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ABSTRACT

This paper deals with generating a near optimal production plan for Flexible Manufacturing Systems (FMS). The production plan is one of the most important aspects for the efficient operation of FMS. First, we define the scope of the production planning problem. Then we develop a set of production rules to be used in an expert system approach to the problem. The expert system has been implemented in Guru 2.0, an expert system development tool. The performance of this expert system is evaluated using a set of small to medium-size problem data. Based on the test results, the expert system approach to the solution of the production planning problem appears to be an efficient method.

INTRODUCTION

Production planning in flexible manufacturing systems (FMS) is concerned with the organization of production in order to satisfy a given master production schedule. It also deals with achieving a higher degree of utilization of the system's resources. Production planning is grouped into hierarchical subproblems: batch selection problems and machine loading problems (Stecke, 1985; Looveren et al., 1986). Batch selection is the first decision in production planning and all subsequent decisions are influenced by this decision. The batch selection and machine loading problems are linked and hence they are solved sequentially in order to generate a production plan for processing the given production order.

The important issues involved in the batch selection problem are selection of part types for the batch, selection of the type and number of tools required to process the batch, and assignment of the tools to machines. In addition, the other issues that need to be considered are the determinaiton of the batch size and the batch processing time. Machine loading deals with the allocation of fixtures, pallets, and operations to the machines.

Many approaches have been proposed for the solution of the batch selection problem in FMS. For example, a non-linear integer programming model (Freville & Plateau, 1986; Khade, 1990), an integer programming model (Stecke, 1983; Khade, 1990), and a heuristic solution algorithm (Sarin & Chen, 1987; Kajagopalan, 1986; Kumar, 1986) have been attempted. In our approach, we combine the batch selection and macine loading problems. This comprehensive problem is larger and more complex than the batch selection problem alone and cannot be solved satisfactorily by the above methods. Therefore, the motivation for this research is to develop an expert system to solve the problem of generating a complete and near optimal production plan. Guru 2.0, an expert system development tool, has been used to develop our expert system.

We begin with the problem description in which we define the input and output of the expert system. Next, a brief description of expert systems is given. This is followed by the production planning model along with its assumptions and constraints. The execution of the expert system is illustrated using a sample problem. Finally, we present computational results of the 10 test problems with analysis.

PROBLEM DESCRIPTION

The aim of FMS production planning is to organize the production order as dictated by the given master production schedule and to utilize the system's resources as efficiently as possible. FMS production planning is concerned with those decisions that have to be made before actual production can commence. As discussed earlier, production planning is divided into two hierarchical subproblems, batch selection and machine loading. The batch selection and loading problems are linked and hence they must be solved sequentially in order to generate a production plan. The production plan is used as an input to the next operational problem, the scheduling operation.

Batch selection consists of the selection of part types, the selection of the type and number of tools required to process the batch, the assignment of the tools and machines, and the determination of batch size and batch processing time. One batch is selected at a time from the parts given in the production order. If a part is selected in the batch, its entire order quantity is processed in that batch. The next batch is selected from the remaining production order and additional orders received, if any. The objective in the batch selection problem is to maximize production efficiency of the system for given resources. The commonly pursued objectives are: maximizing production rate, maximizing batch size, minimizing production costs, or a surrogate of these objectives. The specified resources of the system are the number of CNC machines, the number of tools, processing time, and the capacity of material-handling system. According to Looveren and Stecke, the production planning problem, consisting of both the batch selection and machine loading problems, is too large and complex to be solved satisfactorily by integer programming models (Looveren et al., 1986; Stecke, 1985). This is due to the very large number of integer variables and the very large number of constraints.

The input and output of the batch selection are as follows:

INPUT

1. Production order - The production order specifies the number of different part types, quantity of each part type, and due date for each part type.
2. Processing time for each operation of each part type.
3. Type and number of tools available.
4. Type and number of machines available.
5. Tool magazine capacity of each machine type.
6. Number of slots required for each type of tool.

OUTPUT

1. Selected subset of part types in the batch.
2. Number and type of tools selected.
3. Tool-machine assignments.
4. Total processing time and size of the batch.

Each part has its own part program that specifies the operations required and the processing time of each operation. The parts included in the batch are processed simultaneously by the system. The most commonly used objective function in production planning is the maximization of production rate or a surrogate of production rate (Stecke, 1986).

EXPERT SYSTEMS

An expert system consists of three major components:

1. A user inference
2. An inference engine
3. A stored expertise

The user interface enables the user to interact with the expert system. The inference engine carries out the reasoning needed to step through the problem solution process. The stored expertise contains an expert's knowledge about a problem. This knowledge may be represented as a set of production rules (Holsapple & Whinston, 1987).

A complete production plan can be generated using Guru 2.0, an expert system development tool. Guru is a menu driven, totally integrated package. As a Guru expert system reasons about a problem, it can consult other rule sets, execute procedures, examine databases and interact with the user. A Guru rule set consists of:

1. Initialization Section
2. Goal Section
3. Rule Section
4. Completion Section

In the Initialization Section, specified operations are carried out prior to the reasoning process. The Goal Section defines the goal sought by the Inference Engine. The Rule Section contains the Stored Expertise and is represented as a set of rules. The Completion Section contains a set of operations to be carried out once the goal has been achieved.

PRODUCTION PLANNING MODEL

ASSUMPTIONS

1. Pallets and fixtures are always available in sufficiently large numbers.
2. Each (Machine No., Tool No., Process Time) 3-tuple corresponds to a unique operation.
3. The minimum number of copies of each tool type is greater than or equal to the number of machine types.
4. All tool types can be mounted on any of the machine types.
5. The number of tool slots required by each tool is uniform for all machines.

INPUT

1. A production order consisting of: Part Number, Quantity, Profit Per Unit, and Due Date.
2. A set of machines, each with a fixed number of tool slots and processing time available.
3. A set of tools available along with the number of slots required for each tool.
4. For each part type, the machine/tool assignment along with the processing times required.

The input data resides in the following Guru tables:

Exhibit 1. Guru Data Tables

PRODUCTION TABLE (max size 100 x 4)

Part Number	Qty.	Profit	Due Date
P9	90	.93	1
P4	90	.85	1
P7	93	.80	1
P10	84	.84	1
P8	88	.77	1
P12	92	.73	1
P3	77	.73	1
P5	81	.68	1
P2	69	.77	1
P6	72	.71	1
P1	73	.70	1
P11	75	.62	1

MACHINE TABLE (max. size 25 x 3)

Machine Number	Tool Capacity	Time* Available
M1	26	240
M2	25	240
M3	24	240
M4	25	240
M5	24	240
M6	25	240

TOOL TABLE (max. size 25 x 2)

Tool Number	No. of Slots
T1	2
T2	2
T3	2
T4	2

*Processing time available in minutes

Exhibit 1. Continued

PART TABLE (max. size 25 x 3)

Part	Machine Number	Tool No.	Proc* Time
P1	M2	T1	.76
	M3	T2	1.03
	M6	T3	.62
	M2	T4	.33
P2	M3	T1	1.00
	M2	T2	.76
	M6	T3	.49
	M5	T4	.37
P3	M5	T2	.31
	M1	T3	.74
	M4	T4	1.02
P4	M3	T1	.32
	M1	T3	.37
	M4	T3	.46
P5	M3	T1	.34
	M2	T2	.39
	M3	T3	.79
	M5	T3	.69
P6	M1	T1	.66
	M2	T2	.70
	M1	T3	.43
	M4	T3	1.00
P7	M1	T1	.33
	M5	T1	.79
	M6	T2	.67
	M4	T3	.32
P8	M2	T2	.33
	M2	T3	.79
	M4	T4	.38
	M6	T4	1.03
P9	M1	T2	.74
	M3	T2	.46

Part	Machine Number	Tool No.	Proc* Time
P10	M3	T1	1.03
	M2	T2	.61
	M2	T3	1.02
P11	M4	T1	.29
	M2	T2	.75
	M4	T4	.25
	M7	T6	.32
	M7	T7	.33
	M10	T8	.29
	M10	T9	.33
P12	M4	T1	.32
	M2	T2	.75
	M3	T3	.76
	M1	T5	.79
	M9	T6	1.01

* Processing time per operation in minutes

Process

In our expert systems approach, the batch selection and machine loading problems are combined to generate a complete feasible production plan which maximizes the total profit for the batch selected and achieves a user specified production efficiency. (Production efficiency is defined as the total machine time utilized divided by total machine time available.) The process begins by prompting the user to input the following data:

1. Batch processing time
2. Minimum production efficiency
3. Down machines

Then an initial batch list of part types selected from the current production order file is generated. The part types in the production order are ranked according to profit generated and are considered for selection based on this rank order. In the selection process the following resource constraints are checked:

1. Does the part require a machine which is down?
2. Is the due date met?
3. Are there sufficient tool slots available on the required machines?
4. Is there sufficient processing time available on the required machines?

If the constraints are met, the part is temporarily included in the batch, otherwise it is temporarily rejected. This process continues until all part types in the rank order list have been considered. By generating the batch list in this fashion, the machine loading has indirectly taken place since each tool, machine, and processing time of each part type in the batch list corresponds to a unique operation. By selecting the part, the appropriate tools and operations have been assigned to each machine.

Next, a total profit is calculated for this initial batch list. Then a Guru rule set, Exchange-Parts, is consulted which reintroduces the rejected parts by replacing (one at a time) previously selected parts (i.e., parts selected prior to the rejected part). If a rejected part is successfully exchanged with a selected part, the procedure will attempt to construct a feasible trial batch list by including additional rejected parts. The profit and efficiency of this trial batch list is calculated and compared with the profit and efficiency of the incumbent batch list. If the trial profit is greater than the incumbent profit and the trial efficiency is greater than the incumbent efficiency or the user specified minimum efficiency, the incumbent batch is replaced with the trial batch. The output of this section is a new incumbent batch list which attempts to maximize profit.

The current efficiency of this incumbent batch list is displayed and the user is given the opportunity to modify the minimum efficiency threshold value. If the current efficiency is greater than or equal to the threshold value, the goal has been achieved with the incumbent batch. Otherwise, a procedure is invoked which replaces parts in the incumbent batch list with rejected parts in an attempt to meet the efficiency threshold with the highest possible profit. The procedure pairs up rejected parts with batch parts in an attempt to exchange the parts and create a batch list with a higher efficiency. If the processing time of the rejected part is greater than the processing time of the paired batch part, then the parts are candidates for exchange. Next, the system resource constraints are checked to determine whether or not an exchange is feasible. If the constraints are satisfied, then the parts are exchanged and a new profit and efficiency are calculated. The procedure will save this new batch list if its profit is higher than the current maximum profit. This process is repeated until the minimum efficiency level has been reached or the reject list has been exhausted or until a maximum execution time has been reached. The output of this module is a complete feasible production plan.

The expert system displays all feasible batch solutions during execution and allows the user to select a solution which meets a minimum efficiency and/or profit and exit the system.

Output

The output consists of the final batch list of part types and quantities along with the efficiency, profit, a machine/tool incidence matrix, and a machine loading incidence matrix.

SAMPLE PROBLEM

Input Data

See Exhibit 1, Guru Data Tables

The user is prompted to enter the minimum production efficiency. The response for this sample problem is 80%.

Next the user is prompted with the following menu:

MACHINES AVAILABLE

1. M1
2. M2
3. M3
4. M4
5. M5
6. M6

Enter the number of a down machine or enter 0 if all machines are up. The response for sample problem is 0.

Output Data

Exhibit 2

INITIAL BATCH LIST

Part No.	Qty
P9	90
P4	90
P7	93
P10	84
P8	88
P3	77

Profit = $429.13
Efficiency = 70%
Execution Time = 40s

INTERMEDIATE BATCH LIST

Part No.	Qty.
P9	90
P4	90
P7	93
P5	81
P8	88
P3	77
P2	69

Profit = $466.78
Efficiency = 80%
Execution Time = 2m 48s

The user is prompted with the following message:

THE CURRENT EFFICIENCY IS 80%
ENTER THE MINIMUM EFFICIENCY ______
(user responds with 90%)

The Efficiency module then generates the following output:

FINAL BATCH LIST

Part No.	Qty.
P9	90
P6	72
P7	93
P5	81
P8	88
P3	77
P2	69

Profit = $441.40
Efficiency = 90%
Exec. Time = 4m 2s

MACHINE TOOL MATRIX

MACHINE	TOOL			
	T1	T2	T3	T4
M1	x	x	x	
M2		x	x	
M3	x	x	x	
M4			x	x
M5	x	x	x	x
M6		x	x	x

The user is then prompted with:

PRESS ENTER TO VIEW THE MACHINE LOADING MATRIX

The Machine Loading Incidence Matrix is displayed in Exhibit 3 on the following page.

Exhibit 3. Machine Loading Matrix

OPERATION	MACHINE					
	M1	M2	M3	M4	M5	M6
01	x					
02			x			
03	x					
04		x				
05	x					
06				x		
07	x					
08					x	
09						x
010				x		
011			x			
012		x				
013			x			
014					x	
015		x				
016				x		
017						x
018					x	
019		x				
020					x	
021				x		
022						x
023					x	

COMPUTATIONAL RESULTS AND ANALYSIS

The test data for the expert system model is generated by a BASIC program. First, a random number generator is used to generate a uniform distribution of numbers between 0 and 1. Then random numbers having a normal distribution with varying means and standard deviations are generated from this uniform distribution and are used to generate the data for the Machine table, Tool table, Production table and the individual Part tables. The data are stored in BASIC data files and are then converted into Guru tables by the Guru procedure Import-Tables.

The expert system model was tested with the following problems:

Exhibit 4

Prob. No.	PRODUCTION ORDER Parts	Tools	Machines	Processing Time Per Machine (min)
1	30	10	8	480
2	20	9	6	480
3	39	12	9	480
4	25	10	6	240
5	35	11	10	480
6	18	7	6	240
7	15	7	4	240
8	12	6	4	240
9	27	11	9	480
10	32	12	11	480

The computational results obtained from the expert system are summarized in Exhibit 5 below. The number of parts in each problem varied from 12-39. The number of tools varied from 6-12, and the number of machines varied from 4-11. The processing time varied between 240 and 480 minutes. The efficiency for the 10 problems varied from 86% to 94% with the average efficiency at 90.5%. The execution time varied from 16 seconds to 6 minutes 52 seconds with the average execution time at 2 min. 5.5 seconds. The large variation in execution time that occurred in problem 3 and problem 10 is due to the large number and particular mix of parts, tools and machines along with the high efficiency threshold. It seems from these computational results that the execution time increased with the increase in the number of parts, tools and machines. Also, for a given problem, the execution time increased exponentially with the increase in efficiency level. For some problems, such as problem 1, the efficiency achieved was the maximum possible for this expert system.

Exhibit 5

	EXPERT SYSTEM MODEL		
Problem Number	Effic.	Profit	Exec. Time
1	94%	987.80	0m 16s
2	86%	940.20	0m 52s
3	91%	1281.08	6m 52s
4	91%	562.17	0m 39s
5	90%	1488.58	0m 48s
6	91%	617.17	0m 59s
7	91%	401.50	1m 58s
8	91%	464.23	0m 52s
9	90%	1247.78	1m 24s
10	90%	1446.64	6m 15s

The problems were executed on a 386/33 PC with 4MB RAM

CONCLUSION

The expert system was able to solve the large and complex problem of generating a near optimal production plan for Flexible Manufacturing Systems. Currently in industry the efficiency of production plans in FMS is averaging about 85%. Our expert system was able to generate near optimal production plans with efficiency averaging over 90%. In addition, these efficiencies were achieved with relatively small execution times.

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