MANUFACTURING RESEARCH AND TECHNOLOGY 3

Modelling and Design of Flexible Manufacturing Systems

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FOREWORD

Many companies have realized that in order to compete in today's world market, they must rely on innovative developments in manufacturing technology. To increase productivity, companies are applying computer controlled machine tools, automated materials handling and storage systems. Due to the progress in manufacturing technology and organization the Flexible Manufacturing concept has emerged.

A typical Flexible Manufacturing System (FMS) requires high investment in manufacturing components and computer control. Modelling has become an essential part of the FMS design and management methodology. This book shows the importance of modelling of FMSs.

Chapter 1 presents a review of planning models and basic components of FMSs.

Chapter 2 focuses on modelling and design aspects of materials handling systems.

Strategic planning aspects are discussed in Chapter 3.

Chapter 4 presents new approaches to production and process planning.

The stochastic modelling in FMS design is exploited in Chapter 5.

High rate of FMS utilization can be ensured by appropriate design of information, decision and expert systems discussed in Chapters 6 and 7.

One of the modern tools applicable to modelling of FMSs - the Petri nets - are overviewed in Chapter 8.

In Chapter 9 case studies as well as suggestions for successful implementation of FMSs are discussed.

Andrew Kusiak
Editor

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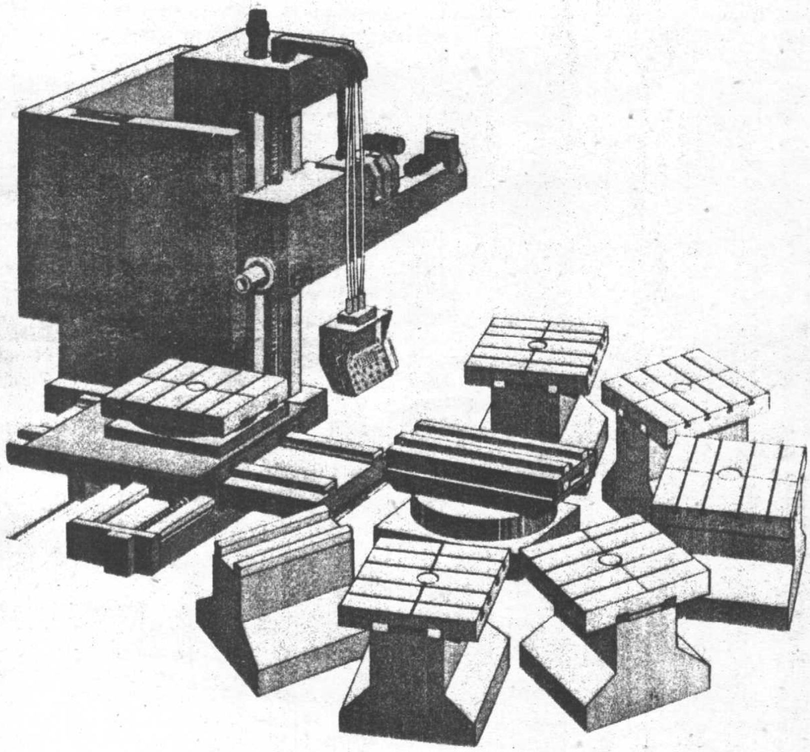
1. INTRODUCTION



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A REVIEW OF FMS PLANNING MODELS

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ABSTRACT

This paper reviews FMS planning models. First, the planning problems at different levels of the decision hierarchy are defined. Then planning techniques (queueing networks, mathematical programming, simulation) are discussed within the FMS framework. The planning problem/planning techniques framework further allows to classify past research efforts and to pinpoint interesting areas for further research.

1. INTRODUCTION

Flexible Manufacturing Systems or FMSs can be defined as computer controlled production systems capable of processing a variety of part types. Figure 1 summarizes the main components of such a system :

- numerically controlled manufacturing machines (NC, DNC, CNC) including the tools to operate these machines,
- an automated material handling system (MHS) to move the workpieces through the system,
- on-line computer control to manage the entire FMS, including the NC machines and the MHS.

The systems that are termed 'Flexible Manufacturing Systems' may differ enormously in the extent of automation and the diversity of the parts. Following our definition, Flexible Machining Centres (FMC) and Flexible Assembly Systems (FAS) should be considered as special types of FMSs. However, the specific planning problems in these systems are not discussed in this paper. It should also be clear that Flexible Material Handling Systems (FMHS) are not covered by our definition. More detailed classifications of FMSs are given by Dupont-Gatelmand[18] and Browne et al.[7]

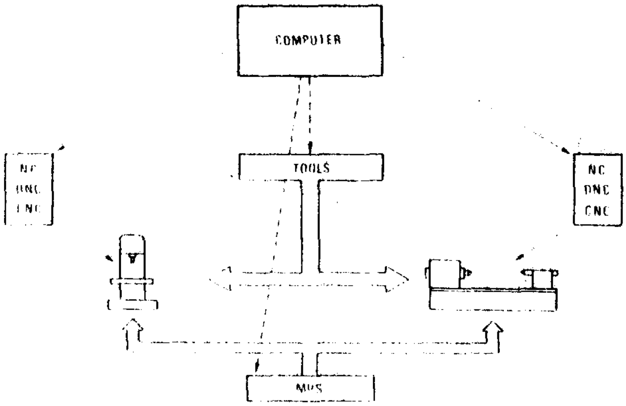


Fig. 1 : The FMS concept

FMSs possess characteristics of both transfer lines and job shops. Fixed sequence transfer lines are typically aimed at large volume production, high machine utilization and short lead times. On the other hand, traditional job shops are designed to manufacture small series of a variety of products. This flexibility is usually paid for with a low utilization rate of the production facilities, long lead times and high in-process inventories. The highly integrated FMSs offer the opportunity to combine both the efficiency of transfer lines and the flexibility of job shops.

Although FMSs can offer tremendous benefits, such as higher machine utilization, lower unit costs, shorter lead times, higher quality and quicker response to market changes, these potential advantages are not easy to realize. As a matter of fact an FMS is a very complex system consisting of many interconnected components of hardware and software, and with many limited resources such as pallets, fixtures and tools. This complexity makes the successful implementation of such a system very hard.

Both technical and organizational problems may be faced during the installation of FMSs. Technical aspects to which special attention should be paid are e.g. chip removal, swarf clearance and retrieval, design, maintenance and control of fixtures, tool management and tool condition monitoring. A detailed discussion of these technical problems is given by Hartley[27]. Obviously, the solution of these technical problems is a prerequisite for success. However, the successful implementation of an FMS will depend as much upon the selection of efficient planning and control policies. Managing production for an FMS is more complex than for transfer lines or for job shops because :

- each machine is quite versatile and capable of performing many different operations,
- the system can manufacture several part types,
- each part type may have alternative routings,
- there is little slack in the system because of the interrelated components and the requirement to operate in real time.

To summarize, in setting up an FMS one is confronted on the one hand with increased capabilities (i.e. a larger number of decision variables) and on the other hand with additional constraints. This creates the need to develop new and appropriate planning and control procedures to take advantage of the system's capabilities for higher production rates.

The purpose of this article is to provide a review of planning approaches and techniques suggested in the rapidly growing literature on FMS. Section 2 defines different planning problems which should be considered when designing a control system for FMSs. Sections 3 to 5 show to which extent queueing networks, mathematical programming and simulation analysis can be used to solve these planning problems. Conclusions and references are given in sections 6 and 7 respectively.

2. THE FMS PLANNING PROBLEM

Given the complexity of FMSs, it is clear that a single analytical model cannot solve all planning problems . The classical three level view of the organisation (Holstein[31]) can be used to provide the hierarchical framework wherein several smaller subproblems can be identified. Figure 2 puts the strategic, tactical and operational levels of this traditional hierarchical planning structure in an FMS context.

An FMS is usually but a part of a larger manufacturing environment. Therefore, the overall objectives and production targets determined at the corporate level will serve as inputs to the three levels of the FMS decision hierarchy.

2.1. Strategic Level

The strategic level is typically the responsability of top management and deals with long term decision making. Decisions at this level are really crucial and should be taken with utmost care. During the design phase the (in)flexibility of the system is determined to a large extent. The design process is summarized in figure 3. One can distinguish between a technical and an economical design part.

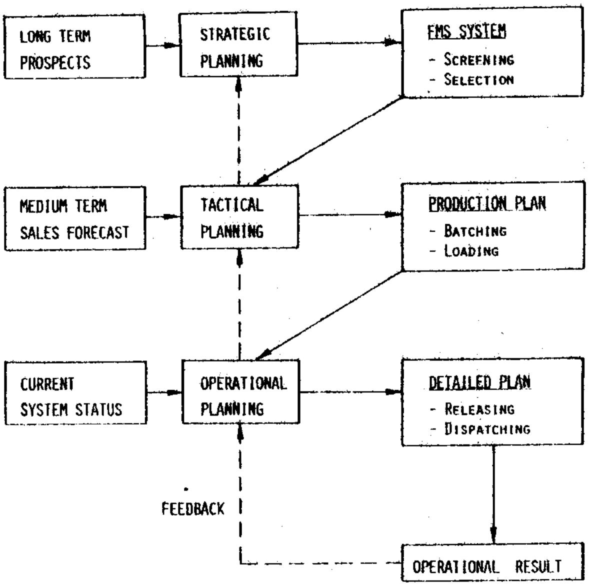


Fig. 2 : Hierchical planning structure

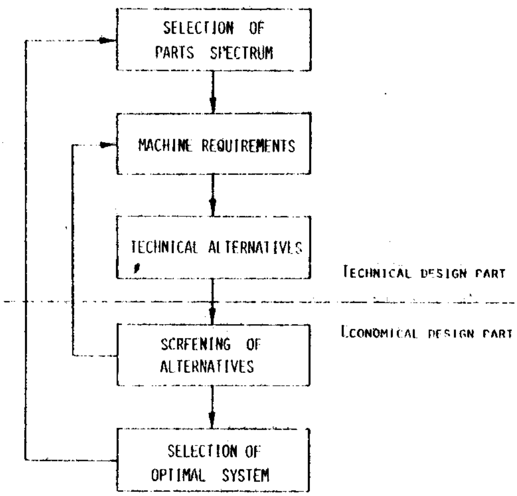


Fig. 3 : The design process

The technical part starts with the selection of a parts spectrum. Ideally, one should make a specification of what will be manufactured by the system during its whole lifetime. In reality, this means one should try to design a system for a family (or families) of parts, rather than for a number of very specific parts which may be out of the market before the system is installed. This implies that the selection should be based on a well-thought long term production plan. Only in this way will the system possess the flexibility to respond to changing markets and allow for quick and efficient design or process changes. Given the general specification of the parts spectrum the machine requirements can be defined. An examination of the technical characteristics of the part types (e.g. shape, material, dimensions, number of faces, precision) allows for the selection of an appropriate machine tool for each operation as well as for the choice of cutting tools and conditions. This in turn allows one to specify the required number of machine tools of each type. In most cases, several feasible technical alternatives will be available. It is clear that the techniques of group technology (Hyer and Wemmerlöv[36]) and CAD/CAM (Groover and Zimmers[26]) are indispensable decision aids in the technical design part.

Of course, it is not sufficient to ensure technical feasibility. The expensive FMS should also perform well with respect to economic criteria. Here a distinction can be made between the screening problem and the selection problem.

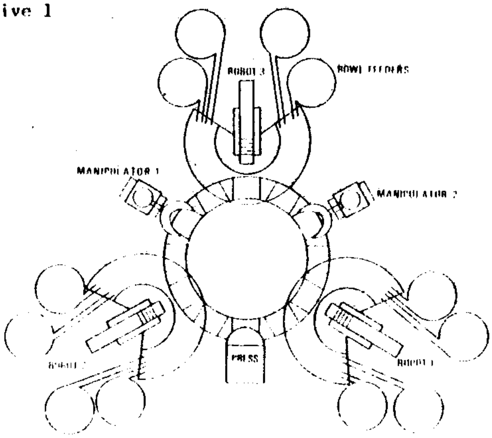
The screening process should allow for a preliminary economic evaluation of alternatives in order to identify inefficient designs. The criteria are system performance measures like utilization and production rates. After this initial screening process only a few alternatives remain. For these alternatives the system should be defined in more detail : type and capacity of the material handling system, type and size of the buffers, number of pallets, number of tools and fixtures, computer system, etc.

Finally, the alternative with the largest net savings should be identified based upon a selection procedure which considers technical (e.g. technological progress) as well as financial (e.g. interest rates) parameters, internal (e.g. inventory levels) and external (e.g. lifecyle of products) parameters. Typical benefits attributed to FMSs, like improved flexibility and benefits due to integration synergy are difficult to quantify. New questions emerge for which a clearcut answer cannot readily be found in conventional accounting systems. E.g. what is the influence of faster introduction of new products in the future on the financial results ? The traditional investment analysis scheme should be extended towards a more integrated vision which considers both quantitative and qualitative elements.

To minimize technical, organisational and economic risks one may opt for a stepwise installation of the FMS (Eversheim and Pferdmenges[22]). Several machine tool manufacturers supply modular systems that can be extended at any time. This also creates the opportunity to fit existing machines into the system.

Figure 4 illustrates the design process is not completed when technical feasibility is reached.

Alternative 1



Alternative 2

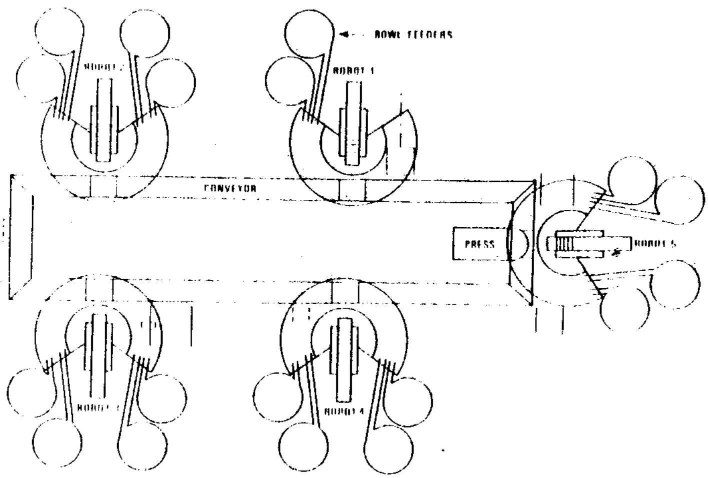


Fig. 4 : Alternative designs for a flexible assembly system

This figure shows two alternative layouts for a flexible robot assembly system for the manufacture of valve housings. The main difference between both systems is the way in which workpieces are moved through the system. It is clear that alternative 2 is more flexible. It can be installed in a modular way, is not so vulnerable to breakdowns and can easily be extended in case new part types are introduced. Although it is difficult to put an exact figure on the value of this flexibility, it will be an important element, together with cycle times and investment costs, in making the final selection. More examples illustrating the design process are given by Warnecke and Vettin[69].

It should be clear that the various steps in the design process (figure 3) are interrelated. In screening alternatives, it may be necessary to add a machine or a carrier in order to achieve feasibility. Similarly, an "optimal system" is always defined with respect to a particular parts spectrum. It may be useful to investigate the effect of different parts spectra on the design of the system.

In the sequel we do not consider technological issues. Our attention will be restricted to the economical part of the design process : i.e. to the screening problem and the selection problem.

2.2. Tactical level

An FMS has the ability to produce a family of parts in a flexible way. To realize these potential benefits, careful attention must be paid not only to design, but also to planning of the system once it has been installed.

Since FMSs are usually only part of a multistage manufacturing system, inputs and outputs are dictated by the master production plan. This plan specifies availability dates for raw materials and components, and due dates for finished products. The FMS production planning problem consists of organizing production such as to satisfy the master production plan as well as to obtain an efficient use of system resources (machines, pallets, fixtures, tools). In an FMS of reasonable size, this planning process is quite complex. Again, it is helpful to decompose the problem into a set of smaller and manageable subproblems.

At the tactical level several problem classifications have been suggested (e.g. Suri and Whitney[66], Stecke[59]). In this paper a distinction is made between the batching problem and the loading problem (figure 5).

The batching problem is concerned with parts and part related issues such as due dates, pallets and fixtures. The batching objective is to organize production such that orders are completed on time, taking into account the limited number of pallets and fixtures. This usually results in splitting up the production requirements into a number of subsets or batches (selection of part types and part mix). It is clear that batching cannot be done efficiently without considering system performance at all. However, at this level only aggregate measures like average machine group workloads are checked. Defining an aggregate routing mix is one way to provide a link between batching and system performance.

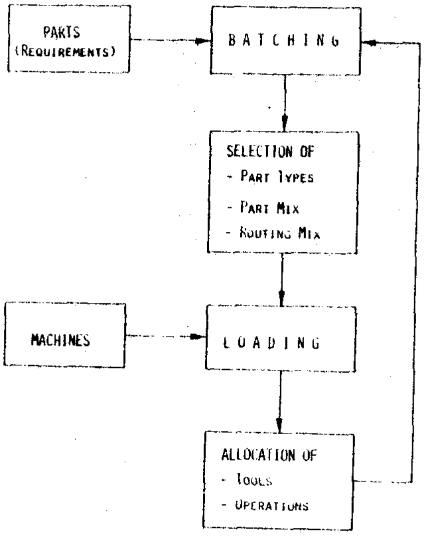


Fig. 5 : Batching and loading

Given the batches, it should be decided in more detail how to manufacture each of them, i.e. which operations will be performed on which machines and with what tools. This problem is called the loading problem.

From the above it is clear that the batching and loading problems cannot be completely separated, e.g. a good part mix may be infeasible because of limited tool availability. Therefore, iterations between the batching and loading problems may be necessary.

The following example illustrates the complexity of the batching problem. Consider a manufacturing system consisting of four machining centres (M1 to M4) and a robot to move parts between machines (figure 6). The production requirements for the next period are :

part type A : 15 pieces,
part type B : 15 pieces,
part type C : 15 pieces,
part type D : 15 pieces.