REVERSE SCHEDULING AND ITS USE FOR INTELLIGENT FMS JOB ASSIGNMENTS

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Abstract

In flexible manufacturing systems, one of the factors the level of success depends on is the effectiveness of the methods used for solving scheduling problems. Heuristic approaches are commonly used to generate practical solutions for specific scheduling problems. These approaches are different and heavily affected by the constraints that the environment imposes. Among the tools used are computer simulations, expert systems and optimisation methods to get more efficient schedules. But the question is: how good these schedules are? It is very difficult to estimate the goodness of the schedule. It is hard to get criteria to measure the goodness and, if they exist, it is not easy to use them.

In this paper the idea of reverse scheduling is introduced as a method for solving the FMS scheduling problem and to estimate its goodness. The idea of reverse scheduling was proposed by professor J.Somlo and it is in some respect similar to the idea of reverse engineering. At the use of the reverse scheduling method the ideal schedule is first generated. Such generation is done in a way that the resources of the system are fully utilised. Then, the input data sets are generated which can give the ideal schedule. These data sets are given by fictitious process plan results. After that, using the generated process plans, a traditional 'forward' scheduling is performed. The obtained schedule is compared with the ideal using of a single performance index or combination of indices. On this basis different scheduling algorithms utilising different priority rules are compared.

The goodness of the priority rules is estimated, and expert systems strategies are developed. To use the result of reverse scheduling, statistical properties of the process plans of FMS tasks should be estimated. The knowledge base, which has been developed using the reverse scheduling will be able to recommend the suitable scheduling strategies to be used in similar situations.

Keywords: reverse scheduling, ideal schedule, priority rules, expert systems.

1. Introduction

A flexible manufacturing system (FMS) is an automatic manufacturing system to produce many kinds of products in small lots. FMS is becoming an increasingly popular mode of automating batch production type for small and medium sizes.

Job-shop type operations are mainly performed by such systems, that is the flow of work materials is not fixed while that of mass production is. For producing many kinds of products in FMS efficiently not only good hardware is needed, like numerically controlled machines, robots, material manipulation systems, etc., but good software is also important to manage FMS effectively. Then, appropriate scheduling is needed to realise FMS actions.

Scheduling is performed as a part of the production planning. Schedules are used as guides for production for establishing manufacturing resource requirements such as manpower, tooling, machine capacity and other facilities. The quality of schedules used at all levels of production has a major influence on the effectiveness of a manufacturing organisation.

Barrankin (1952) states, 'Among the problems econometrics and engineering has put to mathematics, the scheduling problem is one of the most interesting and challenging'. Scheduling within a manufacturing organisation ranges from long-term projections to detailed task scheduling. The master schedule offers the overall plan for supplying material to execute production and sales over a relatively longer period of months or years. More detailed schedules are generated for each order and each operation to complete the order.

The function of long-term scheduling is to help planning for production and plant operations over a long period of time. The objective of this type of planning and scheduling is to identify product batch sizes to reach a particular target, such as a monthly forecast. Schedules for production during various time periods are generated on the basis of customer orders, internally and externally generated orders for restocking inventories, and sales forecasts. The output of this function is a plan for the overall level of production: 'The master schedule.' It typically involves time periods of months, weeks, or days. The master schedule represents the overall manufacturing program to which all of the following detailed planning and scheduling will be engaged. It must present the feasibility of the production schedules, and the detailed plans, which evolve from them can be executed.

The short-term detailed schedule organises short periods of time. It provides means of checking the progress towards achievement of production targets, which has been set in the master schedule. Targets include meeting the required delivery dates for completion of all work on the jobs; minimising in-process inventories; maximising machine and labour resource utilisation. Meeting such production targets requires optimal sequencing of jobs combined with efficient utilisation of resources, which is subject to environmental and procedural constraints.

A detailed schedule consists of a pair of start and completion times for each operation. A schedule is called feasible if no two time intervals associated with the same resource or the same job overlap. Often, to be feasible, a schedule also needs to satisfy some other requirements, such as due dates, available number of machines or pallets, storage spaces, tools.....etc.

Solving a scheduling problem is the determining of a feasible schedule that optimises a given criterion. Such a schedule is called optimal. In scheduling literature, there are three main types of workshops considered.

In a flow-shop, all the products visit the machines with the same ordering. In a job-shop, for each job, the order in which the operations are processed (routing) is fixed, but not necessarily the same.

In an open-shop, each job must still be processed on a fixed set of machines, but the routing is not fixed.

Job-shop scheduling in FMS is a complicated task. It plays an important role as a software for realising an efficient production line. The most difficult phase of job-shop scheduling is the formulation of the scheduling criteria, suitable for different production environments, because:

a) Scheduling objectives may change relatively depending upon the decision makers even for similar production situations.
b) Scheduling objectives are multiple and some of them are conflicting.
c) Scheduling objective measures of importance in multiple objectives could change in time affected by the production environment.

With job-shop scheduling problem, exact algorithms for solving this problem are usually based on Branch and Bound methods. However, these methods require significant computing times, and they are not able to solve realistic size problems.

For this reason, heuristic procedures are developed. These procedures can be classified into three main classes:

List scheduling algorithms

They are simple to implement. Operations are assigned to machines according to some priority rule.

One-machine scheduling

In this class the multi-machine problem is solved by iteratively solving one-machine scheduling problems. The shifting bottleneck procedure (ADAMS et al., 1988) is a good example of this class.

Local search algorithms:

Simulated annealing and taboo searches are among the most popular methods in this class. They are very simple to implement, but require often a huge amount of computation in order to yield a good solution.

Multiple objective job scheduling is too complex to be solved as a combinatorial optimisation problem. In such situations expert systems approaches are used in scheduling (ISIS, FOX and SMITH (1984), KIM and FUNK (1988), GRANT (1986), KAŅET and ADELSBERGER (1987)).

Production scheduling is very complex, and it has been proved to be an NP-hard problem even for single objective production scheduling in which algorithmic solution procedures are not sensible for problems of a realistic size. As the problem size increases, the time required to find the optimum solution increases exponentially. Therefore, these problems are approached using heuristic methods, if a problem is large and NP-hard, where NP hardness of a problem is not a sufficient reason to resort to heuristic methods. It must also be so large that numerical methods are intractable.

2. Job Assignment Goodness Measures

There are different kinds of models of manufacturing systems and many methods for solving scheduling problems (e.g. network models, mathematical programming models, simulations, queuing theory approaches, and heuristic algorithms). The mathematical programming methods can offer an exact solution to small-scale scheduling problems, but it is very difficult to choose and formulate any optimisation criterion.

A realistic and more common method is to use heuristic algorithms and simulations. With these methods exact solutions cannot be obtained, moreover, it is not an easy task to find measures to estimate how good the schedule is? Therefore the task is not only to assign sets of jobs to given machine tools under certain constraints. But the main and critical task after generating a feasible schedule is to try to measure the goodness of it.

Measuring here means the process of comparing some features of a schedule with those of an optimal schedule. The optimal schedule is defined as 'the schedule which optimally utilises system key resources.'

The detailed evaluation of fine scheduling is a difficult problem, because of the difficulty of formulating an adequate criterion for the measurement of 'goodness' of the schedule.

3. Some Existing Methods for FMS Job Assignments

FMS job assignments have been treated widely in the literature. The following section represents a short review of some of them.

- In CONWAY and MAXWELL (1967), BAKER (1974), F. SIMON (1982), and COFFMAN (1976) a basic mathematical background of the scheduling problems is given in details with explanations of some important scheduling algorithms.
- In HITOMI (1979), an attempt is made to formulate and solve flexible system job assignment problem, including optimisation for cutting conditions.
- In SOMLO, NAGY (1976) the secondary optimisation problem was formulated and solved which takes into consideration the connection between the optimisation of manufacturing data and that for FMS job assignment.
- System-level optimisation problems were formulated and solved in SOMLO (1986), and HORVATH, SOMLO (1981).
- T. WATANABE and SAKAMOTO (1984, 1986), analysed the FMS job assignment problem using heuristic dispatching rules in computer simulation.
- KIM, FISHER and FUNK (1988) presented an expert system for FMS scheduling problems, as well as an interactive graphical-based computer model for a knowledge acquisition method, which utilises human pattern-recognition abilities. It was found that a human scheduler can obtain an optimum or near-optimum schedule in short periods of time.
- HIDEO FUJIMOTO et al. (1995) proposed an algorithm of applying genetic methods to the simulation of dispatching rules, where an FMS scheduling system is modelled as a four-level simultaneous decision-making problem. The genetic algorithm and simulation approach are integrated to get the best combination of dispatching rules in order to find a job assignment according to given performance measures.
- YOSHIDA et al. (1973) dealt with the optimisation of group scheduling, for which the quality of a solution was measured in terms of a single criterion.

4. The Reverse Scheduling Method

The first paper (J. SOMLO, Ali ELBUZIDI: Reverse Scheduling – A new Approach to the Solution of FMS Scheduling Problems) about this idea was written for RAAD'96, (the Fifth International Workshop on ROBOTICS

IN ALPE-ADRIA-DANUBE REGION (Budapest, Hungary 10-13 June 1996)).

The objective of the reverse scheduling idea is to make an attempt to formulate a measure of the goodness of schedules through comparing the performance indices of a given schedule with those of an ideal schedule. This ideal schedule is generated in such a way that the key resource of the production system is fully utilised.

The input data sets (corresponding to process planning results given data bases)are generated, from the 'Ideal Schedule' in reversed way. Then a real forward scheduling is performed using the generated data sets from the ideal schedule and some selected priority rules.

The performance of the obtained schedules is compared with that of the original ideal schedule in order to measure the level of effectiveness of the schedule obtained using different priority rules. In this manner different scheduling algorithms are estimated, and the goodness of schedules using different priority rules can be compared with the optimal utilisation of an ideal schedule.

5. Outlines of Reverse Scheduling Computer Program and Examples

A computer program was written for reverse scheduling, to generate what is called an ideal schedule and to perform the forward scheduling using a number of selected dispatching rules. The program is capable of sampling the operation processing times according to three statistical distributions (uniform, normal and log-normal).

The first task performed by the program is to build up the processing time matrix of the ideal schedule according to the selected sampling distribution. Using the processing time matrix another matrix of job routing is generated. In such a way that after the selection of the schedule period, the jobs are randomly assigned to the given machines. With the constraints that the same job cannot be scheduled two times to the same machine and the overlapping of the different operations of the same job on different machines is prevented, given that the machines' time is fully utilised.

The arrival times of all of the jobs are assumed to be zero. The calculation of jobs due dates is done in such a way that besides the machine utilisation (MUR) and maximum completion time (MAXCT), the maximum tardiness ($T_{\max}$) and number of tardy jobs (NTJ) is also taken into consideration. The due date is important for some priority rules like slack rule and earliest due date rule. The following equation is used to estimate the numerical value of the due date:

$$DD = AR + CT + Perc^*(AVJO + AVAO),$$

where:

AR	=	Job arrival time.
CT	=	Job completion time in the ideal schedule.
Perc	=	Due date's relaxation percentage.
AVJO	=	The average processing time of the operations of the same job.
AVAO	=	The average processing time of operation of all jobs.

The jobs to be processed on the machines among an initial set of jobs are specified. If at a certain point of assignment process it is not possible to find a job which satisfies the stated constraints, a new job must be added to the initial set of jobs. This process is continued until the target scheduling period is completed.

A routing matrix is built, by comparing the starting times of the different operations of the same job in the ideal schedule. (that is if an operation starting time on machine two is earlier than that for the same operation on machine one. It means that this operation must be processed on machine two then on machine one.)

The process planning data sets for different jobs are extracted from the ideal schedule. Then, the forward scheduling is performed according to some selected priority rules. Spt: Choose the job for assignment that has shortest processing time. Lpt: Choose the job that has longest processing time. Slack: Choose the job that has the minimum slack time. Max_NOP: Choose the job that has the maximum number of operations remaining. Max_OTR: Choose the job that has the maximum operation time remaining. EDD: Choose the job that has the earliest due date. Min_IT: Choose the job that inserts minimum idle time.

The forward scheduling is performed in such a way, where a set of schedulable operation is collected from the set of all operations. This set includes the operations for which the preceding operation has already assigned. This assignment is carried according to the routing matrix. The schedule resulting from this process is an active schedule. Each operation is represented by a rectangle on a Gantt diagram. The length of the rectangle is proportional to the processing time of that operation. These rectangles are moved to the left as far as possible satisfying the non-overlapping constraint. Leap-forging of one rectangle over another is possible provided that there is sufficient idle time to accommodate that operation, keeping the routing of the job unchanged.

Performance indices are calculated for each type of schedules. Then, comparing them with that of for the ideal schedule it is possible to measure the effectiveness of the schedules when applying the different dispatching rules. The best rule is selected from this comparison and reported under the assumed constraints.

The performance indices employed in the program are as follows:

MAXCT = Maximum completion time.
NTJ = Number of tardy jobs.
AVL = Average lateness.
AVER = Average earliness.
AVTR = Average tardiness.
AVCT = Average completion time.
L_{max} = Maximum lateness.
E_{max} = Maximum earliness.
T_{max} = Maximum tardiness.
MUR = Machine utilisation ratio.

The optimisation problem for schedules is that rather simple approaches are the multicriterion optimisation nature.

At the use of reverse scheduling method, the optimisation ideas could be realised using either a single criterion based or combined criteria, that is more than one index at a time. Importance weight can be used for each performance index.

The choice of the input data is done through a separate program. This program produces data file. Such a file contains the constant values for the main scheduling program. The program produces Gantt diagrams for the ideal schedule and for the other schedules using the priority rules. The final and important diagram produced by the program is a decision chart, which gives the best rule to be used for scheduling. The values in that chart are a result of 100 simulation runs for each combination of input data. In case of sampling the operation processing times from normal or log-normal distributions the best rule selection is a function of the mean values and the standard deviation of the distributions. In case of uniform distribution the best rule selection is a function of the mean values and the processing time range. The following examples demonstrate the use of the reverse scheduling method.

Example 1

Single Criterion Case:

In case of the example the FMS consists of 5 machines. The maximum number of jobs is 15. The scheduling period is one shift, that is 8 hours. The processing operation times are sampled from the normal distributions. The minimum mean value is 60 and its maximum is 180 minutes. The minimum

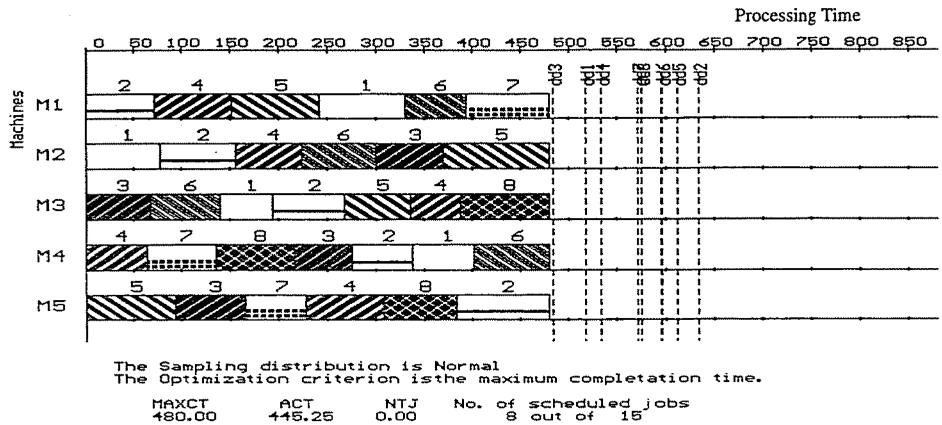

Fig. 1. The generated ideal schedule

standard deviation is 7 and the maximum value is 13. The task is to perform reverse scheduling for all given combinations. In each case 100 ideal schedules are generated, forward schedules using priority rules are obtained. In each time the goodness of these schedules is estimated by comparing the selected performance indices among the set (maximum completion time, number of tardy jobs, maximum tardiness, and machine utilisation ratio) of the forward schedules with that of the ideal schedule and the best rule chosen, which gives the closest value of the performance index to the ideal schedule. These values are calculated as an average of 100 repetitions of the schedule. Two other numbers are given with the chosen scheduling rule to support the choice. These numbers are the number of times the chosen rule was the best out of the total number of runs (frequency). The other number is the ratio between the value of the selected performance index of a schedule to that of the ideal schedule. This ratio is to measure the closeness to the ideal schedule. *Fig. 1* shows the Gantt diagram of the ideal schedule, where the Y axis represents the machine tools M's and the X axis shows the processing time in minutes. Each rectangle represents an operation of a job. The numbers above the rectangles are the operation numbers. The vertical dotted lines represent the due dates of the different jobs. MAXCT, ACT, NTJ are the maximum completion times, average completion times and number of tardy jobs of the schedule in order. *Fig. 2* shows the forward schedules using the selected priority rules.

The decision chart (*Fig. 3a*) shows the combinations of the mean and standard deviation given on x-axis and y-axis. The obtained best scheduling rule at the intersection of the value of the mean and the standard

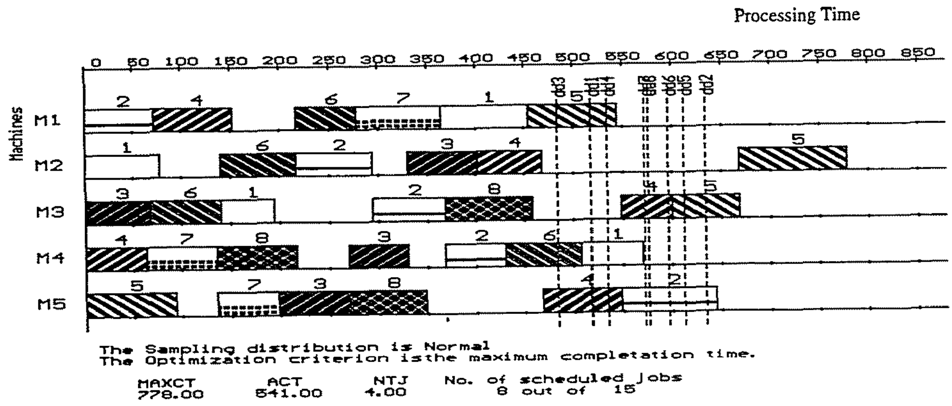

Fig. 2a. Forward schedule with SPT

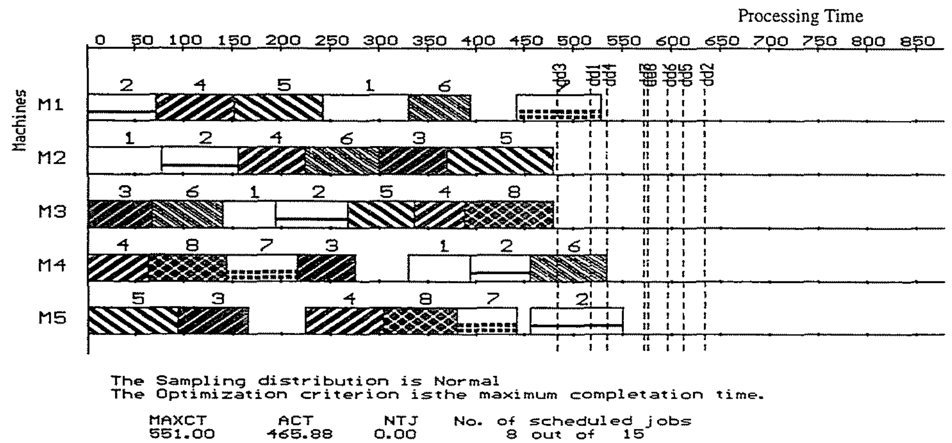

Fig. 2b. Forward schedule with SLACK

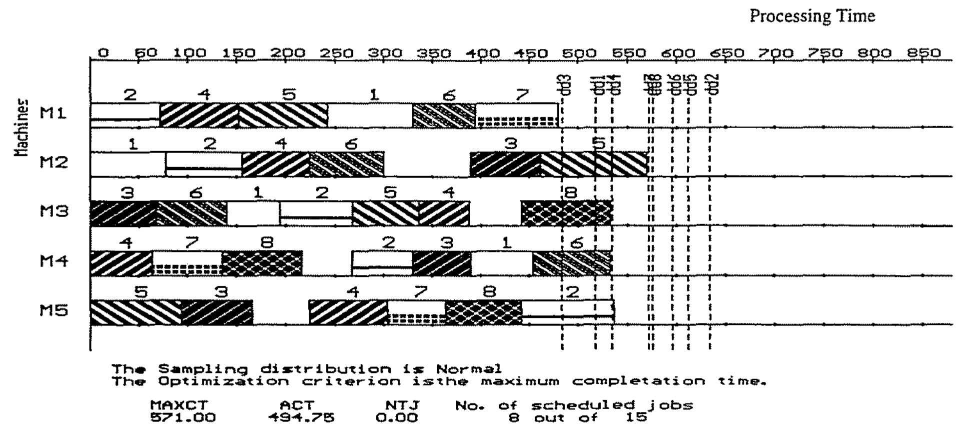

Fig. 2c. Forward schedule with Max-Nop

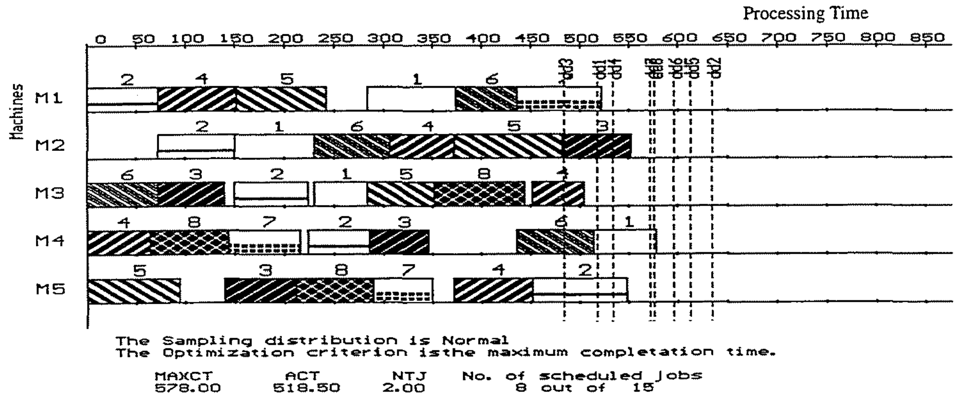

Fig. 2d. Forward schedule with Max-OTR

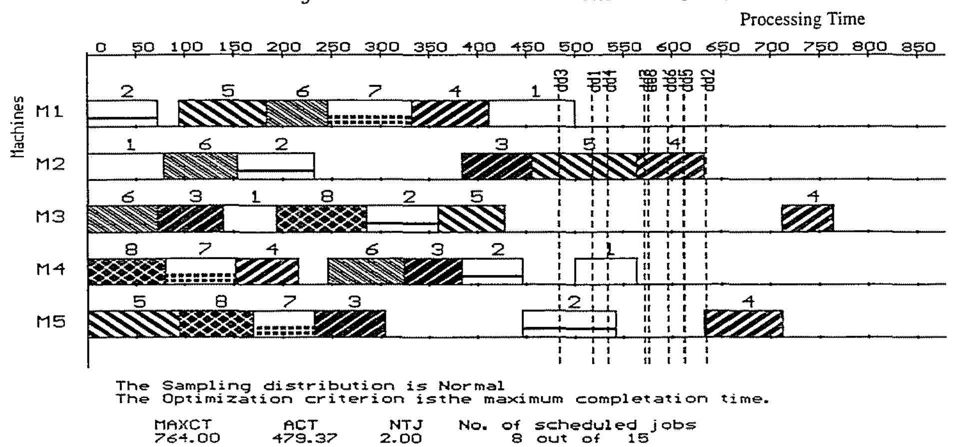

Fig. 2e. Forward schedule with Min-IT

deviation is represented by a square filled with different patterns to show the best rule. In *Fig. 3b* it is the same as *3a*, except inside the square representing the best rule two numbers give the frequency of the choice and the goodness ratio.

Example 2

Combined Criterion Case:

The scheduling problem in this case is similar to the previous one in *Example 1.* The only difference is that the performance index used to select the best scheduling priority rule depends on more than a single performance index. It consists of the combination of three indices with proper weighting

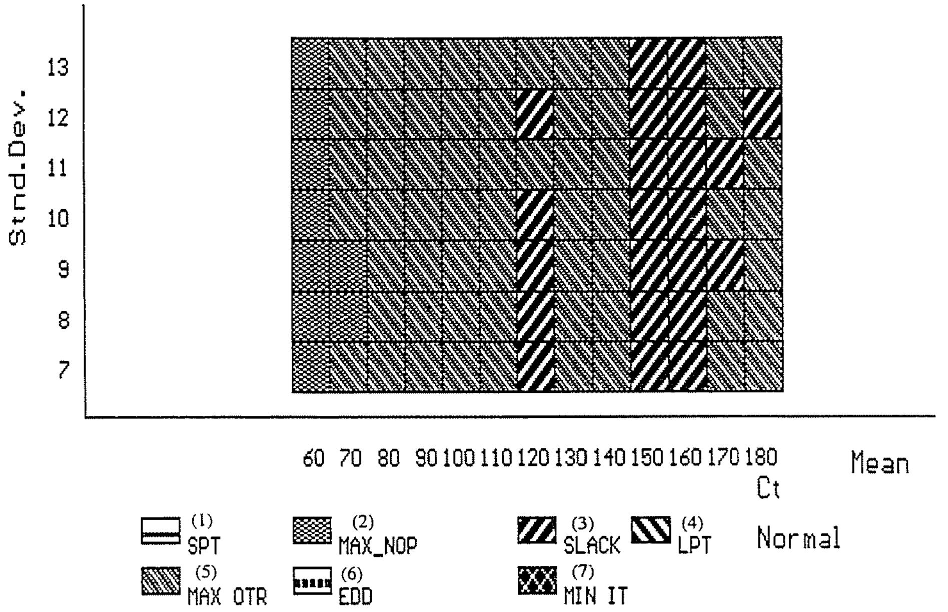

Fig. 3a. The decision chart of the best rule selection

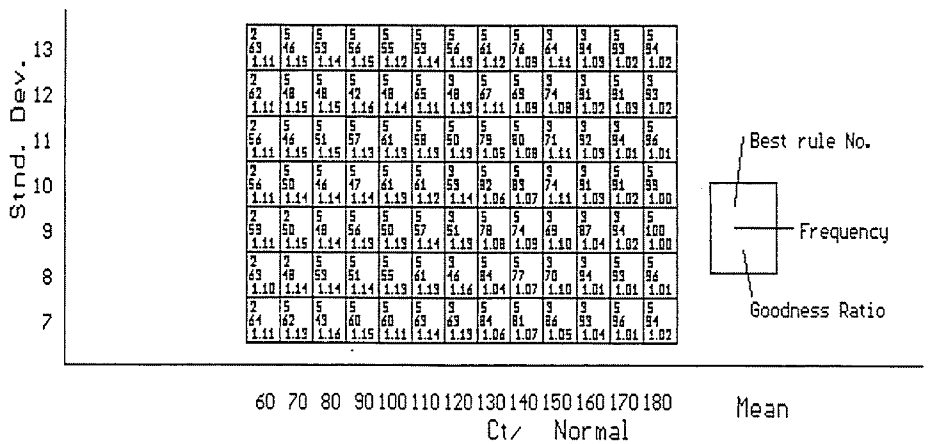

Fig. 3b. The decision chart of the best rule selection Supported with the frequency of the choice and the goodness ratio

coefficients.

$$ELR = W1 * CT + W2 * NTJ + W3 * T_{\max}.$$

It should be noted that the selection of the proper weighting coefficients is a complicated task and it affects very much the consequences.

The ELR function is evaluated for each priority rule, where this depends on (CT) maximum completion time, (NTJ) the number of tardy jobs, and ($T_{\max}$) maximum tardiness of the schedule using that priority rule. The weights w_1, w_2 and w_3 are added to give the scheduler the ability to decide about the importance of each index according to the system environments. These weights could represent the proportionality between the costs of the used performance indices. *Fig. 4a* demonstrates the best rule decision chart. The square represents the type of the rule chosen. As in *Fig. 3a*, except the number inside the square it gives the value of the evaluation function (ELR) of the best rule in this case. The Optimal ELR (ELRO) value for the ideal schedule is given at the bottom of the chart.

6. Knowledge Base for FMS Scheduling

Over the last decade computer integrated manufacturing systems were effectively applied to control production processes. The use of knowledge based scheduling systems has been explored by many researchers in the AI field to solve scheduling problems. (FOX (1983), constraint-directed search; and GRANT (1986) Lessons for O.R. from AI.). The process of revising a factory schedule is handled either by manually revising the original schedule, or by periodically running the scheduling system to create a new schedule.

A knowledge base can be developed to solve FMS scheduling using the reverse scheduling method. The process of the developing of such a knowledge base can be described briefly as follows:

The statistical properties of the processing times of the operation to be scheduled must be analysed, and the input data that describes the scheduling environment must be recorded, too. Then reverse scheduling problem should be solved for that particular situation. The selected priority rules should be applied to develop forward schedules. For the estimation of the goodness of the scheduling strategies, different criteria can be formulated either for a single performance index or a combination of a group of some selected performance indices. Then, the expert system can be used to select the best possible rule. Selecting the best scheduling strategy for prespecified situations, a knowledge base can be constructed, which serves for the solution of actual FMS scheduling problem with similar conditions.

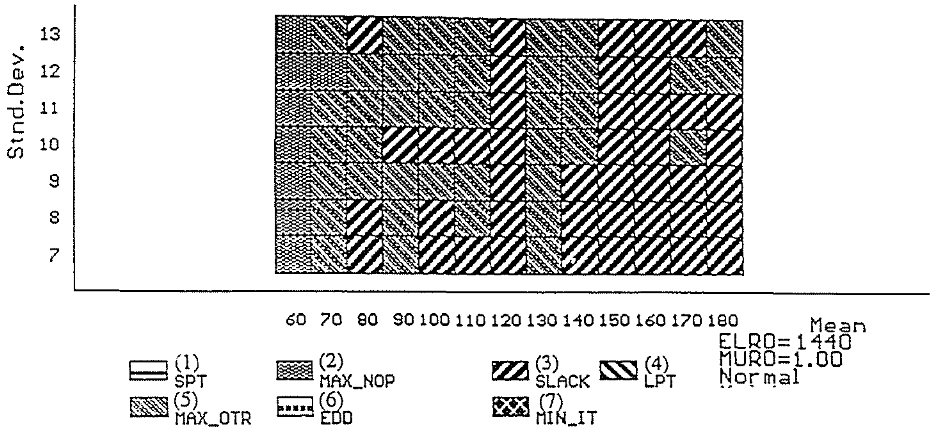

Fig. 4a. The decision chart of the best rule selection (Combined-criteria case)

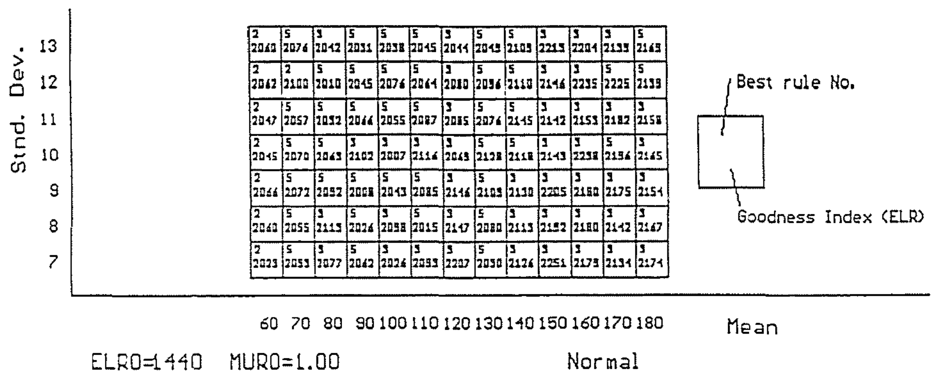

Fig. 4b. The decision chart of the best rule selection (Combined-criteria case) supported by goodness Index (ELR)

The solution of actual FMS scheduling problem, using a knowledge base depends on the statistical analysis of the input data of the scheduling problem. The best scheduling strategies are determined by the use of simulation methods, where the input data to the reverse scheduling method can be adapted very easily to generate different scheduling situations with different scheduling strategies.

7. Summary

In this paper the new idea of reverse scheduling was analysed as a method for the solution of FMS scheduling problems. The ideal schedule generation, and forward scheduling made it possible to estimate the goodness of the priority rules. The two examples given demonstrate the use of reverse scheduling method to select the best priority rule obtained from the combination of given statistical data. The results of the method can be utilised by an expert system data base. This expert system can recommend the best scheduling strategy in future for similar scheduling conditions, without the need for solving a new scheduling problem by running the scheduling program. This is true where the time available to get a solution for the scheduling problem is very short (e.g. adaptively controlled systems).

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