A RELATIONAL DATABASE APPROACH
TO THE
JOB SHOP SCHEDULING PROBLEM

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ABSTRACT

This paper will attempt to illuminate the advantages of an approach to the job shop scheduling problem using priority based search algorithms and database technology. It will use as basis a system developed for and implemented at a large manufacturing plant. The paper will also attempt to make some predictions as to future developments in these techniques and look at the possibility of including new technologies such as expert systems.

OPSOMMING

Die voordele en toepaslikheid van prioriteits-gebaseerde soek-algoritmes en databasisstelsels op die taakwerkswinkelprobleem sal in hierdie artikel uitgelig word. 'n Stelsel wat by 'n groot vervaardigingsonderneming geimplementeer is, sal as uitgangspunt gebruik word. Toekomstige ontwikkelings in bogenoemde tegnieke en die moontlike insluiting van ekspertstelsels sal ook ondersoek word.

1. INTRODUCTION

The advent of the computer created the expectation that a large number of processes previously performed manually might be automated. Many attempts suffered disappointment as potential users discovered the limitations of earlier systems. These limitations were largely due to the relative primitive supporting software which was in turn caused by the lack of computing power.

The automation of any process essentially requires the specification and design of two components : The method in which data is to be stored in secondary storage and the control procedure required for the manipulation of the information. These two components are traditionally referred to as the database and the computer program which are equivalent to the human functions of knowledge and reasoning. The primitive way in which these functions were performed by computerized systems (compared to human knowledge and reasoning) limited successful computer applications to well structured processes.

Accounting systems belong to the class of well structured processes and as such constitute the first major successful computerized application. The batch processing nature of early computer systems combined with sequential methods of data storage and third generation languages provided sufficient means to automate accounting processes.

Human methods of knowledge storage and retrieval are not always sequential, resulting in a large number of processes that did not fit well into the framework described in the previous paragraph. Manufacturing systems, for example, require random access to data and only function well in an interactive and non-sequential mode.

State-of-the-art database management systems and fourth generation languages may be used to structure and automate a considerable subset of the systems within the manufacturing

domain. Numerous successful systems exist today of which the material requirements planning (MRP) system is a highly acclaimed example. These systems are successful primarily for the reason that the data manipulation processes required are highly structured and in most cases strictly sequential. A considerable number of similar applications may still be automated using these methodologies. This would require a shift in emphasis away from the traditional information system approach to a more application directed approach.

Many applications are unstructured to the extent that non-sequential methods of reasoning are required with the result that a large number of decisions are still left to human experience and inference. Expert systems provide a means for storing at least part of this knowledge (or experience) and to draw inferences in an unstructured environment. An expert system is also capable of explaining it's reasoning making it particularly useful for the replacement of human expertise. The relative position of the three general classes of computer languages on the structured-unstructured continuum is illustrated in figure 1.
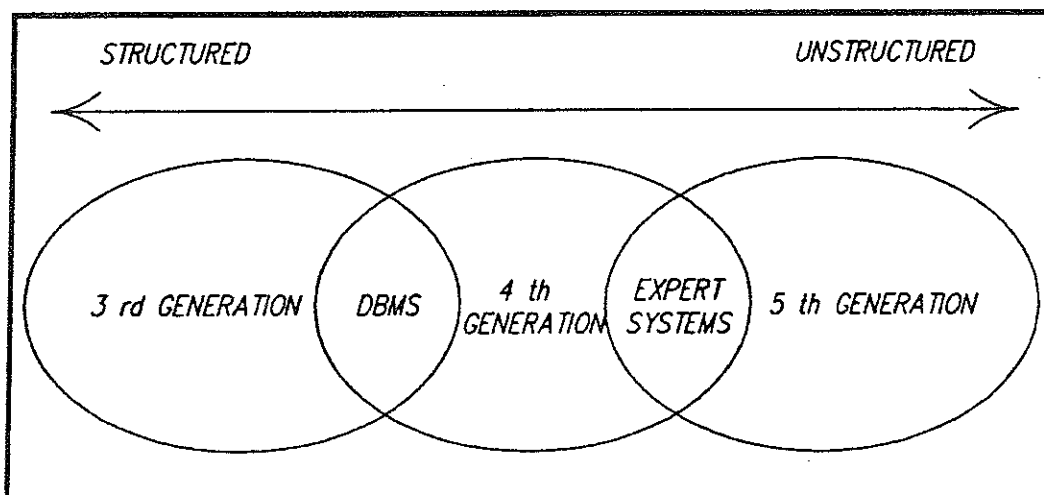

FIGURE 1. LOCATION OF COMPUTER LANGUAGES ON THE
STRUCTURED-UNSTRUCTURED CONTINUUM

The general job shop problem has always proved to be analytically difficult and time consuming to solve satisfactorily. The purpose of this paper is to investigate and illustrate the possible usefulness of database management systems and expert system methodology in the problem solving process. The applicability of these methodologies in the job shop scheduling problem will also be investigated.

2. RELATIONAL DATABASE MANAGEMENT SYSTEMS

Relational database management systems are becoming increasingly popular in traditional information system applications. State-of-the-art relational database management systems are complemented by a set of extremely powerful relational algebra (or relational calculus) operators for the purpose of data definition and manipulation.

Relational algebra may provide a means to define the old familiar problems in a new and novel fashion. For example, all operations of a product to be performed on a particular machine could be defined as the intersection of the relation embodying all the required operations to manufacture the product and the relation embodying all possible operations performed on the machine.

Date [3, p313] identifies the three major components of a relational database system as follows :

*   A structural component,
*   an integrity component, and
    a manipulative component.

ie structural component consists of any number of n-level lations. This is the only data structure supported in the lational database (in contrast to hierarchical and network

systems). Data and relationships are both represented using this common approach resulting in a more consistent and simple representation than is possible under the hierarchical and network views. A greatly simplified database consisting of three relations is shown in figure 2. The relations represent the data structures required for the part, workstation and standard routing entities as well as the relationships between the entities.

The relationship between the standard routing relation and the part relation is defined completely with the inclusion of the part number column in the standard routing relation. (The same applies to the relationship between the workstation and standard routing relations with the inclusion of the workstation number column in the standard routing relation.)

PART

Part number	Part description
10	Bush
13	Washer

WORKSTATION

Workstation number	Workstation description
100	Lathe
111	Grinding Machine
201	Milling Machine

STANDARD ROUTING

Part number	Station number	Sequence	Duration
10	100	10	10
10	100	20	15
10	111	30	12
13	201	10	3

FIGURE 2. RELATIONAL REPRESENTATION OF SAMPLE DATABASE

The integrity component consists of an entity integrity rule and a referential integrity rule. The entity integrity rule requires that no attribute participating in the primary index may be null.

(A primary index is an attribute or combination of attributes that identifies a row in a relation uniquely.) The referential integrity rule essentially implies that the values in the part number column of the standard routing relation must be a subset of the values in the part number column of the part relation.

The manipulative component of the relational database system should support the full set of relational algebra operators. The full set includes the following operators : select, project, product, union, intersect, difference, join and divide. The set of relational algebra statements shown in figure 3 would result in the relation containing all operation numbers in the standard routing relation for part number 10 on workstation number 100 (figure 4).

Select from Part where Part Number = 10 giving Temp1

Select from Workstation where Workstation Number = 100 giving Temp2

Join Temp1 and Standard Routing over Part Number giving Temp3

Join Temp2 and Temp3 over Workstation Number giving Temp4

Project Temp4 over Operation Number giving Result

FIGURE 3. A SET OF RELATIONAL ALGEBRA STATEMENTS

RESULT

Operation Number
10
20

FIGURE 4. RESULT OF DATA MANIPULATION STATEMENTS

A database management system is said to be fully relational if it includes all three components, each providing at least the capabilities discussed above. Any further reference to relational database systems will imply fully relational systems.

A relational database system provides the system designer with a structured environment within which to represent his problem using relations and relational algebra.

Structured knowledge may be defined unambiguously using relations while relational algebra provides a means with which to infer knowledge. The inference method must be well structured and the knowledge upon which it draws defined explicitly in the system. The relational system may be used to model a large number of applications and at the same time provides a much needed interface with conventional information systems.

3. EXPERT SYSTEMS

An expert system is defined by Kumara et al. [7] as a "tool which has the capability to understand problem specific knowledge and use domain knowledge intelligently to suggest alternate paths of action". Expert systems should provide the means to draw upon a knowledge base and infer knowledge from it in an unstructured fashion.

For example, the expert system may know that a task is to be processed on a certain workstation. It may also know that only cylindrical objects may be processed on a lathe. Given the fact that the object to be processed is cylindrical it should be able to infer that the workstation is a lathe or, alteratively, given the fact that the workstation is a lathe it should conclude that the object is cylindrical. The inference in this case is unstructured for the reason that the system does not know which knowledge will be supplied and which it has to infer.

An expert system normally consists of three major components :

*   Declarative knowledge (facts),

*   procedural knowledge (rules), and

*   a control structure (inference mechanism).

The more declarative knowledge a system is supplied with, the less procedural knowledge it needs. In order to match or exceed human speeds of reasoning a considerable amount of declarative knowledge needs to be supplied.

Knowledge may be represented inter alia using semantic networks, predicate calculus and frames (ALTY and COOMBS [1]). Using predicate calculus the rule :

$$V(X)(\text{processed-on } (X,Y) \text{ \& lathe } (Y) \rightarrow \text{cylinder } (X))$$

could be read as :

"All products processed on machines that are lathes are cylinders".

Provided with the following facts :

processed-on (Bush, Machine-A), and
lathe (Machine-A)

the expert system would conclude that "Bush" is a cylinder.

The third component is the control system used to apply the rules to infer new knowledge. The control system should be non-procedural in contrast to most conventional programming languages. The strictly sequential control systems used in conventional languages create problems when new knowledge needs to be inferred and when inexact reasoning is needed. As mentioned

previously this deficiency is largely due to the fact that the system does not know which knowledge will be supplied and which knowledge needs to be inferred.

Traditionally expert systems were developed using the list processing language LISP. Recently PROLOG has become increasingly popular with the provision of logic processing using predicate calculus. A number of expert system shells are also available. With a built-in inference mechanism all that remains for the user to do is to supply the system with facts (declarative knowledge) and rules (procedural knowledge).

4. THE JOB SHOP SCHEDULING PROBLEM

The job shop scheduling problem is the most general and difficult to solve of the detailed operations scheduling problems. The problem may be defined as the task of scheduling and sequencing the operations of n tasks (or work orders) on m different (or similar) workstations. Despite a considerable amount of effort by researchers in the field the largest problem reported to have been solved optimally has less than 10 tasks and 10 workstations [4].

In general a task may have any number of operations, each consisting of a setup and unit time and related uniquely to a workstation. A move time between operations may be required while certain operations may be allowed to overlap. A task may also have any number of alternative routes or operations.

The task of finding an optimal schedule is considerably complicated by that fact that a number of criteria exist for which an optimal schedule may be found. The most important of these are :

*   Minimum tardiness,

* minimum task makespan, and

* maximum workstation utilization or minimum total makespan.

Klein [6] makes the following provocative statement : "All MRP systems sold today are defective". He claims that the schedule is far from optimal since sequencing is not considered. One of the problems he mentions is the evaluation of alternative routes.

Kamenetsky [5] specifies the following conditions for a feasible production schedule :

* The material has to be available,

* the tooling has to be available, and

* the production centre has to be available.

Traditionally MRP systems emphasize the first requirement. Tooling requirements have to be planned outside of the system and workstation availability is only considered in an aggregate fashion through the infinite capacity planning system. Kamenetsky claims that smart scheduling and sequencing systems might enhance the capability of planners to deal with the staggering number of options available to them.

Kumara et al. [7] suggests that expert systems should be used to provide a scheduling system that has the knowledge and understanding of qualitative measures which the human scheduler possesses.

Such a system should interface with a database management system to draw upon the comprehensive information provided by the MRP and shop floor control systems. An MRP system provides work order due dates based on company wide criteria while the shop floor control system should be used to inform the job shop scheduling system of actual events on the shop floor. This might include information such as the completion of operations, breakdown of

workstations and unavailability of material. This would in turn affect the MRP system. A possible representation of such an integrated approach is shown in figure 5.
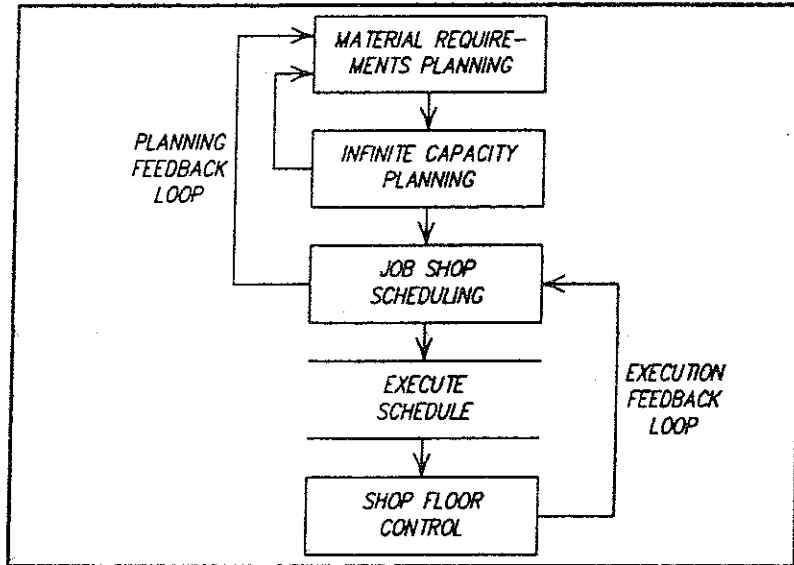

FIGURE 5. INTEGRATED PRODUCTION PLANNING SYSTEM

5. APPLICATION OF RELATIONAL DATABASE MANAGEMENT SYSTEMS AND EXPERT SYSTEMS TO THE SOLUTION OF THE JOB SHOP SCHEDULING PROBLEM

A job shop scheduling system is being developed for implementation at a large manufacturing plant to meet the requirements of the shop floor planners. Initial experience with the system is very encouraging with management even using the schedules for longer term capacity planning in the absence of a fully functioning MRP system. Since sequencing is explicitly evaluated in the system the plans prove to be extremely realistic.

The system was developed using a "relationally complete" (Date [3, p321]) database management system and a fourth generation language. It is currently implemented on a microcomputer running under the MS-DOS operating system. The normal planning period requires the scheduling of 2 500 operations on 100 workstations

which the system accomplishes within 20 minutes. Longer term
planning involving 10 000 operations takes approximately 6 hours
to accomplish on the microcomputer.

Although work order due dates might easily be accepted from an
MRP system the scheduling system is currently running in a
stand-alone environment. It uses an intuitive approach to create
schedules with the emphasis on validity rather than optimization.
The following parameters are considered and evaluated during the
schedule generation process :

*   Alternative routes and operations,
*   overlaps between operations,
*   move times between operations,
*   workstation specific capacities which might vary from week
    to week,
*   dynamic allocation of overtime requirements up to a user
    specified maximum,
*   any number of identical machines in a workstation,
*   tooling requirements, and
*   earliest work order start dates for multi-level
    dependencies.

The system distinguishes between jigs and fixtures and consumable
tooling. The requirements for jigs and fixtures are handled in
much the same way as workstations with a fixed capacity, while a
material requirements planning approach is taken for consumable
tooling.

The conceptual model of the relevant database entity
relationships is shown in figure 6. Note that the operations and
tooling requirements are copied from the standard routing file
and the standard tool usage file during the work order creation
process. This allows considerable flexibility for work order
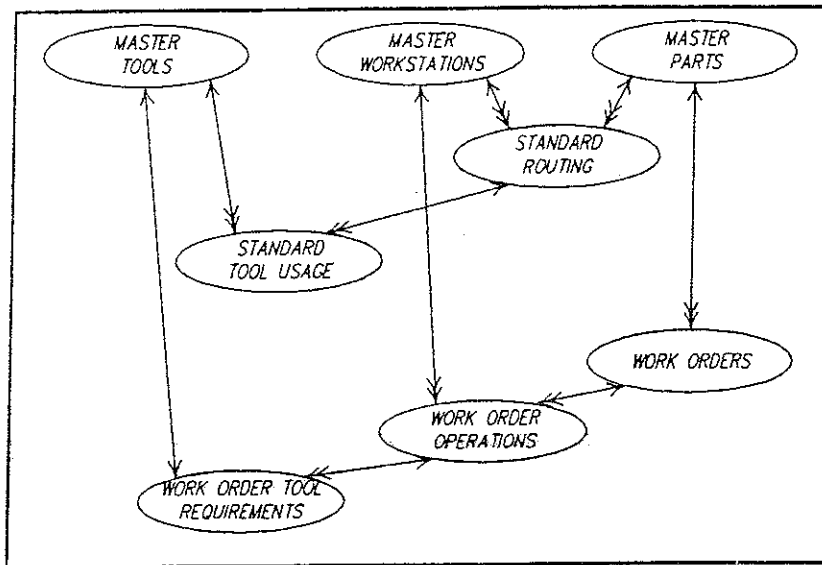customizing.

FIGURE 6. ENTITY RELATIONSHIP MODEL

A backwards scheduling algorithm is used to schedule work orders for completion as close as possible to their due dates. A choice is also made by this algorithm between alternative operations. Work order operations are split if identical machines and tooling are available.

A forwards improvement algorithm is used to compress work order makespan and improve workstation utilization. This is accomplished by changing operation sequences and removing unnecessary slack. Overtime is also allocated where necessary to meet due dates.

Schedules are constantly revised based on the following information received from the shop floor control system :

*   Completion or partial completion of operations, and

*   workstation breakdowns.

Future research will include an investigation into optimization techniques and a comparison with optimal schedules. Investigation into the applicability of expert systems indicates that improvement in the following areas might be expected through use of expert system methodologies :

*   Choice of alternative workstations,
*   allocation of overtime, and
*   choice and weight of optimization criteria.

Although the current system is based on a relational database system it is conceivable that expert system routines might be included where required. Software limitations might necessitate the system to be redesigned around an expert system using a relational system only for data storage and manipulation. The character of the system will only be resolved when a final choice of software has been made.

6. CONCLUSION

One of the primary functions of any practicing engineer is to solve problems. In many cases this involves designing a computer software system to improve productivity. Modern software is rising to the occasion with capabilities far exceeding that of previous systems while at the same time improving the productivity of the systems designer.

Relational systems provide the potential to structure and manipulate data using relational calculus. Combined with fourth generation languages these systems are used to automate a large number of structured applications.

In an unstructured environment expert systems are used to replace human experience and reasoning. Since the development of expert systems is non-trivial and time consuming such a system has to be

properly justified. Expert systems may be used productively to automate repetitive tasks and to enhance the capabilities of conventional systems.

The job shop scheduling problem may be solved using a combined approach. Relational database management systems may be used to ensure the validity of the schedules and expert systems to ensure optimality.

7. REFERENCES

1. ALTY J L and COOMBS M J, Expert Systems : Concepts and Examples, NCC Publications, 1984.

2. BAKER K R, Introduction to Sequencing and Scheduling, John Wiley and Sons Inc., 1974.

3. DATE C J, An Introduction to Database Systems, Third Edition, Addison-Wesley Publishing Company, 1975, 1977, 1981.

4. GRAVES S C, A Review of Production Scheduling, Operations Research, Volume 29, Number 4, 1981, page 646 to 675.

5. KAMENETSKY R D, Successful MRPII Implementation can be Complemented by Smart Scheduling, Sequencing Systems, Industrial Engineering, Volume 17, Number 10, 1985, page 44 to 52.

6. KLEIN L R, Manufacturing Planning and Control : Who's Responsible?, CIMtechnology, Volume 5, Number 3, 1986, page 13 to 15.

7. KUMARA S R T et al., Expert Systems in Industrial Engineering, International Journal for Production Research, Volume 24, Number 5, 1986, page 1107 to 1124.