GENESYS: an expert system for production scheduling

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Abstract
Planning and scheduling are forms of decision making, which play a crucial role in manufacturing as well as in service industries. In the current competitive environment, effective sequencing and scheduling has become a necessity for survival in the marketplace. A great challenge for today's companies is not only how to adapt to this changing, competitive business environment but also how to draw a competitive advantage from the way in which they choose to do so. Intelligent solutions, based on expert systems, to solve problems in the field of production planning and scheduling are becoming more and more widespread nowadays. Proposes an expert system, which uses the prevailing conditions in the industrial environment in order to select and "fire" dynamically the most appropriate scheduling algorithm from a library of many candidate algorithms.

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Introduction

In recent years the growing complexity of industrial manufacturing and the need for higher efficiency, shortened product life cycle, greater flexibility, better product quality, greater satisfaction of customer's expectations and lower cost have changed the face of manufacturing practice. A great challenge for today's companies is not only how to adapt to this changing business environment but also how to draw a competitive advantage from the way in which they choose to do so. As a basis to achieve such advantages, companies have started to seek to optimize the operation of their manufacturing systems.

Production scheduling is one of the most critical parts of a manufacturing system. Classen and Malstrom (1982) state the importance of scheduling:

> Hundreds of robots and millions of dollars worth of computer-controlled equipment are worthless if they are underutilized or spend their time working on the wrong part because of poor scheduling.

Since traditional, centralized manufacturing planning and scheduling mechanisms were found insufficiently flexible to respond to the new situation of global competition, many manufacturing companies decided to adopt intelligent solutions. Expert systems (ES) technology provides a natural way to overcome such problems, and to design and implement distributed intelligent manufacturing environments.

In the past decade there has been a virtual explosion of interest in the field known as expert systems (or, alternatively, as knowledge-based systems). Expert systems provide powerful and flexible means for obtaining solutions to a variety of problems that often cannot be dealt with by other, more orthodox methods. One relative study reported an investment of over $100 million in artificial intelligence (AI) research by large American manufacturing companies, some of which have already achieved impressive results (Dornan, 1987). Typical examples are Digital Equipment Corporation's XCON, Boeing and Lockheed-Georgia Corporation's GenPlan.

On the other hand, many researchers and authors have strongly supported the view that expert systems can make a significant contribution to improving production planning and scheduling (Kusiak and Chen, 1988; Badiru, 1992; Jayaraman and Srivastava, 1996; Zhang and Chen, 1999). This paper proposes a knowledge-based expert system approach as a tool for effective production scheduling in small to medium sized manufacturing companies. The authors' main goal is to advocate the concept of solving scheduling problems using an ES approach and to show how a system of this kind can be developed. For the benefit of the readers who may be unfamiliar with ES, the key concepts of ES are briefly explored first and a systematic methodology for their development is then introduced. An on-going prototype system development that concerns production scheduling with dynamic selection of appropriate scheduling algorithms is then discussed.

Intelligent production scheduling and managerial implications

In the current competitive environment, with global markets, increasing global competition and shorter product life cycles, a company's choices and shifts among various manufacturing policies – having different implications for manufacturing objectives such as customer's satisfaction, manufacturing efficiency, inventory investment – should be made faster and at a strategic level. Nowadays, effective planning

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and scheduling has become a necessity for survival in the marketplace.

Research (Advanced Manufacturing Research, Inc., 1996) has shown that a company with an effective production scheduling can achieve the following:

- Reduction by 10-15 percent in production costs, which can lead to the doubling of the profit margin of the company.
- Reduction by 8-10 percent in inventory costs.
- Increase by 30 percent in "on time" deliveries to the customers.

On the other side, the scheduling function interacts with the other functions of a company. It is affected by the middle-range planning, which examines the stock levels, the demand forecasting and the requirements plan, in order to achieve the optimization of the combination "Production – allocation of resources". In this context, the construction of a feasible, optimized (as far as possible) production schedule from the production manager, without the support of an information system, is a very difficult and time-consuming procedure that requires not only deep knowledge of all data and parameters of the production system at any time but also specific knowledge in the particular field. In addition, often the production manager, without a decision support tool, is not in the position to achieve a multi-criteria scheduling objective, because these criteria may conflict with each other. For instance, satisfying the most significant customers may be in conflict with the criterion of meeting the due dates; and that results in a further delay to several customers who are, for various reasons, less significant to the manufacturing company.

In this framework, during the last decade a lot of manufacturing companies decided to adopt intelligent solutions, since the traditional manufacturing planning and scheduling mechanisms were found insufficiently flexible to respond to changing production styles and highly dynamic variations in product requirements (Kusiak, 1990; Meredith *et al.*, 1994). A mid 1990s survey reported by Durkin (1996) has revealed manufacturing industry to be one of the most widely applied areas for expert systems (ES).

In addition, another study (Wong *et al.*, 1994) examined the current utilization of ES and their benefits in manufacturing among the 500 largest industrial companies in the USA. They invited all *Fortune 500* industrial corporations (based on the 1990 ranking) to participate in a mail survey. In this study, production scheduling emerged as the most common application area for ES. Concerning the benefits reported from the use of this technology, the interviewees said they received from their ES:

- better customer service;
- reduction in time to complete tasks;
- organizational learning;
- increases in production;
- more effective use of resources;
- reduction in staff.

Moreover, many researchers have regularly written about the use of ES in production planning and scheduling and the potential benefits of them (Mertens and Kanet, 1986; Liebowitz and Lightfoot, 1987; Kanet and Adelsberger, 1987; Deal *et al.*, 1992; De Toni *et al.*, 1996; Pham and Pham, 1999; Li *et al.*, 2000; Metaxiotis *et al.*, 2001). According to these researchers, ES can help organizations to cut costs by reducing the need for some personnel, preserve and disseminate scarce expertise throughout the organization, give better consistency to decision making, improve quality of products.

Taking into consideration all the above mentioned, the authors present in the following sections the key features of this specific technology and propose a prototype expert system for production scheduling, giving in parallel insights in how to implement such an intelligent system for production scheduling.

The expert systems technology

Basic components of expert systems

ES are one of the most commercially successful branches of AI. Welbank (1983) defines an expert system as follows:

> An expert system is a program, which has a wide base of knowledge in a restricted domain, and uses complex inferential reasoning to perform tasks, which a human expert could do.

In other words, an ES is a computer system containing a well-organised body of knowledge, which emulates expert problem solving skills in a bounded domain of expertise. The system is able to achieve expert levels of problem solving performance, which would normally be achieved by a skilled human when confronted with significant problems in the domain (BCS, Expert Systems Specialist Group). As illustrated in Figure 1, an ES consists of three main components, which include the knowledge base, the inference engine and the user interface.

The knowledge base is the heart of the system and contains the knowledge needed for solving a specific problem. The knowledge may be in the form of facts, heuristics (e.g. experiences, opinions, judgements, predictions, algorithms) and relationships usually gleaned from the mind of experts in the relevant domain. Knowledge can be represented using a variety of representation techniques (e.g. semantic nets, frames, predicate logic) (Jackson, 1986; Ignizio, 1991; Mital and Anand, 1994), but the most commonly used technique is "if-then" rules, also known as production rules.

The inference engine is employed during a consultation session, examines the status of the knowledge base, handles the content of the knowledge base and determines the order in which inferences are made. It may use various inference methods.

The user interface part enables interaction of the system with the user. It mainly includes screen displays, a consultation/advice dialogue and an explanation component. In addition, expert systems provide interfaces for communication with external programs including databases and spreadsheets.

Expert system development approach

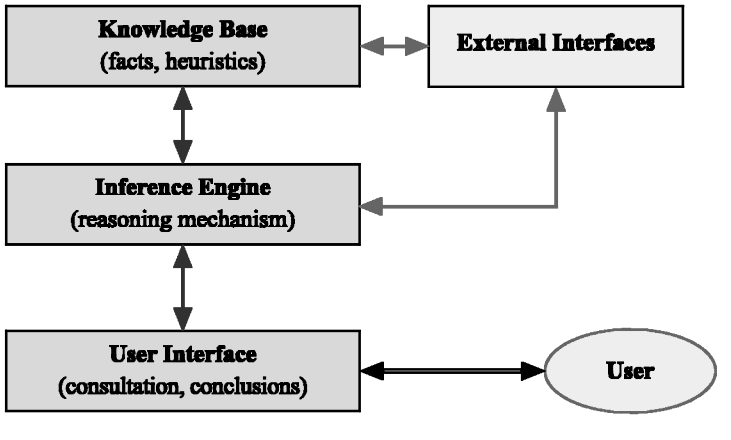
A successful ES development needs a well-planned course of activities, as shown in Figure 2. It is important that a systematic approach is adopted from the identification of the problem domain, through the construction of the knowledge base and eventually to the implementation and validation of the system.

Concerning the implementation of ES, there are mainly two groups of development tools (Huntington, 1985; Townsend, 1986; Baker, 1988):

- Computer programming languages, either conventional (e.g. C++, Pascal, etc.) or AI languages (e.g. PROLOG, LISP, etc.). Using these languages, the system designer has a great deal of freedom in choice of knowledge representation techniques and control strategies. However, use of these languages requires a high degree of expertise and skill.
- Expert system shells. They attempt to combine the flexibility of AI languages with the cost-effectiveness and provide more general development facilities. There are a number of commercial shells available in the market with varying features (Nexpert Object, XpertRule, KnowledgePro, CLIPS, ReSolver, EXSYS, VP-Expert, ACQUIRE, etc.). Most of them are relatively low priced and provide a rule-based knowledge representation mechanism.

It is common knowledge that the knowledge acquisition stage is the major bottleneck in the development of expert systems, regardless of the domain. In few words, the success of an ES depends on how much knowledge it has and how qualitative that knowledge is.

Figure 1
Expert system's architecture



The proposed expert system for production scheduling

Following step by step the development approach described above, a complete prototype expert system called "GENESYS" (GENeric Expert SYstem for Scheduling) has been developed that aims to schedule the production of small and medium sized manufacturing companies in the most effective way, taking into consideration the prevailing conditions (production characteristics, constraints, performance criteria, etc.) in the industrial environment.

Since the scheduling problem becomes extremely complex very often, even for simple problems, when dynamic uncertainties such as machine breakdowns, tool failures, order cancellation, due date changes and uncertain arrival of jobs appear, we should always keep in mind that the search for an optimized solution (when possible) for realistic applications can be very expensive and time consuming. In scheduling one should be mainly interested in a feasible, good solution and this "attitude" is reflected in the proposed expert system. In this section, the authors first discuss some key aspects related to the problem domain and the "knowledge engineering" part of the system development before describing the main features of the proposed prototype system.

Problem analysis

Production scheduling is a decision-making process that exists in most manufacturing systems and its role is strategic. In a few words, scheduling is the process of allocating limited resources to tasks over time in order to produce the desired outputs at the desired times, while a large number of time and relationship constraints among the activities and the resources are being satisfied (Morton and Pentico, 1993). A proper allocation of resources enables the company to optimize its objectives and achieve its goals. The scheduling function is a very complex task that today is largely done manually in manufacturing companies. The complexity of the scheduling task arises from several factors; various machine environments, many details of processing characteristics and operating constraints, several uncertainties and different performance measures by which the production schedule is evaluated.

In modern industries there are many different combinations of machine configurations and consequently of production systems, as presented in Figure 3. These are:

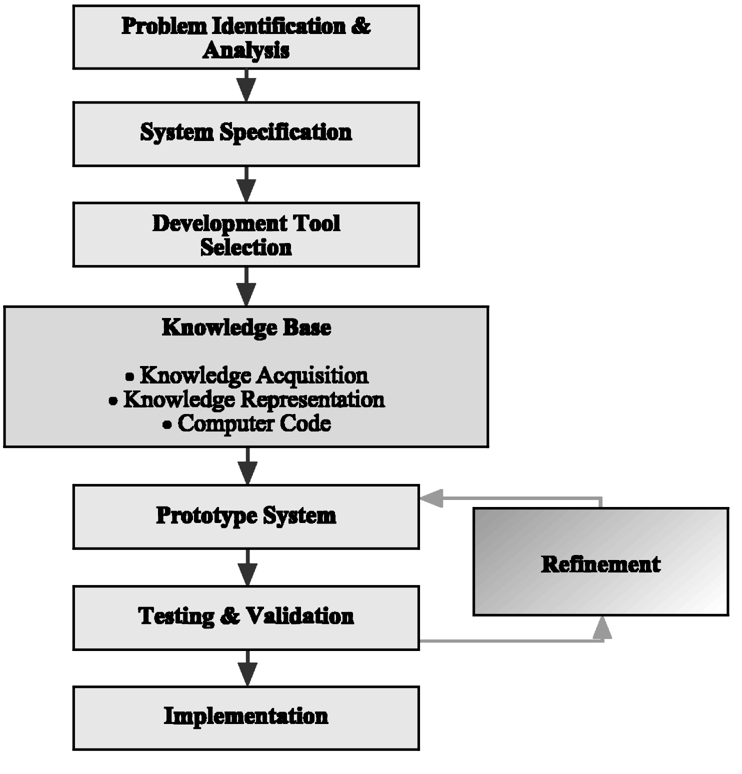
- *Flow shop*. Jobs have to undergo multiple operations on a different number of machines. They have the same routing and the same job sequence is maintained throughout the system. Another version of this shop is the flexible flow shop.
- *Job shop*. It is a manufacturing environment that produces a wide variety of products. Each order many be individually routed to its unique combination of work centers.
- *Batch shop*. In a production system of this type, the production of identical finished or unfinished products is massive and it is preferable to have a batch processing in order to achieve large economies of scale. Flow of jobs in these systems is not totally linear, but it is less complicated than in open shops.
- *Flexible assembly systems*. Here we have a limited number of different product types and a given quantity of each product type must be produced by the system. A material handling system is responsible for the movement of jobs in a flexible assembly system.
- *Multiprocessor task systems*. In these systems, tasks require processing by one or more machines at a time.
- *Multipurpose machine shop*. In this case there are a number of multipurpose machines, capable of processing different jobs.
- *Just-in-time*. The basis for JIT concept was the production system of Toyota after the Second World War. A definition of this system is:

> The JIT is simple: Produce and deliver finished goods just in time to be sold, sub-assemblies just in time to be assembled to finished goods, fabricated parts just in time to go into sub-assemblies, and purchased materials just in time to be transformed into fabricated parts (Schonberger, 1982).

Job processing has many distinctive characteristics and is often subject to constraints that are peculiar. For example, sometimes a job can start only after a given set of jobs has been completed. Such constraints are referred to as precedence constraints. In other cases, it is not necessary to keep a job on a machine until completion, so preemption is allowed. If the order in which the jobs go through the first machine is maintained throughout the system, then permutation is confirmed. Recirculation may occur in some shops, when a job may visit a machine more than once. If some jobs are more important than others, then we attribute to them a priority factor known as weight.

Machines often have to be reconfigured or cleaned between jobs. This process is known as setup. If the length of the setup depends on the sequence of jobs, then the setup times are sequence-dependent. Machine breakdowns imply that machines are not continuously available. Blocking is another phenomenon that may occur. If a shop has a limited buffer

Figure 2
Expert system development approach



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in between two successive machines, it may happen that when the buffer is full the upstream machine is not allowed to release a completed job.

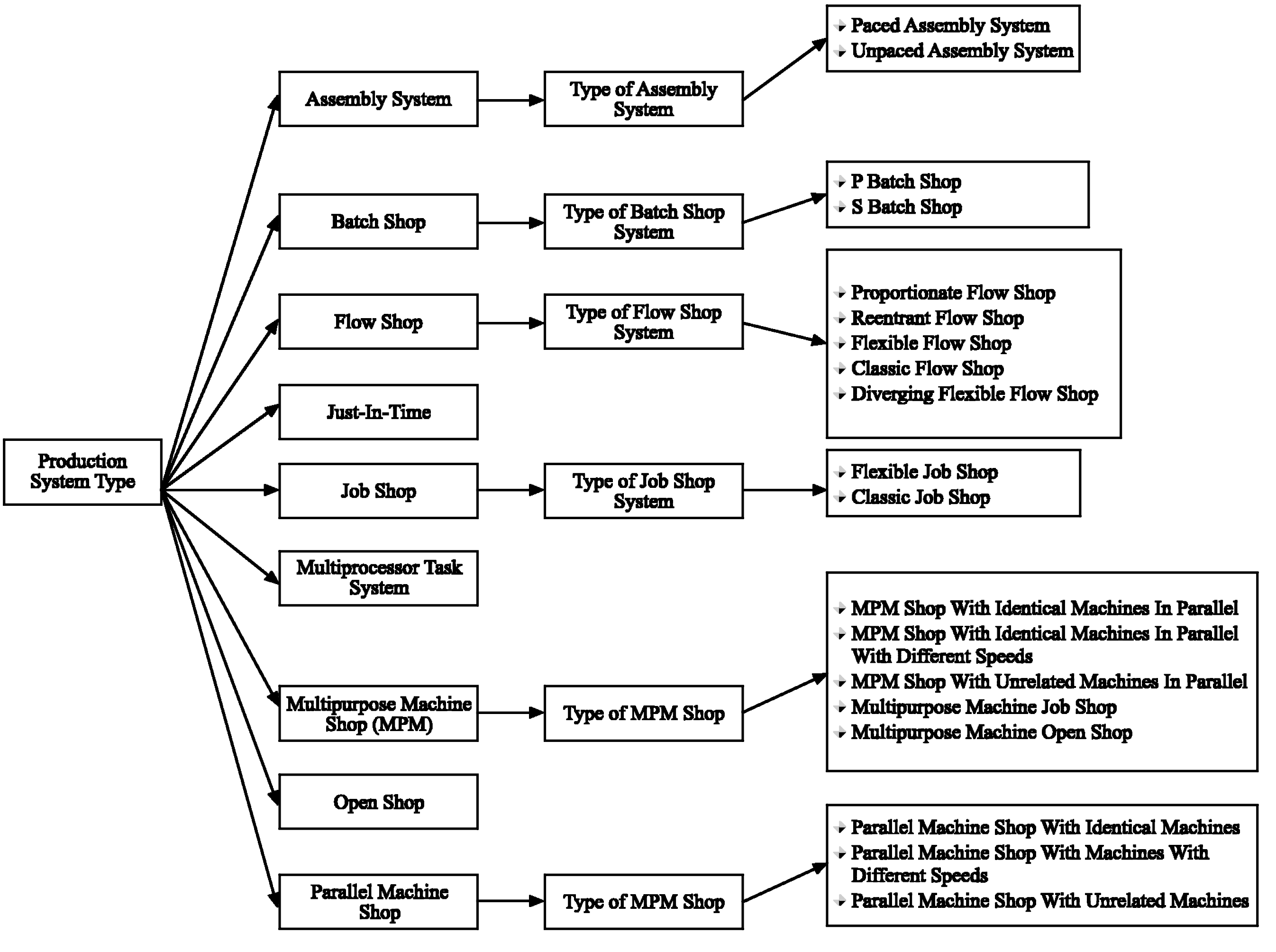
Many different types of objectives are important in operations scheduling. Meeting due dates, as a reflection of customer satisfaction, is one of the scheduling criteria that is frequently encountered in practical problems. The natural quantification of this qualitative goal involves the tardiness measure. Such measures may be the minimization of the flow time of jobs, the total tardiness of jobs, their total completion time, the number of tardy jobs or of the WIP inventory costs and others (Pinedo, 1995; Pinedo and Chao, 1999).

The knowledge base

Having analyzed the production scheduling problem domain, the next crucial step was the acquisition of the necessary knowledge concerning the different techniques that are used for its solution. This knowledge was acquired from various sources available. Such sources included production scheduling textbooks, papers, specific company literature, and in some cases direct interviews with subject experts associated with the production scheduling academia. Some knowledge refinement was necessary as differences in knowledge prevailed from different sources of knowledge, due to the fact that conclusions for the specific problem are changing because it is under continuous investigation. The knowledge acquisition stage is both difficult and time consuming and is generally the major bottleneck in the development of an expert system.

In GENESYS, the knowledge base is structured as following: there are classes that operate like "libraries" containing information about the nature of the production system – machine environment, particular characteristics and production objectives. The user defines the shopfloor conditions and the system proposes the best approach in order to solve the scheduling

Figure 3
Various types of production systems



problem. This approach may be either a dispatching rule or a scheduling algorithm.

A dispatching rule is a rule that prioritizes all the jobs that are waiting for processing on a machine. The prioritization scheme may take into account the jobs' and the machines' attributes, as well as the current time. Whenever a machine has been freed, a dispatching rule inspects the waiting jobs and selects the job with the highest priority. Dispatching rules are used for the minimization of various performance measures such as mean, maximum and variance of flow time and tardiness especially in dynamic shops (i.e. with a dynamic arrival of jobs during the scheduling period). The knowledge base contains some classic but, in some cases, particularly efficient dispatching rules while new, "state-of-the-art", rules have also been included.

The use of algorithms is mostly resorted to in the case of static scheduling problems. In the proposed expert system, we tried to incorporate a wide range of algorithms of different types. There are optimization algorithms that try to supply an optimal solution where it is possible, heuristics, approximation algorithms, which are useful for difficult problems, and algorithms that try to improve existing solutions (improvement type algorithms).

Figure 4 presents the most important dispatching rules and algorithms that have been incorporated in the proposed expert system (Brucker, 1997; Singer and Pinedo, 1998; Kaskavelis and Caramanis, 1998; Djellab, 1999; Rajendran and Holthaus, 1999; Armentano and Ronconi, 1999; Mercado and Bard, 1999; Holthaus and Rajendran, 2000; Jayamohan and Rajendran, 2000; Demirkol and Uzsoy, 2000; Armentano and Scrich, 2000).

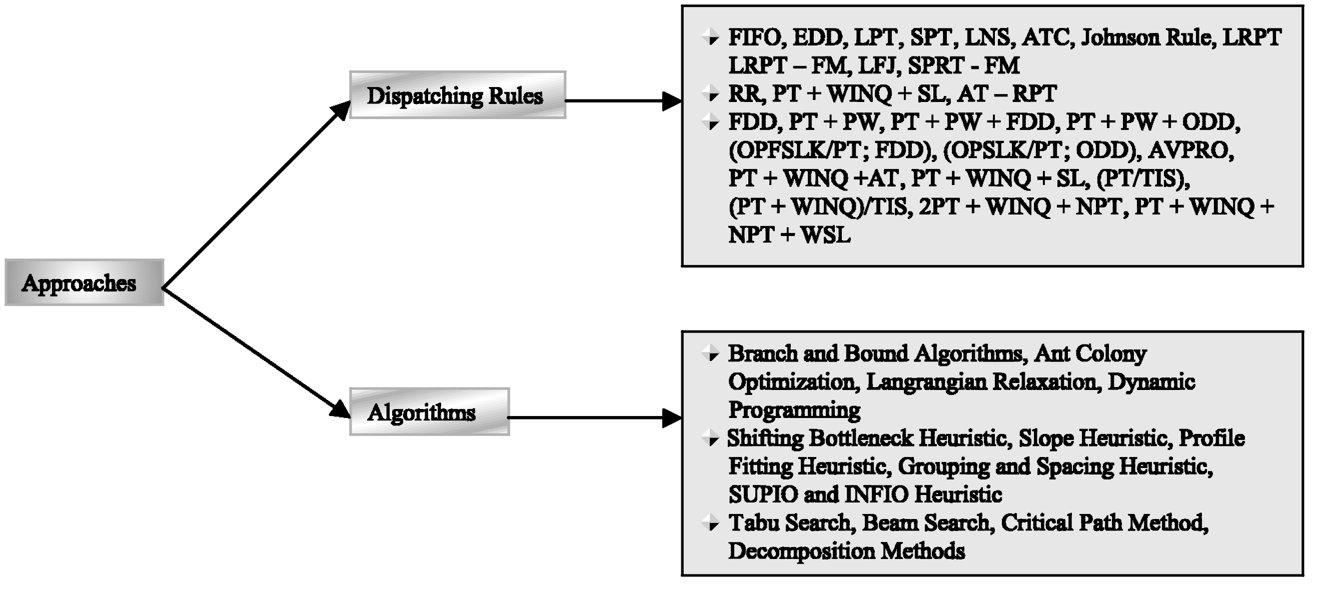
Construction and features

Having acquired the required knowledge, the next step is to represent this knowledge in a computer usable form. A PC-based expert system shell (NEXPERT OBJECT™ by Neuron Data*) was chosen as the development tool. In this shell, the knowledge is represented by rules in "if-then" format. The NEXPERT architecture is event-driven. It can integrate messages from the outside world or external programs, which themselves might have been triggered by NEXPERT rules or objects. It is able to use backward (deductive) or forward (evocative) reasoning. These inference mechanisms are completely interdependent. How a given rule is processed at a given time depends upon the events as well as upon the current focus of attention.

The knowledge base of the GENESYS system includes 280 rules. The operation of the current prototype system comprises three stages. In the first stage, as presented in Figure 5, the user is required to respond to the questions and provide data for the parameters concerning the structure of the production system, so that its basic nature (e.g. flexible flow shop or paced assembly system) can be identified.

In the second stage, the user defines the objective to be minimized (e.g. total completion time). This objective may be a

Figure 4
Dispatching rules and algorithms



single objective or a combination of two others, where it is possible (see Figure 6).

Finally, in the third stage the system collects information about the particular characteristics of the production (e.g. precedence constraints or permutation).

We must stress the fact that the steps above are not followed sequentially. The user has the possibility at the start of a simulation to give a value at any data he wishes or to ask the system if a specific scheduling method is appropriate for the examined production system. Then, the expert system evaluates the given information and, if it is necessary, asks for further information. The whole procedure is interactive and dynamically updated. The different parameters are taken into account and then a specific action is proposed in a short phrase. The user has the possibility to consult the extended manual that accompanies the system in order to acquire further information about the proposed solution.

The integrity of the proposed system was thoroughly examined, by testing each possible combination of production characteristics for which there is a possible solution (for several combinations, the problem of scheduling remain unsolved in real-life manufacturing systems). In all cases tasted, the final conclusion of the system was consistent with the processes being used in practice. In the following example we give a rule used by the system:

IF the production system is of type flow shop
AND production goal is minimization of mean tardiness
AND number of machines is between 5 and 15
AND number of jobs is between 1 and 500
THEN use PT + WINQ + SL dispatching rule.

In Figure 7, a typical screenshot of the operation of the proposed expert system is presented.

Figure 5
Identification of production system

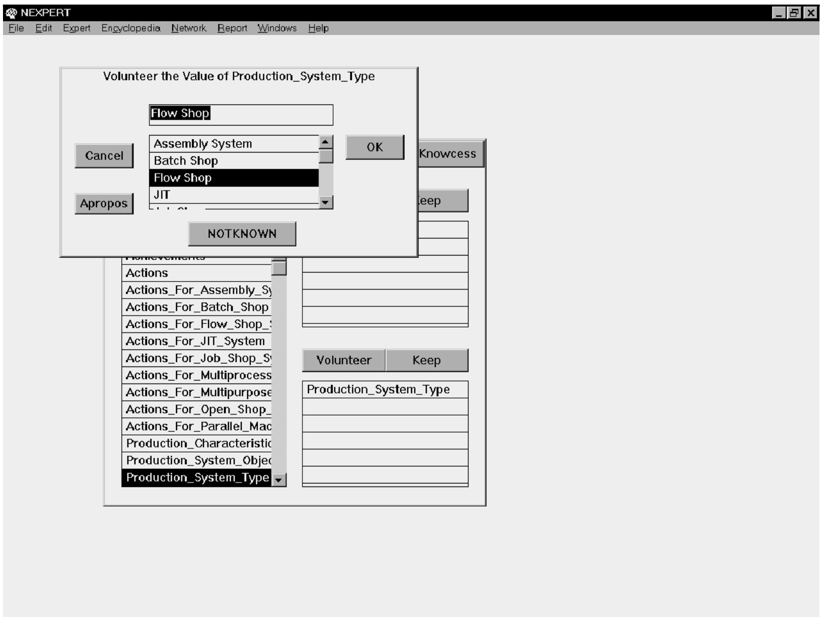
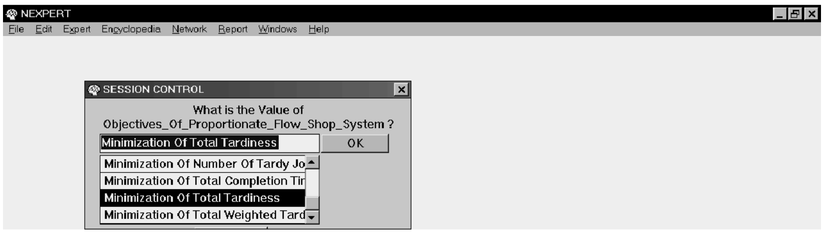


Figure 6
Definition of scheduling objective

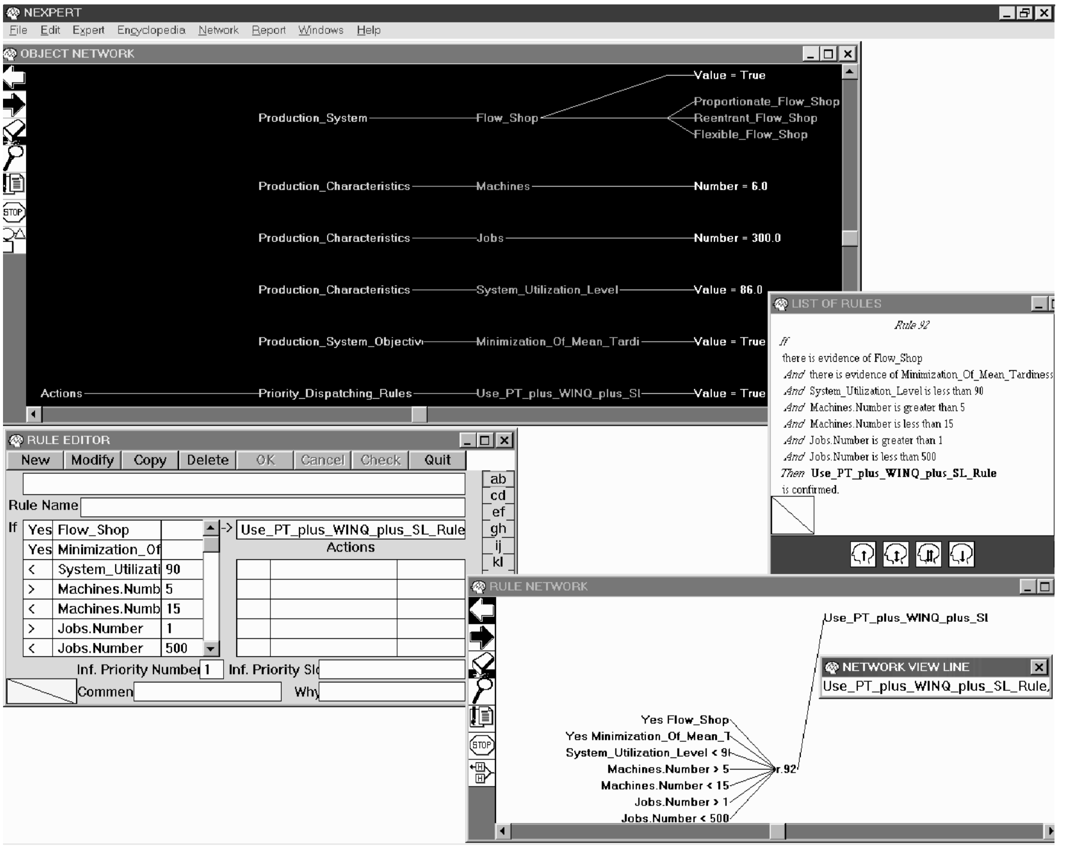


Conclusions and recommendations

The rule-based expert system, GENESYS, has been proposed for the "solution" of the production scheduling problem in manufacturing systems. The system described in this paper is an ongoing prototype and further expansion of the system is being undertaken by the authors. The authors have started working in the way of interconnecting the developed software to an Integrated Management Information System of Enterprise Resources (Singular Enterprise, SEN)[1], which consists of a number of subsystems regarding financial and sales management, monitoring of production cost accounting, resources scheduling, warehouse management, allocation management and equipment sustenance.

It is our belief that the usefulness of Expert Systems (ES) in production planning and scheduling will gain more recognition, if they are properly integrated with Operations Research (OR) techniques – especially simulation – or if they are embedded in ERP systems. We should keep in mind that since,

Figure 7
Operation of GENESYS



in general, most operations management problems are not isolated problems, then an isolated ES cannot solve the problem of the manufacturing manager exactly.

Note

1 Targeting the market of enterprises and organisations the private and public sectors, Singular, one of the biggest software houses in Greece, developed an Integrated Enterprise Resource Planning (ERP) information system for small and medium sized commercial enterprise and manufacturing companies in the private and public sectors, covering managerial activities and supporting the daily operations of a company, such as: financial management, sales management, cost control, manufacturing management, inventory control and logistics, assets management etc. It is planned to expand this system in order to support the production scheduling section on a daily basis as regards to operations directly affecting the production procedure.

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