ADVANCES IN MANUFACTURING TECHNOLOGY

Edited by
P F Mc Goldrick

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Peter McGoldrick

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The Consortium is an independent body and was established at a meeting held at the Loughborough University of Technology on 17th February 1978. Its main aim is to promote production engineering education, training and research. To achieve this the Consortium maintains a close liaison with those Government Departments and other bodies concerned with the initial and continuing education and training of professional engineers and responds to appropriate consultative and discussion documents and other initiatives. It organizes and supports national production engineering education and research conferences and symposia. The Institution of Production Engineers, with whom there is a close working arrangement, undertakes the secretarial duties.

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Contents

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Work Scheduling in Flexible Manufacturing Systems under Tool Availability Constraints

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Summary: Some of the planning problems in flexible manufacturing systems (FMS) are introduced and the impact of tooling considerations is observed. The effects of tool variety, product variety and product similarity on the frequency of two types of tool change, due to product variety and due to tool wear, are identified. It is shown that when variety is great, tooling availability constrains scheduling decisions.

The problem area is illustrated with reference to an example FMS, for which it is shown that tool capacity constrains scheduling decisions. The possibility of developing a part launch sequence which would minimize the need for tool changes is considered but was found ineffective. Dynamically selecting jobs from queues so as to minimize tool change is also found to be ineffective. A linear programming model[5] is described, but it was found to require further evaluation.

A tooling post-processor for a simulation model is presented which computes the number of tool changes in any work schedule. For the FMS considered it is found that the number of tool changes due to product variety is small compared to those due to tool wear. It is concluded that the assumptions underlying some of the FMS planning problems must be reconsidered in view of this result.

Introduction

When a flexible manufacturing system (FMS) is being planned initially decisions must be made on the following problems:

1. The product range problem: of the parts which potentially could be produced on the system which should actually be produced on it?
2. The process planning problem: what operations are needed on the parts? What tools will be needed? How should the operations be allocated to machines?
3. The machine capacity problem: what types of machine are required? How many machines of each type are required?
4. The transport problem: how should the parts be moved around the system? What should be the capacity of the transport system?
5. The fixturing problem: how should the parts be clamped? How many fixtures of each type need to be provided?
6. The pallet problem: are the parts to be palletized? How many pallets are needed? Will all pallets be of the same type? How many parts should be carried on one pallet?

These problems define the overall structure of the FMS and its operating principles. Once the FMS exists they set the framework which constrains the day-to-day operating decisions. The operational decisions have been arranged into an hierarchical scheme:[1]

1. The part type selection problem: from the set of part types that have production requirements determine a subset for immediate and simultaneous processing.
2. The machine grouping problem: partition the machines into machine groups in such a way that each machine in a particular group is able to perform the same set of operations.
3. The production ratio problem: determine the relative ratios at which the selected part types will be produced.
4. The resource allocation problem: allocate the limited number of pallets and fixtures of each fixture type among the selected part types.
5. The loading problem: allocate the operations and required tools of the selected part types among the machine groups subject to technological and capacity constraints of the FMS.

It has been stated[2] that any solution to the loading problem must comply with certain constraints, namely:

1. each required operation and all associated tools must be assigned to at least one machine;
2. an operation can be assigned only to those machines capable of performing it;
3. the tools required for the entire set of operations assigned to any machine must not exceed the capacity of the tool magazine of that machine;

and that to improve system performance:

1. the workloads assigned to each machine should be balanced (in some sense) to avoid unnecessary bottlenecks;
2. when feasible, consecutive operations should be performed on the same machine to minimize the number of part movements required;
3. tool space permitting, operations should be assigned to more than one machine to increase flexibility when routing parts in real time.

Tooling is clearly a major consideration in these decisions, in particular the machine grouping and loading problems. Strictly speaking, an operation is a collection of mini-operations by various cutting tools which, for reasons of fixturing or part orientation, are to be done together on one machine. The way operations are defined is to some extent arbitrary, and will affect the machine grouping and loading decisions, but for the present they will be considered to be predetermined. The basic data in an FMS will therefore include a list of the operations needed on each part, the machine or machine group where each is to be done and its duration. For each operation there will be a list of the tools required and the cutting time of each tool.

In order to consider the scheduling implications of tooling, some terms should be introduced. *Tool variety* describes the number of different tools required by a part in its manufacture. *Product variety* measures the number of different parts in the system at any time. If *tool complement* is the set of tools needed to be present in a machine's magazine to carry out a specified set of operations on some set of parts, then it will increase with the product and tool variety. On the other hand, the tool complement will be reduced by increasing *product similarity*, the extent to which the different parts require the same tools. For large tool and product variety the complement may exceed the capacity of the tool magazine. Once this situation arises it will be necessary to change tools from time to time as different parts arrive at the machine. We will refer to these changes as *tool changes due to product variety*. This paper deals with the constraints this situation places on work scheduling decisions.

In addition to tool changes due to product variety there will be *tool changes due to tool wear*. Since the life of each tool is measured in terms of cutting time, it follows that, for any given level of production, the number of tool changes due to wear within any production period will be approximately constant. However, the interval between changes of each individual tool will increase with tool variety and product variety, but decrease with product similarity.

An example FMS

Earlier work[4] has described an FMS for the manufacture of complex castings. It comprises five similar computer numerical control (CNC) horizontal machining centres and one special horizontal machining centre with a facing head. All of the machines have a tool magazine with a capacity of 100 tools. Castings are fixtured and moved on pallets by an automatically guided vehicle (AGV). At each machine there are two pallet stands acting as buffers between the AGV and the machine table. There are also two pallet stands at the load/unload area. There are thirteen pallets. Initially seven part types were to be produced on the system.

When the initial planning decisions were made, the operations required on the castings were categorized as roughing, semi-finishing and finishing operations, as well as facing head operations. The operation times varied from around 15 min up to four hours. Taking the forecast requirements and operation times into account the following initial solution to the machine grouping and loading problems had been proposed:

Machine group	Operation type	Machine numbers
1	Facing head	1
2	Roughing	2 and 3
3	Semi-finishing	4 and 5
4	Finishing	6

Commissioning the facing head machine was delayed and since information is not yet available this has been omitted in the rest of this paper. The sequence of operations on the castings is illustrated by the following typical example:

Operation number	Operation type	Machine group
1	Load	L/UL
2	Rough	2
3	Finish	4
4	Semi-finish	3

(*continued*)

Operation number	Operation type	Machine group
5	Refixture	L/UL
6	Rough	2
7	Finish	4
8	Reclamp	L/UL
9	Rough	2
10	Refixture	L/UL
11	Semi-finish	3
12	Semi-finish	3
13	Finish	4
14	Semi-finish	3
15	Unload	L/UL

This sequence involves three stages in different fixtures, involving roughing operations followed by semi-finishing and/or finishing operations, and normally facing head operations. During one of the stages most of the parts will be brought back to the load/unload area for re-orienting within the same fixture, in this example at operation 8.

At the initial design stage it had been decided that the two roughing machines would have similar tool sets, but the two semi-finishing machines would have slightly different sets because it was expected that more than 100 tools would be needed for the semi-finishing operations. This would permit some semi-finishing operations to be done on either machine 4 or machine 5, while some operations could be done on only one or other of the machines. (This explains the successive semi-finishing operations, numbers 11 and 12, in the operation sequence above.) It should be noted that this implies a more complex definition of the machine grouping problem than given previously.[1] It was found when detailed planning was done that the total number of tools for the initial seven parts was 288, some tools being needed on more than one type of operation. The number of tools needed for each type are:

Roughing operations:	107 tools
Semi-finishing operations:	115 tools
Finishing operations:	89 tools

This gave the following number of tools used by each part on each machine:

Part number	Number of tools required on machine					System total
	2	3	4	5	6	
1	56	56	28	67	28	235
2	40	40	50	55	35	220
3	39	39	55	36	36	205
4	43	43	24	55	22	187
5	40	40	43	33	30	186
6	34	34	21	28	17	134
7	19	19	27	31	9	105

Ignoring common tools, the number of tools which would be added to the magazines for each successive part are:

Part number	Number of tools required on machine					System total
	2	3	4	5	6	
1	56	56	28	67	28	235
2	18	18	29	13	23	111
3	13	13	15	3	18	62
4	7	7	0	4	3	21
5	6	6	8	3	9	32
6	6	6	3	7	6	28
7	1	1	3	5	2	12
Total	107	107	86	102	89	491

Because the number of tools required exceeds the magazine capacity tool changes due to product variety will be unavoidable.

The situation is complicated by the fact that tools vary in size. Some have a diameter greater than the spacing of the tool pockets in the magazine, and therefore neighbouring tool pockets cannot be used. In fact there could be four types of tool:

1. single tools, which take only one tool position;
2. centre tools, which take up three positions, the pocket the tool is placed in and the positions on either side;
3. fat tools, which take up only one position, but because of their size cannot be positioned in the pocket next to another fat tool;
4. handed tools, which are asymmetrical and take two positions, the one the tool is in and the adjacent one on its left or its right depending on the handing of the tool.

This means that the nominal magazine capacity, 100, is not the actual number of tools which can be held, but larger by an amount which depends on the positioning of the tools in the magazine. In this FMS there are 28 centre tools, 32 fat tools and 228 single tools, distributed among the machines. If we assign all the centre tools, then intersperse single and fat tools until all fat tools are assigned, and then fill the magazine with single tools the following situation will be found:

Machine number	Centre tools	Fat tools	Pockets used	Tools assigned	Single tools unassigned
2	11	13	100	78	29
3	11	13	100	78	29
4	0	11	86	86	0
5	0	12	100	102	2
6	17	9	100	66	23

The problem of tool changes due to product variety may be quite serious on machines 2, 3 and 6.

Part launch sequence for minimum tool changes

Sequence technology is based on the principle that it is possible to work out a sequence of processing parts on a machine which will minimize the required change-over time, given data on the changeover time between each pair of parts. Perhaps it would be possible to apply this principle to the FMS with the objective of minimizing the number of tool changes due to product variety. The tool lists for each part on each machine were examined and the similarity between each pair of parts on each machine calculated as the ratio of the number of tools common to both parts to the total number of tools used by either part. The best sequences of processing the parts were worked out. Unfortunately, different sequences were obtained for each machine and yet another sequence for the system as a whole, although there was some similarity between them.

Previous work[6] evaluated several part launch sequences, but found that none made any noticeable difference to the system's performance. It was concluded that this was due to two factors: first, the operation sequences require parts to return to the load/unload area and the roughing and semi-finishing machines several times during processing, so that very soon after launching parts the initial priorities have little influence on the progress of parts; second, since only one set of fixtures of each type was available, after the first part of each type had been launched on the FMS the launching of subsequent parts depended on fixtures being released by previous parts of the same type, rather than by some externally determined priority.

Consequently, we must reject the idea of some part launch sequence for minimum tool changes.

Dynamic priority decision-making

If a launch sequence does not seem feasible perhaps it would be possible to select parts from queues within the model so as to minimize the required tool changes dynamically. Earlier work[6] investigated various rules, and again concluded that none made any significant difference to system performance. In addition to the possible reasons mentioned above it suggested that since transport times are short in relation to the operation times, there were few occasions when the AGV had any choice of part to move. Consequently, although the matter is being examined further, this possibility does not appear to be fruitful.

A linear programming model

In view of the above it would seem that a more explicit control of product variety and tool variety is required. A linear programming model has been formulated[5] which selects from a list of orders to be processed a subset of orders to be launched to comply with tool and machine capacity, and possibly other constraints. It seeks to minimize an attainment function defined as the summation of the products of deviation from some desired level and a weighting factor for each parameter. The parameters which are included are:

1. the machine hours available at each machine;
2. the capacity of each machine's tool magazine;
3. the number of 'standard' tools at each machine;
4. the number of 'non-standard' tools required by each part at each machine;
5. the due date of each order;
6. the number of each type of tool available.

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