FLEXIBLE MANUFACTURING SYSTEMS IN PRACTICE

APPLICATIONS, DESIGN, AND SIMULATION

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Preface

This book has been written for all those interested in flexible manufacturing systems (FMS) and other forms of computerized manufacturing systems (CMS). It is thus aimed at practicing manufacturing engineers, at industrial and production engineers, at managers of these functions, and at those in programs at universities, colleges and polytechnic schools leading to first or higher degrees in these disciplines.

The book has also been written for a much larger industrial readership. The introduction of an FMS in a company is much more than the introduction of a new advanced technology system. It may represent a change in direction and approach that should be reflected right through to a company's business objectives. Ideally, implementation of an FMS should result from meeting a company's business objectives. However, a company can frame its business objectives to exploit new technology only if those at the top understand the technology and communicate those objectives so that they are understood by all employees. Thus this book should be of interest to all engaged in manufacturing.

The book is being published at a time when interest in flexible and other types of computer integrated manufacturing systems is increasing and this interest is being translated into orders for systems. The two main reasons for this are that the benefits of flexible manufacturing are being increasingly appreciated and that an FMS offers a means of implementing parts of two other modern approaches to manufacturing: just-in-time (JIT) and computer integrated manufacturing (CIM). FMS and these newer approaches have implications for those involved in manufacturing industry, and it is important that workers in all disciplines and functions understand tham. In the past, few manufacturing engineers have had to be involved in the details of the design of manufacturing systems. Either the design has been subcontracted to a specialist contractor (particularly where it has involved a larger integrated system) or the manufacturing system has just evolved through purchases of individual machines. It will be shown that flexible manufacturing systems are different from other forms of manufacturing systems in a number of ways. A prime difference is that they need to be designed by a collaborative team which involves both supplier and vendor personnel. Thus many engineers now need to know what is involved in the design of an FMS.

Designing a flexible manufacturing system has many similarities with designing other products. The product design process goes through a series of stages from a tentative specification, through a layout stage supported by order of magnitude calculations, on to a detailed stage, where the design is more thoroughly analyzed and checked and optimized if possible. Those involved in the design must appreciate both the details and limitations of the hardware elements of the product, and the approaches, methodologies, and approximations of the mathematical tools used to analyze and improve the design. So it is with an FMS. It is this important combination of FMS hardware and the mathematical tools used in the design that is the subject of this book.

The book starts by putting flexible manufacturing systems into their wider manufacturing system context and by explaining the origins of FMS. Some of the pioneering systems are then reviewed and the benefits of FMS are discussed. The detailed elements and the technology of systems are presented by using examples from many systems. System hardware, software, control, management, and current developments that may affect how systems develop in the future are all reviewed.

The FMS is not just another piece of capital equipment that can be bought off the shelf. It requires the customer and vendor to collaborate closely in many aspects of system design and specification. It is here that computer modeling and simulation techniques are indispensable to ensure that the many possible combinations of the FMS hardware and storage components are investigated fully with regard to system performance before final specifications are fixed. Furthermore, the models can continue to be helpful when the FMS is in actual operation and the system supervisor needs help with planning and scheduling.

The range of modeling tools discussed in the book is wide since an FMS is such a complex system. However, an effort is made here to integrate these complementary tools into a single framework for FMS planning. Since the life cycle of an FMS includes both its design and operation, the models will find use in each portion of the life cycle. The most generally useful model types are those of computer simulation and queueing-network models. These modeling approaches are discussed as they apply to both the design and the operation of an FMS. The design process further requires economic justification of these rather expensive systems, and consideration is given to the new approaches that the peculiar (non-labor-intensive) perspective of FMS imposes on economic models. The operation of an FMS, by the definition of flexibility, implies complex problems associated with planning, loading, and scheduling. Two approaches are described for these extremely complex problems, one for formulating the problems to illustrate their complexity and the other for solving them in a realistic time frame.

Both authors have had considerable experience lecturing on FMS and simulation to students and industrialists in the United States and Europe. They have also worked closely with a number of companies in applying many of the analytical design methods so they are very familiar with the realities of designing and analyzing systems. The book reports on more than these experiences, however. In researching the industrial realities of flexible manufacturing, we have visited many U.S. and some European companies. Thanks are due to the engineers of these companies who gave their time to explain their systems and discuss their experiences. We thank The Whitworth Foundation for providing funds for Roger Hannam to undertake these visits. The companies that we visited and many other companies have supplied data, information, and illustrations for use in the book and we gratefully thank them for their assistance.

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Introduction

1.1 A HISTORICAL PERSPECTIVE

This book deals with many aspects of the design, operation, and simulation of flexible manufacturing systems (FMS).* FMS represent the latest advance in types of integrated manufacturing system whose origins can be traced back to early forms of mass production. The developed world owes much of its standard of living to mass production techniques and to those engineers and entrepreneurs of the past who pioneered them.

Henry Ford is perhaps the best-known example of such a pioneer. By creating a system of manufacture that integrated and linked sequences of assembly operations, he was able to bring the purchase of a standard automobile within the reach of many who previously had looked upon automobiles as toys for the enthusiast or conveniences for the rich and well-to-do. The reduced cost of automobiles led to an expanded market for them,

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*"FMS" will be used for both singular (system) and plural (systems).

which in turn led to growth in the size of the companies manufacturing them and in the size of workforces employed building them. Those employed had to accept that the type of work that needed doing within the automated environment was radically different from what had been done before. It required different skills and different training and resulted in a different social environment at work.

Most would agree that automating the production of cars produced a large benefit for the general population. It also produced a social revolution which is still continuing, the effects of which were, and are, far-reaching. Expanding markets for one product often lead to growth for supporting industries so that the initial change is doubly beneficial. One side effect, for example, of the growth in the number of cars has been the need to build more roads. Thus, a multibillion-dollar road construction industry has grown up on the back of the automobile industry. The need for new and better roads is still evident today. The railroads, however, have suffered from the success of the automobile.

Similar examples of the changes resulting from automating manufacture could be recounted for many industries. The automation of manufacture has, almost without exception, improved the general standard of living by reducing the cost of products. It has also generated employment, but the type of employment has been different and the change to automation has inevitably had industrial and social side effects. The process of adjusting to the social side effects has not always been easy for those involved in the change, but the number of jobs created has invariably exceeded the number of jobs destroyed.

Today's revolution in many forms of manufacturing has been based on many factors, as will be described in Chapter 2, but the main factors have been developments in electronics and computers. Computer developments have, of course, affected all aspects of life from the factory floor to the office and the home. Offices are now full of word processors and personal computers, and the two-car family has now, in addition, become the two-computer family. If the computers in junior's toys and the washing machine are included, the count will be larger. Silicon Valley is now as famous as Detroit, with many thousands of workers doing jobs that did not exist 10 years ago. In many respects, FMS is based on a combination of ideas that exploit developments from Silicon Valley and Detroit.

As will be seen, FMS can be considered the latest stage in a continuing process of improving the efficiency of manufacture through automation, although the ideas behind flexible manufacturing are more wide-ranging than this, as will be explained in Chapter 3. Although the early FMS have been in operation now for over 10 years, the use of such systems is still a new and unknown experience for many companies and certainly for the up-and-coming generation of engineers. The basic approach is relatively easy to understand – it has features of Henry Ford's assembly lines – and the benefits seem attractive. However, this level of understanding leads to an appreciation of (and often apprehension of) the complexities of FMS. A series of questions arise. What really is an FMS and how does it differ from other types of manufacturing system? How is a technical specification for an FMS developed? How can the system be matched to required production volumes? How can the system be operated to give optimum performance? Is FMS the same as unmanned manufacture? Why do some people have flexible manufacturing cells and others have flexible manufacturing systems? How does FMS relate to newer manufacturing strategies such as Just-in-time (JIT)? The list of potential questions requiring answers is vast, and this book has been written to provide some of the answers.

1.2 A PREVIEW OF FMS DESIGN

Designing an FMS requires the ability to answer the questions just posed and many similar ones. In particular, it requires a knowledge and appreciation both of the hardware of FMS and of the software tools which play an important part in their design and analysis. These tools are the mathematical and operations research techniques of simulation, mathematical programming, and queueing theory. Just as computers have contributed to the development of FMS, so their availability has contributed to the growth of software tools that enable the techniques mentioned to be used effectively on today's computers in analyzing possible designs for FMS.

Figure 1.1 illustrates a modern FMS. Its hardware comprises eight horizontal spindle machining centers, two coordinate measuring machines, a washing unit, and pallet load and unload stations with storage carousels all linked by automatic guided vehicles. One very important element of the hardware that is not

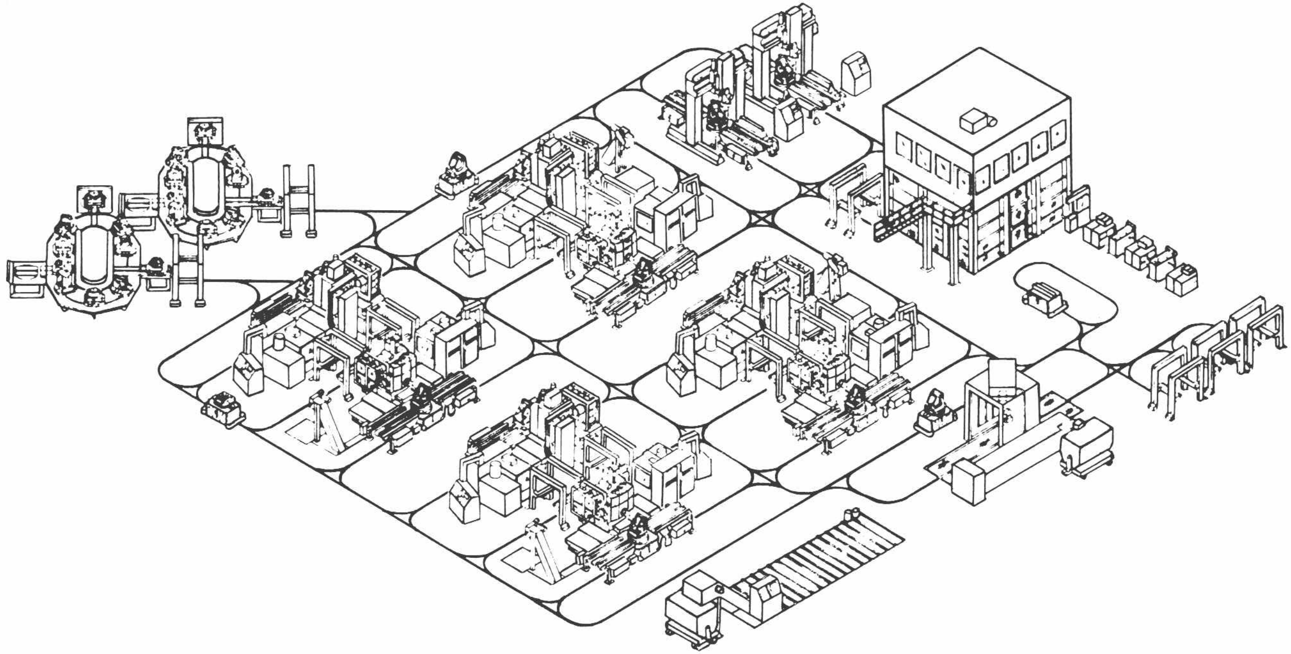

Fig. 1.1 The layout of flexible manufacturing system installed at Vought Aerospace, Dallas, Texas. (Courtesy Cincinnati Milacron.)

shown is the computer hardware, which, together with its associated software, controls the system. A more detailed description of the elements of this and other systems will be postponed until the place of flexible manufacturing within manufacturing systems has been discussed and until some of the pioneering systems that launched the elements and ideas of FMS have been presented.

In the preface, it was pointed out that the design of an FMS has similarities to other design procedures. One starts with a specification having few details and creates certain design proposals. Given some form for the design proposals, preliminary calculations can be carried out to check the feasibility of the proposals against the specification. As the layout is firmed up, more thorough analysis can start to establish more detailed proportions of a design. The design of an FMS goes through all these stages, but the procedures lead to a manufacturing system rather than product. As with designing a product, a design team must bring to bear their knowledge of both the engineering hardware and the mathematical analysis tools available to ensure the final design which will both work and be cost effective. A design team must carefully ensure their proposals are technically sound, offer economic benefits, and are financially justifiable.

An FMS is not just another piece of capital equipment that can be bought off the shelf. Such systems are complex combinations of various types of capital equipment which have to be brought together, interfaced, and made to work in unison. System complexity means that systems need to be designed by a team comprising various specialists. To match a system to a particular manufacturing company requires that the customer and vendor collaborate closely in many aspects of system design and specification. It is here that computer modeling and simulation techniques become important to ensure the modes of operation of the system are investigated fully before final specifications are fixed. Users will continue to find modeling and simulation helpful when they have a system in operation and the workpiece mix or schedules alter. For larger part mixes, continued use of simulation is essential.

FMS were originally developed for metal-cutting applications, and this is still by far the major area of their application. For this reason, the book is biased toward metal-cutting systems. However, the principles of FMS are more widely applicable, and recently the integrated approach of FMS has been applied to linking forming, shearing, and many other types of manufacturing process. The applications of simulation and modeling similarly