Production Management: Methods and Studies
B. Lev (Editor)

EXPERT SYSTEMS IN PRODUCTION MANAGEMENT

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This paper analyzes the use of expert systems in production management and provides both an historical perspective and a review of some recently developed expert systems for production management problems. Current expert systems in production management fill two gaps associated with traditional optimization and heuristic methods. First, optimization and heuristic methods do not process semantic information. Second, optimization and heuristic methods usually are focused on a single problem or a single goal, rather than multiple interlocking problems or goals. Production expert systems attack these problems by using computer languages oriented toward processing semantic rule-based information and by coordinating the use of multiple optimization and heuristic methods in conjunction with semantic information to meet multiple goals.

1. INTRODUCTION

The purpose of this paper is to analyze the use of expert systems as a tool in production management. This paper reviews the characteristics of production expert systems (PES) and some of the limitations of PES's. The paper also provides an historical perspective and a review of some recently developed PES's.

1.1 Artificial Intelligence and Expert Systems

Rich [1, p.1] defined artificial intelligence (AI) as "...the study of how to make computers do things at which, for the moment, people are better." Barr and Feigenbaum [2, p. 1] have defined artificial intelligence as "...the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics associated with intelligence in human behavior...." These definitions indicate that AI is the study of developing computer programs to perform tasks and do analysis that humans currently use knowledge and reasoning to carry-out.

Knowledge-based expert systems (ES) are a branch of artificial intelligence. Expert systems perform tasks normally done by human experts that possess a particular knowledge. Accordingly, expert systems are developed by programming the computer to make the same decisions as the human expert using a similar knowledge base.

Typically, ES's perform intellectually demanding tasks rather than mechanical tasks. In addition, ES's usually explain their reasoning to make the consultation more palatable to the user and to enable the user to find errors in the expert system's reasoning (Barr and Feigenbaum [2]).

Structurally, ES usually have three major components: database, knowledge base and inference engine. The database includes the data used by the expert system. This is usually the same data that a human expert would use to solve the problem. The knowledge base provides the set of knowledge that is used by the system to process the data in the database. The knowledge that a human expert would use often is expressed as a set language-based rules. The inference engine provides the basis to use the knowledge base to process the database.

1.2 The Importance of AI and ES to Production Management

AI has both practical and theoretical implications for production management. First, in practice, AI offers the opportunity to automate tasks formerly done by humans. AI and ES provide a neophyte with the ability to work with a system to produce expert-based decisions and an experienced decision maker with the ability to produce improved decisions. AI and ES also allow a single expert to work with a computer program to produce multiple expert-based solutions.

Second, in the area of theoretical developments in production management, AI forces the explicit analysis of a body of knowledge before and after it is programmed. This can lead to the determination of gaps in the knowledge base of the area of production management, which can point out the need for subsequent research. The development of an ES also forces the developing of an understanding of the particular decision process and decision processes in general. Third, the resulting model offers another alternative to other models that have been offered to represent decision makers in production management problems (e.g., Bowman [3]). These models can be used to compare to actual decision makers or other models to analyze the quality of the decisions produced by the models.

1.3 The Plan of this Paper

This paper proceeds as follows. Section 2 addresses the characteristics of a PES. Section 3 provides an historical perspective and reviews some PES applications. Section 4 discusses some of the limitations of PES and section 5 is concludes with a summary of the paper.

2. CHARACTERISTICS OF PES

Researchers such as Hayes-Roth et al. [4], Fox [5], McDermott [6] and others have delineated a number of facets of an ES. These include Expertise and Decision Characteristics, Mode, Task Domain, Task Characteristics, Knowledge Representation, Knowledge Implementation and Inference Engine.

2.1 Expertise and Decision Characteristics

The expertise should be in short supply (Fox [5]) or an expensive resource. Thus, the expertise would not be readily available on demand. Further, there should be a difference between the decisions that are made by an expert and the decisions made by an amateur (McDermott [6]). Otherwise there would be no need for an expert.

The expertise should not be easily acquired by the user. Fox [5] suggests that the decision should require a short reaction time. In these two situations the user could develop expertise without having to consult the expert. McDermott [6] adds that the decision should be a high value decision. These conditions ensure that there is a cost/benefit contribution of the ES.

The expert and decision characteristics clearly reflect the production management environment. First, there is disappearing expertise in production management due to seniority and the recent recession (Fox [5]). Second, there is clearly a difference in many aspects of production between the amateur and the expert. Third, many of the decisions must be made in real time. Fourth, production management decisions can have high costs if the wrong decisions are made. Accordingly, production management is an ideal environment for the development of ES.

2.2 Mode

ES have been used to develop programs that perform in an educational mode, an advisory mode and a replacement mode.

ES are now being used to model educational activities that previously could not have been placed in a computer model. STEAMER (Williams et. al [7]) is an example of a program that is used to train students in the principles of propulsion engineering. The program provides both qualitative and quantitative simulation coupled with explanation capabilities.

Most ES are designed to function in an advisory manner. Typically the systems make a recommendation and the user reviews the decision and the the logic behind the decision before it is executed. Most of the PES discussed in section 3 function in this mode.

A few ES are designed to replace the decision maker. Glover et. al [8] designed a system that they suggested should be called a "managerial robot" because it was designed to replace the decision maker. The system was designed to schedule employees in an environment of weekly fluctuations.

Although the system can be designed to replace the manager, it does not have to be implemented in that manner. The system can be implemented to advise the user.

2.3 Task Domain

The task domain refers to the type of activity that the PES performs. This paper is concerned with expert systems for use in production management planning. Accordingly, the PES task domains discussed in this paper include the following: Training and Instruction, Assembly of Products, Preventive Maintenance, Scheduling and Sequencing, Facilities Layout and Project Management.

Training and instruction refers to training and instructing in the topics of production management. This domain reflects the unique aspects of instruction. The training and instruction can include the entire spectrum of personnel from plant managers to lower level employees in an equally broad base of topics including management of the plant to specific topics. Assembly of products refers to planning the assembly of the products or configuring the product. This is particularly important for those products with a substantial number of related parts and alternative configurations, such as computers. Preventive maintenance refers to planning the maintenance activities of the firm. A classic example is scheduling the preventive maintenance on computer facilities at a time that causes minimal disruption to normal job processing. Scheduling and sequencing refer to the order of processing jobs and assigning personnel. Facilities layout refers to designing the facilities to allow appropriate proximity of production processes or assigning space to allow development of an appropriate assembly of products. Project management refers to the planning and controlling of personnel and equipment resources to meet the time and quality demands of the project.

2.4 Task Characteristics

At least four dimensions of the task determine whether or not a PES should be developed for the problem: well-structured vs. ill-structured, numeric vs. language, coupled vs. decoupled, and single goal (step) vs. multiple goal (step). Each of these dimensions is actually on a continuum--they are not either/or questions.

The notion of well-structured vs. ill-structured has been discussed by a number of researchers (for example, Keen and Scott Morton [9] and Mintzberg et. al [10]). A problem that is well understood and can be solved with a prespecified set of steps is a well-structured problem. Whereas, the ill-structured problem is not understood and, at the extreme, is filled with unspecified uncertainty. In addition, the problem solving methodology is not clear and is discovered iteratively.

The numeric vs. language (semantic) question determines whether the problem can be solved using numerically-based optimization techniques and approximating heuristics or a logical analysis of language-based relationships (rules). Language-based information is used in the solution of a broad base of problems, for example, configuring computers.

The question of whether (or the extent to which) the task can be decoupled from adjacent or sequential tasks is critical in the development of expert systems. If a task can be decoupled then it is much easier to describe the knowledge required to accomplish the task. The knowledge to accomplish the task is very specific and may include only a small amount of general knowledge. If the task is smaller then it generally is easier it is to develop an ES. If the task is tightly coupled with other tasks then a broader base of knowledge is required to solve the task since any solution must account for the relationships between tasks. This paper assumes that at some level of generalization the task can be decoupled.

The single goal (step) vs. the multiple goal (step) is a question of interfacing multiple goals (steps). If the problem requires multiple goals then this would require an expert to determine the priority imposed upon the goals and the approach to accomplish the goals. If the problem requires multiple steps or problem solution techniques then the expert must determine which techniques should be used to solve the problem, the order in which the techniques should be used and when the techniques should be used. Although the primary emphasis in PES has been the sequential use of techniques, the parallel use of techniques has not not been eliminated.

If a problem is well-structured problem then it is likely the problem can be stated in a numeric format and can be solved by a single technique, most likely from the set of operations research (OR) methodologies. In this case a PES can be used to formulate the input and analyze the output of the OR techniques (O'Leary [11]). For example, this type of PES can be used in the analysis of a linear programmming problem.

Alternatively, the problem may be well-structured yet require interfacing multiple OR techniques. This type of problem is amenable to solution by an expert system whose functions include coordinating the multiple techniques. Generally, this is the case with expert systems in facilities layout and scheduling and sequencing.

However, the problem may be well-structured but not readily expressed in numeric terms so that it cannot be solved by numeric-based OR techniques. These problems are particularly amenable to solution using an expert system. The ES developed to solve these problems use language-based rules to represent the knowledge base. (The notion of language-based structure is discussed below.) The task domains of product assembly and preventive maintenance fall into this category.

2.5 Knowledge Representation in the PES

The PES have been developed using two primary methods to represent knowledge that summarizes the expert's understanding of the problem: numeric-based rules (constraints) and language-based rules (rules). The approaches have been used one at a time or together.

Numeric-based rules refer to constraints and networks that describe the quantitative structure of the problem. These constraints can be used in conjunction with OR techniques. The constraints must discriminate among different hypotheses as well as restrict the number of hypotheses.

Language-based rules refer to semantic rules generated from an expert to solve a particular problem. The rules usually take the form "If condition x occurs then take action y or else action z." An example of this rule structure is as follows (Fox [12]), "If order x is shipped then contact manager y or contact manager z." These rules are usually either exact or heuristic statements of process (relationships between subsystem) or structure (configuration knowledge). The rules may or may not include a numeric level of confidence or probability of occurrence.

2.6 Implementation of the Knowledge Base

The rule-based knowledge base is usually implemented using either an artificial intelligence language or an expert system shell. There are two primary AI languages: Prolog (Clocksin and Mellish [13]) and Lisp (for example, Winston and Horn [14]). Prolog has been chosen for Japan's fifth generation computer (Feigenbaum and McCorduck [15]). Lisp has been used in a number of expert systems built in the United States.

The AI languages differ from traditional procedural languages in that they are designed to process language-based information. However, some versions of Prolog and Lisp allow the user to access procedural languages, such as Pascal.

Expert system shells simplify the development of an ES by providing many user friendly features (e.g., Turpin [16]). For example, the inference engine can be specified and does not need to be developed or the knowledge base is unusually easy to install. Fox and Smith [17] build an expert system for factory scheduling using such a language (SRL). Another language, KBS, is used for interactively constructing models and simulating them using AI techniques (Husain et. al [18]).

2.7 Inference Engine

The type of knowledge representation indicates the type of solution approach generated by the inference engine. Generally, PES employ either rule search or some combination of the other approaches.

Rule search is used to analyze language-based rules. In a rule-based system, the inference engine uses either forward or backward chaining approach. Forward chaining is a method of reasoning toward a goal. Backward chaining starts is a method of reasoning that works backward from a goal to determine how or if the goal can be accomplished.

Constraint search (Fox and Smith [17]) refers to the selective relaxation of constraints and the implementation of a problem-solving strategy that best satisfies the constraints. Those strategies may include, e.g., heuristic search and/or Operations Research techniques.

Heuristic search (Feigenbaum and Feldman [19] and AI Magazine [20]) refers to rules of thumb, strategies or tricks that severely limit the search for solutions in the problem space. Heuristic searches do not guarantee optimality or feasibility, but they offer solutions that are "...good enough most of the time."

Operations research (OR) techniques refer to optimization methods, queueing theory, sequence and scheduling theory, etc. These are the methods that may be used by an expert in production management to solve the particular problem.

3. PES APPLICATIONS

This section provides an historical perspective to previous research in artificial intelligence and production and reviews some of the PES that have been developed recently.

3.1. Relationship to "Heuristic Programs"

Some of the earliest efforts in artificial intelligence were developed to solve specific production management problems. Tonge [21 and 22] developed an heuristic procedure for assembly line balancing. Kuehn and Hamburger [23] developed a heuristic program for locating warehouses. Jones [24] tested a number of scheduling rules.

These early efforts were described as "Heuristic Programs" and "Scheduling Heuristics." These labels were used because the solutions did not guarantee optimality and because the solution methodologies used "tricks of the trade" to determine the solutions.

Feigenbaum and Feldman [19] referred to Tonge's [21 and 22] work as artificial intelligence because of characteristics of the problem it solved and the approach it used. The problem was regarded as moderately difficult for intelligent human beings with college training, the problem could be attacked using heuristic methods, and it was cost/beneficial to use the approach to solve the problem. The approach was to seek a "satisfactory" solution, within some percentage of the optimum.

In some cases, such as the assembly line balancing problem, the only practical solutions to these problems are still through the use of heuristics. However, in some cases computer technology or OR technology has been developed to the point where large problems are now feasible using either exact algorithms or more efficient heuristic algorithms that are now available. This is exemplified by the warehouse location problem. Finally, in some cases the optimality structure of the heuristic rules has been studied and some of the cases for which the rules are optimal have been determined, e.g., scheduling rules (Graves [25]).

These efforts would not be viewed as expert systems, however, but possibly as components in an expert system. This is because each of the problems solved using these procedures is a highly specific numerically-based problem, has a single goal or is optimal under specific conditions. Accordingly, they would be treated as an optimization procedure or a heuristic procedure to be used in an expert system.

Historically, the human expert has had to determine which of the approaches to use and in what sequence. Those same concerns are now being approached with expert systems.

3.2 Some Recent PES

Recently developed PES's fall into two primary categories. First, some PES's use semantic-based rules as the basis of the knowledge base. These PES use

backward or forward chaining to determine a solution. Second, some PES's incorporate semantic and numeric-based rules. These PES use heuristics and/or OR techniques for the solution of multiple goal (step) problems. A list of some recently developed PES's is given in Table 1.

TABLE 1

Expert Systems in Production Management Planning by Task Domain

Activity	Program	Structure	Purpose/Discussion	Reference
Training/ Instruction	STEAMER		A PES for Training on Plant Operation.	Williams et al. [7]
Assembly of Products	XCON	Rule	Configure Computers. Developed Based on R1.	Abromson [26]
	R1	Rule	Configure Computers. One of First PES.	McDermott [27]
	OCEAN	Rule	Configure Computers.	Fox [5]
	VT	Rule	Configure Elevators.	Fox [5]
Preventive Maintenance	ACE	Rule	Diagnose Telephone Cable Repairs.	Miller [20]
	RACE	Rule	Computer Preventive Maintenance.	Fox [5]
	IPWBIS	Rule	Determining Sources of Error.	Fox [5]
Scheduling/ Sequencing/ MRP	ISIS	Constraint /Heuristic	Job Shop Scheduling w/ Different Criteria.	Fox and Smith [17]
	PTRANS	Rule/ Heuristic	Generates Plans for Manufacturing and Distribution.	Miller [28]
	IMACS	Rule/ Heuristic	Flow Shop Management.	Fox [5]
Facilities Layout	FADES	Rule/OR/ Heuristic	Equipment Selection & Facility Design.	Fox [5]
Project Management	CALLISTO	Rule/OR/ Heuristic	Resource Constrained Scheduling.	Fox [5]

Product assembly and preventive maintenance are problems that are amenable to rule-based programs. This is because those problems are solved by human experts using large sets of rules that define partial configurations and relationships between the particular subtasks. For example, in R1 (Hayes-Roth et al. [4]) McDermott found 480 rules for the configuration of a computer. Of those rules, 384 rules defined situations with partial configurations and 96 rules that defined situations relating partial configurations.

Scheduling and sequencing systems, such as ISIS, implement solutions to problems that are more extensive than a single objective. ISIS schedules jobs based on conflicting and diverse factors such as due dates, production levels, machine capabilities and cost restrictions using multiple approaches. It does this by implementing multiple techniques to solve the problem.

Facilities layout and project management are problems that require both language-based knowledge and numeric-based knowledge. Each type of knowledge is used in particular tasks to accomplish the overall problem. For example, the scheduling portion of project management uses a numeric-based approach while the analysis of those results requires a rule-based approach.

3.3 Contributions of ES's to Production Management

A primary contribution of ES's is the ability to address problems that are beyond the scope of OR techniques because they are not numeric-based problems. These problems generally are well-structured rule-based problems.

The other primary contribution of ES's is that the determination of the problem specification is not limited to any single technique such as linear programming. Instead the PES's provide coordination and interpretation of inputs and outputs of multiple OR techniques as applied to the particular production management problem.

4. LIMITATIONS OF EXPERT SYSTEMS

A number of general and production management application-specific limitations are associated with PES's. The general limitations of ES occur in three primary areas: technology, choice and implementation of expert knowledge, and specification of the knowledge base.

4.1 Technology

The limitations of ES include the following technology-based problems.

- The size of the knowledge base is limited by current technology (Messier and Hansen [29]).
- The development of expert systems must cope with the current languages, since computers are unable to understand natural language (Messier and Hansen [29]).
- The languages are slow.

4.2 Expert Knowledge

The limitations arising from the choice and implementation of expert knowledge include the following.

- The development of expert systems requires an expert to spend time developing and debugging the system.
- The system developer must choose an expert that can provide the appropriate expert information.
- The knowledge base should include appropriate rules, heuristics and optimization techniques. The wrong rules or inappropriate use of the rules can lead to an ineffective system.
- The determination of expert knowledge from the expert is a difficult process.

4.3 Knowledge Base

The knowledge base is also a source of limitations (McDermott [6]).

- The systems do not have a general knowledge to fall back on if the specific knowledge is insufficient.
- The systems do not learn from their experience.
- The systems have little knowledge of their own scope and limitations.
- The system knowledge base is difficult to debug and remove redundencies.

Recent efforts in ES have relied on specific knowledge about a particular domain. Thus, the lack of a general knowledge base suggests that current generation ES's are limited to the specific problems from which their knowledge derives.

4.4 Production Management-Specific Limitations

The primary limitation of PES's is the technology on which the system is based. For example, systems like ISIS are limited to the existing scheduling technology for the knowledge base.

5. SUMMARY

This paper has explored expert systems and the use of expert systems in production management problems. The paper has analyzed the characteristics of expert systems and the limitations of expert systems in general and PES specifically.

The use of expert systems in production management has evolved because numeric-based optimization, simulation and heuristic methods are inappropriate for semantic rule-based programs and because the methods are geared to solve only a portion of the actual problem facing the organization. Accordingly, the current PES's derive from two different technologies: solving rule-based semantic problems and coordinating and sequencing the use of heuristic and optimization methods in conjunction with a rule-based semantic problem.

ACKNOWLEDGEMENTS

I would like to thank Professor Benjamin Lev for his comments on an earlier version of this paper. Also, I would like to thank the anonymous referees for their comments on an earlier version of this paper. Of course any limitations remain due to the author.

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Production Management: Methods and Studies

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1986

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