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Knowledge Acquisition Methods for Expert Scheduling Systems

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ABSTRACT

The concept of expert scheduling systems is introduced. The problem of knowledge acquisition in this content is discussed. Two specific techniques used for this purpose are illustrated.

I. INTRODUCTION

A common feature of many CIM systems is central computer-based scheduling of both machining operations and material handling processes. With this support, decisions such as which part should be processed next and what equipment should move the part are now fully automated. Unfortunately, the theoretical framework for optimal scheduling in this context is not yet in place. However, expert scheduling systems have been suggested as a viable approach to such real time scheduling when information about the current systems state is available and information about part movements for the near future can be anticipated (Thesen and Lei (1986)). The rationale for such systems is the empirically based observation that it is possible to rank order in advance the quality of schedules developed through the use of different decision heuristics when the current state of the system is known.

The main weakness of the expert scheduling approach is the need to develop an in-depth understanding of the behavior of the system such that appropriate rule selection rules can be developed. This paper reviews two practical approaches to this problem of knowledge acquisition. .They are

1. Simulation Assisted Knowledge acquisition, and,
2. Automated Protocol Analysis

The simulation assisted knowledge acquisition method requires the system designer to become the domain expert through simulation experiments. The automated protocol analysis approach, on the other hand, relies on a written record of data recorded in actual or simulated scheduling processes.

In this paper we will first briefly introduce the concept of expert scheduling systems, then we will describe two knowledge acquisition methods that we have successfully used in designing such systems.

II. EXPERT SCHEDULING SYSTEMS

While most expert systems are interactive systems helping a human user diagnose or solve a problem, the expert scheduling system is a fully automated system. The *user* is the robot control computer and the *problem* is the selection of an appropriate heuristic sequencing rule.

As shown in Figure 1, our real-time expert scheduling system is constructed from five components: the rule base, the data base, the searching mechanism, the scheduling mechanism, and the communication interface. They are discussed below.

A. Data Base and Scheduling mechanism

The data base contains the data files describing the current manufacturing system state. Examples of such data include the current location of robots and jobs, and the remaining time for parts in the system. In addition to these data files, the data base also maintains a Dynamic Resource Allocation Chart (DRAC) which records the current and future allocation status of machines and robots.

B. Rule Base and Searching mechanism

The rule base contains *sequencing* rules and *rule-selection* rules. These rule-selection

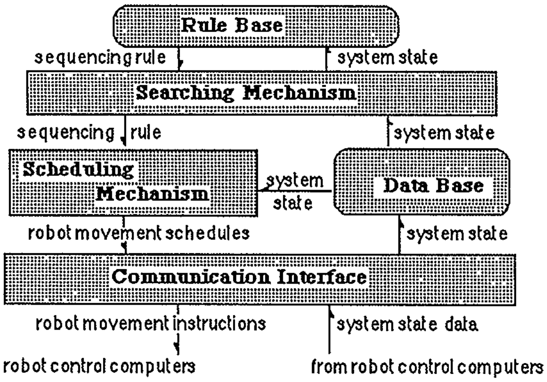

Figure 1: An expert scheduling system

Facts or causal relationships:
IF (part is A) **THEN** (routing is M2-M4-M1)

Experiential judgements:
IF (utilization is high) **AND** (product mix is stable) **THEN** (use FIFO)

Problem solving insights:
IF (large batch) **THEN** (consider processing order P2-P1-P3-P4)

The use of rule-selection rules in the scheduling process makes our expert scheduling system different from most conventional methods. In stead of using a single heuristic rules identifies the most suitable sequencing rule for a given system state. A simple forward chaining mechanism (Waterman(1986)) is used in the reasoning process.

Initial structuring
- Identify a knowledge representation scheme (given when a shell is selected)
- Identify knowledge elements (e.g. "weight)
- Identify operators (e.g. "*", ">", "is")
- Identify relationships (e.g. "weight > 100 Kg")

Rule development
- Identify all possible "answers" (e.g. LIFO, FIFO, ALF, NRF)
- Formalize rules (e.g. IF(weight > 5 Kg) AND(batch > 200 items) THEN(mould = green sand)

Prototype evolution
- User interface design
- Initial verification
- Corrections and additions to the rule base

Table 1. Outline of the different steps in the design of a knowledge base for an expert system.

Whenever a change in the system operating conditions is detected, the rule base is searched to find the appropriate rule-selection rule(s) for the new systems state. The sequencing rule recommended by the rule-selection rule is then used to make step-by-step robot movement decisions. The following are three typical rules from a knowledge base for a scheduling system for a flexible manufacturing system.

C. The Communication Interface

The communication interface of this expert scheduling system is responsible for the data communication between the scheduling system and the robot control computer. Inputs to the scheduling system include the locations of robots and jobs, and the starting times of machining operations, etc. Output from the scheduling system tells the robot control computers where and when to move robots.

D. An Application

The problem that motivates this study is one that occurs in an automated circuit board processing system. As shown in Figure 2, this processing system consists of a sequence of chemical tanks (which may be considered as machines). Several asynchronous material handling robots, sharing a single track, move packaged circuit boards from one tank to the next in accordance to some specified production program. Random failure and repair of both the chemical tanks and the material handling robots are likely to occur from time to time. Broken robots are usually lifted off the line such that the production relying upon the remaining resources is not impaired. Parallelism in the system allows the choice of one of several tanks for certain critical processes. This enables production in most cases to continue even when tank failure occurs. The problem is to find a sequence of robot movements that maximizes throughput while maintaining strict adherence to production programs.

While few rules for scheduling of automated material handling equipment can be identified in the current literature, the following five were found to be effective for our problem(See Thesen and Lei (1986) for detailed definitions).

1. Average Loading Factor (ALF)
2. Batch Robot Dispatch (BRD)
3. Nearest Robot First (NRF)
4. Job Location Factor (JLF)
5. Job Number Factor (JNS)

These rules are used to identify the appropriate robot to serve the next job. For example, with rule Nearest Robot First (NRF), the robot currently located nearest to the requesting machine is dispatched. In Figure 3 we show how the relative performance of three

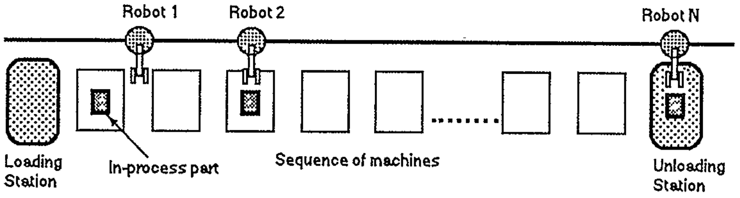

Figure 2 : An automated circuit board processing system

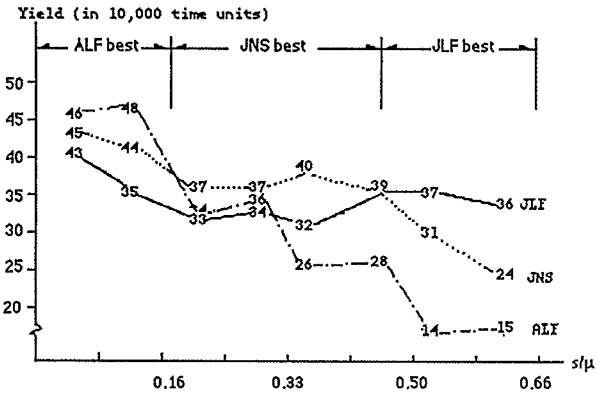

Figure 3: Systems throughput resulting from the use of three different scheduling heuristics for different levels of variability in the treatment times .(from Thesen & Lei (1986).

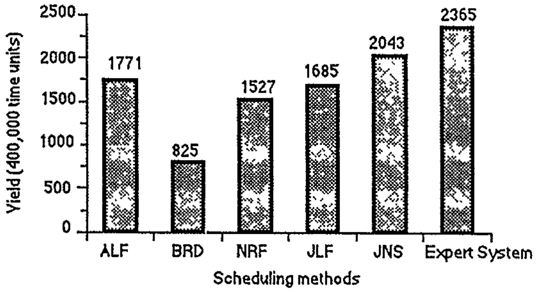

Figure 4: Yield of different scheduling methods

of these heuristics changes as one of the system's state variables (variance of dip times) changes. This knowledge is exploited in the expert scheduling system. In Figure 4 we show the throughput resulting from the use of these heuristics as well as from the use of an expert scheduling system that automatically switches between these rules as the nature of the workload changes.expert scheduling system.

III. KNOWLEDGE ACQUISITION

A. The process

It is the role of the knowledge engineer to capture scheduling knowledge and to integrate it into an overall system that meets the needs of the end user. Towards this end the knowledge engineer must go through the following steps:

- analyze the task to understand the problem and the environment,
- represent the models in a computer system,

Initial structuring

- Non-interactive methods
  - Introspection
  - Observation
  - Interviews
  - Questionnaires
  - Critical incidents(Flanagan (1954))
  - Memorable events
  - Laddering
- Group processes
  - Nominal groups (Delbecq et.al.(1975))
  - Delphi
- Creativity methods
  - Brainstorming(Bouchard (1971))
- Crawford's slips (Rusk and Krone(1984))
  - Synetics

Rule development

- Trace driven (deductive) methods
  - Protocol analysis (Waterman and Newell (1971), Bouman(1983))
  - Simulated experiences(West(1984))
- Inductive methods
  - Bayes' theorem
  - Predictive models

Table 2. Tools and methods for knowledge acquisition .

- make the system available to the user, and
- revise the system as users' needs evolve.

In practice, this process is governed by the knowledge engineer's own "master model" of the knowledge domain as it relates to the design of the expert system. The knowledge engineer therefore needs to carry out a personal knowledge acquisition by talking to experts and potential end users, reading manuals and textbooks, acting as an apparentice, running simulation programs, etc.. A variety of such activities are needed for a knowledge engineer to fully understand the formal knowledge domain.

The results of the initial structuring phase may be thought of as a description of the language to be used to describe the content of the knowledge base. The results of the rule development phase may be thought of as an initial draft of the knowledge base. The results of the prototype evolution phase, finally, may be thought of as the finished knowledge base. Some of the various tools and methods available to the knowledge engineer are listed Table 2. The use of two of these techniques to develop knowledge bases for expert scheduling systems are discussed in the following sections.

B. Automated Protocol Analysis

Trace-driven knowledge acquisition is a method which extracts the knowledge from human experts by analyzing a trace of the effect of *interventions* (i.e.part or robot movements) instead statements or explanations of decisions. Since no analyst/decision maker

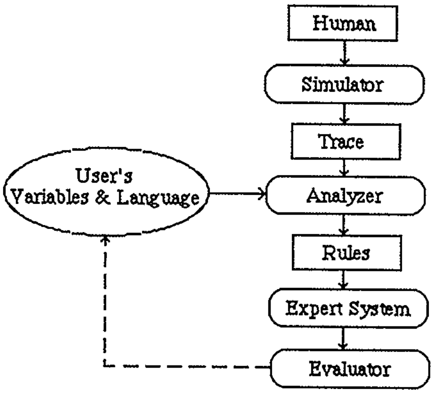

Figure 5. Trace Driven Knowledge Acquisition Process.

dialogue is required, the method can be used when the experts are unable to explain how they make decisions. The method is only applicable when it is possible to develop an unambiguous model of the underlying system, and when it is possible to enumerate all the choices that a decision maker could have made at any point in time.

An overview of the process of trace driven knowledge acquisition is given in Figure 5. Subjects operate a simulated version of the system of interest. A computer screen provides full information about the current system state as well as selected historic and projected information (Figure 6). Simple keyboard controls allows the operator to make the appropriate interventions (such as "pick up part", "move robot")..

A sequential record of all interventions made by the subject as well a record of the state of the system at the time of the intervention is provided to the *analyzer*. The task of the analyzer is to develop a set of decision rules using the available *variables* and *language* that would result in a trace identical to the one developed by the expert.

A *variable* describes an element of the system that may affect the decision process and whose value may change over time (a variable may describe the current utilization of a machine).. The *language* describes the rules for developing relations among the variables or the constraints of the variables.

The trace driven knowledge acquisition process has five steps:

1. Define variables and feasible states.
2. For each state determine the set of feasible interventions.
3. Develop a decision trace.
4. Identify all interventions made by the expert.
5. Identify decision rules that yield these interventions.

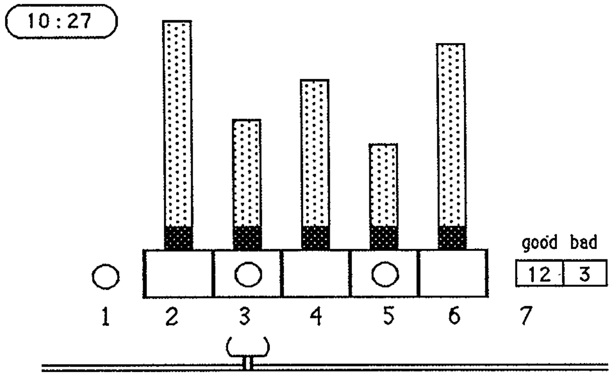

Figure 6. Display of the Real Time Robot Scheduling Simulator

In an experiment involving over 100 different operators we found that the five best subjects made interventions that could be explained by simple decision rules most of the time. For example, for the case when no part could be introduced into the system we found that the rule "Shortest remaining Processing Time First" explained 99.5% of all interventions.

As shown in Table 2 we also found that an expert scheduling system based on the expertize of these five operators performed better than any of the individual operators. This was probably due to the higher consistency of the automated system.

Operator	Yield		Score	Percent
Expert System	60 good	0 bad	60.0	100.0%
Subject A	55 good	5 bad	50.4	84.0%
Subject B	52 good	7 bad	45.8	76.3%
Subject C	49 good	9 bad	41.4	69.0%
Subject D	50 good	11 bad	41.0	68.3%
Subject E	49 good	10 bad	40.7	67.8%

Table 3 Yield of simple electroplating line operated by expert system and by five different experts. The expert system uses decision rules derived from the five experts. "Score" is a weighted sum of good and bad parts.

C. Simulation Assisted Knowledge Acquisition

The simulation assisted knowledge acquisition process is suitable to situations where it is possible to establish a model to predict the effect of input parameters on system performance. The procedure has the following steps:

1. Promising sequencing rules are identified
2. Preliminary simulation runs are used to identify important parameters

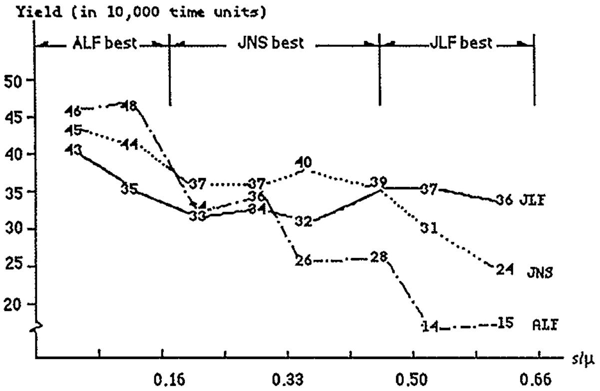

Figure 7: The Performance of Heuristic Sequencing Rules Under Different Operational Conditions (s/μ)

3. A large number of steady state simulation runs are made. Each run determines the best sequencing rules under given system configuration

4. Data from steady state simulation are then analyzed and used to develop the required Rule-selection rules.

An application of this procedure is discussed in Thesen and Lei (1987), More than 2500 simulation experiments were conducted The experiments were performed for a wide range of different parameter values. The data was collected on total throughput resulting from the use of different scheduling heuristics for each set of simulated scheduling conditions. The results of these experiments were tabulated and plotted. One typical result is shown in Figure 7.

The objective of the rule development step is to analyze the simulation results to determine which rule performed best for a given steady state condition. Rules such as the ones shown in Table 4 may result from this analysis.
Two decision ruled that can be extracted from table 4 are:

1. IF N=3, M(t)<25, P=side-peak, UTT=3, and s/μ <0.1 THEN use rule ALF
2. IF N=3, M(t)>25, P=side-peak, UTT=3 THEN use rule JNS

The resulting expert system has been shown to give yields significantly higher that yields attainable by conventional single heuristic decision rules. A typical comparison of yields was given in Figure 3.

s/μ M	0.0-0.1	0.1-0.3	0.3-0.5
8 - 15	ALF	JNS	JNS
15 - 25	ALF	JNS	JNS
> 25	JNS	JNS	JNS

Table 4: Recommended sequencing rules for system operating conditions: number of robot(N)=3, resource profile (P)=side-peak, and robot unit traveling time(UTT)=3

IV. CONCLUSION

Our research has shown that the concept of expert scheduling systems has great promise as a framework for efficient scheduling of material handling equipment. As for all expert systems, the main weakness of our approach is the absence of theoretically sound knowledge acquisition methods. However, we feel that further research will eventually yield such methods. In this paper we described two knowledge acquisition methods that we have used to develop expert scheduling systems that performs better than competing for the same situations (single heuristics for the first case, human expert for the second case).

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