Handbook of Flexible Manufacturing Systems

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Preface

There are a variety of terms related to factory automation, such as computer-aided manufacturing (CAM), computer-integrated manufacturing (CIM), and flexible manufacturing systems (FMSs). Still another term that is used widely in industry with regard to factory automation is CAD/CAM. In fact one can hardly find any engineering journal or conference proceedings that does not have an article on automation of factories. Even so, automated factories are not common, and it could safely be said that the necessary technology is still in its infancy. However, it must be noted that this is a rapidly developing technology and to remain competitive in the marketplace manufacturers in almost any industry must acquire it.

Factory automation is a technology concerned with the application of mechanical, electronic, and computer-based systems to operate and control production. Normally, factory automation has been grouped under three categories: fixed automation, programmable automation, and flexible automation. Fixed automation is a system in which the sequence of operation (or assembly) is fixed by equipment configuration.

In programmable automation, the production equipment is designed with the capability to change the sequence of operation to accommodate different product configurations. The operation sequence is controlled by a program, which is a set of instructions coded so that the system can read and interpret them. New programs can be prepared in order to produce new products. Examples of programmable automation include numerically controlled machine tools and industrial robots.

Computer-aided manufacturing often includes a direct numerical control (DNC) program capable of editing the manufacturing programs, downloading, and receiving feedback data from the numerical control (NC) equipment. It can prepare the schedules, batches, tools, fixtures requirement files, and production plans in a much shorter period of time than with specific packages of business systems such as the master scheduler or the manufacturing resources planner.

Flexible automation is an extension of programmable automation. Its principles are still evolving. A flexible manufacturing system is one that is capable of producing a variety of products (or parts) with virtually no time lost for changeover from one product to the next. A flexible manufacturing system typically consists of a set of cells, a material handling system that connects those cells, and service centers (e.g., material warehouse, tool room, or repair equipment). The cell is an autonomous unit that performs a specific manufacturing function (e.g., a machining center, inspection machine, or a load–unload robot).

Sometimes FMS is defined as "a set of machines in which parts are automatically transported under computer control from one machine to another for processing." In order to justify the adjective "flexible," the manufacturing system must have the ability to process a wide variety of parts or assemblies without intervention from the outside to change the system.

The computer has had a dominant impact on the development of production automation technologies. The term *computer-integrated manufacturing* is so pervasive that it is defined by CAM-I as "a series of interrelated activities and operations involving the design, material selection, planning, production, quality assurance, management, and marketing of discrete consumer and durable goods." CIM is a deliberate integration of an automated system into the process of producing a product. CIM can be considered as the logical organization of individual engineering, production, and marketing/support functions into a computer-integrated system. CIM basically deals with automating the information processing activities in manufacturing whereas automation deals with the physical activities involved in manufacturing. The growing use of computers in manufacturing systems is leading us toward the computer automated factory of the future. The term *CAD/CAM* is used interchangeably with computer-integrated manufacturing. However, CIM possesses a slightly broader meaning than CAD/CAM.

It is quite obvious that CIM is a much more advanced version of a computer automated factory and includes all FMS functions as well as the business of the company. The aim of this handbook is to present the major components of FMSs concentrating on the computer system architecture. It will also include the functions of specific cells consisting of machine tools, pallet changing and tool changing systems, part washing stations, sheet metal manufacturing cells, welding cells, assembly robots with automated hand changing and part loading facilities, and other new developments.

Flexible manufacturing systems are designed for small batch (low volume) and high variety conditions. They are designed to fill the gap between high-production transfer lines and low-production NC machines. However, it must be mentioned that only under certain circumstances are FMSs clearly justified. From literature and trade journals, it could easily be established that FMSs might be appropriate in the following situations: (1) Production of families of parts, (2) random launching of parts into the system, (3) reduced manufacturing lead times, (4) reduced in-process inventory, (5) increased machine utilization, (6) reduced direct and indirect labor, and (7) better management control.

However, designing a good FMS that will work in a particular plant with a fixed product mix is a difficult task. Most FMSs are designed with the help of simulation. Many different simulation languages are available to help in the investigation of the cells' layouts, sizes, types of equipment, and scheduling policies prior to purchase and installation. It is well known that there is a large amount of capital investment in such computer automated systems, so the justification of FMSs must also be analyzed economically.

The characteristics of U.S. FMSs have been surveyed, and it has been found that material-cutting functions are involved in about 84% of the systems and conveyer material-handling systems in about 35%. Approximate capital investment in one FMS ranges from $10 million to $25 million. FMSs with more than $10 million invested have at least 7 machining centers that are interconnected by complex material-handling systems.

This handbook covers various aspects of FMSs in different chapters. It presents in turn the components of FMSs: planning, scheduling, and control; computer control; software; simulation; databases; group technology; a practical method for FMS justification; design of flexible assembly systems; a survey of U.S. applications; and finally the unmanned factory of the future. We are grateful to the authors, who are experts in their fields, for their contributions. These contributions have made this handbook truly state of the art.

The handbook is organized by chapter as follows.

1. Andrew Kusiak details the planning, scheduling, and control involved in FMSs.

2. Vinay S. Sohoni takes an in-depth look at the computer control of FMSs, including the production control, tool control, and traffic control.

3. Gary W. Fischer describes the various software available on the market for FMSs, including those necessary for control and maintenance. This chapter looks at software from the viewpoint of market requirement.

4. Sadashiv Adiga and Maged Dessouky survey the simulation languages and real-world applications of simulation in FMS plants.

5. William D. Engelke makes a detailed analysis of databases in FMSs.

6. Andrew Kusiak writes about group technology as related to FMSs. Dr. Kusiak is an acknowledged expert in this field.

7. Alan M. Behrens and F. Fred Choobineh write about economic aspects of FMS and describe the economic conditions under which FMSs need to be installed.

8. Jim Browne and J. Feargal Timon take a hard look at flexible assembly systems (FASs) and describe various systems that they have designed personally.

9. Ajit K. Patankar writes about FMS installations in the United States. He describes some actual functioning systems of various types.

10. H. J. Warnecke describes the unmanned factory of the future. Dr. Warnecke is an internationally known and acknowledged expert in this field.

This handbook attempts to assess the current status of flexible manufacturing systems, how to effectively acquire and use this technology, and how it is going to grow in the future and eventually lead to the unmanned factory. It is comprehensive and covers all aspects of basic FMS technologies including hardware and software tools available on the market. It discusses current and projected development as well as the acquisition, evaluation, and management of systems. This handbook is intended for manufacturing managers and engineers who currently operate and/or plan to acquire an FMS.

A good deal of deliberation went into selecting the experts who have contributed to the handbook. I, as Editor, would like to acknowledge and thank all the experts who contributed to its production. It is to all these persons that I dedicate this handbook.

Nand K. Jha

Contents

CHAPTER 1

Planning, Scheduling, and Control of Flexible Manufacturing Systems

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I. Introduction

One of the most difficult problems arising in flexible manufacturing systems (FMSs) is the scheduling problem. Scheduling may refer to the following subsystems of a flexible manufacturing system: fabrication, machining, and assembly.

Kusiak (1988) presented a hierarchical approach linking the machining and assembly system, where the overall FMS scheduling problem was structured as an aggregate scheduling (upper level) problem and real-time scheduling (lower level) problem. At the aggregate level the scheduling problem was modeled as

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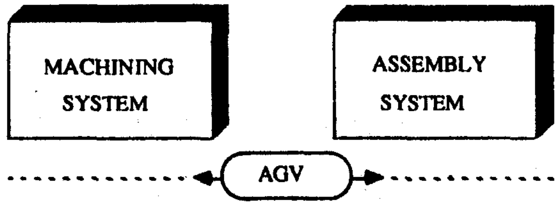

Figure 1. Structure of a manufacturing system.

the two-machine flow shop problem and solved by Johnson's algorithm (Johnson, 1954). To solve the real-time scheduling problem, a heuristic algorithm was developed.

This chapter expands the aggregate and real-time scheduling problem. Some information provided by the aggregate schedule, for example, due dates, are input to the knowledge-based scheduling system (KBSS) discussed in the last section of this chapter. To solve the real-time scheduling problem, classical and knowledge-based approaches are discussed. Readers interested in the classical scheduling theory may refer to Baker (1974) and French (1982). An extensive treatment of the knowledge-based approach to scheduling in manufacturing systems is provided in Kusiak (1990).

Consider a flexible manufacturing system that consists of a machining subsystem and an assembly subsystem. The two subsystems are linked by a material handling carrier, for example, an automated guided vehicle (AGV), as shown in Figure 1.

Consider an example product C with parts to be machined and then assembled (Figure 2). It consists of subassembly A_1, final assembly A_2, and three parts, P_1, P_2, P_3.

Parts P_1 and P_2 are to be machined before the subassembly A_1 is obtained. Assembling P_3 and A_1 results in the product C (final assembly A_2 in Figure 2).

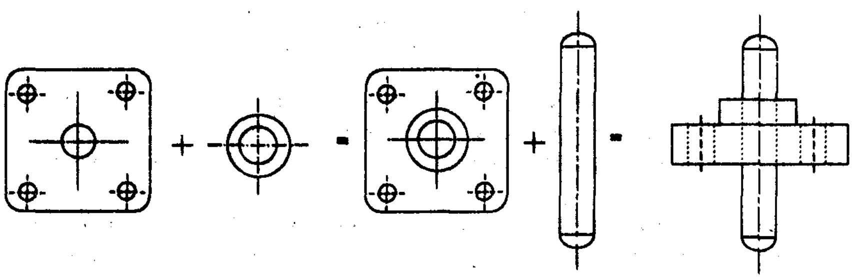

Figure 2. An example product C.

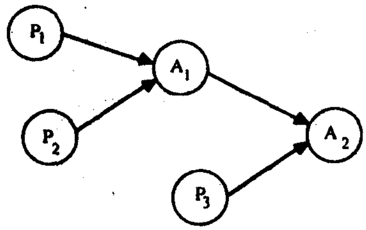

Figure 3. A digraph of the example product C in Figure 2.

The precedences among machining and assembly operations for the product can be represented by a directed graph (digraph) shown in Figure 3.

In this digraph any node of degree 1, i.e., with the number of edges incident to the node equal to 1, denotes a part; and any node of degree greater than 1 denotes a subassembly or a final product.

Another example of a digraph is shown in Figure 4(a). Without loss of generality, in this chapter, rather than representation of the digraph in Figure 4(a), the representation shown in Figure 4(b) is used. The latter representation

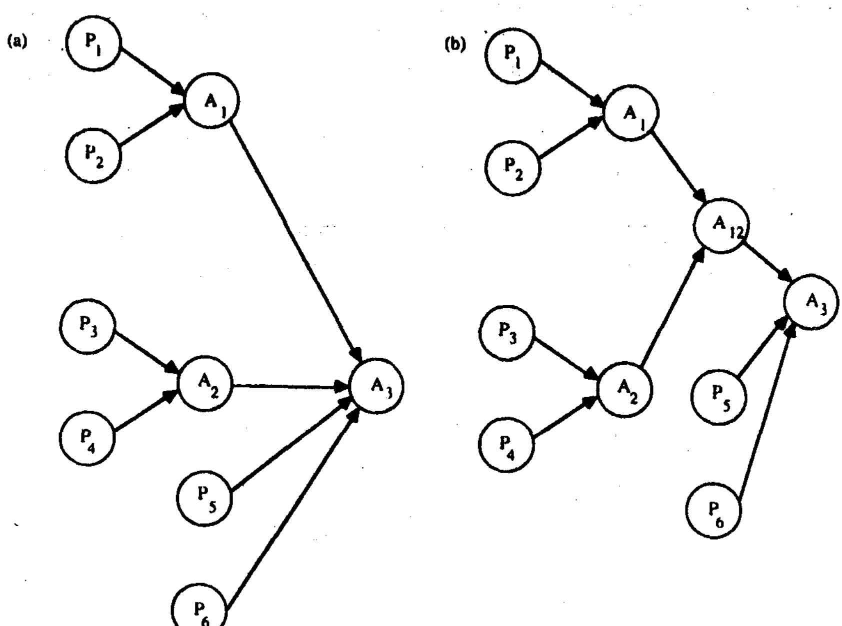

Figure 4. Two different representations of the same product.

does not allow one to assemble at a particular node more than one subassembly with any number of parts. At node A_3 in Figure 4(a), subassemblies A_1, A_2 and parts P_5, P_6 are assembled. The same subassembly A_3 has been obtained using the representation in Figure 4(b), where an additional subassembly A_{12} was inserted.

Four different aggregate scheduling problems are considered:

1. The single-product scheduling problem concerned with scheduling parts and subassemblies belonging to a single product
2. The N-product scheduling problem concerned with scheduling parts and subassemblies for N distinct products
3. The single-batch scheduling problem concerned with scheduling parts and subassemblies for a batch of n identical products.
4. The N-batch scheduling problem concerned with scheduling of parts and subassemblies for N batches of products

II. The Single-Product Scheduling Problem

Consider a digraph representation of the product which consists of a number of parts and subassemblies. In the digraph each node is labeled (a,b,c), where a is the machining time, b is the subassembly time, and c is the level of depth of the node considered. The level of depth is assigned as follows: value 0 is assigned to the root node (for example, node A_2 in Figure 3) and, working backward from the root node to the initial nodes (i.e., nodes P_1, P_2, and P_3), values of increment 1 are assigned. Digraph G from Figure 3 with labeled nodes is illustrated in Figure 5.

Before an algorithm for solving the single-product scheduling problem will be developed, a definition and two theorems are presented.

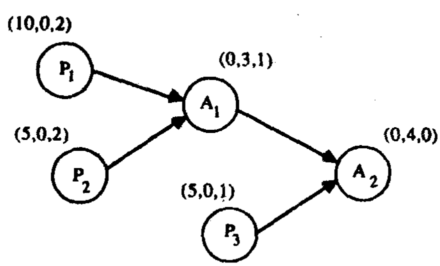

Figure 5. A digraph with labeled nodes.

Definition

A *simple digraph* G_s is a digraph in which each node of a degree greater than 1 has at most one preceding node of a degree greater than 1 [see Figure 6(a)]. Consequently, a *complex digraph* G is a digraph which is not a simple digraph [see Figure 6(b)].

Based on the preceding definition, it is obvious that any complex digraph can be decomposed into simple subdigraphs by removing a number of nodes corresponding to the final assembly or subassemblies.

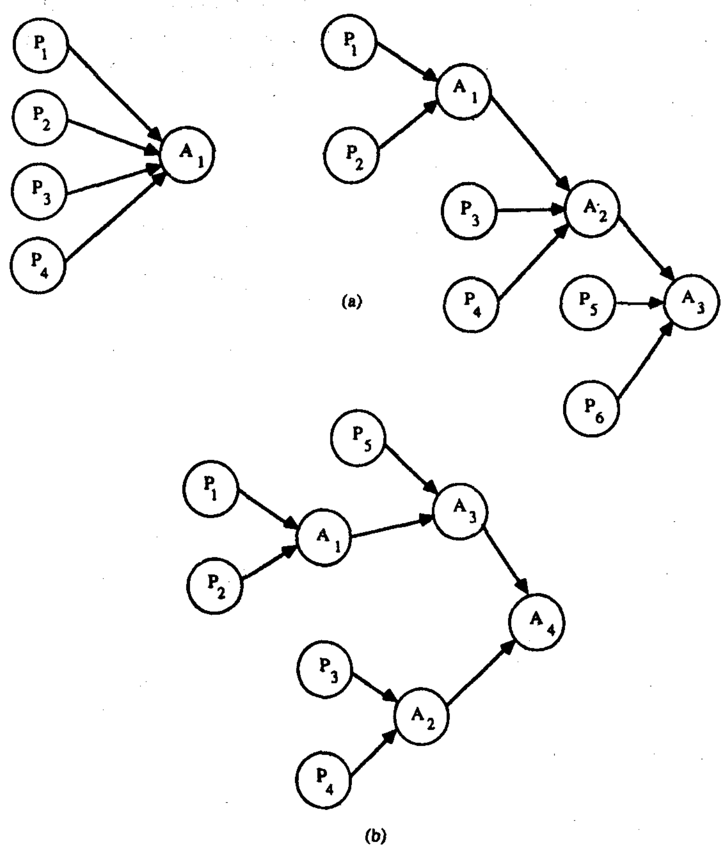

Figure 6. Examples of two types of digraphs: (a) two simple digraphs G_s and (b) complex digraph G.