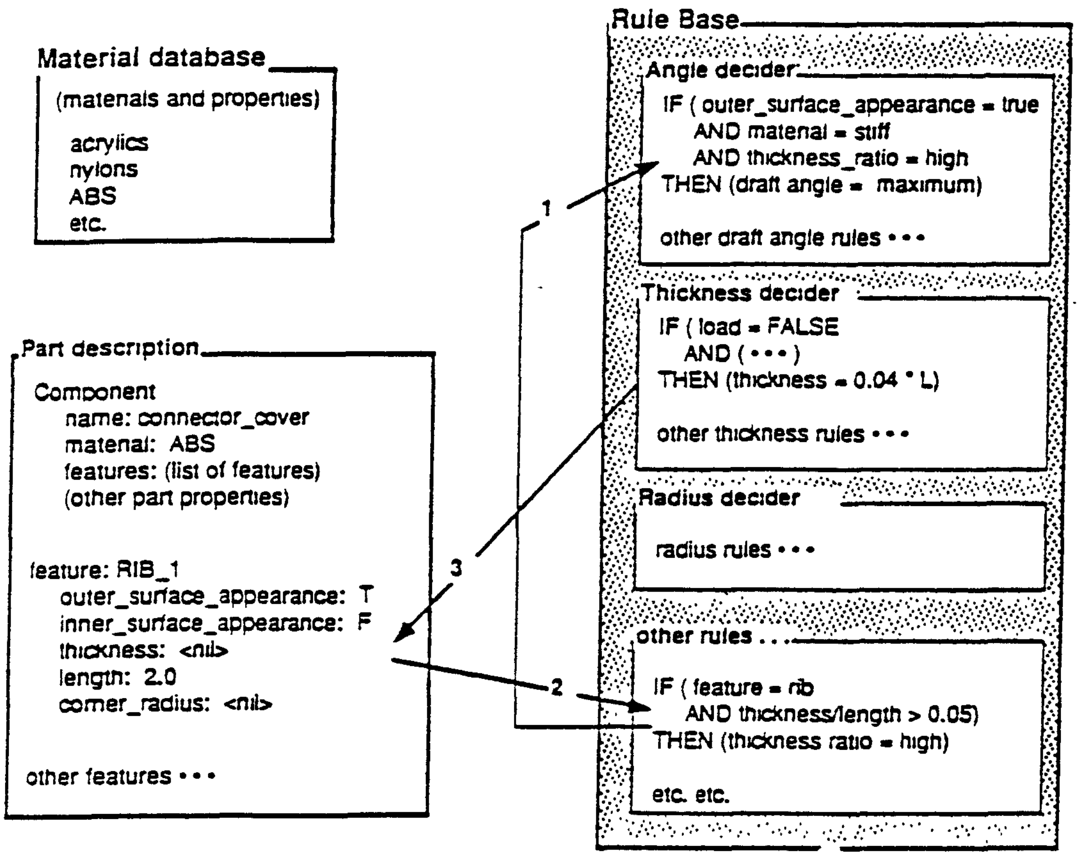


Fig 20. Injection molding advisor -- typical output screen




Material database
(materials and properties)
acrylics
nylons
ABS
etc.
Part description
Component
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features: (list of features)
(other part properties)
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inner_surface_appearance: F
thickness: <nil>
length: 2.0
corner_radius: <nil>
other features • • •
Rule Base
Angle decider
IF (outer_surface_appearance = true
AND material = stiff
AND thickness_ratio = high
THEN (draft angle = maximum)
other draft angle rules • • •
Thickness decider
IF (load = FALSE
AND (• • •)
THEN (thickness = 0.04 * L)
other thickness rules • • •
Radius decider
radius rules • • •
other rules . . .
IF (feature = rib
AND thickness/length > 0.05)
THEN (thickness ratio = high)
etc. etc.
1
2
3

Summary of main strengths:

* Fast
* Straightforward to encode, modify (many tools exist)
* Fast payoff on frequently performed tasks
* Can exceed human performance
* Makes you document and better understand what you do

Summary of main limitations:

* Robustness not assured
* Can be difficult to combine rules with numerical, geometric or algebraic analysis
* The representation of the underlying model (if any) is not evident

====> Solution: Combine with model based approaches

2. Parametric Design

Underlying method: Constraint propagation (either procedural or symbolic)

Applications: Variational redesign of standard components of systems.

Status: Many research efforts; some emerging industrial versions (e.g., Cognition, ICAD, Wisdom, Design Power, Mentor)

Summary of main strengths:

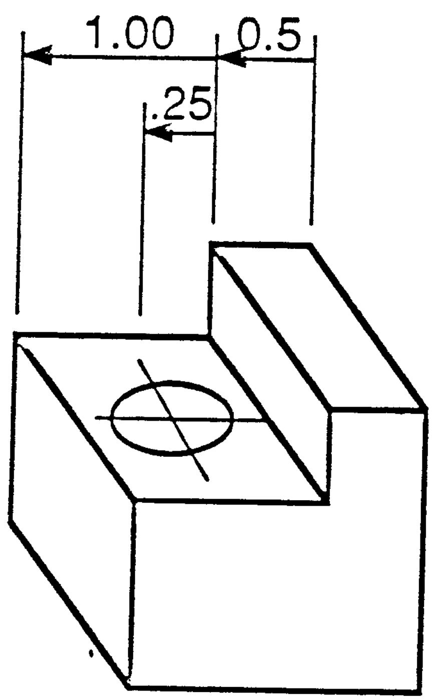
* Saves a great deal of time on routine redesign tasks -- especially when families of similar parts are designed.
* Promotes standardization.
* Reduces chance that details will be overlooked.

Summary of main limitations:

* The system can only catch and propagate the constraint you enter, resulting in "stupid" mistakes (e.g., parts that grow ridiculously thin as you stretch them, or that interfere with each other).

21. Parametric design -- How it works

An example - variational CAD (the "rubber part")



* There are infinite number of such constraints.

=====> *Proposed solution*: Make it easy to specify new constraints for any particular situation, and make it easy to retract them later.

3. Configuration Design

Given a specification

"Convert rotary motion to linear motion"

and a set of constraints

space < 1.0 cubic feet

weight < 20 lbs

velocity < 0.5 feet/second

and a set of components and design solutions with known capabilities

motor catalog

gear catalog

power screw catalog

pulley catalog

block and tackle solutions

rack and pinion solutions

Construct a configuration of components that will satisfy the specification and constraints.

motor + gear set + rack and pinion

motor + pulley + block and tackle

motor + gear set + pulley + block and tackle

etc...

Example: PRIDE system (xerox)

Input: Design task in terms of goals , sub - goals , specifications about paper size etc.

Output: Configuration of rollers and guides for a paper path in a copying machine.

Approach:

* Combine expert design rules for selecting , sizing and locating components with procedures to be executed , table look - ups , etc.
* Exploit object - oriented programming for organizing rules , facts , goals , attributes.
* Exploit backtracking and advice to resolve conflicts.

Scaling problem:

Design is usually very underconstrained --- there is large search space of possible solutions and the space grows rapidly with increasing complexity.

Solutions:

Exploit hierarchy , use heuristics and/or objective functions to reduce the search space , allow user input to guide search.

3.1.1 Industrial Applications

CAD / CAM and Engineering Design

A 1985 survey by Carnegie - Mellon identified 14 expert systems installed in U.S production facilities , 9 being field tested , 38 under development , and 68 in the research phase.

Expert system have been applied to computer aided design tasks and beginning to be used for other CAD / CAM applications.

Technology Assessment

Some experts believe that computer aided design will become one of the primary applications of Artificial Intelligence. AI techniques will be used in the representation of geometrical information in CAD databases. The needs go beyond a mere description of features on a surface. There will be some procedure that classifies the parts of objects for group technology purposes. Smart user interaction is important in CAD. The terminal for example , would "know" the user's preferences in displaying objects.

Expert system will remove a major bottleneck in fully integrating computers into the design and fabrication process by automating major judgements and decisions , and allowing high level engineering expertise to be available to at each step. Most engineering and construction firms have developed specialized expertise to help win contracts for certain kinds of work. When input into an expert system , this expertise can aid design , fabrication , construction and operation of plants , buildings , ships , refineries , aircrafts , and power plants; engineering knowledge is delivered to the costumer as a part of design. Dr. William G. Beazley , a consultant specializing in design automation and expert systems , predicts that " by 1990 , engineers will deliver expert systems and rule bases along with the usual drawings and design reports."

A certain amount of design checking and analysis will be incorporated into CAD systems using AI methods. A CAD system could alert a designer that a design does not confirm to specifications , for instance. An intelligent CAD / CAM system might also perform functions such as selecting the inspections points of manufactured products based on an analysis of it's design.

Computer aided drafting is the use of the computer to create drawing and documentation databases which describes the design. An advance in current technology is that these design databases (sometimes called "smart" or "intelligent" drawings) can report their design content in digital form for direct use by the engineer. This type of computer use provides a single representation of the solution upon which the engineering analysis is based. Some expert system , such as PICON , use industrial process plant design information in the form of rules , frames or other representations to diagnose plant malfunctions. At 1986 American Control Conference , Dr. Bill Beazley , presented a paper which showed that the data structures used in the real time expert system PICON are essentially identical to the CAD data structures used for IGES. The remaining data used by PICON are rules about the plant dynamic behavior. These diagnostic rules about can be generated and cataloged in a library and instanced by the IGES representation. The CAD database would be used to encode a representation of the schematic in the usual way. When the design is completed , an IGES format file is created from the CAD database. Technology exist which can generate the rules from the differential equations and operating specifications of the device. The translator uses the IGES file to "instance" the appropriate set of rules from the library , and produces a rule base. The rule base is used by an expert system to diagnose the plant. Schemes of most commercial CAD databases , IGES , and most commercial expert systems are fixed by vendor implementation.

Software Inventory

ADEPT (Automated Design Expert) system integrates a traditional solid modeler with an expert system equipped with the knowledge of selecting an appropriate meshing strategy for a given solid and includes finite elements theory in general , and about package - specific details in particular. Given a solid to be analyzed , ADEPT uses a combination of features deducted from the solid's geometry and information supplied by the user to determine a modeling strategy and to automatically generate input files for one of a set of analysis packages. (Codetron, Inc)

ALADIN is an alloy design system. Alloy design is a metallurgical problem in which a selection of basic elements are combined and fabricated resulting in an alloy that displays a set of desired characteristics (e.g., fracture toughness, stress, corrosion, cracking.) {Carnegie Mellon University}

ANALYST is an expert system for analysis and design methods. It also provides general word processing and graphics facilities. {System Designers}

ASSEMBLY COMPONENT DESIGN is an expert system for detailed design. It was built using Teknooledge's S. 1 on a timeshared VAX. { Teknoledge}

ASSISTANT is an expert system for automatic construction of the knowledge base for steel classification. { Jozef Stefan Institute }

CADHELP is a expert system that will simulate an expert that is demonstrating the operation of the graphical features of a computer aided design subsystem for designing digital logic circuits. { University of Connecticut }

CASTING DESIGN ADVISOR interacts with engineering analysis routines to compute the characteristics of candidate designs and helps select the casting process to be used. { GE and University of Massachusetts }

CELL DESIGN is an automated tool to aid in the initial design, fine tuning, and continued evaluation and modification of manufacturing work cells. Based on group technology concepts, the system uses built in intelligence, acquired knowledge, management's design objectives, and user interactions to arrange a factory's existing parts and machines in to a set of work cells. It was developed using Intellicorp's KEE software and runs on the symbolics 3600 LISP machine. { Arthur Anderson & Co. }

DABKON is an expert system that assists a designer in the choice of the correct type of bearing for a given mechanical application. The system accepts an input specification of the environment of the bearing is to operate in and outputs a list of bearing types that are useable in that environment. { Senter for Industriforskning }

EQUINOX is a CAD / CAM program for sheet metal design and fabrication , and was the first commercial CAD / CAM package to incorporate an expert system. The expert logic is based on a built in understanding of the fabrication industry. Processes are generated automatically based on part features and selected tooling. Machine and Material characteristics are also taken in to account. { Applicon - Schlumberger }

ESAD (Expert System Assisted Design) is an expert system used on-line by the design engineer in an iterative manner starting with it's initial, approximate model which is an perfected through the assistance provided by the expert system. { Battelle Geneva Laboratory }

ICAD SYSTEM is a knowledge based design modeling system. the ICAD system relies on symbolic processing and object oriented programming technology to break through the limitations of conventional design and modeling system. Output from the system can be provided to CAD system for production drawings and to MRP II system for production planning. {ICAD inc}

MADEMA (Manufacturing Decision Making) is a decision making concept to address issues regarding assignment of resources within manufacturing systems. The method addresses the issues of assignment of resources as multiple attribute decision making problem. The scope of this project is to use AI techniques in a rule based system approach to determine relevant attributes/criteria to be used for decision making within a manufacturing system. { CAM - i}

PROPLAN is a knowledge environment for process planning. The system , implemented in InterLISP-D on Xerox 1108 , integrates the design and the planning stages for manufacturing rotationality symmetric parts. To use the system , the user specifies a part in a simple language that describes the external and internal profiles of the part. These profile descriptions are composed of primitive segments LINE and ARC. These descriptions have been extended to include surface features , such as knurls , threads , and tolerance and finish requirements. Features of a part cannot be described in profiles are accommodated as additional information. {Siemens Corporate Research and Support , inc}

STORAGE SYSTEM TEST is a expert system that manages final manufacturing tests for storage systems. {IBM}

TROPIC is an expert system for computer aided design in the field of electromechanical equipment. { IMAG }

Current Research and Future Outlook

Research at General Electric is exploring an expert system to perform a design primarily by redesigning using a comprehensive formal method of evaluation. Because many actual problems are redesigns , an initial design is usually available as a starting point. If not , a simple algorithm that interrogates human experts can be used to generate one. To begin , the technique is being applied to simple mechanical systems such as V-belts and shafts. Future applications , to such processes as extrusion or injection molding , will include evaluation criteria and redesign rules for geometry and manufacturing.

A project at the University of Wisconsin , puts design catalog information in to programme that automatically performs standard calculations , generate an NC tape , and develops a database.

CRI , Copenhagen , Denmark , has a research project called GRADIENT (Graphical Dialogue Environment). As a whole Gradient is concerned with the design and development of a graphics and knowledge based systems.

Current supervision and Control (S&C) system provide little or no support for the operator at the moments when it is most needed during emergency situations and the dialogue with the operator is generally inflexible and non adaptive. Where graphics display system are used, they function by assembling pre packaged picture to display the process states anticipated by the display designer.

Dr. Margaret Eastwood , Director of Integrated Factory Automation at GCA Corp. believes that a certain amount of design and analysis will be incorporated into CAD systems using AI methods. A CAD system could alert a designer that a design does not confirm to specifications , for instance. Also suggested that an intelligent CAD/CAM system might perform functions such as selecting the inspection points of manufactured products based on an analysis of its design.

T.L.Johnson , Senior Scientist at Bolt Bernek & Newton, sees CAD as one of the primary applications of AI. He feels that AI techniques will be used in the representation of geometrical information in a database.

The user of expert system for HVAC design was proposed by Victor Wright . It is possible that various aspects of HVAC design will be attacked individually. An antral starting place for the implementation of an expert system is specification writing , especially in conjunction with DACC system design. An expert system could scan the drawing database of a CAD drawing and produce the specifications for each type of object in the database.

A computer based facility is being set up at The Sensor Application Center which will ultimately contain detailed information about some 10,000 different transducers. Expert system will be used to answer sensor questions replacing human consultants in all but complex cases. Production design and redesign for automatic assembly is a possible application for expert system. This application has been proposed as a possible research areas at the Battelle Geneva Research Center. Designing and redesigning automatic assembly production is an iterative task , where goals and constraints are often in conflict.

3.2 Artificial Intelligence in Process Planning

A brief history:

Variant --> Generative --> Knowledge based --> Incremental

1. Variant process planning systems

Concept: Retrieve similar plans from the past and piece them together. Use group technology codes to retrieve plans.

Advantages

* fast
* many routine designs exist
* helps formalize and standardize design, planning procedures

Limitations

* limited to existing library
* tedious to encode
* can ingrain suboptimal practices

2. Generative process planning systems

Approach:

Generate new plans from scratch based on library of features and a ssociated sub - processes.

As decision capabilities grow ===> Knowledge based approaches

3. Knowledge based planning systems

Exploit expert system rules and features.

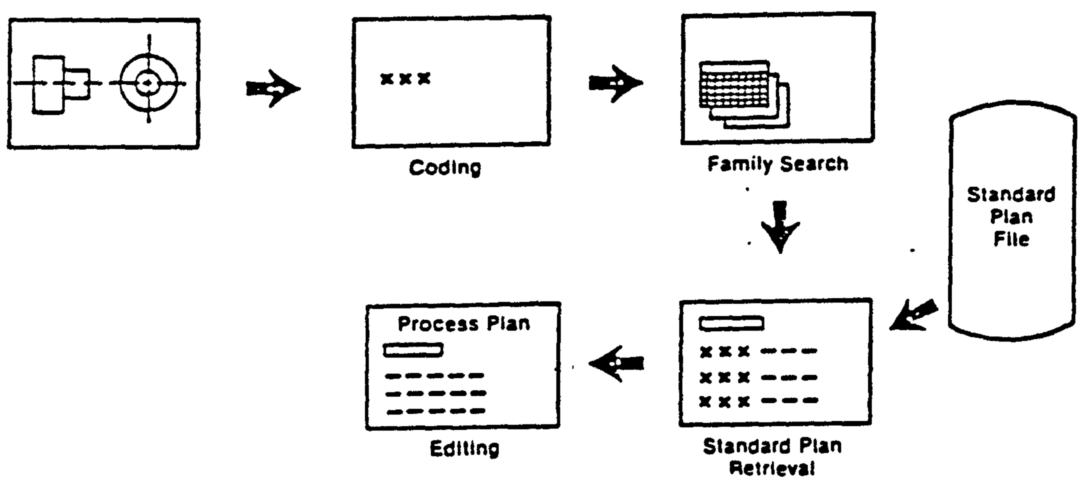
Knowledge based approaches

Approach is similar to the design configuration problem:

Design: "Find a configuration of standard components (with known properties) to achieve a design specifications subject to constraints."

22. Variant process planning systems - basic format

(from Chang and Wysk , 1985)



Planning: "Find a sequence of standard operations (with known effects) to achieve geometric specifications (i.e., the desired geometry of the part) subject to constraints."

How it works:

Input: * Description of the design in terms of features and relationships.

* Knowledge base of operations and characteristics.

- when they can be applied

- what their effects are

- what condition must remain truewhile they are executed

Output: * Ordered sequence of operations -- possibly including tooling, fixturing selections.

Examples:

Machining process planning systems:

* XCUT (Allied Signal)

* PROPEL (LMTI, France)

Use rules organized in to schemes to determine which operations can be applied.

Example: Make hole by drilling

Use - when:

Flat face available

Hole size and length within (range of standard sizes)

Position tolerance not finer than (best hole tolerance)

Effects:

Drilled hole

Position tolerance: as drilled

Finish: as drilled

Knowledge based approaches -- Characteristics:

* Takes 15 -20 minutes for complex part

* Achieves proficiency equivalent to human machinist

Limitations:

* Difficult to be sure that plan will always work

* Slow to replan if one makes a minor change in the design

* Typically has a shallow model of processes (e.g., geometry) so must either manually enter all interactions or else provide a separate program to catch them.

Knowledge based approaches -- Emerging trends

* Exploit standard AI planner -- keep it separate from domain specific issues.

* Have planner interact with external modules for detailed analysis (e.g., about geometric interactions)

* Let external modules use formal engineering models (e.g. "assembly = motion through space with contacts;" "machining = volume removed, cutting forces"). The models have explicit level of details and assumptions, so we know what they catch and what they miss.

* Use dependency structure for plan re-use. Formally annotate for each step in the plan:

- what are the preconditions are
- what the effects are
- what condition must remain true while step is executed.

Then if something changes, go to the dependency structure to determine what preconditions are no longer satisfied, what effects are no longer achieved, etc. Replan.

Incremental planning -- Summary of benefits

* Saves time -- permits interactive feedback at design time.
* Reduces side effects by re - using previous results.
* Highlights the effects of design changes.

Looking ahead

There numerous computer aided engineering tools but for the most part

* They are written by experts for experts.
* They do not share data structures.
* They do not cooperate.

As a consequence , group decision making is slow , iterative , costly. In the future , increasing effort will be devoted to tieing these tools together.

AI can help

* Hierarchical representations with explicit dependencies.
* Propagate constraints among representations.
* Provide intelligent interfaces to conventional engineering programs (e.g. a structural analysis agent = expert system shell serving as an interface to , and backed up by , numerical analysis programs)

Requirements of tieing A.I based tools together

* A framework to permit sharing of representations of designs , plans , constraints , geometry etc. across different domains. Also need a way of altering specific modules when changes occur that affect them.

* Modifications to the tools themselves -- exploit hierarchy , dependencies , incremental computation (as with the PRIAR planner example)

Fig 23. Incremental planning example

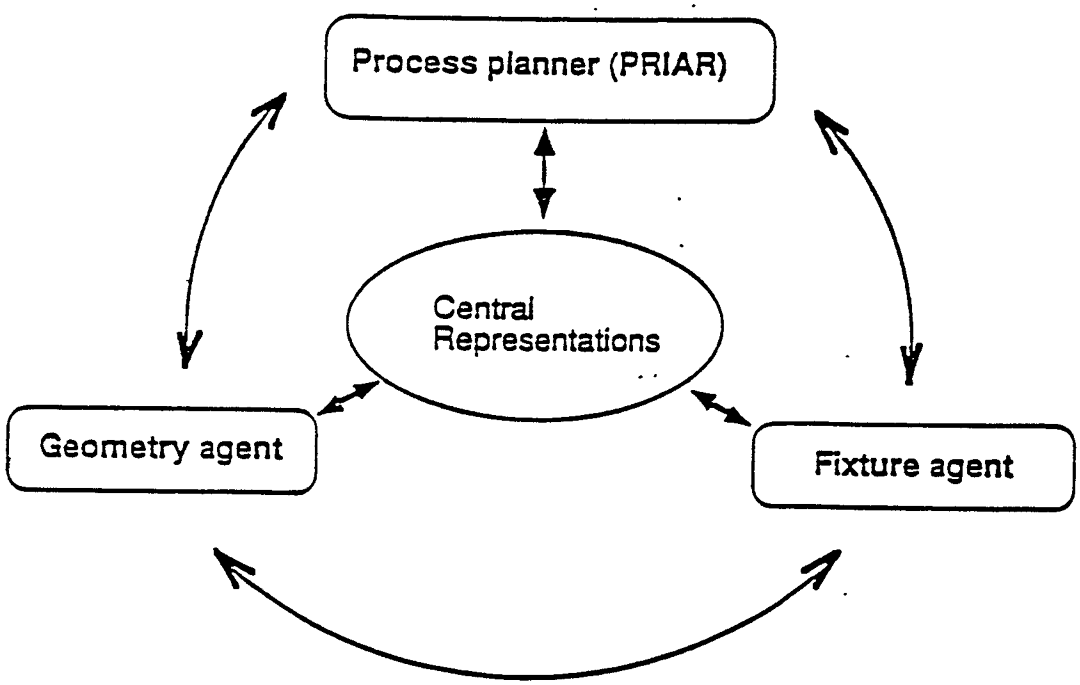
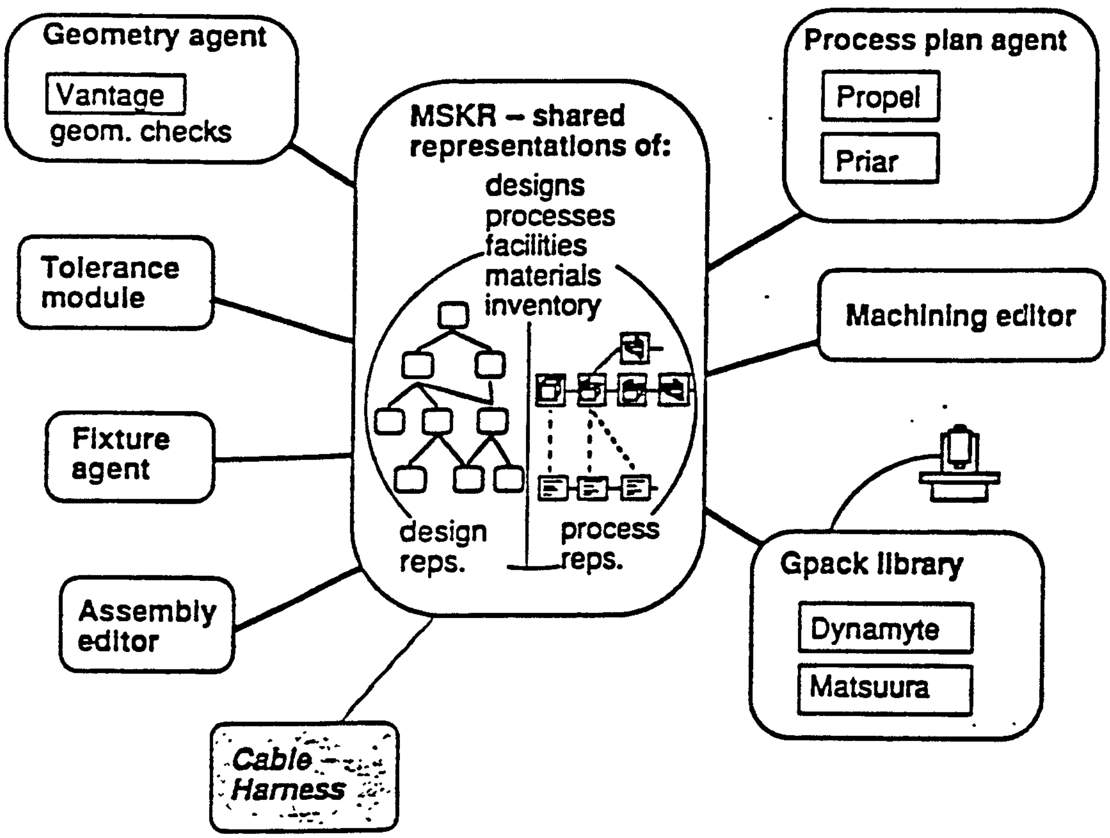


Fig 24. Example of prototype integrated system



Summary

* Expert systems are a well established starting point.

* Other applications such as parametric and configuration design are emerging.

* Process planning has also been a fertile area for expert system approaches.

* Emerging trends:

  - Integration with CAD
  - Enhancing robustness through deeper process models
  - Achieving faster response for interactive use

* In the future, stand alone tools will be integrated -- with ramifications both for the tools themselves and the frameworks in which they are used.

3.3 AI in Process Control

The rapid advance of the computing technology has vastly augmented the capabilities of process control systems. Modern distributed control system can monitor thousands of process variables and alarms, delivering a constant stream of information to the control room. With such systems, a small crew of operators can regulate the operation of immense and complex industrial processes. Refineries, Chemical processing plants, and power generation plants are some of the industries that are benefiting from the rapid growth of the technology. But delivering the data to the control room is only a small part of process control. The incoming data must be analyzed, understood, and acted upon by human operators. And while their abilities match the demands of day to day operations, even the most rigorously trained operators can be overwhelmed by the flood of alarms and upset indications generated by a process interruption or fault. Expert systems in this process can control tasks.

Technology Assessment

The first expert system to become commercially available for industrial process control was PICON, by LISP Machine, inc., in 1984. LISP Machine Inc. has several installations of the system, including one at Texaco, and also has distribution agreements with Leeds & Northrup, Honeywell, and Badger.

A novel method to tune a proportional integral derivative (PID) controller continuously using an expert system was developed by the Foxboro Company. Heuristic reasoning allows the controller to reach tuning decisions based upon performance measures in the same cognitive manner as an expert control engineer. The time response of the error, setpoint minus measurement , is the direct performance measure used for control loop tuning. This time response is broken down in to quantitatively defined features; e.g. , peak heights and peak times , nondimensionalized and complied into a tuning decision based upon knowledge based rules. Test results demonstrate both the robust nature and the ease of use of this controller.

One supplier of the process control software , Ultramax Corporation. Lists the following applications in the general area of operating process control: filtration , extraction , fermentation , distillation , refining (centrifuge)., reaction pressing (for creating composite materials) powdered chemical grinding , cooking (e.g. wood chips) , cleaning , bleaching , paper making , roasting coffee , enhance growth (e.g. , plants , reduce growth (e.g. , organism , crystal formation water treatment , alloy formulation , heat treatment , metal cutting (turning , grinding) , welding (arc , spot) , wave soldering , brazing , casting , forging , cold forming , extrusion , injection molding , spraying , drying , coating , granule and particle production , and process energy conservation.

Software Inventory

APPL (Automated Paint and Process Line) is a real time expert system implemented to control the chemical processing and coating of aircraft parts. {Lockheed Georgia Company}

CHEMICAL PAINT CONTROL is an expert system for chemical paint control optimization. {Exxon}

CONTINUOUS PROCESS PLANT DIAGNOSIS is an expert system for process management. It diagnosis defects in produced products and suggested remedies. It was built using Teknowledge's S.1 on a VAX 11/750. {Teknowledge}

ESCORT is a real time expert system that relieves the cognitive load on users of information systems generating large volumes of dynamic data. Escort is currently configured to help process plant operators in centralized control rooms. The system provides advice to the operators to help them handle and avoid crisis.

EXACT (EXpert Adaptive Controller Tuning) is a self tuning algorithm which continuously monitors a control loop's response to disturbances and adapts the tuning parameters to provide the optimum response to a load upset or setpoint change. It is a knowledge based system that continuously tunes two and three mode control lops as required. EXACT has been applied to three Foxboro products : SPEC 200 system , SPEC 200 MICRO system , and SPECTRUM/ MICROSPEC unit controller. {Foxboro}

FALCON is used in chemical process plants to identify possible causes of process disturbances. To arrive at this causes , the system interprets data that consist of numerical values from gauges and status of alarm and switches. {University of Delaware}

PDS (Portable Diagnostic System) is used in machine processes to diagnose malfunctions in machine processes. The system interprets information from sensors attached to the process. { Carnegie Mellon University and Westinghouse Electric corporation}

PICON (Process Intelligent CONtrol) is a real time expert system for process control that operates in a LMI Lambda/PLUS connected to an existing distributed system via a MULTIBUS or ETHERNET 11 interface. The 68010 processor in the Lambda/PLUS handles calculations (Such as energy and material balances) and other computationally intensive tasks. PICON can monitor up to 20,000 measurements and alarms , and design priorities to alarm to assist an operator in dealing efficiently with a process interruption or fault. PICON can also explain it's reasoning so that the user can correct or the knowledge it needs to make the right decision. {LISP Machine , Inc}

PILOTEX is generic expert system for industrial process control and maintenance. It is used to build applications consisting of standard modules (interface engines and database) , PILOTEX is designed to help manage complex systems that are impossible or to costly to define a valid mathematical model. {ITMI}

PROCESS OPTIMIZATION FOR ENERGY SAVINGS is an expert system for process control. {Texaco}

SUPERVISOR is an expert system for process control and runs on IBM PC. It overlays conventional control software , allowing the user to input rules for supervising a process. {Heuristics , Inc}

ULTRAMAX is a self learning expert system to optimize operating processes. ULTRAMAX learns directly from the results observed from past known inputs. It knows how to learn , and eventually becomes an expert on each process for which it has database. For instance it knows how to pre adjust controlled variables so as to optimally compensate for known changes in unadjustable external variables. {Ultramax Corporation}

Current Research and Future Outlook

The requirements of real time expert systems have been defined in some detail by Saures and Walsh of Martin Marietta. They utilize a goal directed production rule scheme , with the capability of fetching selected rule sets into the environment at execution time. This allows a focus of system resources on current subtasks. They allow user selected inference procedures as well as cost estimates of subgoal evaluation to control the search. They also improve the efficiency of pattern matching , via savings of pattern matching information between evaluation cycles.

The work on an automated reasoning system by Lush and Stratton at the Argonne National Laboratory is an interesting variation of the technology of expert systems. In this application , the deep knowledge or physical knowledge of the plant is used to develop expert rules automatically. The application of forward chaining inference in a process control context was discussed by Fortin , Rooney , and Briston (4.4.5.4) of Foxboro. The knowledge rule consist of deep knowledge as well as heuristics. this synergistic use of both types of knowledge is considered to be vital in control applications.

Amphenol , a division of Allied Signal Corporation , is developing an AI system in the area of process control. The system is being designed for the time consuming job of scheduling the high volume production of a wide variety of connectors for electrical and fiber optic applications.

The Department of Electrical & Electronic Engineering at Heriot - Watt University is researching real time expert system in process control. The project is sponsored by Alvey. The objectives include

1) Developing knowledge representation formalisms and inferencing methods suitable for real time feedback control applications ; and

2) Providing academic support for the Alvey Community Club , in real time expert systems (RESCU)

An investigation into the methods of symbolic modelling of dynamic process undertaken. This has resulted in the development of CASUAL models to represent dynamic physical systems. A framework for an expert system shell , incorporating casual models , has been written. The shell is in PROLOG and allows the use of multi valued logics to represent essential uncertainty and domain specific predicates as primitives for the symbolic model. Some experimental results have been obtained and a comparison with conventional controllers , based on analytical models , has been made. Recent work is focusing on the development of a formal theory of qualitative control , employing the notion of logical state space. Abstraction is defined in logical terms and three forms of declarative knowledge representation are possible at each level: decision rules (shallow empirical rules) , state transition of rules and state variable transition rules.

The potential industrial control applications for expert systems is the installed base of about 6000 distributed process control systems. This number is growing at a rate of about 300 to 500 installation annually. The expert systems for control are equally applicable to other real time applications. LISP machine , Inc. reports that about of its PICON systems are being used for related application areas such as robotics , aerospace , process monitoring of data , and CAD applications.

Bettelle Columbus Laboratories is conducting research , sponsored by the National Science Foundation , to design a knowledge based system for synthesis , execution , and failure recovery of process control procedures.The goal is to develop a methodology , knowledge engineering tool to support the methodology , and dynamically synthesize control procedures.

3.4 AI in Production Management

3.4.1 Scheduling problem

Operations for multiple orders must be scheduled as to:

* Obey the temporal restrictions of production process and the capacity limitations of a set of shared resources, and

* Balance a conflicting set of preferential concerns (e.g. , meeting deadlines, minimizing work in process time, etc.)

Scheduling levels

1. Enterprise level: Finite capacity planning.

* Aggregate resource planning.
* Horizon depending upon lead times.

2. Shop level: Detailed Scheduling.

* Job sequencing.
* Order release dates.
* Activity coordination: tooling, NC programming, personnel.

3. Floor level: Dispatching.

* Real-time job - machine allocation.
* Reactive repair to schedules.

Type of problems

* Flow shop: Semi conductor.
* Assembly line: Automobile.
* Job shop: Steam Turbines.

Complexity

Manifestation

* Number of different products.
* Number of different manufacturing process.

* Number of personnel classifications/skills.

* Alternative process plans.

* Substitutable materials and machines.

* Resource contention.

Impact

Simple enumerative decision procedures do not work.

* If 85 orders , 10 operations , one substitute machine has minimum 10 E 880 schedules.

* Non linear problem.

* NP-Hard.

UNCERTAINTY

Manifestation

- Resource unavailability.

* Machine breakdown.

* Tooling.

* Materials.

- External events.

* Job mix.

* Lead time: urgent order.

* Unavailable personnel.

- Process performance.

* Operator performance.

* Material.

* Machine precision.

* Tool wear.

Incomplete Infrastructure

Manifestation

* No data gathering.
* No data validation.
* No data communication.

Impact

* Information no available to support precise scheduling decision.
* Inability to react to changes which are never seen.

Divided Structure Organization

Manifestation

- Distribution of decision making.
  * Engineering vs Manufacturing.
  * Work centers.
  * Tooling , materials , NC programming , etc.
- Dispersed resources.

Impact

* Poor coordination.
* Poor cooperation.
* Poor resource utilization.

Constraints

Manifestation

* Organization Goals.
  - Meeting due dates.
  - Reducing work in process.
  - Reducing cost.
  - Production levels.
  - Labor size.

- Resource levels.
- Shop stability.

* Physical Capabilities.

- Machine capabilities.
- Machine limitations.

* Causalities.

- Precedence.

1. Operation.

2 Subassembly.

- Resource requirements.

1. Machine.
2. Personnel.
3. Tools.
4. Fixtures.
5. NC tapes.

* Preferences.

- Operation choice.
- Queue position choice.
- Machine choice.
- Operator choice.

* Resource Availability.

- Machine.
- Personnel (machinists , engineers , inspectors , etc.
- Tools.
- NC tapes.

3.4.2 Scheduling Methods

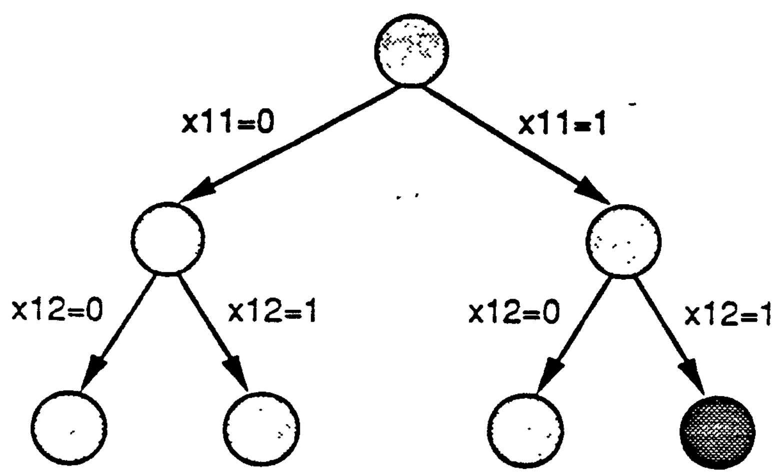
* Mathematical Programming.
* Dispatch rules.
* Expert systems.
* Constraint directed search.

Mathematical Programming

Problem Solving Method 1: Linear Programming

The problem contains integer variables, therefore cannot be solved directly via simplex.

Problem Solving Method 2: Branch and Bound



* Full decision tree has n! leaves. Try to get clever and prove parts of the tree are inferior: then prune this parts away without ever checking.
* Search and prune until exhaust tree or out of time. Exponential in size of problem.

Linear Programming Relaxation

*** Stopping Criterion:** Relax the integer constraint. This creates an L.P. which is easy to solve. The solution is a lower bound.

*** Seed Solution:** Use linear relaxation as starting point for branching.

*** Bounding:** Linear relaxation is a lower bound for B&B. L.P. would have to be solved at each decision point.

Methodology:

Identify and focus on the simpler reformulations of complex problems.

* Model the problem quantitatively.

* Transform a complex problem into one that has a simpler structure

* Select optimization methods.

* Determine the solution to the new problem.

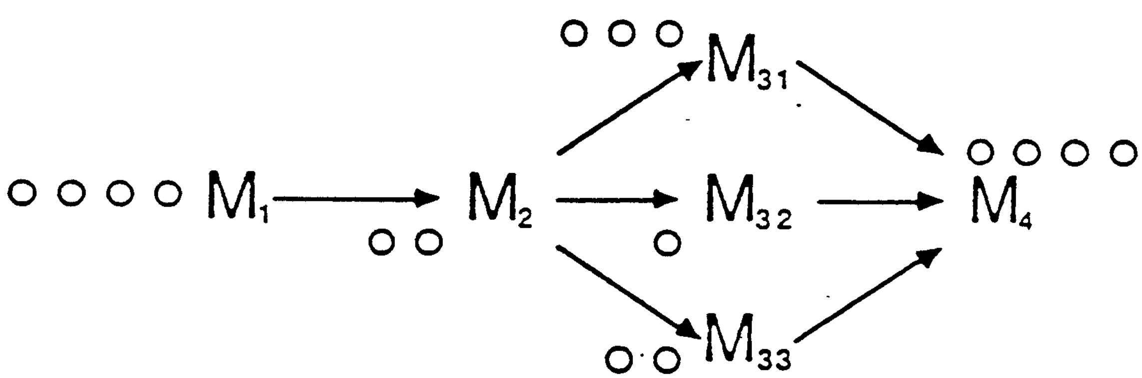
* If the solution is not "close" enough, then reformulate the problem.

Cannot handle the complexity of most factory scheduling problems.

Dispatch Rules

Representation

* Simulation model of the factory.



Problem Solving Method

* Discrete event simulation of the factory.

* When job arrives or machine becomes free local dispatch rules used to select next job to load onto the machine.

* Variety of rules generated which optimize various statistics.

- SPT: Shortest processing time.

- EDD: Earliest due date.

* Simulation results define a schedule.

* One approach uses the results of the first simulation as input to a second simulation (e.g., due dates) to enhance results.

Observations

* Success in scheduling simple FMSs.

* Myopic view of factory, local vs global optimization.

* Attempts to optimize only one or two goals (e.g., tardiness).

* Does not deal with constraints very well.

Expert Systems

Representation

* Object oriented representation of the factory.

* Pattern directed inference in the form of rules.

IF Context = (Job loading)

Step = (Reschedule Bottleneck)

Critical - Order.Ftime > Critical - Order due - date

THEN Subcontract Critical - Order

Problem Solving Method

* Emulating experts occurs by using decomposing the problem into separate tasks.

* Each task is solve using rules extracted from the expert.

Observations

* Has been applied to dispatching of jobs and scheduling small factories.

* Schedulers are not necessarily expert, problem too complex.

* Good starting point for what significant issues a scheduling system should attend to.

* Factories are dynamic, expertise needs to evolve.

Constraint Directed Search

* Heuristic search in the space of alternative partial schedules.

* Constraint knowledge used to:

- Generate states
- Evaluate states

Activity Representation

* Semantic network defines factory knowledge:

- Activities and States.
- Time and Causalities.
- Resources.
- Goals, Milestones and Constraints.

Constraint Representation

* Constraint knowledge elaborated to include:

- Importance.
- Relaxations.
- Utilities.

- Dependencies.

Linear Constraint Directed Search

Pre-search:

* Constraints selected.

* Constraint bound search space: specify decisions, e.g., shifts.

* Constraint define operators, e.g., operation & resource alternatives.

Search:

* Beam search.

* Constraint define evaluation functions.

* Generative Constraint relaxation.

* Generative exploration of sequences.

Post-Search:

* Analytic Constraint relaxation:

  - Dependency directed

  - Heuristic

Fig 25. Refinement perspective

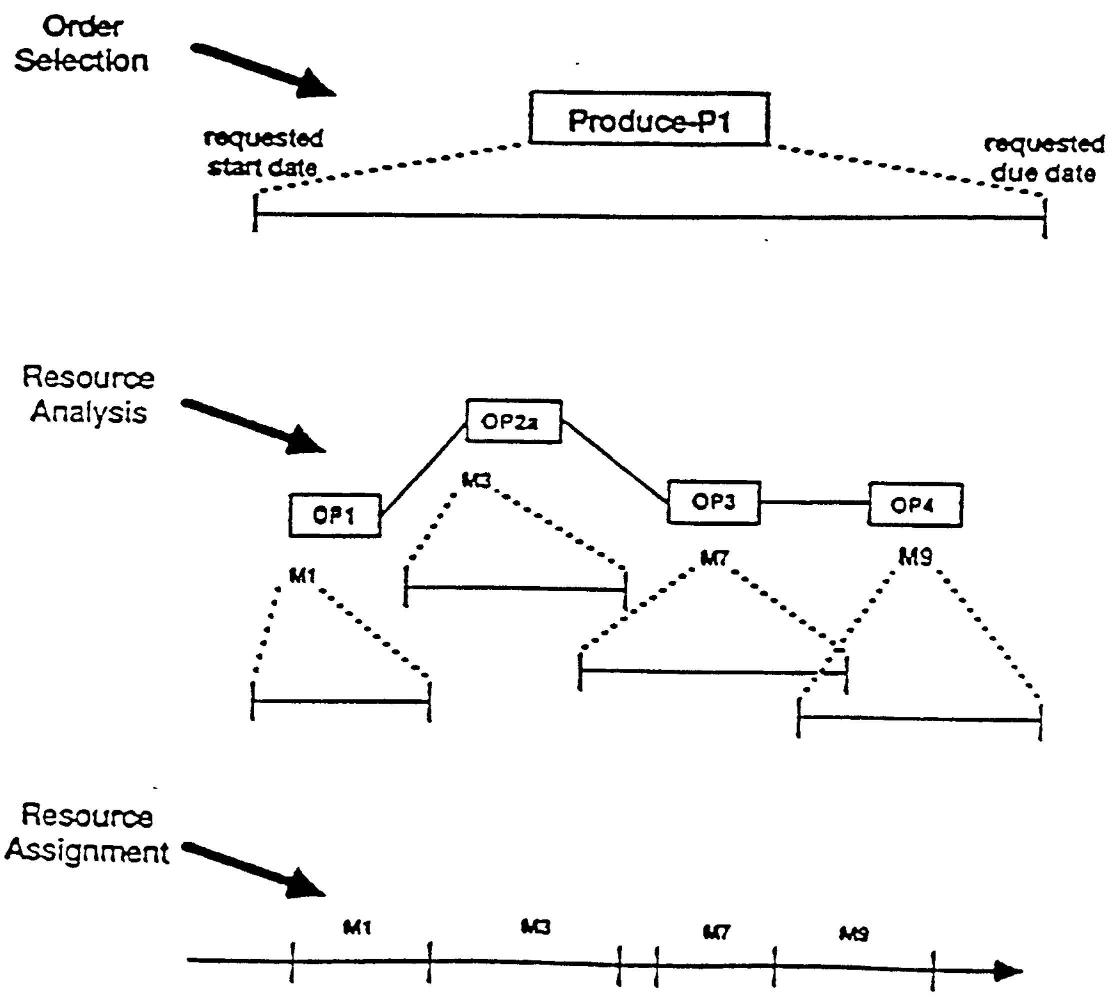
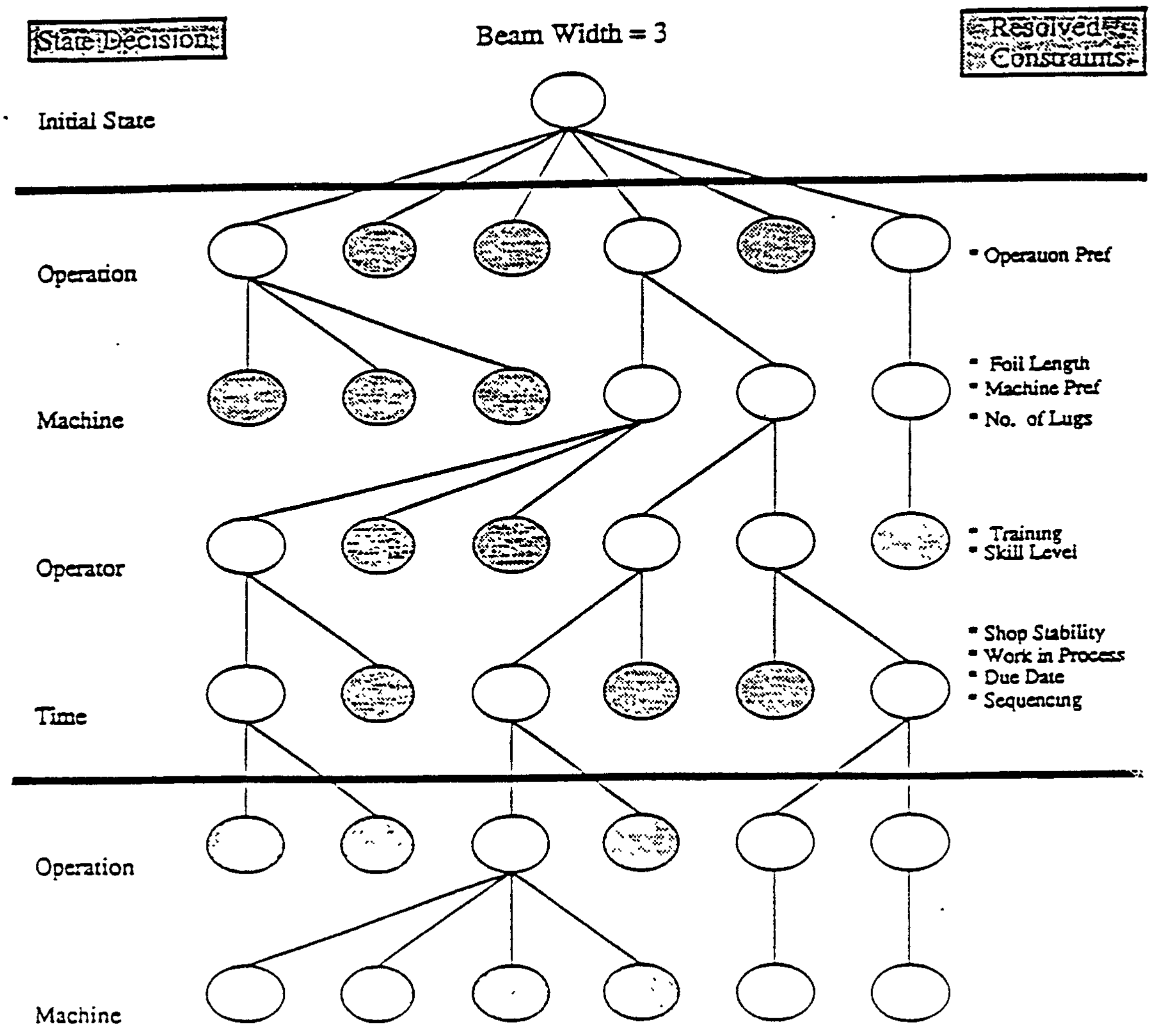


Fig 26. Beam search



Performance

* 85 orders.
* Six priority classes.
* Varying lead times.
* 33 machines.

STATISTIC	SD	SO	ST	SH	All
Number of lots	9	19	14	43	85
Tardy lots	0	2	0	15	17
Avg. Tardiness	0	1.49	0	37	19.05
Avg. Lateness (finishing)	-1.12	-18.54	-6.67	25.06	7.31
Avg. Lateness (starting)	263.81	182.39	84.7	205.53	186.63
Avg. WIP	32.18	94.92	118.63	217.39	154.13
Avg. Processing Time	30.87	30.56	28.92	31.74	30.92
Avg. Queue Time	1.31	64.35	89.71	185.65	123.21
Avg. % Processing Time	96.05%	43.67%	37.27%	21.66%	36.2%

Machine	% Utilization	Avg. Queue Time
ffs*	54.8	0
fss*	39.8	19.4
fps*	33.1	4.9
fts*	93.3	11.7
ilpa	12.9	53.9

Machine Utilization for Version 4 (makespan: 565.8 days)

HIrarchical Constraint Directed Search

* Problem reformulated as simpler search problem solved using dynamic programming.

* Reformulation focuses on contended for resources.

* Solution bounds the times that operations are to be completed if start and due date constraints are to be satisfied.

* Solution to subproblem constrains the search performed on the actual problem.

* Multilevel backtracking.

{ Fox , M.S. , and Smith , S.F. , (1984) , " ISIS: A Knowledge based system for Factory Scheduling" , *International Journal of Expert Systems*, Vol. 1 , No.1 , pp. 25-49.

Fig 27. Architecture

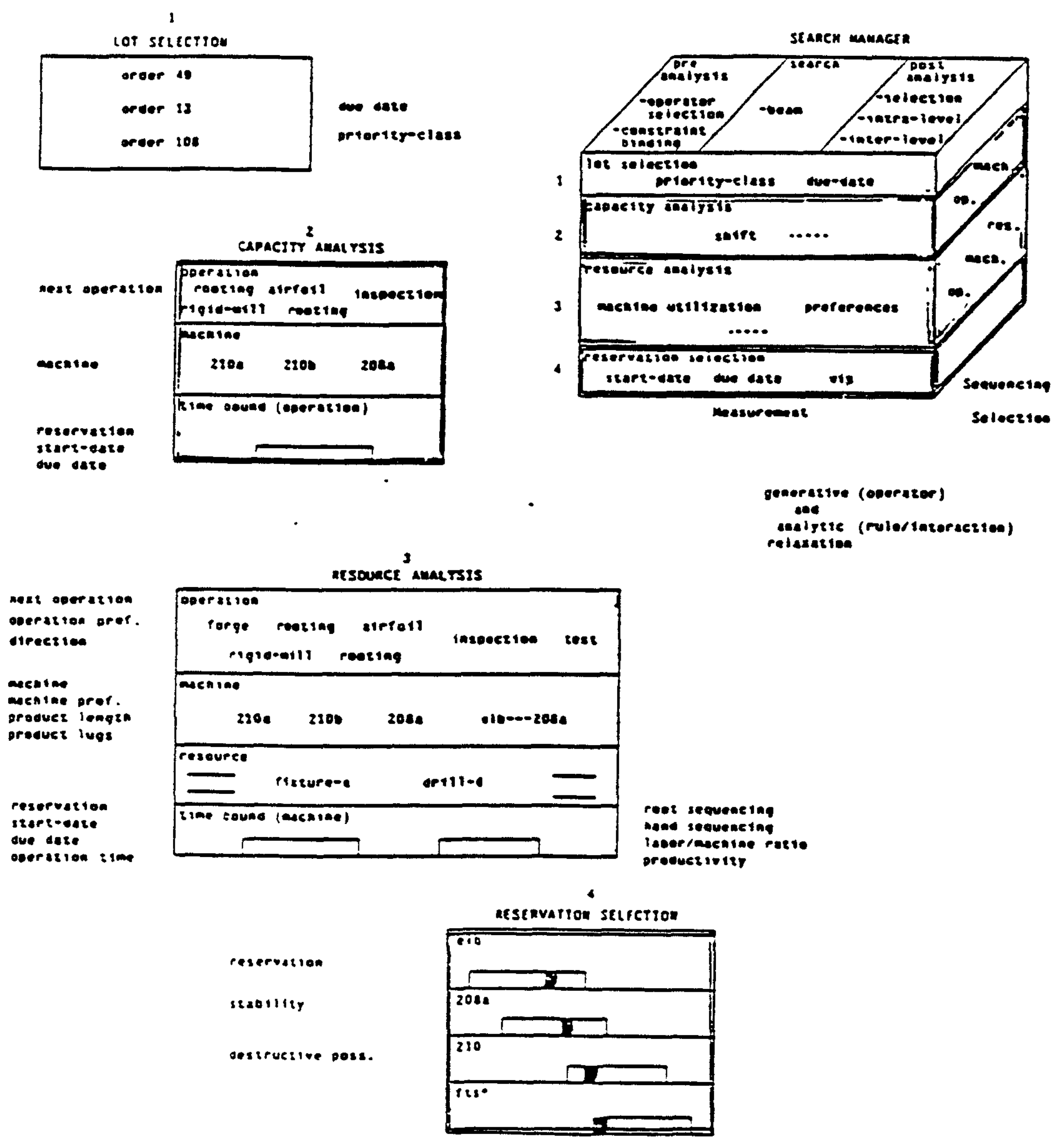
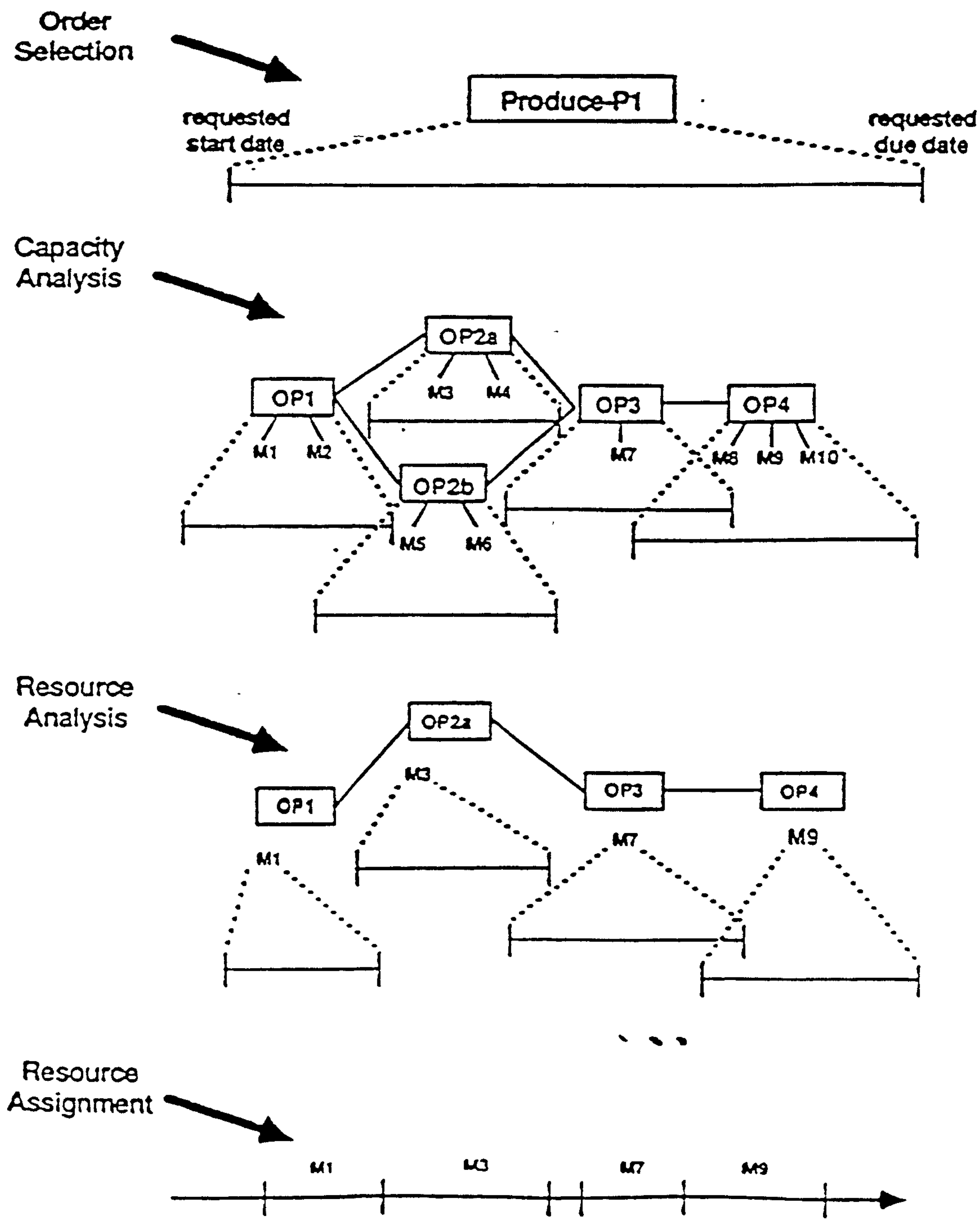


Fig 28. Successive refinement of an order's schedule



REVISED PERFORMANCE

STATISTIC	SD	SO	ST	SH	All
Number of lots	9	19	14	43	85
Tardy lots	0	2	0	15	17
Avg. Tardiness	0	1.49	0	37	19.05
Avg. Lateness (finishing)	-1.12	-18.54	-6.67	25.06	7.31
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fts*	93.3	11.7
ilpa	12.9	53.9

Machine Utilization for Version 4 (makespan: 565.8 days)

OPPORTUNISTIC CONSTRAINT DIRECTED SEARCH (OPIS-1)

* Multiple scheduling perspectives:
    - Order.
    - Resource.
* Order perspective is Hierarchical Constraint Directed Search.
* Resource perspective is a dispatching technique that optimize setups.
* Opportunistic selection of perspective based on resource capacity requirements analysis.
* Search can start at any point in the problem space.
* Reactivity directly supported via opportunism.

Ow , P.S. , and Smith , S.F. , (1988) , "Viewing Scheduling as an Opportunistic Problem - Solving Process" , *Annals of Operations Research* , Vol. 12 , pp 85-108.

Fig 29. Architecture

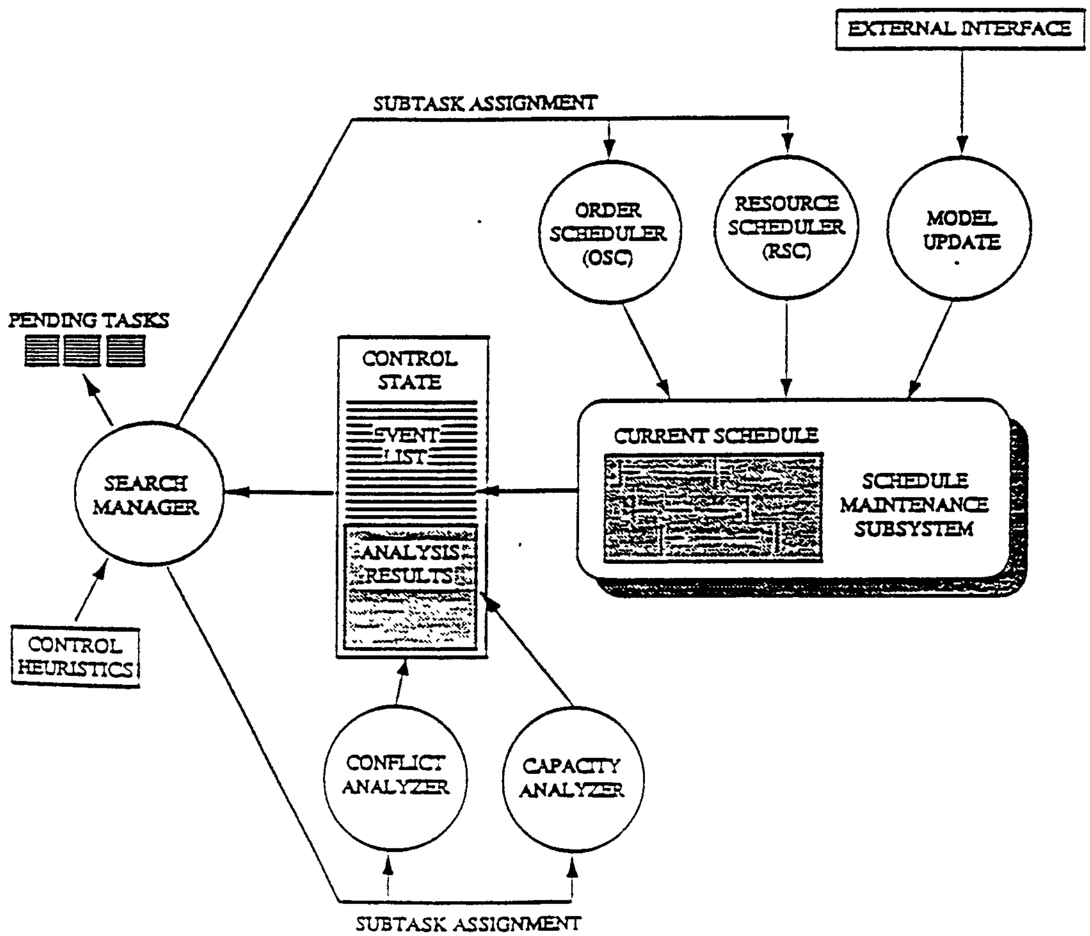


Fig 30. Multi - perspective scheduling in OPIS

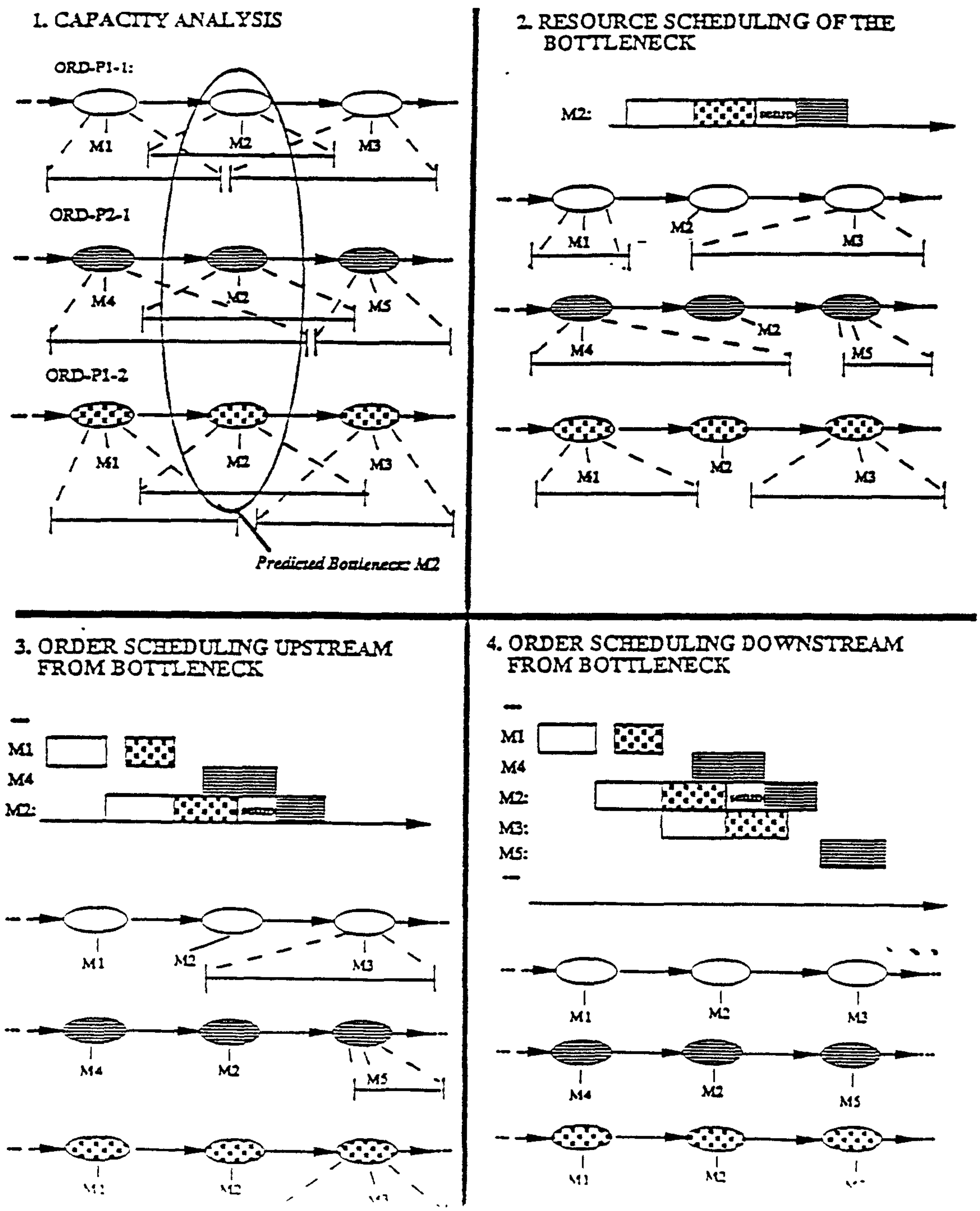


Fig 31. Tardiness performance

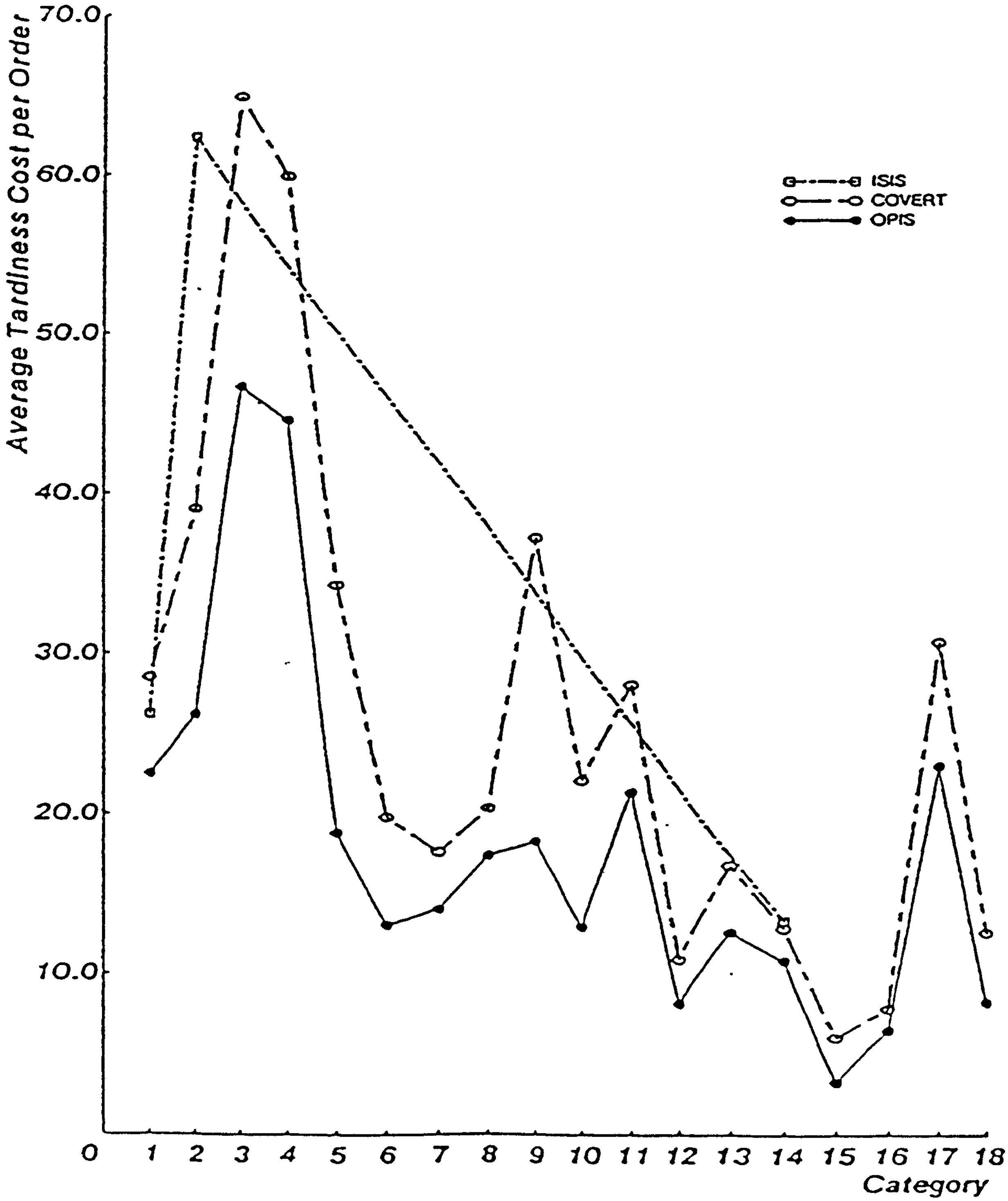
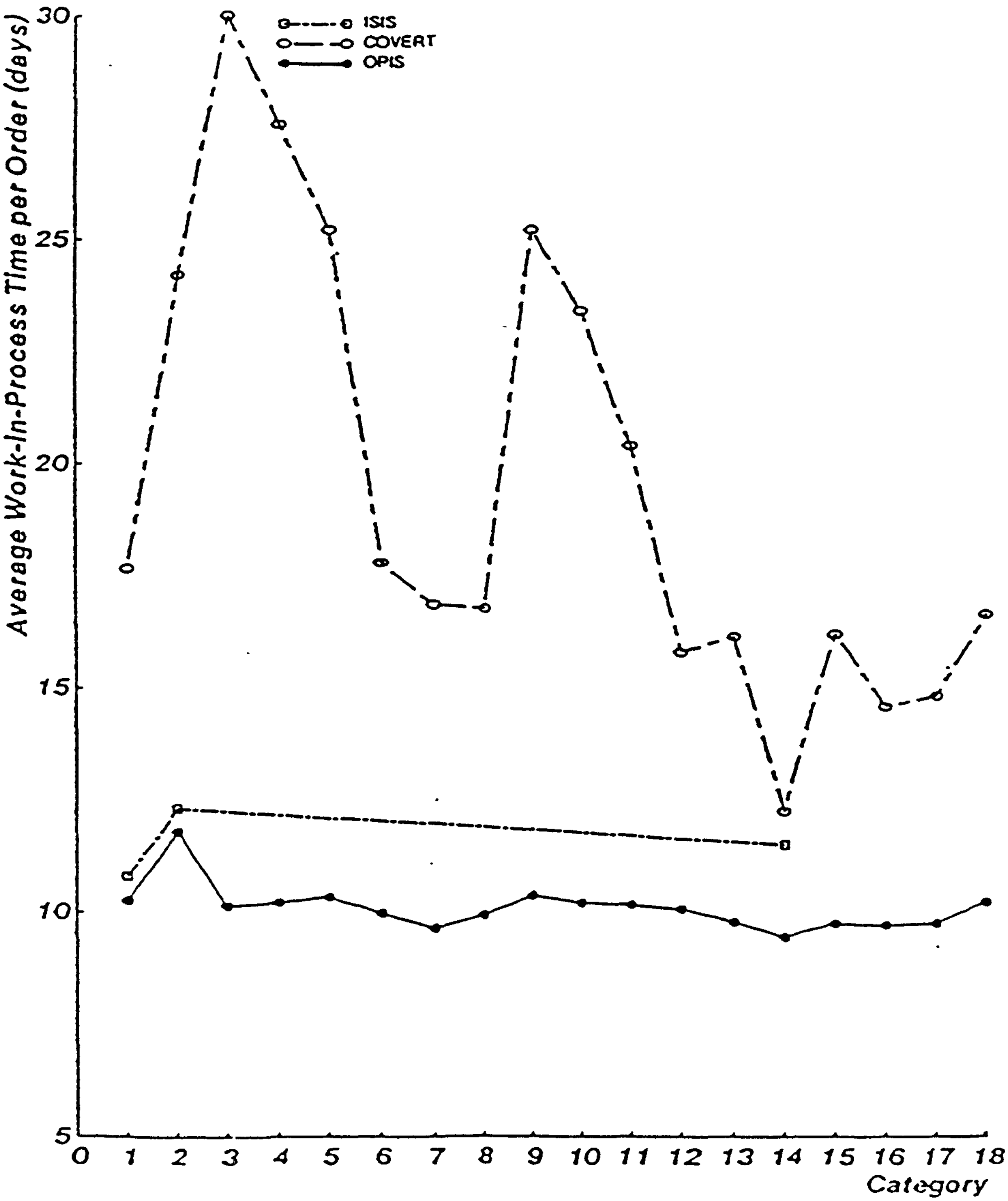


Fig 32. Work - in - process performance



CORTES : Micro Opportunistic Constraint Directed Search

* Extends perspectives to individual activities.

* Decisions made opportunistically at the micro level of activities.

* Finer switching between macro perspectives.

3.4.3 Case study: LMS (Logistics Management System)

Problem : Monitoring , Altering and Dispatching of work in a semiconductor fabrication plant.

At: IBM Corporation , Burlington , VT.

Process Characteristics

* 65,000 part numbers , 13,000 active.

* Each part has a process chain composed of 10 iterations through 3 process steps: Oxidation , photolithography , etching.

* Each iteration differs in time , 15 milliseconds to 20 minutes.

* Each activity differ in machine setup.

* Some processes are batch while others are single thread.

* Lots that wait too long may have to be reprocessed.

Process Management Goals

* *Serviceability:* meeting costumer ship dates.

* *Throughput:* maximize the amount of chips produced.

* *Tool Utilization:* maximize the use of expensive equipment.

* *Cycle Time:* minimize the waiting time of lots , so that inventory and rework due to decay is minimized.

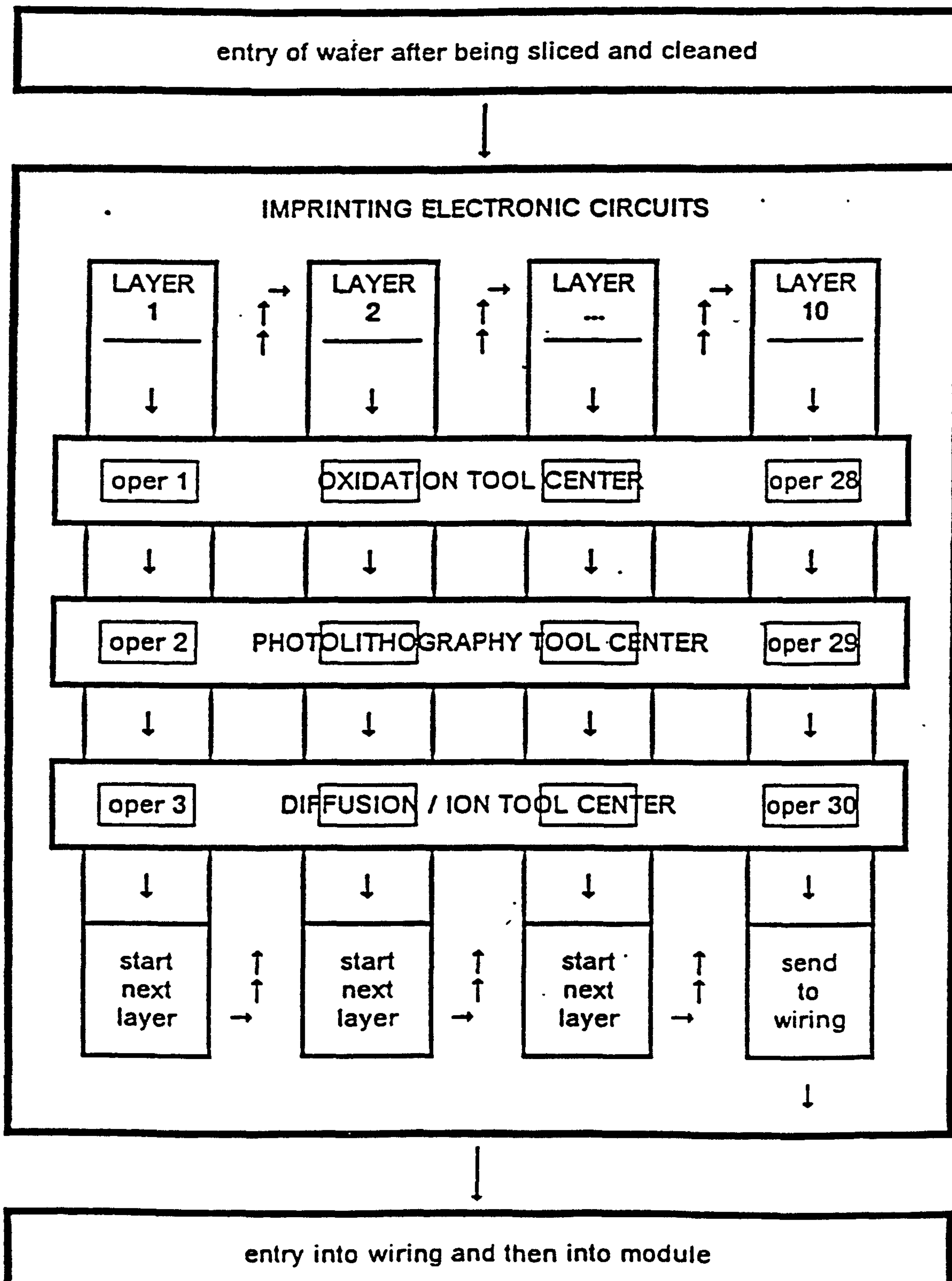
Pre LMS Environment

Systems

* Automated data acquisition.

- Reliable recording of transactions (lots , machines , orders)

33. Fabrication Line : LMS



- Real-time.
- Flow checks.

* Overnight lot prioritization.
* Process , control and logistics knowledge on paper only.

Problems

* Limited reporting capability.
* No real time access to data.
* Limited operator assistance on assigning lots to tools.
* Unable to adapt schedule to changes in operation in real-time , thereby missing opportunities.
* Decision half time too short for daily planning.
* Cognitive overload for human.
* Computational overload for mathematical programming.

LMS Solution

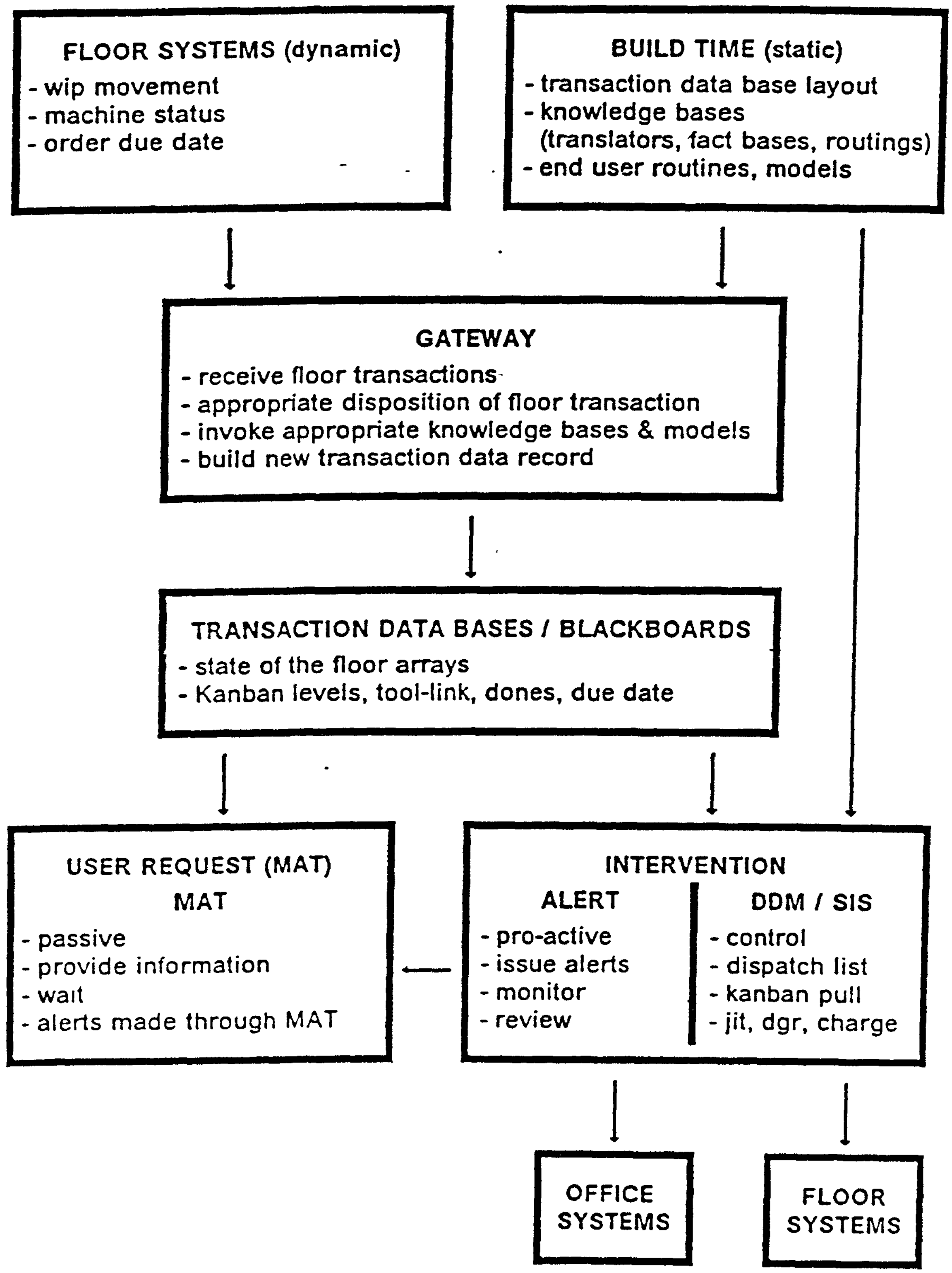
Intelligent system monitoring transactions in a distributed environment.

* Decision support via data acquisition and display.
* Real-time monitoring and altering of significant transactions.
* Decision making via Dispatch Decision Maker (DDM/SIS).

Implementation Steps

1. Tie into and integrate widely separated datasets and existing systems in Real-time (240,000 transactions/day)
2. Develop tools for decision support (information access).
3. Proactive intervention with alerts.
4. Real-time dispatching.

34. LMS Architecture



Dispatch Decision Maker

Intelligent Kanban divided processing into zones.

* Process routing.
* Process specifications.
* Tool state.
* WIP state.
* Tools being used.
* Lot due dates and express lots.
* Upper bound and lower bounds on batch size , trains , protect WIP.
* Pull of downstream Kanban.
* Strategic and tactical guidelines.

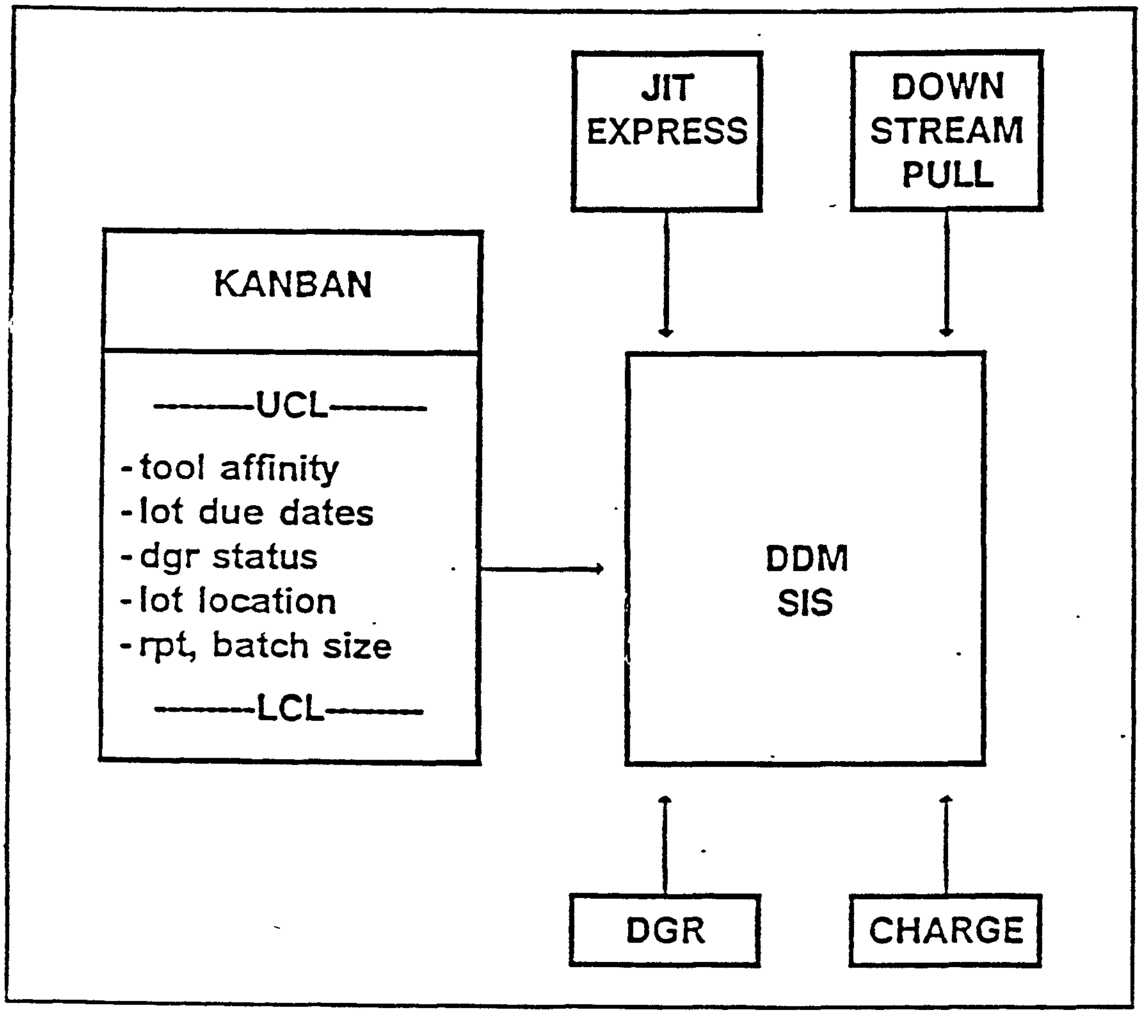
DDM Decision Process.

Multiple experts (advocates) vote to decide which lot to dispatch next from the queue.

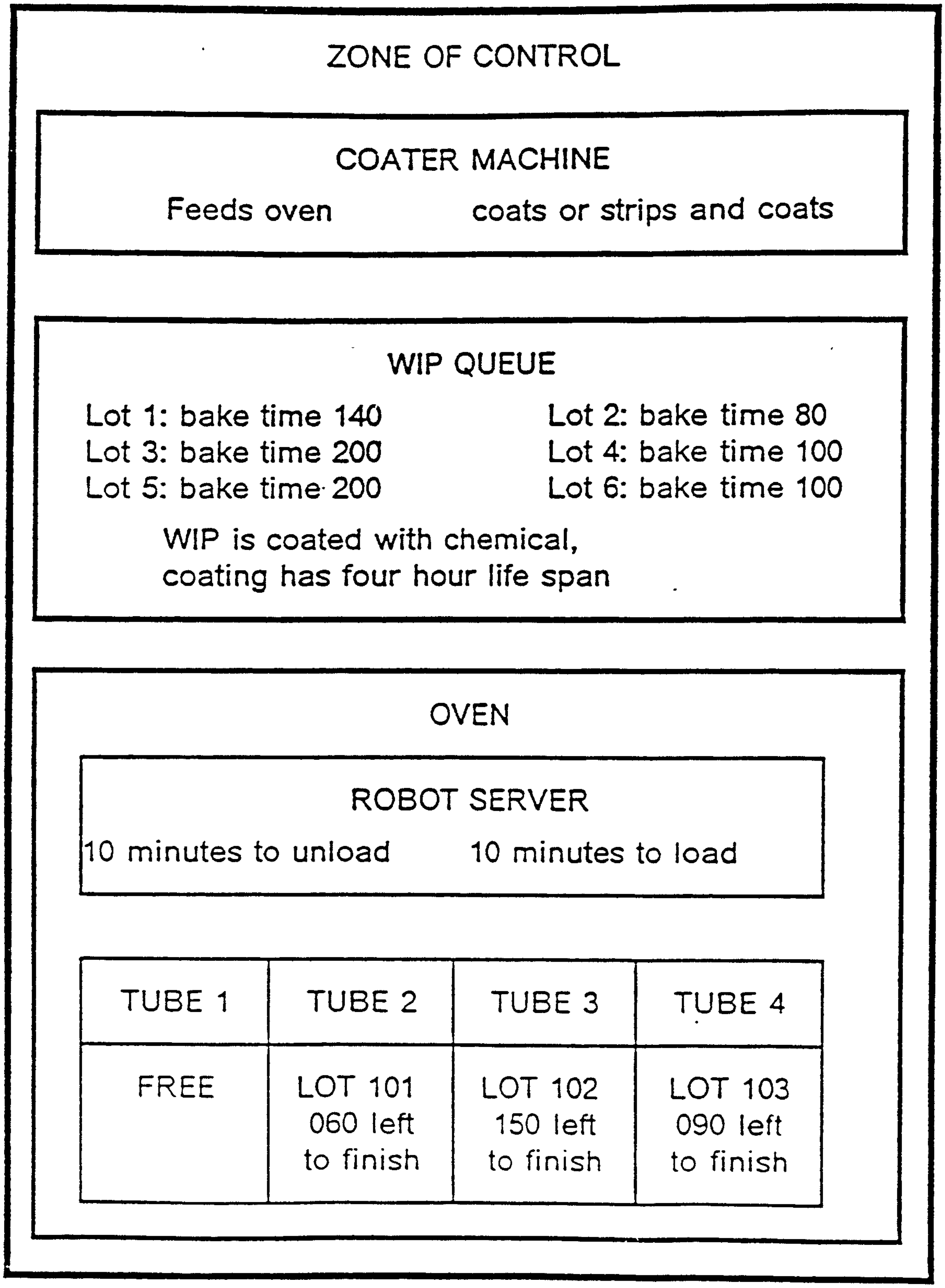
* *Just in Time* - Keep lots on schedule and work on express lots.
* *Daily Planned Output* - Fabricate to plan.
* *Downstream Pull* - Fabricate according to need of subsequent zone.
* *Tool Utilization* - Increase utilization by building long trains that minimize setups.

Weighted average for each lot in queue.

35. DDM Environment



36. Oven Dispatch Example



Voting Algorithm

Each advocate generates a ranking between 0 and 1 for each lot in the queue.

1. If the lot is voted (0) by one advocate it is automatically dropped as a potential selection.
2. If a lot is designed a must (1) it is chosen, unless another lot is also designated a must.
3. If there are no must lots, then the lot with the highest average score is chosen.
4. If two or more lots are designated as must lots, then the lot with the highest average score is chosen.

Performance

Core of the computer integrated manufacturing strategy of IBM's Essex Junction facility.

* Increased output at bottleneck tooling by 20 to 80%.

* In Photolithography alone increase throughput by 35% resulting in a savings of $8 to $10 million a year.

* Reduced cycle time has increased yields due to reduced material decay.

* Throughput increased by 10 to 20% ($100 million impact!).

Conclusions

* Scheduling is a very complex constraint satisfaction task.

* Mathematical optimization is not powerful enough to handle the general case.

* Expert system approach tends to fail due to lack of expertise.

* Constraint directed search appears to provide powerful approach to constructing satisfying solutions.

A little bit of knowledge goes long way!

Diagnosis

Determining the *cause* of discrepancy between a *Devices predicted behavior* and *Observed behavior.*

Approaches:

* Classification problem solving.
* Failure mode analysis.
* Model based reasoning.

Classification Problem Solving

* Identify deviations exist.
* Select cause to verify or refute.
* Map cause onto observed behaviors.
* Mapping is a "Heuristic association".
    - Abstraction of underlying system.
    - May be too complex to reason with.
    - May be unknown.
    - Mapping is uncertain.
* Must be able to enumerate observations and their causes.

Case study : PDS/GENAID

Steam Turbine and Generator Diagnosis (Westinghouse).

* Highly sensored.
* Real-time requirements.
* Mistakes are costly.
* Expertise is mostly heuristic and possessed by few.
* Recipient of 1985 IR 100.

37. PDS

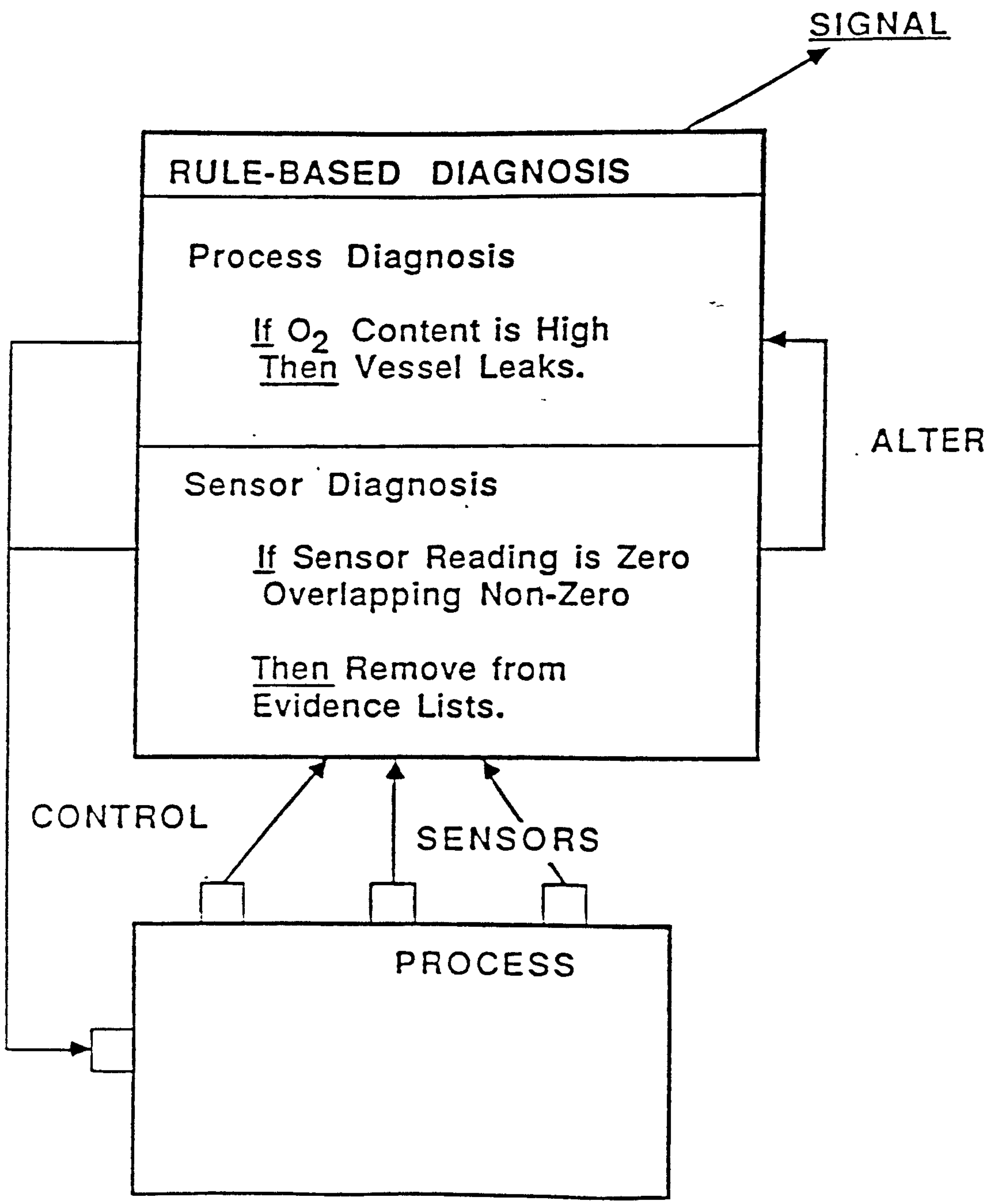
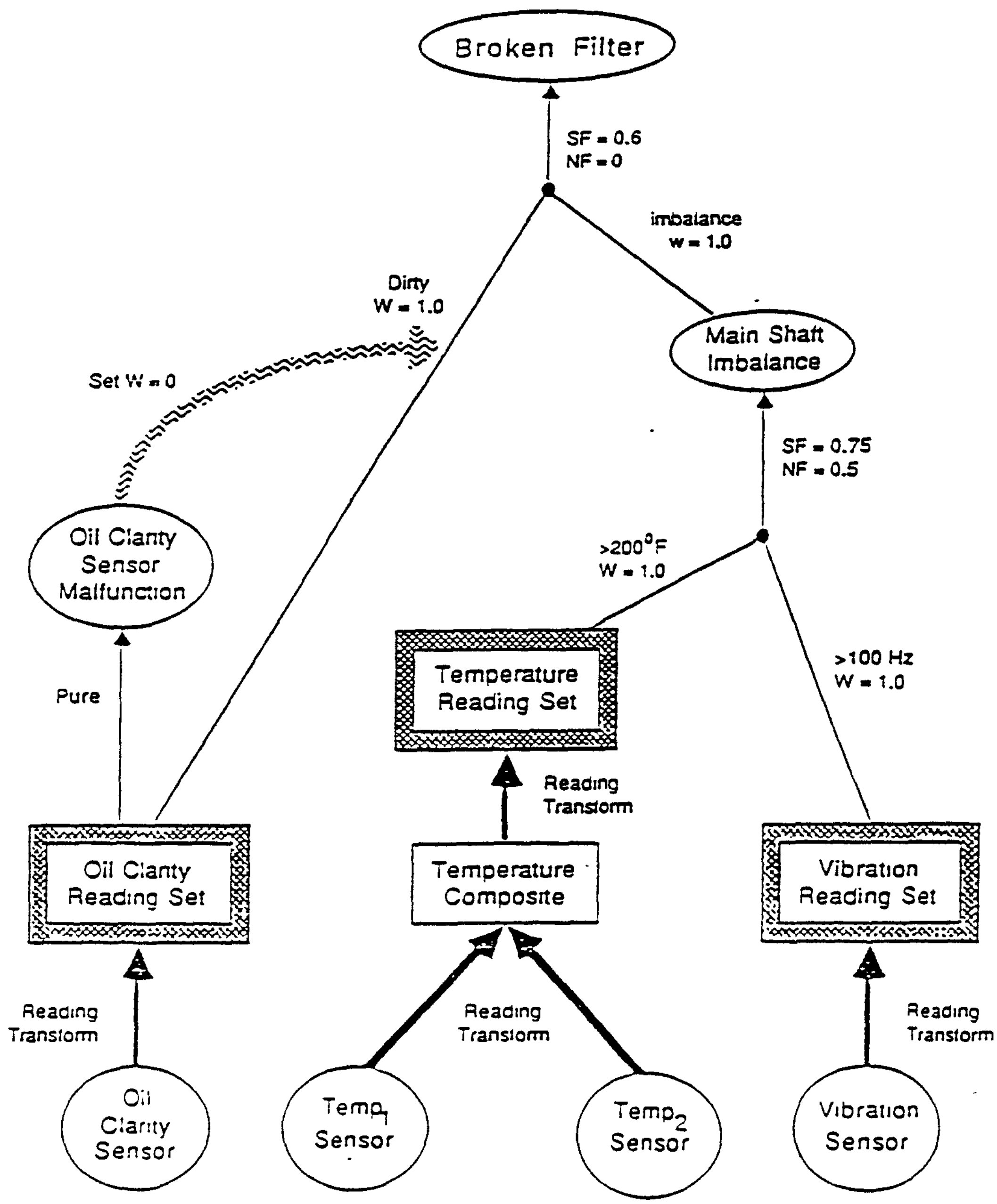

SIGNAL
RULE-BASED DIAGNOSIS
Process Diagnosis
If O2 Content is High
Then Vessel Leaks.
ALTER
Sensor Diagnosis
If Sensor Reading is Zero
Overlapping Non-Zero
Then Remove from
Evidence Lists.
CONTROL
SENSORS
PROCESS

Fig 38. PDS



Broken Filter
SF = 0.6
NF = 0
imbalance
w = 1.0
Dirty
W = 1.0
Set W = 0
Main Shaft
Imbalance
SF = 0.75
NF = 0.5
Oil Clarity
Sensor
Malfunction
>200°F
W = 1.0
Temperature
Reading Set
>100 Hz
W = 1.0
Pure
Reading
Transform
Oil Clarity
Reading Set
Temperature
Composite
Vibration
Reading Set
Reading
Transform
Reading
Transform
Reading
Transform
Oil
Clarity
Sensor
Temp1
Sensor
Temp2
Sensor
Vibration
Sensor

Previous Approaches

* Thresholds for sensor alarms with manual diagnosis.

* Bayesian decision process.

  - Five years in the making.

  - Results too complex.

  - Unable to acquire knowledge of distributions.

Belief Representation in PDS

The system's belief in the existence of an **hypothesis** or **malfunction** is defined by:

mb: belief in it's existence [0,1].

md: disbelief in it's existence [0,1].

cf: certainty of existence (mb - md) [-1,1].

The cracked tube has a belief of 0.9, a disbelief of 0.2 and certainty factor of 0.7

Belief Maintenance in PDS

Propagation of belief from sensors to hypothesis to malfunctions defined by connecting rules.

```
            SF
    EVIDENCE====================> HYPOTHESIS
            NF
```

A rule provides support for either belief or disbelief in it's hypothesis:

* Specifies the sufficiency of evidence in supporting hypothesis (SF).

* Specifies the necessity of evidence in supporting hypothesis (SF).

* Combines rule support with belief in evidence.

* Integrates support of hypothesis from multiple sources.

SIZE

As of 1986.

Sensors	211
Hypothesis	712
Malfunctions	554
Storage-nodes	843
Contexts	4
Piece - wise liners	200
Rules	3976

Performance

* On-line since 1985.

* Monitoring over 15 sites across the US.

* No false positives.

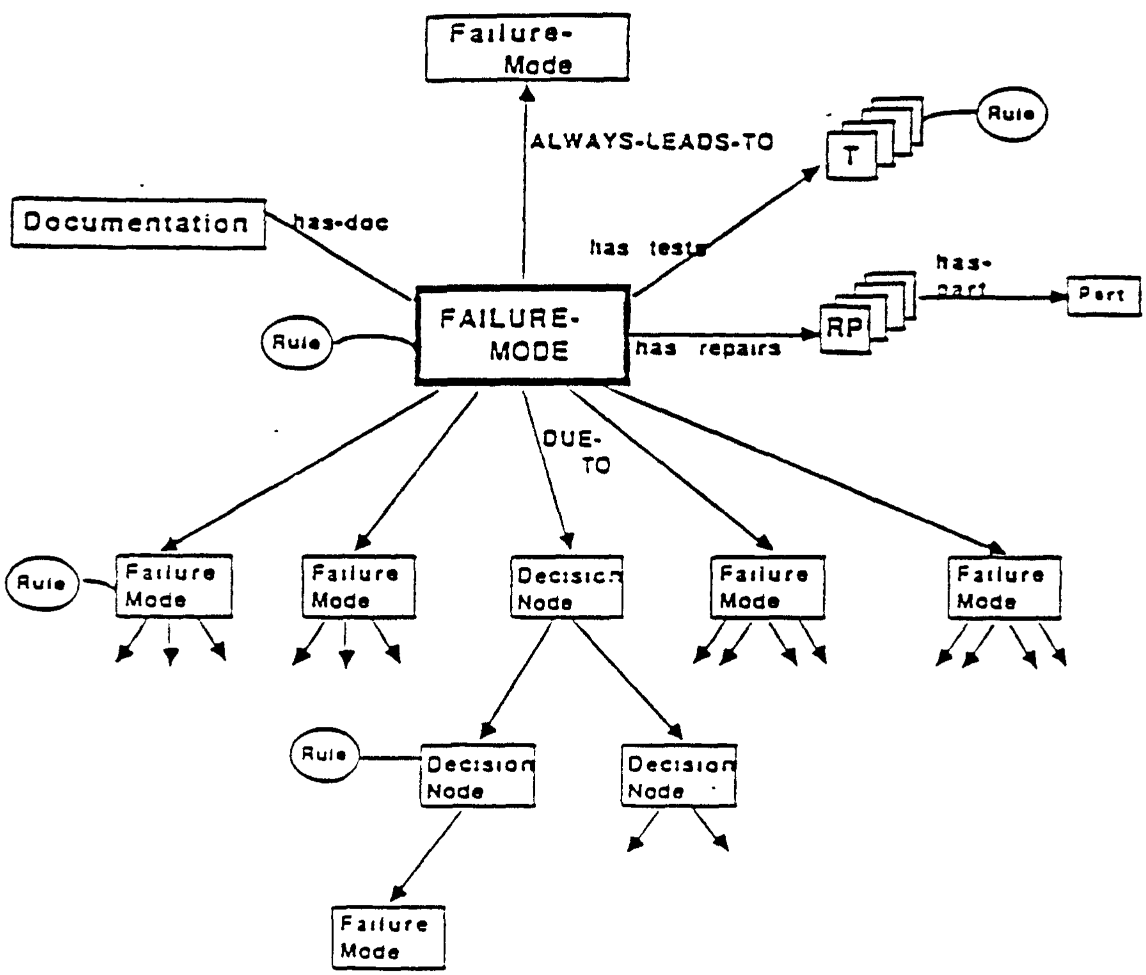
Failure Mode Analysis

* Casual structure relates failure to their causes.

* Each casual path identifies tests to perform to verify validity.

* Final cause prescribes repair.

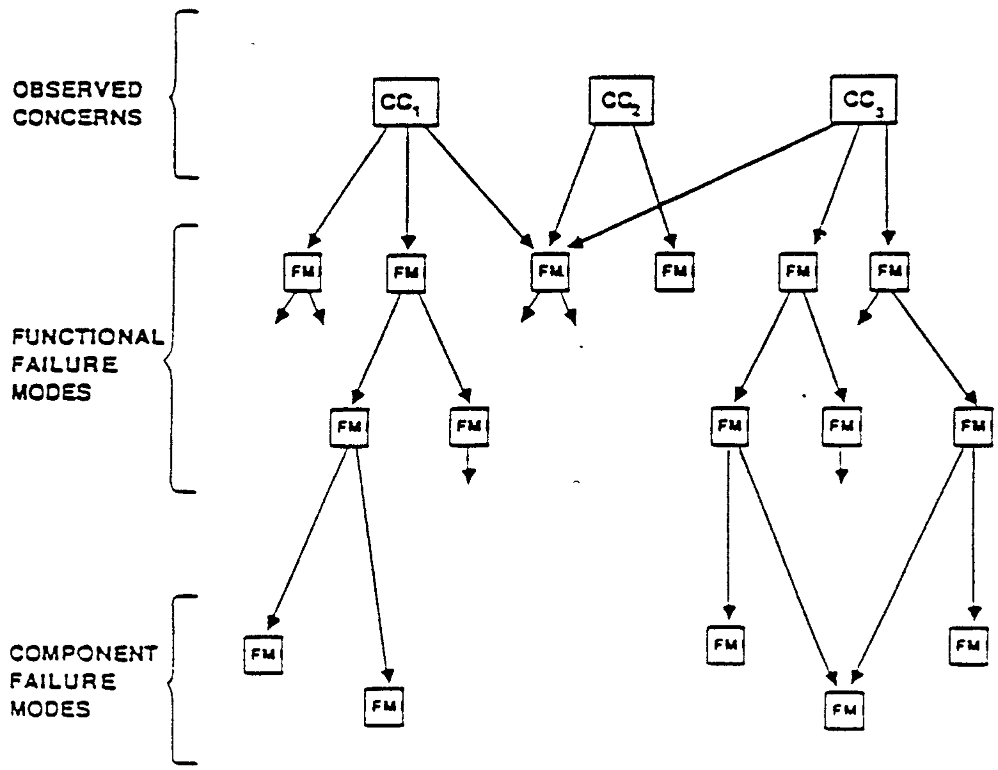
fig. 39



Failure Mode Network

The knowledge base consists of a hierarchical network of failure-modes, augmented with other supported information (tests, repairs , rules , etc):

fig. 40



Model - Based Reasoning

Uses a "deeper" understanding of the device to troubleshoot the problem.

* Structure defines the components and their connections.

* Behavior defines the relationship among its parameters.

* Fault models define how a device behaves with errorful inputs.

* Expectations define what we expect the device to do.

observations predictions

ACTUAL-----------> OBSERVED PREDICTED <---------- MODEL

DEVICE BEHAVIOR BEHAVIOR

DISCREPANCY

Structure

* Hierarchical description of a device by means of

- Components.

- Directed connections - the influence one component has over another.

Supports hierarchical troubleshooting.

* Object centered - isomorphic to the device.

- Examinable.

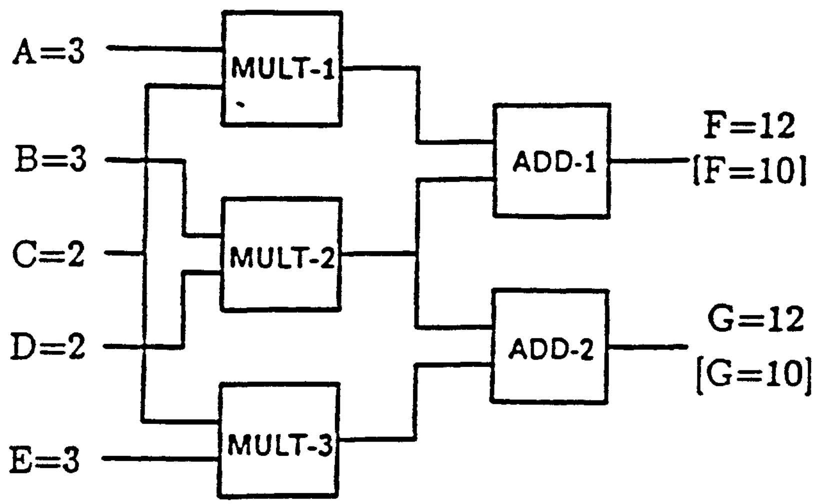
- Simulatable.

* Components may interact in many ways, useful to split into views.

- Magnetic.

- Thermal.

EXAMPLE DEVICE



Behavior

Defines the relationship among the parameters that characterize a device.

* Equations.

* Constraints.

* Rules.

Expectations define what we expect a device to do.

Diagnostic Tasks

Hypothesis Generation: Given one discrepancy, which of the components in the device might have produced it?

Hypothesis Testing: Given a collection of components implicated during hypothesis generation, which of them could have failed so as account for all available observations of behavior?

Hypothesis Discrimination: When, as is almost inevitable, more then one hypothesis survives the testing phase, what additional information should be gathered to discriminate among them?

Conclusions

* Classification problem solving provides a shallow representation of the relationship among signs , symptoms , and malfunctions.

* Failure mode analysis provide a deeper representation of Causalities.

* Model - based diagnosis provides the deepest representation of structure and Causalities , but is limited to small , decomposable , and computationally simple applications.

3.4.4 Impact of AI on Production Management

Job shops are intermittent production systems. The essential distinguishing characteristic in an intermittent system is that it produces a variety of products to a costumers order. Because each order requires distinctive processing , production control is tantamount to order control , and is so called. The objective of order control is to process each order efficiently as it moves through the facility. The objective is accomplished by allocating resources (i.e. , machines , materials , and personnel) according to time (due date) and place (routing) constraints. The allocation of resources in this manner is the purpose of scheduling.

There are two general types of scheduling Aggregate and Detailed. The former plans for overall level of output for a production system , while the later allocates inputs. Aggregate planning (master scheduling) usually involves time periods of three months to year , while Detailed scheduling deals with day to day operations.

Technology Assessment

Process planning is an activity that is performed routinely by industrial engineers in order to schedule and allocate resources for equipment assembly. The planning activity consist of the following: Given a connection of electrical component parts of a printed circuit board together with it's layout diagram , derive the sequence of operations required of a technician (or robot) for the correct assembly of the printed circuit board. The plans that result are called operations sheets.

The job shop scheduling problem has been rather extensively treated in literature , and remains a difficult problem with which to cope on both a theoretical and practical level. Research in AI is beginning to produce commercially useful scheduling system that promise to deal with the combinatorial aspects of the scheduling problem. One such expert system is ISIS, developed at Carnegie - Mellon University by Dr. Mark Fox and his colleagues, and has received considerable attention.

Most job shop scheduling applications, including ISIS, have been manufacturing applications. Repair operations add a new aspect to an already complicated scheduling problem in that the nature and extent of damages frequently cannot be determined until after the repair has been initiated. In this respect, repair operations stand to gain more from improved scheduling efficiency (e.g., reduced work in process inventory levels) than do manufacturing operations. The prospect of AI applications for close shops due to a relatively stable and predictable product line.

Software Inventory

CELL DESIGN AID is an in - house expert system used by Arthur Andersen & Co. as a tool for CIM planning. The program develops manufacturing cells, primarily through application of group technology. In operation, the expert system searches a database to identify all products having similar routing in the machining process. {Arthur Anderson & Co}

DISPATCHER is a printed wire board assembly dispatching system developed by Carnegie Group Inc for Digital Equipment Corporation. Dispatcher maintains database of products, list of manufacturing steps for products, and manufacturing operations able to be performed at each workstation. { The Carnegie Group }

FACTORY LAYOUT is an expert system to assist a system engineer in conceptualizing and testing alternative layouts for product flow in an automated facility. It allows rapid specification and modification of a particular design due to the extremely efficient graphical interface. { Arthur D. Little, Inc. }

FMS (Factory Monitoring System) addresses the need to monitor and control a factory, giving supervisors dynamic access to the factory floor. The system also allows analysis. The factory Monitoring System Architecture is shown in fig. { Carnegie Mellon University }

CDS is a configuration dependent part sourcer in use at Digital Equipment Corporation.

CML is a real-time flexible manufacturing system scheduling and control system developed originally by Carnegie Mellon University for Westinghouse Electric Corp.

FOREMAN'S ASSISTANT is an expert system used to handle machine scheduling functions at the General Dynamics Fortworth Division manufacturing facilities. The Foreman's Assistant for Intelligent scheduling prioritizes manufacturing jobs, thereby relieving the foreman of many of the time consuming considerations regarding scheduling.

GT / CAPP (Group Technology Computer Aided Process Planning) is an expert system that uses Intellicorp as the foundation. It has an Architectural framework leading to generative process planning.

COOKER is a food processing control developed by Texas Instruments for Campbell Soups.

SCHEPLAN is a scheduling system for steel making developed by IBM Research in Tokyo for Nippon Kokan Co.

SMARTWARE is a wave solder diagnostic systems developed by Digital Equipment Corp.

TRINITY MILLS SCHEDULER is an FMS scheduling system developed by Texas Instruments for internal use.

WAVE SOLDER DIAGNOSTIC system was developed by Carnegie Group for Ford Motor's Electronics Division.

HICLASS (Hughes Integrated Classification Software System) incorporates producibility into product design and automates support activities in manufacturing.

HYDRA is an AI based system under development for production management. HYDRA is being designed to operate in a distributed environment in which sophisticated workstations will be used for design , scheduling , process monitoring and control , and decision support. { The Carnegie Group }

ISIS is an expert system based on constraints and preferences expressed as rules. It uses AI search techniques to generate , compare , and rate alternative work center schedules in order to predict the impact of scheduling decisions. It enables engineers and managers to predict what the impact of a rush order will be. The system knowledge base includes frames and rules for modeling both the manufacturing environment and all constraints applicable to scheduling. { Carnegie Group }

OPEX is an expert system for CAPP. It covers a part of the macro level planning activities. { Institute Josef Stefan}

PALLADIAN MANUFACTURING AND LOGISTICS is an expert system used to assist in making better manufacturing and logistical decisions. {Palladian Software}

PTRANS is a system used to generate plans for the manufacture and distribution of computer systems. When an event occurs that makes one of this plans unimplementable , it revises the plan and any other plans affected by that revision. { Carnegie Mellon University and Digital Equipment Corp.}

TEST FLOW DESIGN is an expert system to assist in the sequencing of quality tests and reworks that flows in a multi-product manufacturing facility. { Arthur D. Little , Inc }

TOOLING DESIGN is an expert system that helps prepare a tooling sequence for a machine tool workstation. It focuses on the interaction between timing requirements and hardware needs. { Arthur D. Little , Inc }

XFL is an expert system that takes orders that have been configured and helps plan the physical environment in which the computer system will be installed. It maps the floor layout and determines details such as power requirements and air-conditioning. { Digital Equipment Corp.}

Systems in Industries

DUPONT:

* 200 systems doing equipment diagnosis.
* 200 systems doing process diagnosis.
* 50 systems doing real-time control.
* 50 systems doing scheduling.

15:1 ROI on non scheduling applications , 40:1 on scheduling applications.

SHELL:

* 30 systems in operation.

DIGITAL EQUIPMENT:

* Over 30 systems in operation.

$ 1 Billion savings over 10 years due to AI.

IBM:

* 108 diagnostic systems.
* 40 process control systems.
* 19 planning systems.

Current Research And Future Outlook

CAM-I , the University of Grenoble (France), and United Technologies are researching a rule based production planning system , that will called XPS-E.

Chrysler is developing an expert system to handle plant scheduling, an effort expected to take several years. Eventually the system could be applied to supplier operations such as stamping as well as to final assembly.

Battelle Geneva Research center is developing an expert system that assists in seeing the parameters characterizing ceramics production , which are difficult to define manually or by using existing conventional software packages.

Sun Hydraulics Corporation , a Sarasota FL-based designer and manufacturer of cartridge valves and bodies for hydraulic systems , is developing an expert system to help its staff regulate manufacturing work flow.

Callisto is an intelligent project management system. The Callisto project was born out of the realization that the classical approaches to project management do not provide functionality to manage large engineering projects. Callisto was initiated as a research effort to explore project scheduling , control and configuration problems during the engineering prototype development of large computer systems and to devise intelligent project management tools that facilitate the documentation of project management expertise and in reuse from one project to another.

In 1970s , the focus of manufacturing was on robotics , and the automation of repetitive tasks by computer controlled machines. It is clear that greater paybacks can be achieved through reduction of inventory and work in process, and increasing machine utilization. Concepts such as Just in time and MRP II are becoming accepted industrial practices, and the computer integrated manufacturing (CIM) facility is the goal of most large companies. Since most of the US industries is involved in batch manufacturing, the problem of CIM can be seen as one of scheduling. The factory of the future is visualized as one scheduling inventory on a just-in-time basis and routing production through manufacturing processes in an optimized fashion, with expert systems playing a vital role in this process.

The large potential savings achievable through expert system scheduling, as proven by the $ 10 million annual payback at a Westinghouse plant, will attract significant industrial interest in the next few years, making this one of the hottest areas for expert system applications.

3.5 AI in Energy Management

" *Do we really need to make our computers smarter? It seems so. As the world grow more complex, we must use our ENERGY, food, and human resources wisely, and we must have high quality help from computers to do it. Computer must help not only by doing ordinary computing, but also by doing computing that exhibits intelligence.*" (from Prof. Patrick Henry Winston's book of Artificial Intelligence)

Technology Assessment

Energy management systems (EMS) and facility management systems have been in use for about 10 years. In November 1983 at the World Energy Engineering Congress , American Auto - Matrix introduced the first such system employing AI technology. The system designed as model AI 2100 , utilizes self-learning software. Conventional automation systems are based on computer programs which are fixed. Conversely , the AI 2100 accumulates historical knowledge and uses that experience to recognize and respond to changing conditions.

Energy management systems , such as the AI - 2100 , perform the following types of monitoring and control functions.

* Energy Management - minimizing energy consumption and equipment wear by properly controlling heating , ventilation , air conditioning , lighting and other physical plant equipment.

* Equipment Monitoring - monitoring and controlling the operation of many type of equipment , such as : moving walkways , escalators , elevators , compactors , compressors , automatic doors etc.

* Security - protecting the building , its occupants and contents by properly monitoring and controlling various devices which include: vibration detectors , foil strips , capacitance devices , magnetic contact switches , and infrared , ultrasonic or microwave sensors.

* Fire Management - detecting and appropriately responding to any fire emergencies in accordance with both NFPA and UL standards for fire protection signalling systems.

* Life Safety - protecting both the building and its occupants from potentially dangerous substance such as toxic gases , flammable liquids and gases , and chemical leaks or spills.

* Factory Automation - monitoring and controlling , to a user's specific needs , factory equipment such as: conveyors , machine tools , casting equipment , curing ovens , and finishing equipment.

In 1984 , the same energy management system , incorporating expert system capabilities , was distributed by United Technologies and Barber-Colman. At the 1985 World Energy Engineering Congress , Andover Controls announced an EMS with artificial intelligence capabilities.

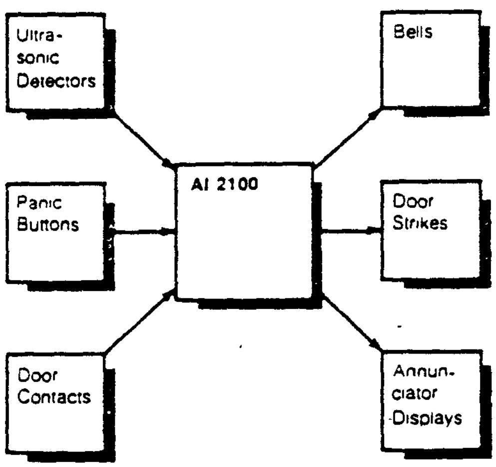
Software Inventory

AI 2100 is a family of three "Building Brain" products MAX , STAR , and REX , which combine distributed control and stand alone operation with networking. the AI 2100 has a built in expert system , allowing the building user to enter rules relating to specific operational facility where AI 2100 is being used. {American Auto Matrix}

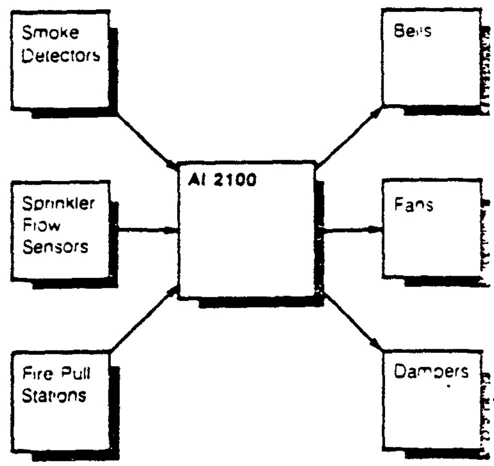
ELECTRIC LOAD MANAGEMENT ADVISOR is an expert system for process management. It advises on power usage. It was built using Teknowledge's M.1 on a PC/AT clone. {Teknowledge}

Fig 41. Features of AI - 2100

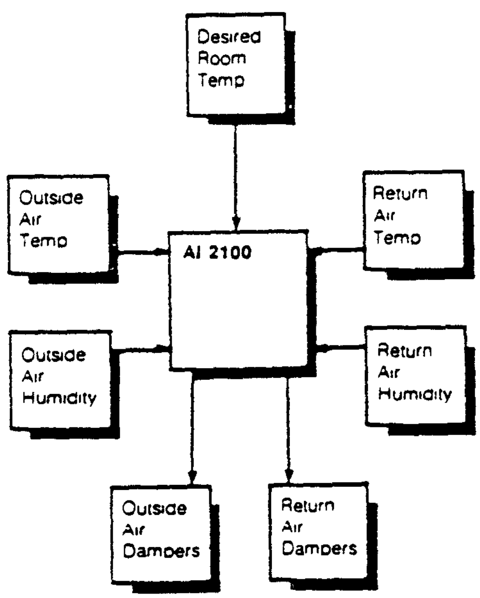
Security Applications



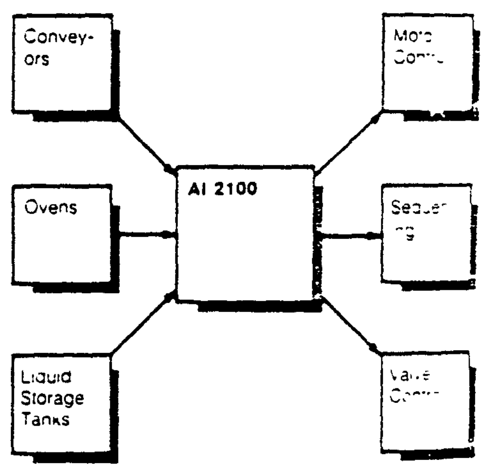
Fire Management Applications



Enthalpy Control



Factory Automation/Process Control



INTELLIGENT BUILDING MANAGEMENT is an expert system used to guide the operation of the HVAC system of a commercial building. {Teknowledge}

Current Research and Future Outlook

The Center for Engineering Systems Advanced Research (CESAR) has recently been established at the Oak Ridge National Laboratory (ORNL) to address long range , energy related research in intelligent control systems. The purpose of this project is to develop efficient strategies to be used by an autonomous robot with hierarchical control structure operating in an unstructured , real world environment. This research is an integral part of a system with complementary efforts in mathematical modeling , real-time control , sensor integration , etc. The work builds upon traditional areas of strength in artificial intelligence (i.e. , knowledge representation , inferential reasoning , and parallel planning) through the application requirements of real time decision making and on-line learning.

The US Army Construction Engineering Laboratory (CERL) has awarded a contract to the Institute of Gas Technology and two other firms to investigate the application of the expert system to energy management. The project will develop and maintain knowledge based systems including the provision of public access to the systems. Included will be programming , evaluation , and fielding of expert systems using microcomputers and special AI computers.

A project at Virginia Polytechnic Institute is investigating the use of expert systems for load management. Under sponsorship of a co - op , the objective is to forecast short term electric demand patterns and utilize this information to guide load management and purchase of power from utilities.

The use of expert systems in HVAC system design was proposed by Victor Wright. The first expert system that addresses the task of HVAC design will probably be developed by large equipment manufacturers. They have economic resources , and the knowledge base , but not in a form suitable for direct incorporation in to an expert system. An expert system developed by an equipment manufacturer could play a number of roles that would benefit not only the manufacturer but also the costumer by performing tasks such as selection and configuration of large machines and systems , on - line troubleshooting of machines and systems. Several manufacturers of EMS are known to be conducting in - house research in this area.

An expert system could be developed and used for the performance of energy audits. A knowledge engineer would interview expert level energy auditors and assess audit case histories to determine principles , facts , judgements , and rules of thumb which are experts use to develop professional recommendations for appropriate energy conservation measures. The knowledge engineer would use this information to select knowledge representation schemes and reasoning strategies. A prototype expert system would be built and refined. In operation , the expert system would develop energy conservation recommendations based on the field data and expert knowledge. In the field , a technician would enter observations (in English , not a computer language) and would check the reasonableness of each of the recommendations until the programme is fully debugged. Such an approach differs from conventional energy programs which perform basic calculations and provide numerical results. The recommendations from the expert system would be understandable by the non-technical user.

Infrared scanners are used to identify heat patterns that may be associated with leaks , faulty stream traps , or heat losses that waste energy. AI - based image analysis techniques have been used for a wide range of applications from industrial inspection to mineral exploration. There exist a good potential for applying similar techniques to the assessment of infrared data for energy conservation.

3.6 AI in Quality Assurance

A major emphasis of current programs in manufacturing automation is related to the inspection and quality assurance area. Advanced sensors, such as machine vision systems and laser gauges, are being developed to perform the repetitive inspection task more economically and, in many cases more accurately, than with the use of such computer based advanced sensor systems in the generation of digital data for every part inspected. This data may be statistically analyzed to guide modifications to the manufacturing process to optimize the output. For example, drift in the dimensions of a machine part may be recognized and the machine tool wear which caused the problem may be compensated for or corrected before any parts out of specifications are made.

Assessing Technology

Specifications for manufactured products are influenced by a variety of factors, including governmental regulations, liability, consumer requirements, and economics. These factors often change, resulting in a modification of quality assurance requirements. An expert system can serve to assist a company in assessing and keeping up with such changing conditions. When corporate policies on quality control change, for example as the result of a new federal regulation, an expert system overlaying the manufacturing process could implement that change wherever appropriate in production and inspection procedures.

Industry is beginning to move from a defect detective approach to a defect preventive approach. Future machine controllers will incorporate expert systems which modify manufacturing variables to improve the operation before it even begins.

Software Inventory

COMPONENT EVALUATION is an expert system that evaluates proposed changes in a components mix for quality control. It was built using Teknowledge's M.1 on a PC/AT clone. {Teknowledge}

CORNING GLASS is an expert system developed to diagnose breakage problems that occur at the lehr. Product defects caused by other processing steps manifest themselves then the ware cools as it leaves the lehr. Diagnosing breakage helps isolate the upstream problem that requires correction. The system was developed using Texas Instrument's Personal Consultant. {Corning Glass , PA}

ERNEST is used internally to manage the quality assurance program for software development and control. {Systems Designers Software , Inc.}

PRODUCT LABELS assists in the preparation of a legally acceptable product label for consumer and industrial products. It assesses the relative risk of using different labeling schemes , under a variety of conditions. {Arthur D. Little , Inc.}

PRODUCT SAFETY helps manage and identity of risks associated with bringing a new product to market. It focuses on industrial chemicals and similar commercial products. { Arthur D. Little , Inc.}

QUALITY CONTROL ADVISOR is an expert system for batch manufacturing. It was built using Teknowledge's M.1. {Teknowledge}

SPINPRO is an expert system that designs ultracentrifugation procedures. The investigator and the program participate in a question and answer dialogue in which the research goals and sample characteristics are defined. At the conclusion of the dialogue SpinPro produces four reports. One report summarizes the questions posed by Spinpro and answers provided by the investigator. The second report describes an optimal ultracentrifugation procedure to achieve the stated goals using the optimal equipment. The third report is similar , but outlines a procedure based upon , and constrained by the centrifuge equipment available in the investigator's laboratory. A forth report compares the two procedures and the effectiveness of each in performing the run. Thus , the program performs the role of an expert advisor , offering knowledgeable advice and comparing alternativeness. The Spinpro Ultracentrifugation Expert System was developed in InterLISP (InterLISP_D on a Xerox 1108 , and InterLISP-10 on a DECSYSTEM-2060}, and runs under Common LISP on the IBM PC/XT. {Backman Instruments , Inc}

Current Research and Future Outlook

It is reported that pharmaceutical companies are experimenting with expert systems in testing of drugs for side effects. The expert system would provide rules to overlay a database , altering the company to potential problems and advising on what should be reported on FDA. Many medical expert systems involve drug usage , this application is a spin-off of this type of expert system.

According to this type of application , it will be a significant part of the projected $ 250 million market for AI in robotics in 1998.

The AI market in robotics is projected by G. Allmendinger of the Yankee Group (Boston , MA) to be $ 250 million by 1998. Minimizing factory product defects will be a major use of AI , as sensors in machine tools are tied back to database so they can anticipate when something is about to go wrong.

3.7 AI in Machine Diagnosis and Troubleshooting in Field Service

The maintenance of a complex item of equipment involves a diagnostic procedure incorporating many rules as well as judgement decisions by the maintenance mechanic. Experience is a very important factor in determining the ease with which a mechanic can locate a failure problem and implement the appropriate correction.

Current Technology

Expert systems are now being utilized to assist maintenance personnel in performing complex repairs by presenting menu driven instruction guides for the diagnostic task. These expert systems incorporate the knowledge of mechanics who are vary experienced in the maintenance and repair of that item of equipment.

The Polytecnico di Milano (Italy) has a case study that presents how an expert system solves the general problem of Industrial maintenance (diagnosis and repair).

A workshop , entitled Joint Services Workshop on Artificial Intelligence in Maintenance , was held in October '83 , in Boulder , CO. The primary objective of the workshop was to provide an exchange of technical information among personnel involved in ongoing research and development in artificial intelligence applicable to automatic testing , maintenance siding , and maintenance training. A second objective was to identify both theoretical and practical applications issues in the use of AI in maintenance.

General Motors uses an expert system, built using S.1 (Teknowledge), to increase the accuracy and efficiency of service technicians over 10,000 independent dealerships.

Ross Laboratories has created an expert systems, using EXSYS, to diagnose problems in equipment used in their manufacturing areas for use by non technical workers. The expert system has custom user interface to EXSYS via external program calls to make the system more friendly and descriptive to avoid the fears of first time computer users.

Softwares in Industries

ACE (Automated Cable Expertise) analyzes daily telephone cable repair reports, diagnosis specific trouble spots, and suggests what repair is needed. The system has been implemented in Fort Worth, Texas for the use of Southwestern Bell. ACE has proven so successful that most of the preventive maintenance being carried out now in Forth Worth was suggested by it. {AT&T Bell Laboratories}

ASCIT (All-purpose, Simple to use, Computer-based Interactive Tool) is a system that can easily be adapted to facilitate maintenance and diagnostics of any complex piece of equipment or machinery. The first use of ASCIT was for a complex system abroad a U.S Navy Submarine. ASCIT provides user access to system information which includes textual descriptions, visual information (picture, drawing, and schematic), and step by step audio and visual information on preventive, troubleshooting, and corrective maintenance. {Newport News Shipbuilding}

AUTO-MACH is an expert system which diagnoses automobile fuel systems. It's organization and strategies are patterned after MDX, an expert diagnosis system. Auto - Mech is implemented in a recently developed language called CSRL {Ohio State University}

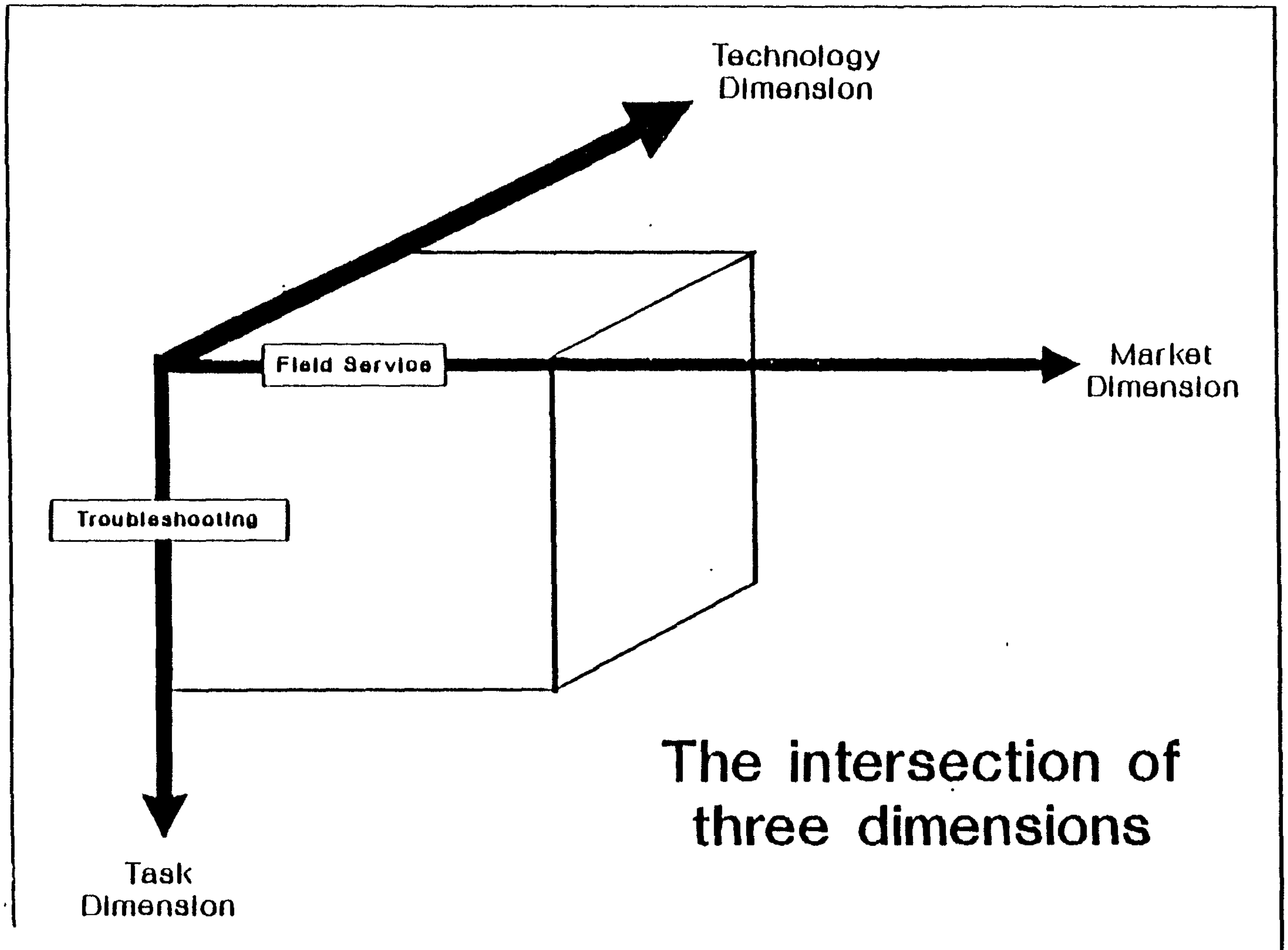


Fig 42. The market, the task, and the technology

Typical Field Service Organization

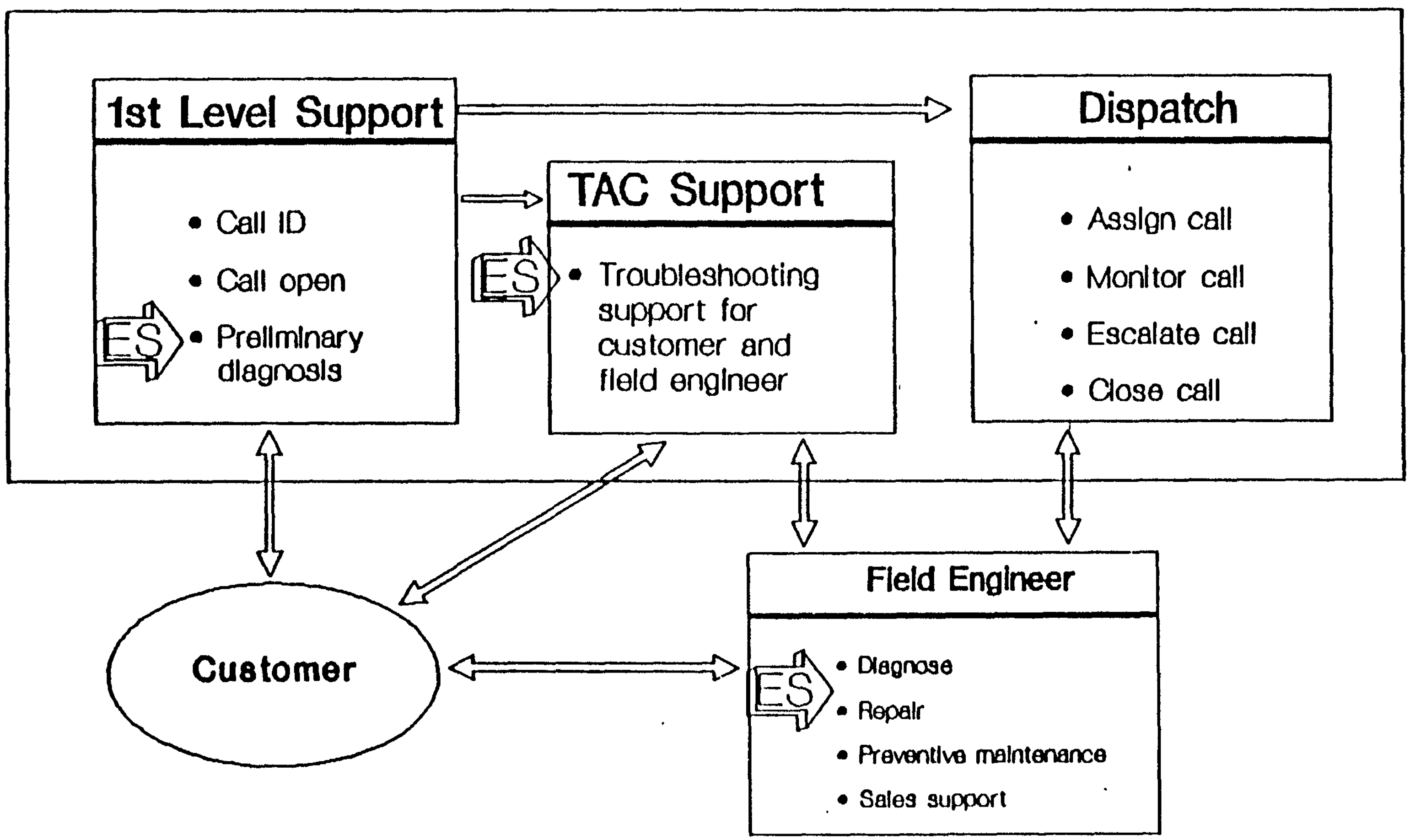


Fig: 43

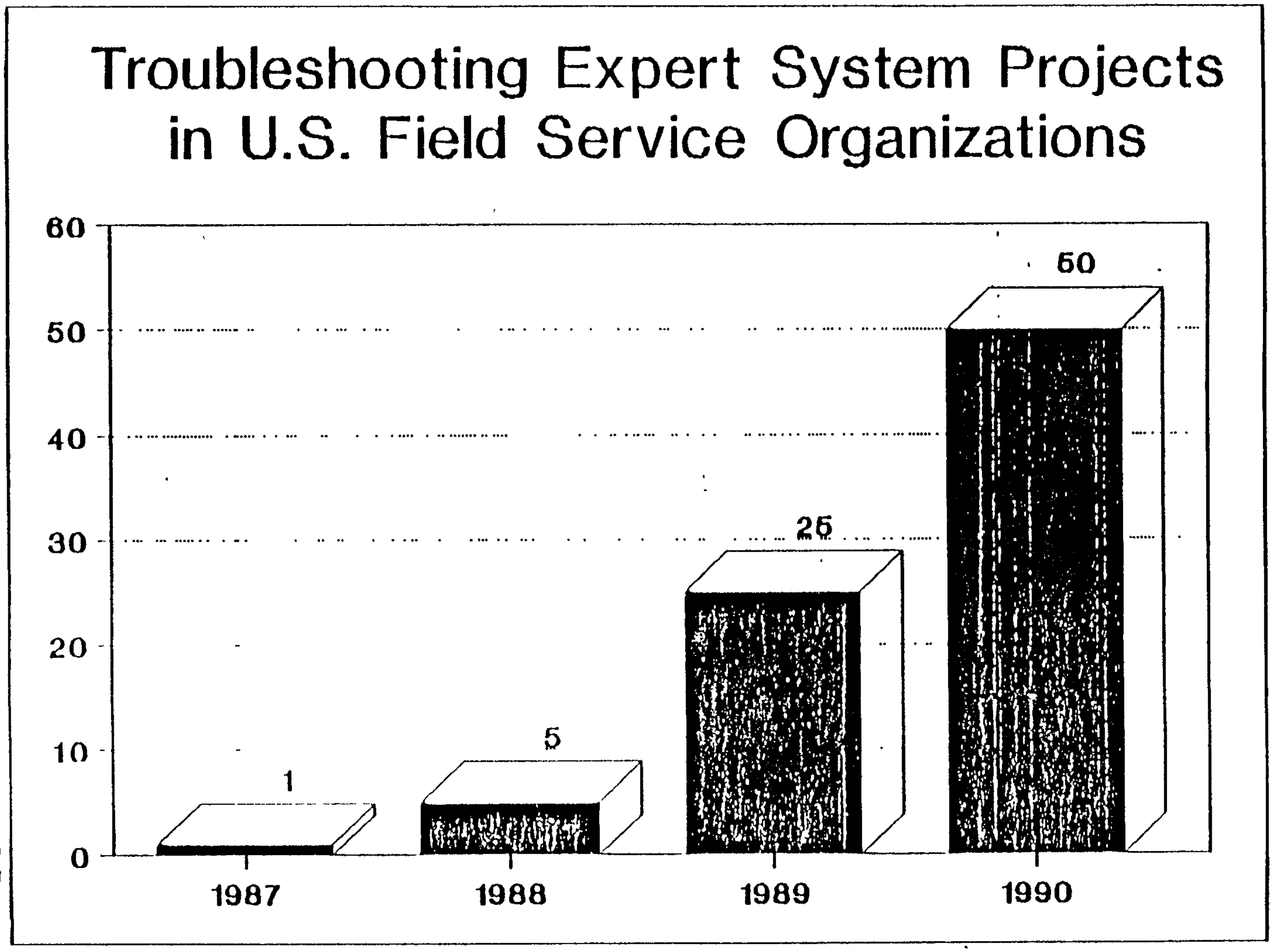


Fig 44. History

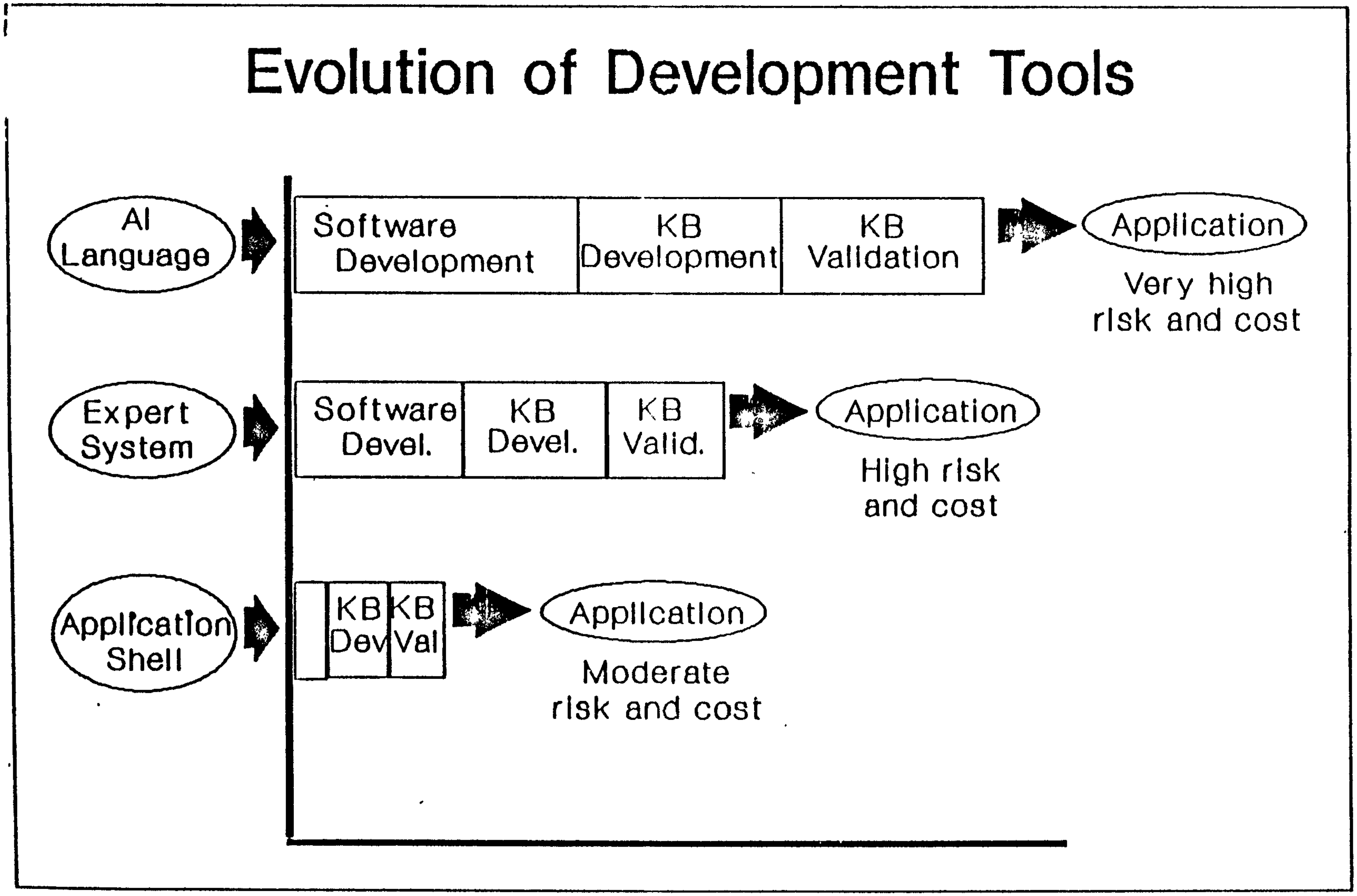


Fig 45. Evolution

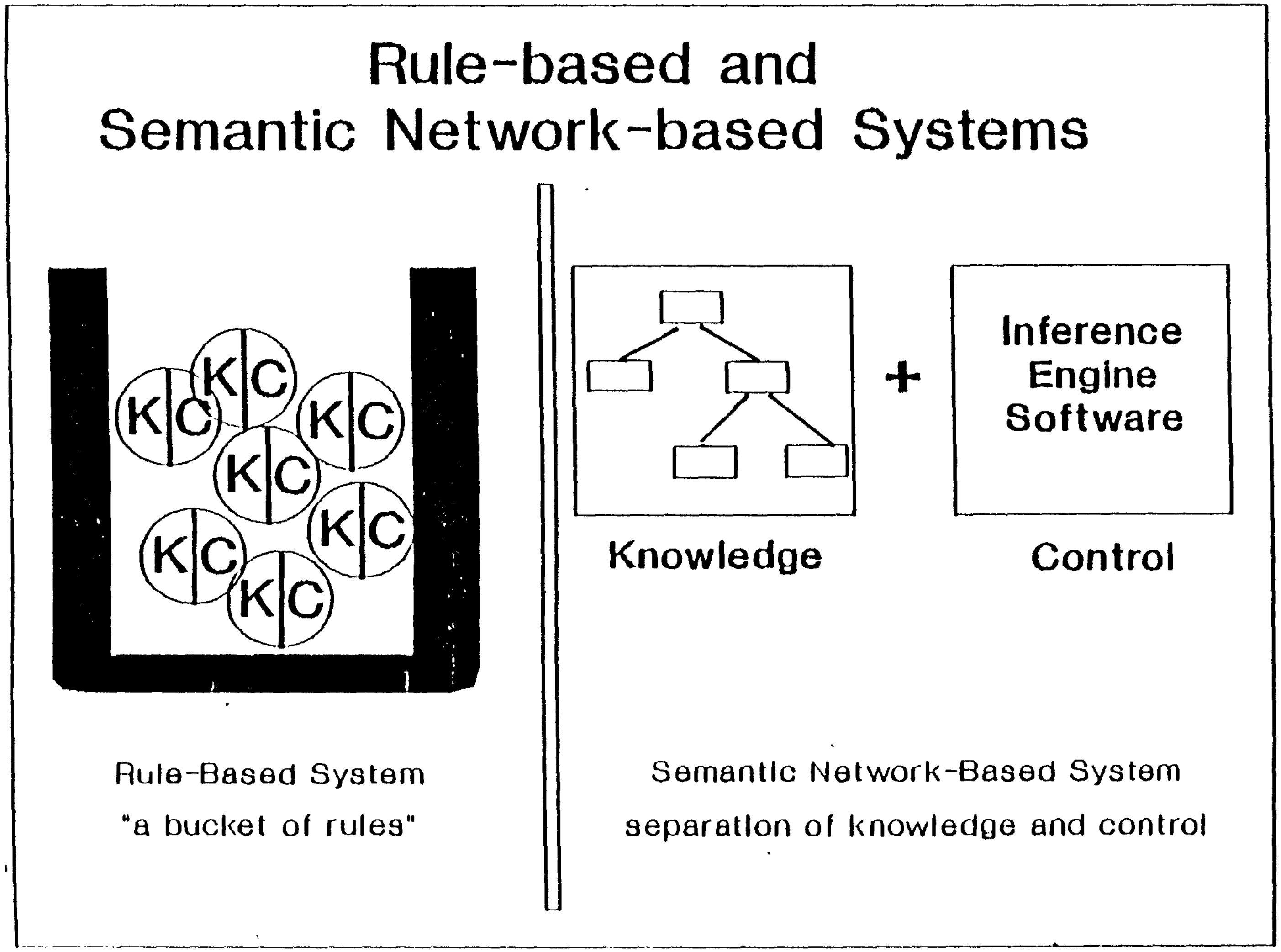


Fig 46. Architecture alternatives

Types of Semantic Networks

Type	KB Models		
Deep Causal Models	Actual structure and function of product	•generates strategy •good for new applications	•hard to build •hard to modify •hard to specify strategy
Fault Models (Weak causal models)	Faults in product and their causal relationships	•captures existing strategy	•cannot handle new problems •behavior can be inflexible
Troubleshooting Models	Faults in product and their causal relationships	•captures existing strategy	•cannot handle new problems

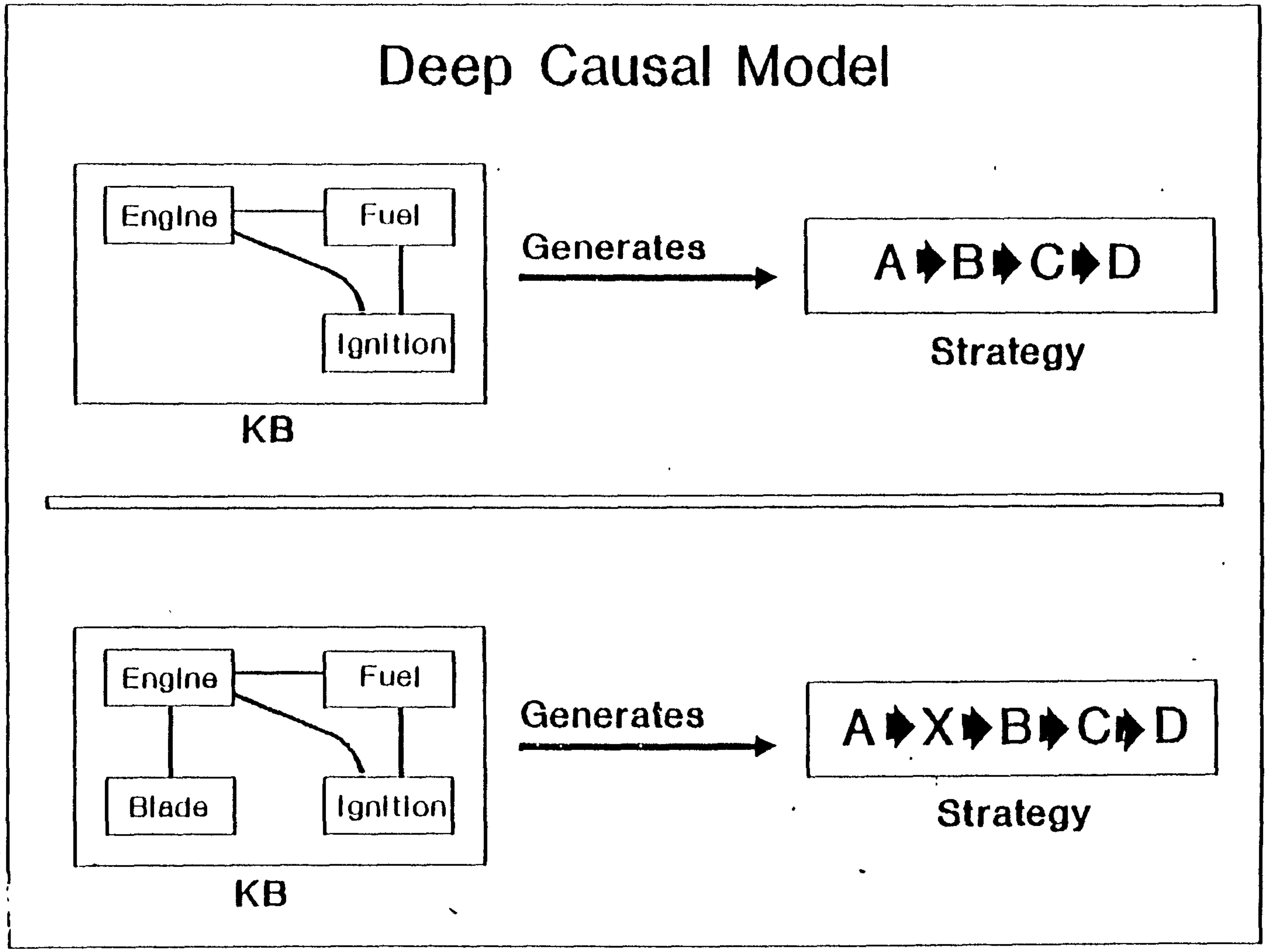

Deep Causal Model
Engine
Fuel
Ignition
KB
Generates
A ➧ B ➧ C ➧ D
Strategy
Engine
Fuel
Blade
Ignition
KB
Generates
A ➧ X ➧ B ➧ C ➧ D
Strategy

Fig: 47

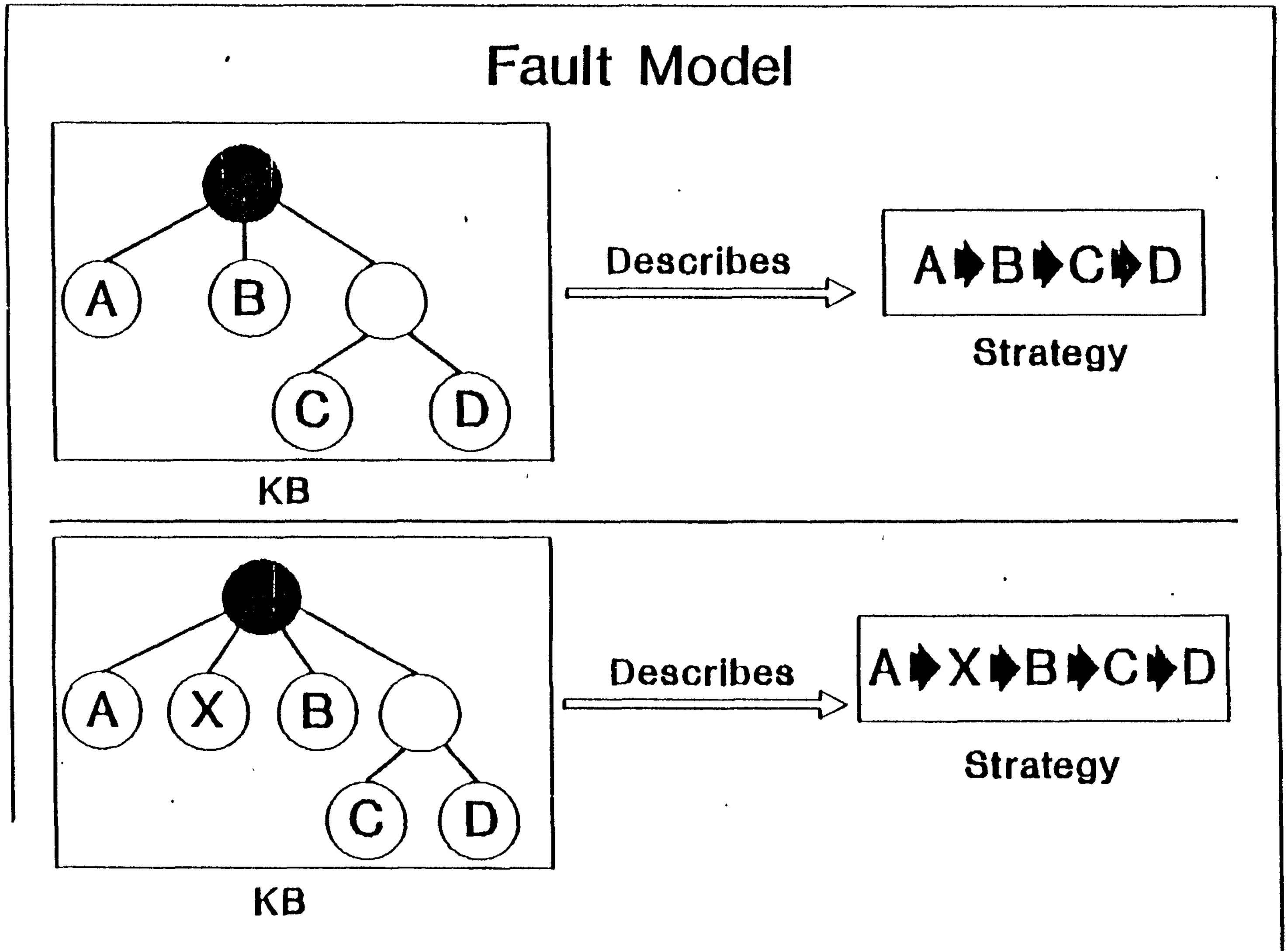

Fault Model
A
B
C
D
KB
Describes
A➧B➧C➧D
Strategy
A
X
B
C
D
KB
Describes
A➧X➧B➧C➧D
Strategy

Fig: 48

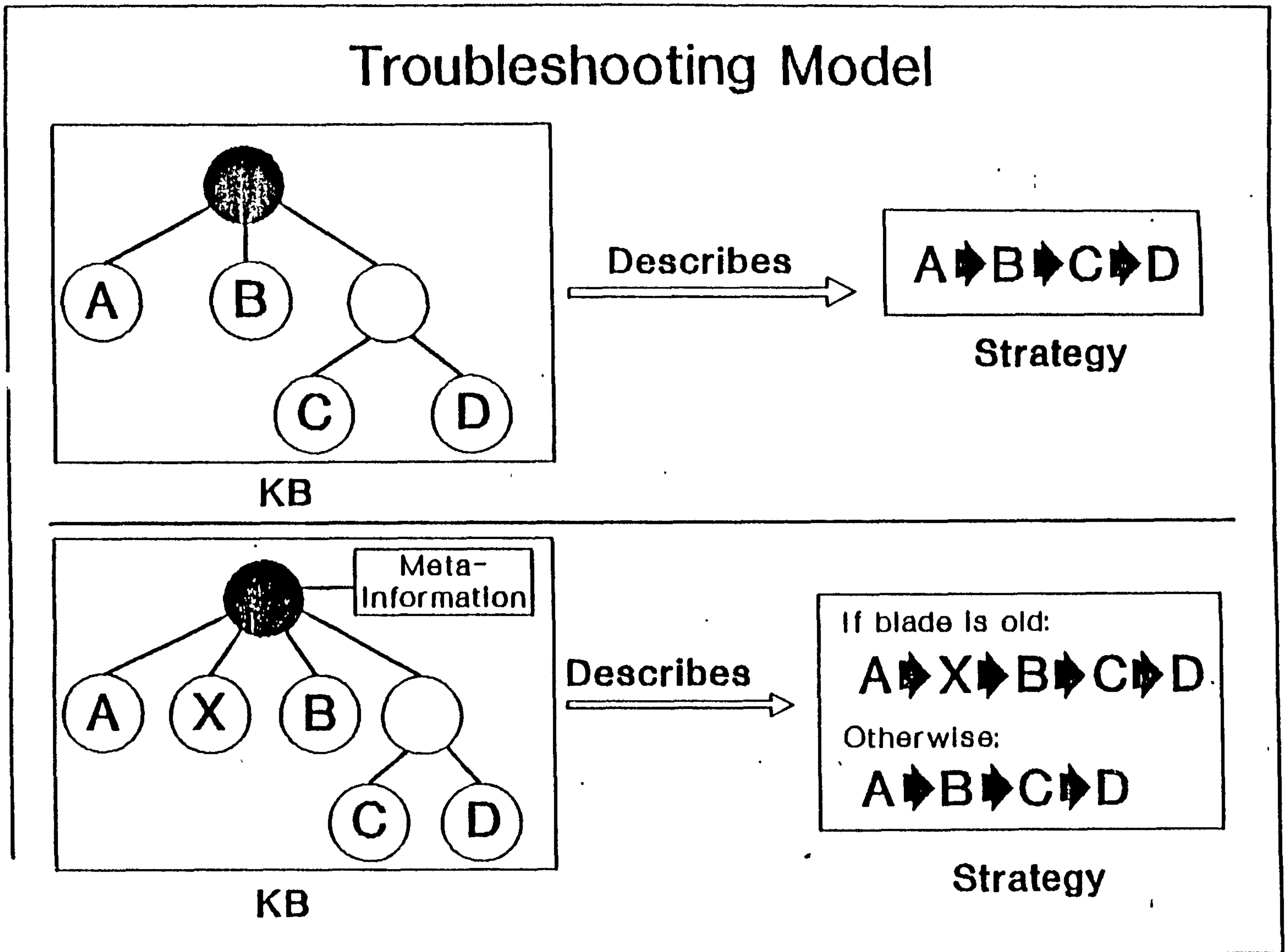

Troubleshooting Model
A
B
C
D
KB
Describes
A B C D
Strategy
Meta-
Information
A
X
B
C
D
KB
Describes
If blade is old:
A X B C D
Otherwise:
A B C D
Strategy

Fig: 49

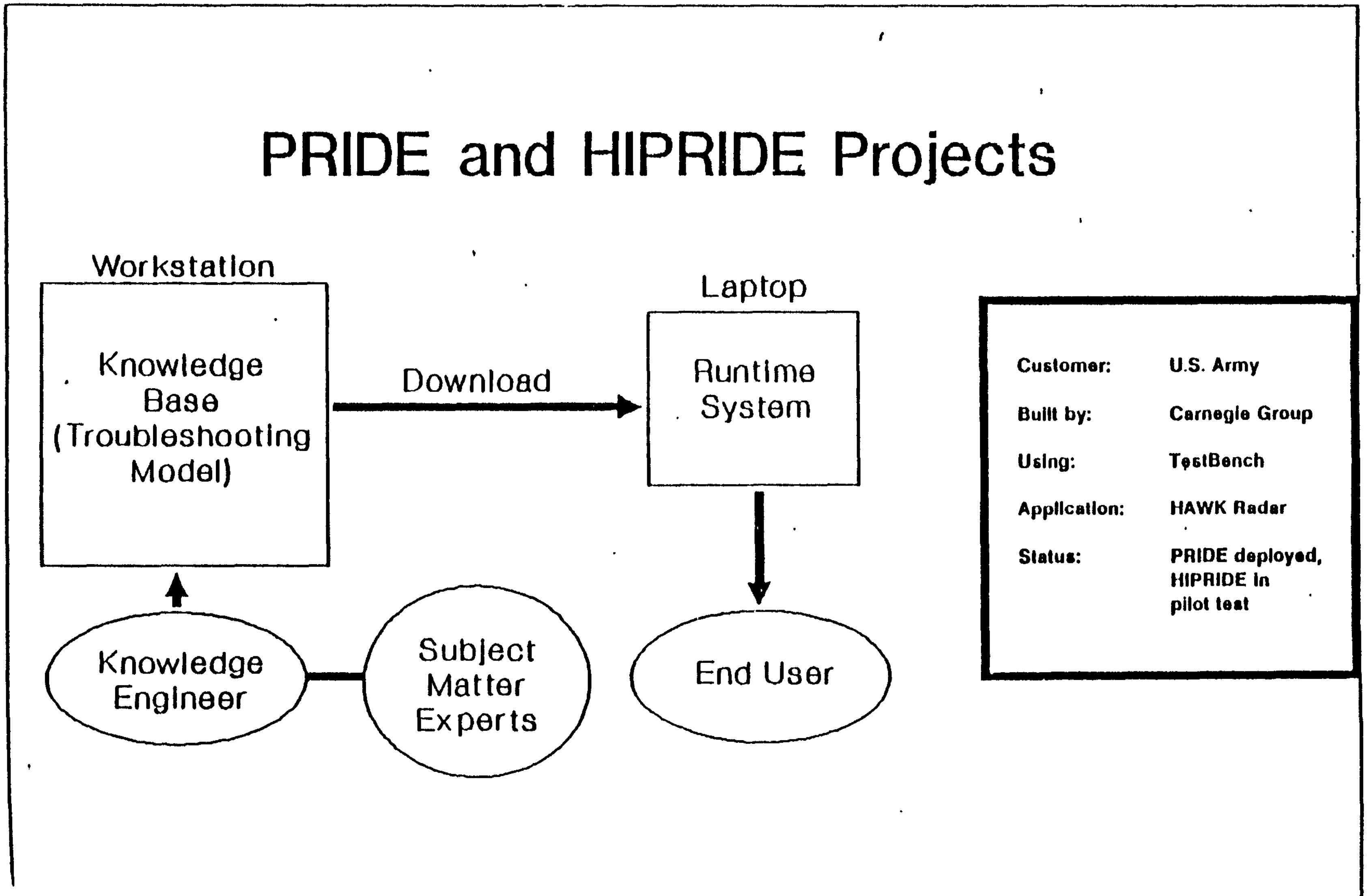


Fig 50. Example

COMPONENT TROUBLESHOOTING is an expert system that diagnoses and gives operators advice concerning various aspects of component failure in a process control facility. It is targeted at a facility for demilitarization of obsolete projectiles. {Arthur D. Little , Inc.}

DELTA (Diesel - Electric Locomotive Troubleshooting Aid) was the first maintenance expert system to become commercially available. DELTA is now being used in railroad "running repair shops" to assist maintenance personnel in isolating and repairing a large variety of diesel electric locomotive faults. The system was initially known as CATS-1. {General Electric}

DIAMOND is a knowledge based system for fault diagnosis and maintenance planning for rotating machinery. Its main purpose is to increase the efficiency and user friendliness of systems for condition monitoring of rotating machinery. {Kongsberg Kvarto}

FAN VIBRATOR ADVISOR is an expert system that troubleshoots industrial fan problems. {Stone and Webster Engineering.}

ICLX is an expert system that aids technicians diagnose faults in rod milling processes. {British Steel Corp}

IDM (Integrated Diagnostic Modules) is an expert system model using two layers of knowledge. The system uses shallow , experimental knowledge on one level , and deep , functional , or physical knowledge on another. IDM exhibits a clearly defined but flexible control over knowledge propagation between different experts embodying various knowledge types within a problem domain. {Southwest Research Institute}

IN-ATE is an expert system shell specifically and exclusively designed for fault diagnosis. In addition to accepting expert rules , IN-ATE can also generate expert rules from CAD/CAM and reliability data. {Automated Reasoning Corp}

MAINTENANCE ASSISTANT is an expert system developed and delivered on a Texas Instruments portable professional computer , using personal consultant. It is used for diagnosis , adjustment , repair , and maintenance procedures on the ASEA 6 , 60 , and 90 robot series. no knowledge of computers or programming is required. {Ford Motor Company Robotics Center}

MDIS (Maintenance and Diagnostics Information System) is a multi-domain knowledge acquisition system that supports integrated diagnostics , maintenance , training , data collection and data analysis. {Boeing Aerospace}

MICRO IN-ATE is the Apple Macintosh C language implementation of IN-ATE , an expert system environment specifically designed for fault diagnosis. MICRO IN-ATE includes : Schematic capture (CAD/CAM Input); Interactive Expert Rule Editor; Digitized photographs; IEEE-488 Bus support; LISP Interceptor; Windows , Menus , and Icons. Cost $ 5000 to 9500 { Automated Reasoning Corp}

MICROTROUBLESHOOTER is an IBM PC-based expert system for diagnosing faults in complex equipment. It allows general input to the system in the form of a decision tree , and is not set up for any particular kind of equipment. {Mainwork ,Ltd}

TSHOOT is a recursive expert troubleshooting system developed using Xerox's LOOPS. The TSHOOT approach towards troubleshooting is based on the concept of hierarchical partitioning , connectivity/casuality , function , and expert supplied heuristics. TSHOOT is a combination of deep level knowledge and the shallow type of knowledge commonly found in diagnosis systems. {Allen Bradley Co.}

VIBRATIONS, GM's Computerized Automotive Maintenance System, is an expert system is hosted on a GM-CAMS Technician Terminal, currently being installed in GM dealerships. It is intended to provide the platform upon which new expert system technology will be implemented. GM-CAPS itself is a new service tool that provides to service technicians the ability to accurately and reliably diagnose and repair on-board electrical systems and components. The system is easy to use and no computer skills needed. {General motors}

Current Research and Future Outlook

Vanderbuilt University is conducting research on the design of an expert system to aid field service personnel in the diagnosis and repair of faults in electronic gasolene pumps. The goals of the research are to model the thought processes of human troubleshooting experts, and to encode this processes in the expert system to increase the productivity of the service personnel.

Under the direction of Georgia Tech., the CSANET project is investigating the representation of common-sense casual model of nuclear power plant operation and their use in two expert system prototypes. One of this systems is directed toward the diagnosis of the problems in the primary coolant loop of pressurized water reactors. The second system models an instructor training nuclear power plant operators in emergency procedure EZRO.

The Navy AI Center is currently developing a series of increasingly sophisticated expert consultant systems for guiding a novice technician through each step of an electronics troubleshooting session.

Siemens Corporate Research and Support, Princeton, NJ, is developing an expert system to locate and suggest the remedy for a fault in one of their German robotic manufacturing facilities.

Westinghouse Corporation is reported to be considering an expert system to oversee maintenance problems on its "people mover" transit system at Atlanta's airport.

The elevator maintenance market is of special interest to Westinghouse because numerous elevator installations are covered by service contracts. Diagnosing the problems of elevator is normally done by human experts who go to sites where problems occur.

Solarton under sponsorship by Alvey is researching IKBS in mechanical health monitoring. The objective of the project is to produce techniques which will allow monitoring of the health of machines to become more automatic, comprehensive and reliable, and which will help in their design and operation. The techniques developed will produce an expert system which is able to control its own data analysis.

More expert systems are expected to be developed for diagnosis than for any other industrial application. The reason is this application ideally lends to rule-based procedures.

The wide range of major corporations already involved in maintenance diagnosis applications provides a clue to the activity which will be seen in this area in the future. The list includes AT&T, Boeing, Campbell Soup, Digital Equipment, FMC, GE, NCR, Siemens, and Westinghouse.

The big three automakers are exploring potential applications as part of their AI Research. To counter the shortage of knowledge engineers, GM has been drawing on outside resources. It is one of six investors in Teknowledge, Inc., an AI firm in Palo Alto, CA. GM is also reported to be an early purchaser of two software packages from Palladian Software Inc., MA. Palladian Financial Advisor , and Operations Advisor. In large corporations as GM, the need of each division and assembly plant must be considered in applying an expert system.

Chrysler is developing an expert system to handle plant scheduling, an effort expected to take several years. Eventually the system could be applied to supplier operations such as stamping as well as to final assembly. Chrysler has also begun work on an expert system for machine diagnosis. However completion of a system that can detect a fault , and perhaps provide some self-directed corrective action , is considered a long term project.

Bentelle Geneva Research Center is considering the possibility of using expert systems in diagnosing and repairing faults of widely commercialized products , e.g. , cars and officemachinery , which require a lot of specific experience and knowledge.

3.8 AI in Manufacturing Simulation

The use of expert systems will link simulation with the computer aided design (CAD) process.

Most manufacturing process designs are, in fact, redesigns. Initial designs are usually available at the starting point, if not, human experts could input the initial designs. Intelligent CAD systems, using iteration, then modify the initial designs to acceptable or optimum levels through evaluation and redesign. For each redesign , the system formally evaluates specific characteristics of the current version according to the criteria and scales established in consultation with human experts. The intelligent system then recommends or actually performs the redesign. The system repeats this process until the design achieves the acceptable performance determined by its evaluation. Knowledge of evaluation criteria and redesign rules are represented in production rules or in frames and rules in more complex cases. Such an intelligent CAD system has been experimentally developed by J.R. Dixon and M.K Simmons of GE.

Current Technology

There are numerous rules that an expert applies in designing a manufacturing workcell or process. Currently , users of simulation packages must provide the initial layouts and design as inputs to the systems. However , intelligent simulation systems could provide users with some degree of design expertise. For example , based on an analysis of their design, systems could perform functions such as selecting inspection points of manufactured products. These systems could even evaluate various robot models and select the ones that are optimum for an application. Intelligent system can also alert designers when designs do not confirm to specifications or safety requirements.

Artificial Intelligence techniques could be used in the representation of geometric information in a database. The needs go beyond a mere description of surface features. There could be some procedure that classifies parts of objects for group technology purposes. Smart user interaction is important in computer-aided design. An intelligent terminal, for example, would "know" the user's preference in displaying objects.

AI Softwares for Manufacturing Simulation

CHEMICAL PROCESS SIMULATOR is an expert system for simulations of complex chemical processes. {Eastman Kodak}

FACTOR-ES is an expert system module used in conjunction with the manufacturing simulation package SCHED/SIM. The expert system helps automate the simulation process in three areas: (1) It allows human expert knowledge about a manufacturing process to be input in to the simulation model. 2) The iterative requirements associated with a simulation are automated. Changes can be made to parameters and analyzed using the expert system. 3) The expert system assesses progress in the simulated operation , and advises the user when to develop the next schedule. {Factrol}

SIMKIT works with KEE to give system developers the needed software tools to build libraries of graphically - displayed simulation objects. The simulations are knowledge based and the simulations can be used as graphic drivers to KEE based expert systems to create intelligent simulations. User can quickly construct or modify simulations to generate different "what - if" test scenarios and Simkit provides explanation and validating expert system performance. The end user does not need to know anything about the simulation's underlying knowledge base because it remains accessible to the system developer for integration with KEE based expert systems. {IntelliCorp}

SIMULATION CRAFT is an artificial intelligence based simulation system that increases the productivity of simulation experts and enables non experts to develop simulation models. Simulation craft incorporates the knowledge of simulation experts to create three expert systems; one each for model creation , model execution , and model analysis. These expert systems perform tasks, such as helping the user specify the model, designing the simulation experiment, and analyzing the simulation results, which could otherwise have to be performed by simulation experts. Thus Simulation Craft reduces the time as well as the programming and simulation experience required to create, execute and analyze simulation models. {The Carnegie Group}

XFRAC (Expert System for Fracture Analysis) is an advisory system for determining the type and cause of fractures in metals, as found in machine components. {Computas Expert Systems}

Current Research and Future Outlook

FADES (FAcility Design Expert system) is a prototype system developed at Perdue University to design programmable manufacturing operations. It consist of a PROLOG interpreter, a knowledge base consisting of algorithms , economic models and expert decision rules , a database with existing company data (products demands , machine specifications , etc) , along with task specific data. The logic in FADES knowledge base falls into four primary areas: 1) Workstation technology selection and economic investment analysis; 2) Development of relationship ratings among workstations (location factors such as product flow, need for machines to be on sturdy floor, away from column, etc); 3) Development of an optimal combination of candidate workstations and sites, with cost; and 4) Retrieval of needed data from other locations in company.

Strong interests has been shown in AI technology by major developers of manufacturing simulation software. It is expected that much future simulation software will incorporate expert systems as a component of the system.

3.9 Intelligent Robots in Manufacturing

Robot Control and Programming

Control of robot arms ranges from highly repeatable open loop devices to servo controllers that utilize external sensors in the control of robot actions. Open loop devices may be as simple as sequencer and positionable mechanical stops for a pick and place robot, to more complex devices using stepper motors to reproduce a desired motion. Servo-devices can use internal sensors, such as joint position sensors, or external information sensors such as force, proximity devices, and vision (operating under computer control). Servos operating only on internal sensors require very careful positioning of the workpiece. Servos utilizing data from sensing the external environment, require more complex processing of the signal, but much more flexible systems. The controller, in addition to controlling the manipulator motion, often serves as an interface to the outside world. Coordinating the robot's motions with machines and assembly lines and turning on and off machines that it is operating.

Programmable robots are servo controller robots of two basic types: "point to point" and "continuous path". Point to point robots are directed by a programmable controller that memorizes a sequence of arm and end-effector positions. Hundreds of points may be memorized. The robot moves in series of steps from one memorized point to another under servo control using internal joint sensors for feedback. Because of the servos, trajectory control between the memorized points is possible and relatively smooth motions can be achieved.

Continuous path robot do not depend on a series of intermediate points to generate a trajectory , but duplicate during the playback process the continuous motions recorded during the teaching process. Thus these robots are used for painting , arc welding , and other processes requiring smooth continuous motions.

Computer controlled robots are capable of being programmed "off - line" using a high level programming language and do not have to rely on being physically taught. Sensory robots are computerized robots that interface to the outside world through external sensing such as sight or touch. These "intelligent robots" are capable of adapting to a variety of conditions by changing their goals or preprogrammed decision points.

The most common method for programming a robot is the lead-through method , in which the operator leads the robot through the desired positions locations by means of a remote teach box. These points are recorded and used to generate the robot trajectory during operation.

The emphasis in programming research today is on software programming of computer controlled robots. Work on sensor controlled manipulation is extending the scope for programmability. Interacting with the robot by means of software provide more flexibility than the other programming methods and allows for conditional actions or flexible adaptations. Various high level robot programming languages such as VAL (Unimation) and AML (IBM) , are now beginning to become available to aid in the software generation.

Intelligent Robots

Real world industrial environments pose some challenges to which the basic industrial robot cannot cope , such as picking parts from a bin , processing out of place parts , parts out of dimensional tolerance , etc.

Therefore , it is desirable that the robot interface to the outside world through external sensing such as sight or touch. These "intelligent robots" are capable of adapting to a verity of conditions by changing their actions based on relating the sensed information to their goals or programmed decision points. Vision and tactile sensing are the two primary methods used to make robots intelligent.

Tactile or touch sensors provide industrial robots with the ability to recognize parts and to determine their relative position and orientation through such methods. The problem of interpreting tactile data to recognize and orient parts is similar to the problems of visual imaging , however the tactile imaging device has only a partial view of the part. The use of tactile sensor is forecast to increase within this decade.

Expert Systems in Robotics

Some researchers do not distinguish between AI and Robotics; instead a unified model that encompasses both is used. An intelligent robot should be able to think , sense , and effect. Thinking is primary a brain function. Sensing (seeing and touching) and effecting (moving and manipulating) are primarily body functions. The thinking function executed by a computer is the domain of AI. Sensing and effecting are based on physics , mechanical engineering , electrical engineering , and computer science. Planning and execution of tasks entail both body and brain functions and are the functions and are the concern of both AI and Robotics.

Professor Barry Soroka of the University of Southern California has outlined the application of expert systems to robotics. Dr.Soroka discussed four types of robotics problems which may be helped by the use of expert systems.

1. Kinematics and Design: For the operation of a robot arm, the kinematic problem must be solved associated with going from a desired Cartesian position and orientation back to the joint angles required to achieve it. An expert system could probably be implemented to replace the human expert in the symbolically tedious work of producing such solutions.

2. Robot Selection: Because of this shortage of experienced application engineers, an expert system could diffuse applications experience among a wider community of users.

3. Workspace Layout: When robots are to be installed in a new workspace, an expert system could be used for workcell layout.

4. Maintenance: Expert systems could lead the user through the symptoms of trouble, request test measurements, suggest adjustments and repairs, and monitor the process of fixing the robot.

Soroka noted some reasons why the application of expert systems in robotics has been slow to develop : (1) AI is concerned with symbols while robotics is concerned with mathematical details ; (2) AI utilizes languages like LISP on large computers, while robot systems run on smaller computers and use assembly language for speed ; (3) AI works on high level problems such as planning , while robotics deal with low level problems such as friction and compliance.

A demonstration expert system is being used by GCA Corporation to identify the correct robot for a particular application.

ITMI is developing a new robot cell control language developed in LISP. It will run on a variety of machines which support common LISP. This new cell control language is designed to be easy to use , highly interactive , and powerful. The control language is divided in to four main parts: the robot core, the various utilities needed to support the system, the enhancements which can go on top of the system , and the interface to outside systems , such as vision and tool control.

Lockheed-Georgia Company has used industrial robots since 1981. A research project is now underway for expanded efficiency in manufacturing aircraft.

ADAPTIWELD , developed by Adaptive Technologies , inc. is one of the first arc welding systems to provide a commercial system in this area. It incorporates knowledge of skilled welders in its information and control base. A three dimension vision system gathers information on the characteristics are stored in the computer memory of the system controller and manipulated the expert system to perform a complete welding function without direct human supervision. The expert system approach allows the system to perform autonomous welds , and the user easily adapts to the system for unique welding requirements. The knowledge base allows the operator to transfer knowledge to the welding system .

Type Selection of Robot and Gripper Kinematic Topology Using Expert Systems

Application of theoretical kinematics to type selection of robot topology and gripper configuration based on functionality seems to have taken a back seat to some of this other considerations. Unfortunately , a poor selection of basic kinematic configurations will haunt a designer who is trying to assure good dynamic performance of a robot for particular generic task.

Often very little time is spent in optimal kinematic structural (topology) design in the early stages of a design process. Type synthesis is the first phase of kinematic synthesis (design) of mechanisms. A more recent work by Datseris and Palm included discussion of kinematic topology of grippers and enumeration of closed loop kinematic chains with one or more gear pairs.

These two noteworthy works begin to illustrate the power of kinematic structural analysis. Graph theory has been used for some time by kinematics to help study and identify kinematic structures.

Type Synthesis expert systems program

An expert system program , TYSES (TYpe Synthesis Expert System) , has been written as a prototype for type selection of mechanisms. The topology of a mechanism can be defined by a set of parameters: the degrees of freedom , the number of links and joints , their connectivity , type of joint , and which links are ground and input. Since the dimensions of the links are not included we are still dealing with topologies , not mechanisms. TYSES employs only planner mechanisms.

With the separation of topology and function , the steps of type synthesis can now be organized into an expert system. the components of the system are shown in fig. The Rulebase initially contains general information about mechanism topology and mechanism function. For example , one rule might be: "if there more than two slider joints in any loop , then the topology is invalid " , which concerns mechanism topology. Another rule might be , "if there are four links , then the topology cannot produce parallel motion" , which concerns mechanism function.

The second introduces one of the features of this and many other expert systems. While the rule is generally valid , four-bars can produce parallel motion under certain undesirable conditions. This is simply a good rule of thumb , but it is not always true. TYSES handles this situation by allowing the designer to assign a weight to each rule , 1 to 10. The higher the number , the more sure designer should be of the rule's usefulness. The designer starts with a set of requirements and enters them via the parser , which will interpret the dialogue and convert it into its internal format. This rules are then added to rulebase.

Once the designer has entered all the requirements , the Topology Generator enumerates topologies. As each topology is generated , it is assessed by the Evaluator , which will incorporate the requirements in the Rulebase in order to rate each candidate from good to bad. When the Topology Generator has enumerated a set of topologies satisfying the requirements , it sends them to the sketcher to be graphically displayed to the user.

The Parser

TYSES begins by asking for the demands to be met. The designer enters these as English sentences in a restricted form , such as verb - subject , subject verb - object , or IF- subject verb - object - THEN- subject - verb - object. The Parser then tries to "understand" them by picking out the key words it has in its vocabulary and marking this words as subject , verb etc. If the sentence parses correctly , it is stored in the rulebase , and the designer must assign a weight , which is stored along with the rule.

When the Parser is sent an input sentence , it first changes all lower case characters to upper case and then checks for a command (such as HELP or QUIT) . It next checks for words that do not apply to type synthesis , such as words referring to dimensions , gear joints etc. If there are no inapplicable words , it continues by picking out the words of the sentence that also exist in its vocabulary and any numbers in the sentence. If there are any other words in the sentence , the Parser will tell the user it doesn't understand them and will ask for another input sentence.

The next step taken is to convert all key words in to generic key words:

degrees of freedom is converted to DOF, pin is converted to revolute, and so on. The words are then reorganized into a standard form, either verb - subject - object or IF - verb - subject - object - THEN - verb - subject - object. The last step is to check the sentence semantically by seeing if the subject and object agree with the verb. The allowable combinations of words are stored in a "semantic tree" in the system.

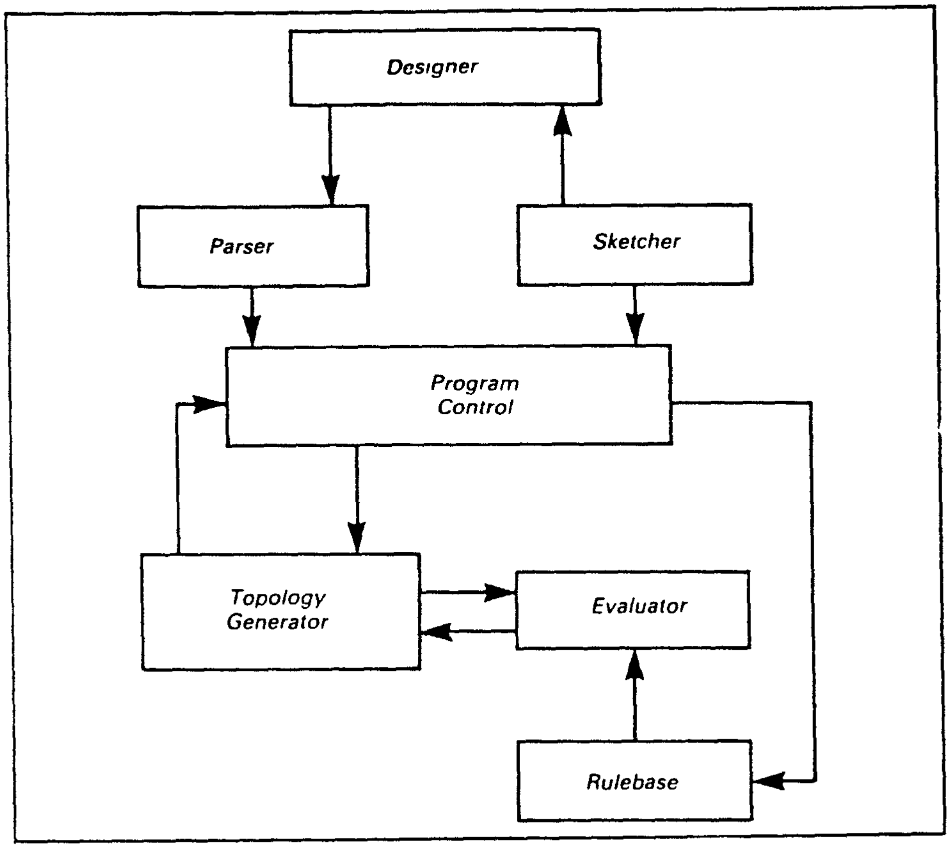
The Topology Generator

Problem representation. The Topology generator uses a "state-space" representation, chosen for its ability to enumerate different topologies. This representation consist of "states" and "operators" A state is the condition of the topology generation process at a certain point, as defined by a set of "state variables". The set of operators transforms one state in to another by modifying the state variables. Beginning with a "start state", the continuous application of these operators will generate the entire state space.

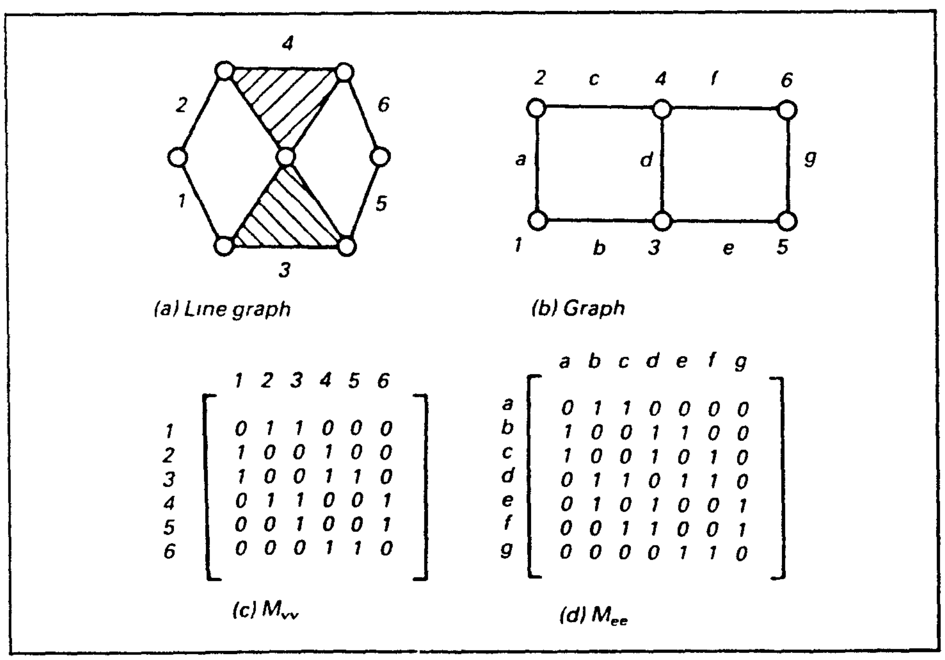
Before this introduce some of the notation from graph theory used in the development of TYSES. A six bar watt chain is shown in fig. This representation is called the *line graph.* The graph of this chain is derived by representing the links with vertices and the joints with edges. A representation useful for computer implementation is the vertex - vertex adjacency matrix of the graph, Mvv shown in fig. Adjacent vertices are represented with non zero entries in Mvv. An equivalent matrix, Mcc, is shown in fig. Adjacent edges are represented with non zero entries in this matrix.

The state space TYSES uses is three dimensional, with five two - dimensional planes. Each planes represents the generation of one step in the type synthesis process. For convenience, each of this steps can be represented by a character: N while specifying the number of links and

Fig: 51



System organisation of TYSES



(a) The six-bar Watt linkag (b) Graph of the Watt linkage· links become vertices and joints become edges, (c) The vertex adjacency matrix of the linkage, (d) The edge adjacency matrix

degrees of freedom; C while generating the basic kinematic chains (BKCs); G while specifying the ground link; I while specifying the inputs; and J while specifying the joint types. The two steps N and C must be done first, but the last three (G ,I and J) can be done in any order, provided the first two have been completed.

Heuristic search: Because the enumeration of all topologies will result in an unlimited number of possibilities (called a combinatorial explosion), a search technique is needed that uses general knowledge about the state space to limit the search. This heuristic knowledge is information that may not guarantee optimal search but will limit the search. A search technique called A (or "best - first") is chosen, allowing the designer's requirements to be used as the heuristics.

The Evaluator: Knowledge representation

In order for the Evaluator to use the information in the knowledge base, the knowledge must be represented in a form that is easy to store, find, and modify. TYSES uses a production system chosen for its modularity and expendability. This consists of a rulebase, a context and an interpreter. The rule base contains productions in the form of situation - action pairs, or IF - THEN rules: if the situation occurs, then the action is performed.

The interpreter does the evaluating. It searches the rulebase for productions , looking at each productions IF part to see if it is true according to the context. if it is true, the production is fired by determining if the THEN part is true for the given context. By continually firing productions , the interpreter can rate a topology from zero to some maximum.

The Sketcher

The Sketcher is a component in the program that scatches the topologies on the screen. The Scatcher is given the Mvv adjacency matrix and assigns random dimensions to the topology. it then places the joints on the screen in such a way as to make the mechanism look balanced and with no crossed edges. Then the joints are connected , and ternaryand quaternary links are filled in solid.

Type synthesis of a gripper mechanism

As an example of how expert systems play a role in type selection we will use TYSES to select topologies for gripper mechanisms for robots.

Requirements:

1. Low - cost design.
2. Easy to manufacture.
3. Reliable design.
4. Symmetric straight line outputs.
5. Adjustable control.
6. Input slider on robot arm.

Requirement 1-3 suggest use of pin and slider joints only. Requirement 4 dictates an output slider and the need to design one side of the mechanism only. The fifth requirement indicates that both sides have two degrees of freedom , as well as suggesting more than a single loop mechanism. Also the input is a slider.

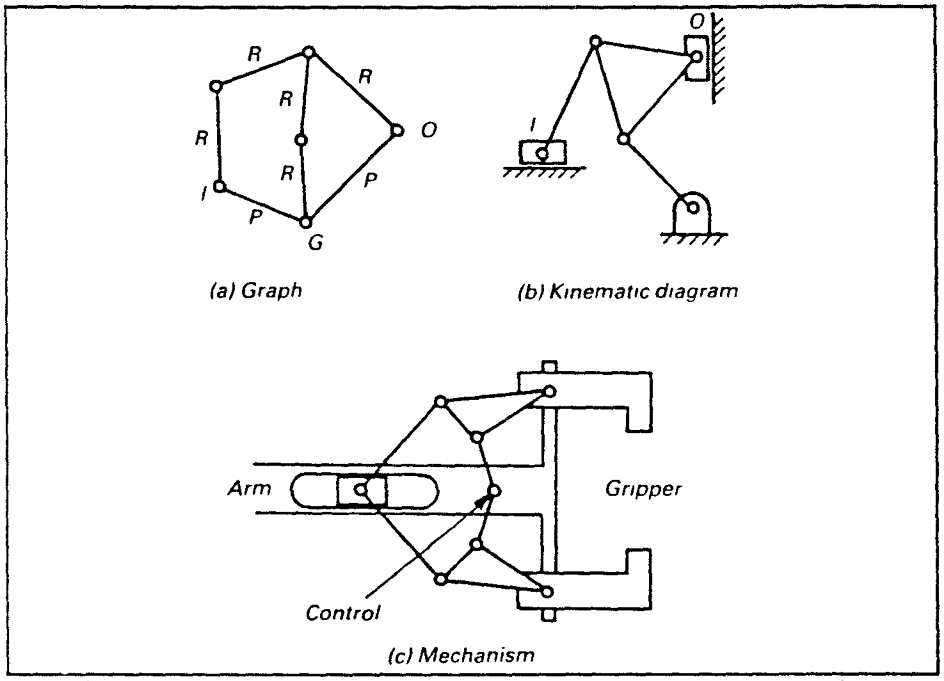
Fig shows two mechanisms that satisfied the requirements: a Stephenson and a Watt type six bar linkage. The graph , the kinematic diagram and an unscaled sketch of the mechanism are shown for both solutions.

Sample TYSES session

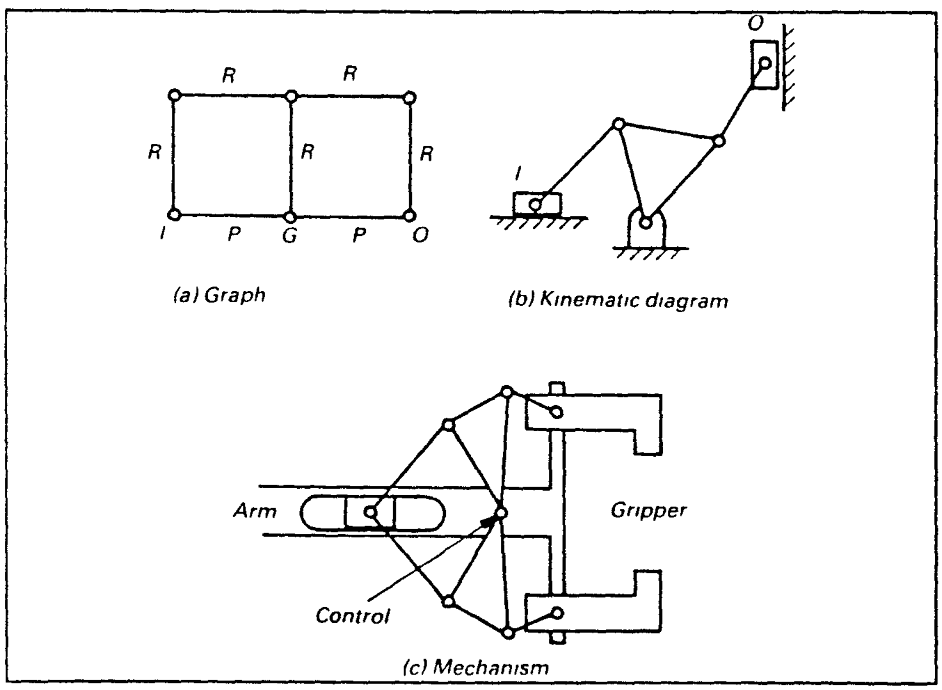
```
(TYSES)
Welcome to TYSES  Are you an expert? No
Terminal type? Nongraphics

Do you want to specify the maximum number of inputs? Yes
Maximum number of inputs: 1

Any other restrictions on the inputs? Yes
→ THE INPUT MUST BE GROUNDED.
Weight (1-10)? 7
→ THE INPUT MUST BE A SLIDER
Weight (1-10)? 6
→ OK

What is the number of outputs?
one of:
1
2
3
4
5
6

What is the number of outputs? 1
Enter the order of the path traced by output 1: 1

Any other restrictions on the outputs? Yes
→ THE OUTPUT LINK MUST BE CONNECTED TO A PRISMATIC JOINT
Weight (1-10)? 10
→ THE OUTPUT MUST BE GROUNDED
Weight (1-10)? 9
→ OK

Do you want to specify the maximum number of links? No

Any restriction on the types of joints? Prismatics and revolutes only

Any other requirements? Yes
→ AT LEAST 6 LINKS
Weight (1-10)? 6
→ AT LEAST 2 LOOPS.
Weight (1-10)? 6
→ THE LOOP WITH THE INPUT SHOULD NOT CONTAIN THE OUTPUT
Weight (1-10)? 7
→ END

How many solutions should I search for? 2

Do you want ONLY solutions that COMPLETELY fulfil your requirements? Yes

What would you like to see while I'm searching? Dots? [confirm]

Searching
```

Sample TYSES session

Fig: 52



(a) The graph of a Stephenson linkage, (b) The kinematic diagram of the linkage, (c) Its implementation in a robot gripper



(a) The graph of a Watt six-bar linkage, (b) The kinematic diagram, (c) Its use in a robot gripper

Discussion and Remarks.

The first mechanism (Stephenson) is felt to be the superior mechanism. The output is attached to ternary links, giving stronger support to the gripper. If the gripper is impacted for some reason , these ternaries will take most of the force. The control of the Stephenson is further from the output than on the Watt. This allows finer control of the Stephenson since the control is not directly connected to the link that drives the output. It also be felt that better transmission angles could be achieved with the Stephenson without having awkward dimensions and a clumsy gripper.

Type selection of mechanism is a critical part of the mechanism design process. Choice of robot or gripper topology using an expert system designed not only to allow enumeration of possible solutions but also functionality can be powerful tool.

Current Research

Research at Vanderbilt University is being initiated on developing expert systems using PROLOG a kernal language. Initial applications are aimed at robot troubleshooting. Future applications include management of complex system and planning and control of intelligent robots.

Mc Donnell Douglas has three projects underway using expert system to solve problems in off line programming. One project involves AI methods in collision detection and avoidance, as well as in robotic grasp and trajectory planning. Another project deals with off line robot dynamics and involves sensory reasoning. The system project will guide a robot in deciding what to do next in a cell of six to eight machine tools.

Thinking Machines Corp. has two projects focusing on robotics. One will develop very flexible and adaptive manufacturers that are intended to be concerned with the development of a general problem oriented computer language that can be used to describe manufacturing and assembly tasks for a robot system.

At Georgia Tech, Dr. William Underwood is investigating the knowledge and reasoning required to automatically produce robot plans to fabricate aircraft parts.

The Jet Propulsion Laboratory is working on a three part, closed loop control system that is directly applicable to robots. The system has three parts: (1) DEVISER, a planner/scheduler expert system;
(2) FAITH, a system diagnostician; and
(3) PPER, (Planning and Execution with Error Recovery), to link the other two modules together. The control is a predicate logic rule based system. The system will operate in a robot as follows: Goals are entered into the planner/scheduler which constructs a plan and comes up with a set of measurable sensor states. The execution monitor detects errors by comparing the predicted states with the actual measurements it makes with the sensors. Any discrepancy between the two indicates that something is wrong. The diagnostician then determines what actions should be taken to recover from the error. {Leonard Friedman}

A project at the University of Texas at Austin is developing a working, intelligent, and adaptive hierarchically controlled robotic system. The system will be used to test and develop various AI motion planning algorithms in real world systems. A highly sophisticated working system is essential to developing and testing motion planning algorithms that are capable of intelligently determining the desired robot motion based on general verbal commands while being able to adapt to changes in environment.

3.10 AI in Machine Vision

The field of machine vision has its birth in the artificial intelligence laboratories at Stanford, MIT, and other universities in the 1970s. Techniques such as connectivity analysis, which represented the leading edge of artificial intelligence at that time, are now commonplace in numerous commercial machine vision systems. With the fundamentals of providing computers with vision capabilities already successfully implemented, AI researchers are now turning their attention to more advanced concepts such as the implementation of expert systems in vision systems, three - dimensional capabilities, and model based machine vision.

Expert Systems in Machine Vision

There is an almost universal agreement among machine vision experts that AI will be a major factor in the growth of the field the only question is when.

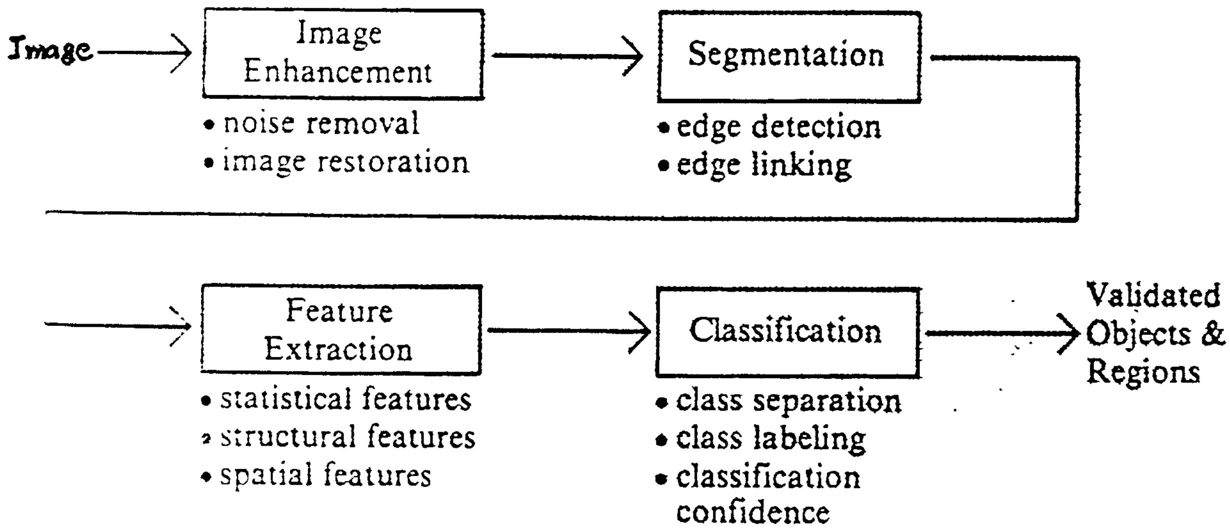
Dr. John Gilmore, Director of the Artificial Intelligence Branch of the Georgia Tech Research institute, has provided the following comparison of a classical image processing system with an image understanding system which incorporates AI techniques.

Image understanding is a combination of the data extraction techniques of image processing with the information exploitation techniques of AI to produce a system that understands images by analyzing the statistical information and symbolic relationships contained in a scene. Classical image processing is purely a statistical approach to analyzing image data as shown in fig 53.

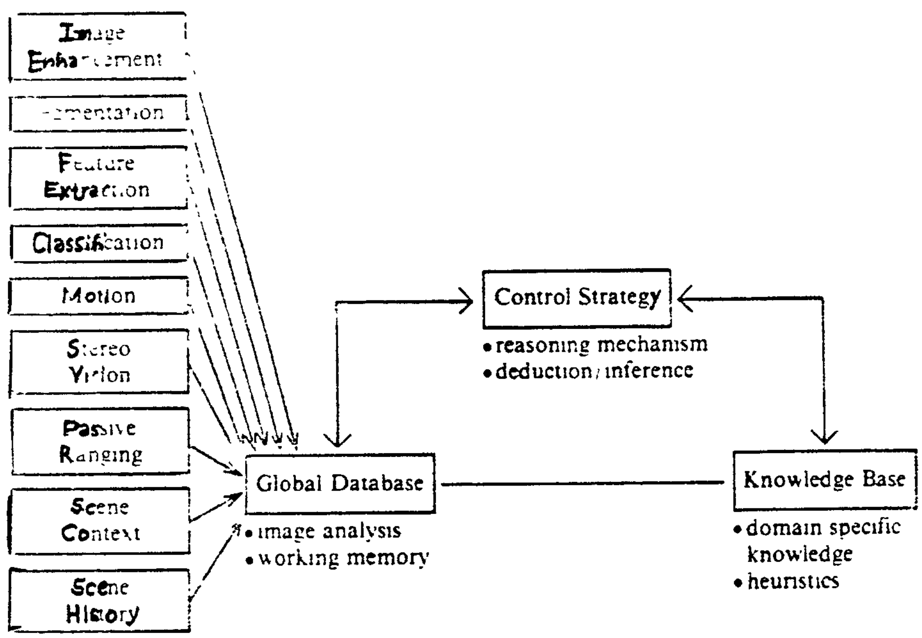
In the classical image processing system, a digitized image is acquired and analyzed in light of its image enhancement requirements. Image enhancement
can take two forms: (a) the removal of sensor - induced noise to produce a clean image for further processing or (b) by the restoration of image features lost due to blurring or pixel resolution effects in the sensor. Once an image has been enhanced it is passed to the segmentation process.

The goal of segmentation is to produce accurate edge boundaries defining the objects and regions contained within an image. This is accomplished in two steps. First, edges in the image are detected by convolving a weighted filter with the image. Second, the edges extracted during image detection are linked together to form closed boundaries. Given a closed object, boundary feature extraction computer statistical, structural or spatial filters based on the pixels contained within the object boundary.

This information in computed for all of the objects and passed to classification. The classifier tries to find a class separation between the various objects so that they may be labeled accurately. For example, if the goal of the system is to identify tanks within an image, the classification process will have a list of the features that describe objects that are tank size such as haystacks, cows, and trees. The classifier selects an objects from the image (object x) and compares this object with the features vector of the ideal tank, a tree, a haystack, and a cow. The classifier may determine that object x is a 93% match to tank, a 73% match to haystack, a 47% match to cow, and a 13% match to tree. It would then label object x as a tank with a 94% confidence and pass this information back to the user.



53. Statistical approach to analyzing image data.



54. An image understanding system.

An image understanding system (see fig.) incorporates all of this processing with a number of additional algorithms and reasoning mechanisms.

Stereo vision algorithms that deduce depth information are used to provide information as to whether an object projects upward like a mountain or downward like a sinkhole. Optical flow algorithms provide information as to an object's motion in terms of a measured direction and velocity. Passive

ranging algorithms provide the system with a rough approximation of the range from the sensor to each of the objects contained within an image. This is very useful -- knowing that something looks like an airplane but is only 12 meters away would indicate that it is actually some sort of bird.

Symbolic reasoning focuses on the physical, functional and spatial interactions of the objects contained in an image. For example, if the system is looking for a tank, several non-numeric features or knowledge may be examined. Facts such as "tanks are typically found on roads or in fields," "tanks have motion," "tanks form columns," and "tanks are not found in the sky or in lakes" form positive evidence of the statistical classification of object x as a tank if it is found on a road, in a column, and in motion, but negative evidence of object y being a tank if it is found in a lake, is isolated, and exhibits no motion over time.

Image understanding systems typically exploit system feedback in the generation and validation of hypotheses. For example, consider a convex object on a road with a tank classification confidence of 93% at time 1 (T1). At T2, the object is still convex though it has started to grow in an oblong fashion and its classification confidence of tank has now dropped down to 82%. At T3 the confidence has dropped to 71% and the object has grown more oblong and is no longer labeled as tank, but is given a high score of 92% for being scene clutter.

In a symbolic processing environment scene, history can be exploited to validate and accurately interpret a sequence of images. In this example, the symbolic processor may look at all the information known at T1 first. At T1, the object had a high classification confidence of tank and was on a road. Inquiring about the type of road may determine that the road the object is on is comprised solely of dirt. Looking specifically at the object in T2, an indication of motion may exist. Knowing that tanks moving on dirt roads tend to produce dust clouds, a hypotheses can be generated that the recognition of a tank decreased because the dust cloud was not segmented as a different object, but instead was absorbed into the tank segmentation in T2, T3, and T4. To validate this hypothesis, a window can be placed around the object in T4 and the segmentation algorithm can be run with lower thresholds. If a tank is detected with a high classification confidence, then the hypothesis is validated and the existing parameters can be adapted for the rest of the image sequence.

Applications

Cambridge Robotic Systems, Inc. (Watertown, MA) has developed a knowledge-based inspection system Cambridge System 85, that can distinguish real errors from production variables. The knowledge-based electro-optical system visually detects flaws in layers of PCBs. One side of an 18 x 24 in. PCB can be inspected in less than 20 sec with 0.5 mil resolution. The system was demonstrated at Nepcon East and costs $350,000 including maintenance and other support.

International Robomation/Intelligence (IRI) (Carlsbad, CA) has developed an advanced multicomputer system, SDX Expert Vision System, that combines high-speed UNIX-based C program processing with AI-based symbolic processing based on LISP programs. The new system utilizes IRI's S512 multi-computer architecture. This design integrates image analysis and process control functions with knowledge-based AI expert systems capabilities for building expert vision systems in the factory.

Dalek Corporation (Atlanta, GA) has developed DIPS, an image processing system written in LISP and FLAVORS for Symbolic 3600 series machines. DIPS includes commands for image manipulation, edge detection, texture filtering, histogramming and thresholding, arithmetic and boolean operations, and local and global image segmentation.

EPI (Expert Photo Interpreter) builds a computer-based model of the expertise of an experienced photo interpreter. The model represents the conscious, cognitive behavior of a specially trained photo interpreter. It emulates conscious expertise which is, at least potentially, capable of being verbalized and of being modeled by means of the expert system paradigm. The key feature of this approach is to train experts in such a way that they are conscious of how they perform their interpretation. EPI was developed by PAR Technology Corporation (New Hartford, CT).

Research

VEST (Visual Expert System Textbed) is an expert system available for license to industry and government developed by Prof. John Gilmore's group at the Georgia Tech Research Institute. VEST's image processing system provides the user with a selection of image enhancement, segmentation, feature extraction and classification techniques. VEST is available in both menu and subroutine library formats.

Once the components of an image have been classified, they are fed into the second phase of the VEST system for heuristic processing by a knowledge-base system architecture. Image processing information is stored in a semantic frame representation for exploitation by VEST's knowledge base. This knowledge base allows users to develop application specific rules. VEST's knowledge-based architecture is a subset of features available in the full-scale GEST expert system shell.

The Spatial Artificial Intelligence (SpAI) group at the State University of New York is concerned with making computers do spatial tasks that are currently done better by humans. SpAI tasks involve reasoning about, or solving problems with, models of spatial structure. Many problems in the domains such as computer vision, robotics, computational geometry, topology and expert systems are SpAI tasks.

The following SpAI tasks are currently being investigated: computer programs (in LISP and C) demonstrating an example in each task are running on one of the departmental VAXes. Two knowledge-based spatial reasoning systems under development are for performing neurological diagnosis which involves reasoning with the three dimensional neurological structure of the body. Equipment failure diagnosis involves models of the physical, as well as the behavioral, structure. A key element of the approach is developing intelligent interfaces involving computer graphics. These projects are being developed jointly with Prof. Shapiro's group

3-D Machine Vision

2-D machine vision systems can be designed to deal with the real world by providing information on the third dimension on a real-time basis. They may use an inferential system, inferring depth by comparing similar objects. Such approaches tend to be both slow and imprecise.

3-D machine vision systems may utilize a range-finding scheme (generally employing a laser), structured light or binocular vision to see in three-dimensions.

Range finding and structure light techniques are easiest to implement. Both techniques rely for depth cues on the way light (or other radiation like sound waves or X-ray) reflects from the surface of objects. Range finding systems typically time the reflection of a laser beam to the object and back again to measure its distance -- similar to radar. Three - dimensional vision systems that rely on range finding or structured light are inherently limited because they require interaction with the object under observation. Although these systems may be adequate from many practical applications, a vision system should be "passive" to avoid putting constraints on the observed objects or their environment.

Binocular Vision

Two camera vision systems use the same approach as human vision of binocular parallax -- the slight disparity between the two eyes' views of a scene -- as a depth cue. The greater the parallax, the closer an object.

A major stumbling block to the development of practical machine vision systems based on binocular parallax is the "correspondence" problem -- objects in each view must be matched with one another before the disparity between the two views can be determined. Matching is a problem because, as a result of parallax, an object appears in slightly different places in the right and left views and may be partially or totally obscured in one view. Moreover, there is a question of what the system should treat as objects -- integral objects, such as trees and chairs, or simpler objects such as edges?

MIT researchers are attacking these problems by reducing objects in a pair of binocular images to their outlines and then matching edges by thickness, orientation, and contrast with background. Once this has been done, they can compute the depths of the edges from their parallax and interpolate intermediate points.

The technique has worked successfully in computer simulations at MIT and elsewhere. Indeed, MIT is building a hardware prototype for a practical system that will use a pair of television cameras for eyes and microcomputers for visual processing. The system will processs a stereo image in one to four seconds, fast enough for many practical applications.

Future robot vision systems will need many other depth cues to supplement binary parallax -- just as human depth perception does. One possible cue being studied by Sidney Liebes at Stanford is the way corners of cultural objects, such as buildings, project onto the image plane. The cue could be used in matching binocular images. Other cues currently being explored in the laboratory include the way objects cast shadows or overlap in space. One of the first 3-D systems installed was by Robot Vision Systems, Inc. at Cummins Engine (Columbus, IN). The system, Shown in fig. is able to check dimensions of an engine block in less than one hour. Manual inspection required 40 hours.

Model-Based Computer Vision

Most research efforts in vision have been directed at exploring various aspects of vision, or toward generating particular processing modules for a step in the vision process rather than in devising general purpose vision systems. However, there are currently two major U.s. efforts in general purpose vision systems: The ACRONYM system at Stanford University under the leadership of T. Binford, and VISIONS systems at the University of Massachusetts at Amherst under A. Hanson and E. Riseman.

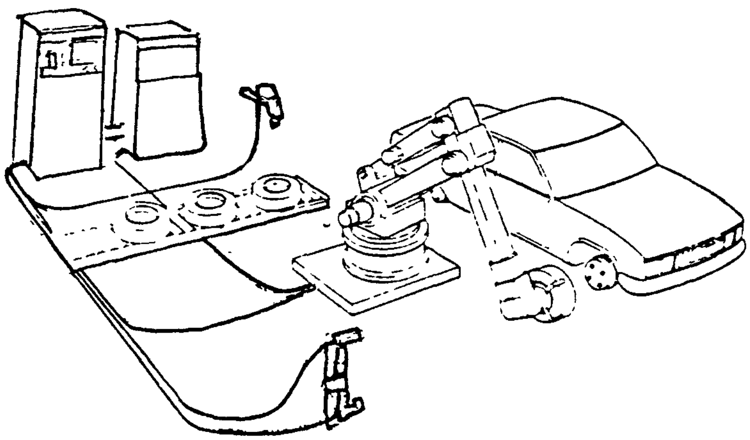
The ACRONYM System is designed to be a general purpose model based system that does its major reasoning at the level of volumes rather than images. ACRONYM has four essential parts: modeling, prediction, description and interpretation. The user provides ACRONYM with models of objects (modeled in terms of volume primitives called generalized cones) and their spatial relationships; as well as generic models and their subclass relationships. These are both stored in graph form. The program automatically predicts which image features to expect. Description is a bottom-up process that generates a model-independent description of the image. Interpretation relates this description to the prediction to produce a three-dimensional understanding of the scene.

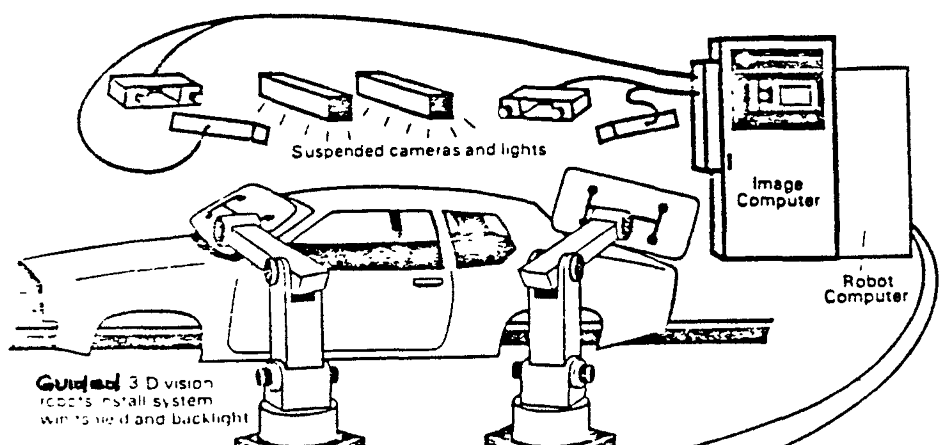
The VISIONS system can be considered to be a working tool to test various image understanding modules and approaches. Rather than using specific models, its high level knowledge is in the form of frame like "schemas" which represent expectations and expected relationships in particular scene situations. VISIONS is based on monocular images and does its reasoning at the level of images rather than volumes.

ACRONYM

The ACRONYM geometric modelling/reasoning system under development at Stanford University will model real-world industrial parts (both specific objects and generic classes of parts), perform programmable inspections, pick parts from bins, and perform automated assembly operations, all by extracting 3-D information from monocular images. To provide general-purpose vision for manufacturing, CAD-generated models help predict observable image features by employing generalized cones defined by a planar cross-section and space-curve spine, through use of a "sweeping-rule" concept.

55. The Machine Vision International 3-D system

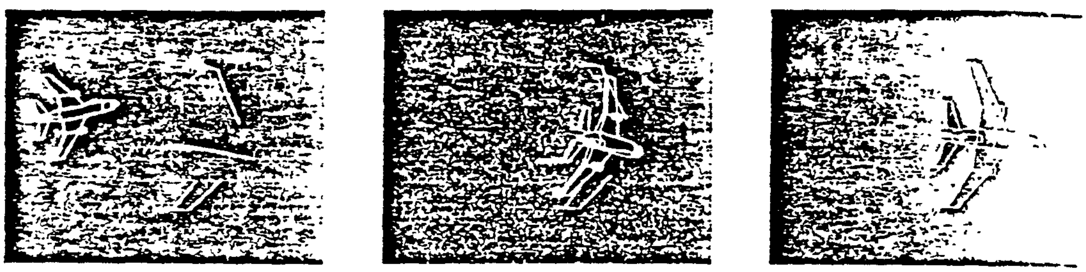




The vision system involved in this work relies upon propagation of symbolic algebraic constraints for predicting image features as well as for extracting 3-D information from image-feature measurements. This research is being integrated with extensive studies to find image-intensity boundaries in images and to describe surfaces through stereoscopic vision. An example of the ACRONYM vision system is shown in fig.

ACRONYM originally used models of specific objects to direct qualitative geometric reasoning systems in labelling images. Now it has been expanded to include object class recognition and extraction of three-dimensional information from images. It now combines algebraic and geometric representation with geometric reasoning. New techniques had to be developed, including addition of a class and subclass relation representation scheme, based on the use of symbolic algebraic constraints. A partial decision procedure on consistency of sets of nonlinear inequalities was formulated and a geometric reasoning system which can deal with underconstrained spatial relations was developed. Image features and relations between them which are invariant over variations in the models and camera parameters are identified by a geometric reasoning system, first to give guidance to low-level image description processes, then to provide coarse filters on image features to be matched to local predictions. Noisy measurements can be used to construct algebraic constraints. Local matches are combined subject both to consistently meeting predicated image feature relations and the formation of consistent set of algebraic constraints.

Fig 56. An example of the ACRONYM vision system



Stanford's ACRONYM system tries to identify sketchy features (right) with jet model (left)

System expands model to fit features, which were extracted from an actual image of a jet

The match is successful, enabling the system to identify the features as belonging to a jet.

CHAPTER 4

CONCLUSION

There exist a number of applications of AI in manufacturing today. They are beginning to impact manufacturing both on the shop floor and in engineering design. The number of systems will continue to increase at an even larger rate as corporations acquire more AI expertise and feel more comfortable about its applications. While financial , office and natural resources and closely related tasks will benefit from AI , the manufacturing floor offers the greatest challenge. This is because the high value added associated with process improvement. AI for real time control is an excellent , yet largely untapped application. Eventually tying AI to Robotics , Machine Vision , and Voice recognition will create unusual capability in manufacturing.

More systems which capture scarce expertise and make it available throughout the organization will be created. Systems that enhance our problem solving by making better decisions more quickly will be created. Systems that integrate more knowledge about the factory floor and , hence , make better decisions will ba created. There will be increased accessibility to these systems by people who are not computer oriented through the natural language and explanation facilities.

The future appears to be rosy , but there are barriers along the path. The problem is that there are few people who really understand AI. There are people who have book knowledge of AI but do not understand AI from a point of view of actually building real , large systems. It so happens that AI is like a guild. It is a guild in a sense that there are masters , journeyman and apprentices. The problem is there are not enough masters or any masters at all to guarantee a project's success. The possibilities of success may be enhanced if the corporations work with the masters, start small, lowers its expectations, make sure that the problem can be done by people before solving it with a computer. Only then will it be possible to successfully apply Artificial Intelligence to industrial problems. AI have lots of promise but it must be applied cautiously. The education and training is crucial.

The impact of AI is twofold:

1) On the communication of a system with the outside world, i.e. human operator and/or industrial process. Oral input - output and computer vision have been presented at the level.

2) On the intelligent control of complex systems. Research and development on expert systems for process control have been presented.

AI is a mean for making robots intelligent. In the longer term robots will only be elements of Computer Integrated Manufacturing systems including CAD/CAM, communications, controls, etc. AI will certainly be used in these various elements but it will at first be of primary importance in linking these elements together.

Expert systems are most suited when : the domain knowledge is vast, the problem is ill - defined, and the solution to a problem related to expertise. While designing an expert system it is essential to follow a structured approach. In manufacturing engineering problems attention should be focused on the knowledge coordination aspects. Manufacturing engineering is an area in which many problems would be amenable to solutions using expert systems. The applications discussed in this thesis give an idea about some of the prototype systems developed and how the manufacturing engineering domain can benefit from the application of expert systems methodology.

The U.S. Government is accelerating its commitment to, and confidence in AI techniques. This goes beyond the use projected in military systems, and includes ambitious plans for the use of AI in space programs. AI is planned for manufacturing applications by the U.S. Air Force and they hope to form an AI in Manufacturing Research Institute shortly. *The inescapable conclusion that the manufacturing area is a ripe one for growth.*

Beyond today's use, we could forecast an excellent future for AI use, due to the potentially high value added, when applied successfully.

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