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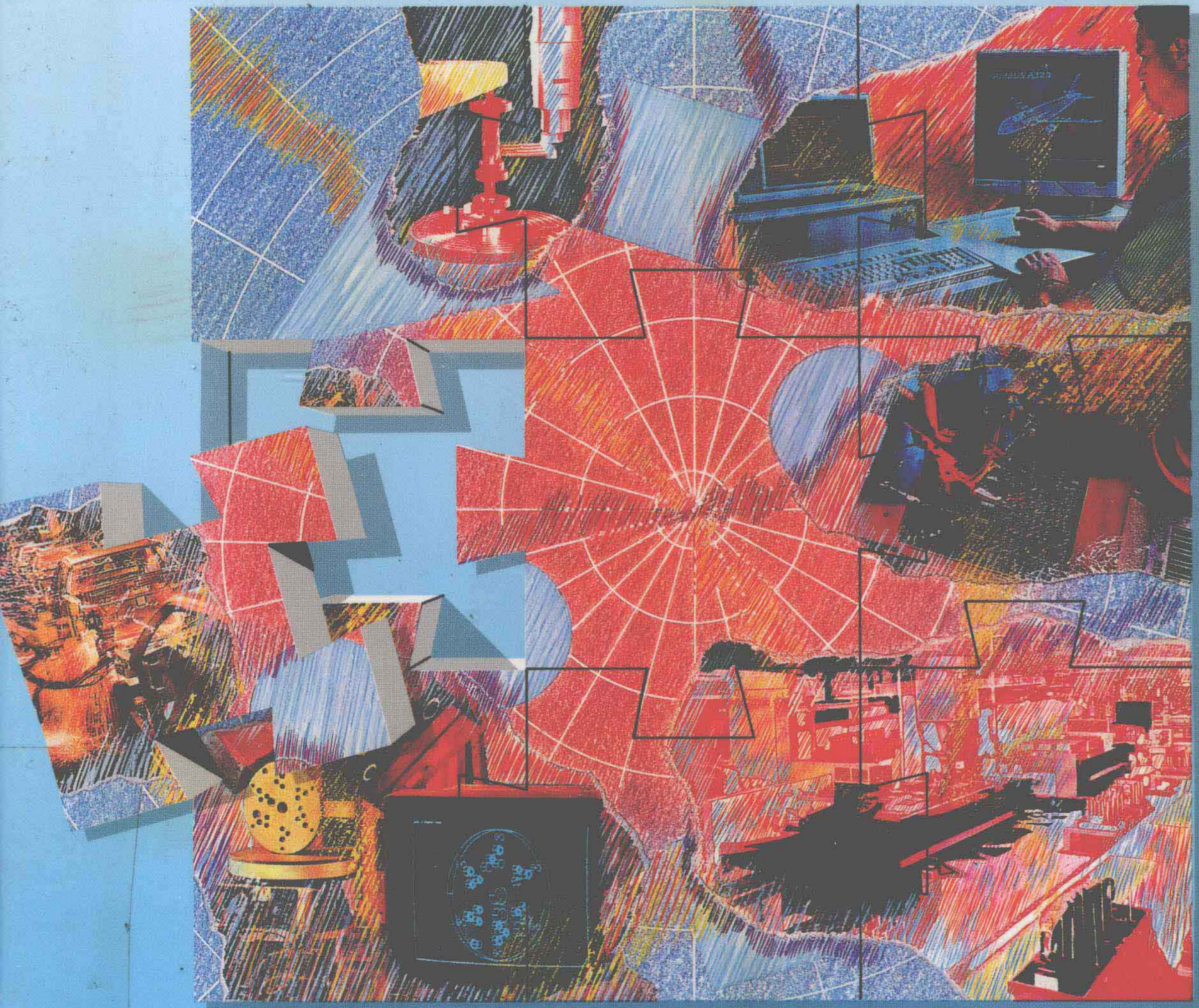

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Preface

For the industrialized nations, the manufacturing industries have become the most important contributors to prosperity. However, it becomes increasingly difficult to meet customers' demands and compete on the international market. Thus, manufacturing industries must be able to react quickly to prevailing market conditions and to maximize the utilization of resources. Conventional means of 'hard' automation are now no longer able to meet these challenges, since they are very poor in information processing. Within recent years, computer technology, in conjunction with software technology, has made available to the manufacturer tools which can greatly improve their reaction to a new market situation, speeding up the design of products, improving process planning, maximizing resource scheduling, and streamlining production flow through factories. When the computer has become a major component of a manufacturing system and helps to plan and operate it, we call it Computer Integrated Manufacturing (CIM).

The manufacturing systems of the future have to be flexible, and for this reason they must be reprogrammable. But any increase in flexibility will entail higher installation costs. Thus, it is necessary to provide a streamlined and uninterrupted production process which is highly efficient and reliable. Information processing plays a major role in obtaining these goals. Information is considered an important resource whose true value is often difficult and impossible to estimate. Information gathering, processing and evaluation is a key task in many new business concepts, such as rapid prototyping, simultaneous engineering, design for manufacturing and assembly, modularity, programmability and standardization.

There are several definitions of CIM. In this book we define CIM as it commonly used in industry. CIM conveys the concept of a semi- or totally automated factory in which all processes leading to the manufacture of a product are integrated and controlled by computer. It includes computer-aided design (CAD), computer-aided process planning (CAP), production planning and control (PP&C), computer-aided quality control (CAQ) and computer-aided manufacturing (CAM). CIM is concerned with common data models which can be used for the entire design and manufacturing cycle. Thus, CIM is centered around the decisions regarding the planning and controlling of the data flow, data processing and data dissemination in a plant. The tools are models, algorithms, artificial intelligence methods, software engineering aids, computers, data communication systems, interfaces to man and machines as well as interfaces between machines.

Since CIM starts with CAD, basic knowledge of this technology is required.

This book only covers new CAD technologies such as standardization of design data needed for manufacturing. Conventional CAD methods are already covered adequately in the existing literature.

This book, which introduces the reader to CIM, is intended to be an aid to the senior and graduate student who wishes to understand CIM systems, and to help engineers design and implement such systems. Of course, CIM is a concept which can be applied to many manufacturing operations such as the making of aircrafts, cars, machine tools, plastic toys, garments, footwear and so on. For this reason, the book emphasizes concepts, methods, structures, standards, interfaces and protocols. Examples of flexible manufacturing cells and systems are given. In particular, the chapters on *Flexible Manufacturing and Assembly Equipment* and *Control Structures of Manufacturing Systems* in the CIM area discuss typical parts manufacturing problems.

The reader interested in applying CIM technologies in a particular plant must be familiar with the product and the processes already in place. This book will aid in the conception and design of CIM components and planning and control systems. As the design and manufacture of different products varies considerably – for example, the manufacture of cars compared with shoes – students should broaden their knowledge with specific case study material. This will enable them to supplement their knowledge of the general principles of CIM gained from reading this book with a specific knowledge of how an individual product is manufactured. For this reason, the reader should become familiar with manufacturing process of particular interest, learning in detail how its products are made and shaped.

In Chapters 1 and 2, we introduce the reader to an overall concept of manufacturing. This is because a factory can only be understood as a complex system consisting of many activities and components. It makes no sense to consider an activity or a component by itself. In the real world, there is a strong interdependence between all manufacturing functions, and information is passed back and forth between them. Every function and subfunction must be operating as an integral part of the whole system. The reader who is not fully familiar with manufacturing is encouraged to revisit these chapters once they are more comfortable with all activities described later in the book in order to gain a deeper understanding of a system concept of manufacturing. The multiplicity of components entering into the design and operation of a plant makes necessary a good knowledge of the global behavior of a total manufacturing system; this is what we are trying to convey to the reader in the two introductory chapters.

The chapters of the book have the following contents. Chapter 1 introduces the reader to the operational principles of a complete manufacturing system. The role of the computer and its contribution to flexibility are discussed. The manufacturing system is divided into functional modules and, for each module, the input data, data processing activities and output data are explained. An effort is made to show the information flow through an entire manufacturing operation. In the conclusion, the chapter emphasizes the importance of hierarchical planning and control of a manufacturing system.

Chapter 2 discusses the role of manufacturing models for information technology in computer-operated factories. With the emergence of modern manufacturing technology, attempts are being made to build manufacturing systems from generic hardware and software modules. These modules are configured to a specific manufacturing system with the help of a generic manufacturing model. Several models are discussed, and their particular features are pointed out. One of the most important existing developments is the ESPRIT-CIM-OSA model, which is supported by the European Commission. This work will greatly influence the conception of future models for manufacturing. In the second part of this chapter, the Karlsruhe–Amherst model is discussed. An attempt is made to show how the most important manufacturing activities can be presented by one model. Details of many of these activities are described in later chapters.

Chapter 3 is intended to give the reader an overview of modern aids for planning and setting up complex manufacturing systems. Planning tools are quite numerous and employ operations research and artificial intelligence methods, simulation tools, Petri nets and other examples. Emphasis is placed on the application of planning tools, and it is assumed that the reader will obtain a basic knowledge of them from the existing literature. Planning methods like simulation, Petri nets and expert systems are the structuring tools for the design of complex systems.

Chapter 4 is an excursion into the design and operation of modern flexible manufacturing and assembly systems. After a short introduction to NC machines, flexible manufacturing cells and flexible manufacturing systems, numerous real machining systems are introduced. The presentation starts with simple manufacturing machines and shows how they can be interconnected to complex production facilities with automatic tool selection and material feeding, and transportation devices. The discussion includes the selection of workpiece spectra for flexible manufacturing.

Chapter 5 is about control structures for computer-aided manufacturing systems. The chapter starts with a concept of structuring control into hierarchical layers. For this layer concept, the control hardware and software is explained. There is a thorough discussion of the computer-aided organization of manufacturing resources, such as tools and manufacturing accessories. The chapter concludes with an overview on NC machine and robot programming. This chapter builds on experience gained from existing flexible manufacturing systems, and numerous examples are given.

Chapter 6 is concerned with in-plant communication. A CIM system can only work well if planning and control information is correctly distributed in a timely manner. There are several topologies from which a communication system can be constructed, and communication must follow well-defined access protocols. Modern communication systems use the ISO/OSI reference model to specify the topology, access methods and formats of the information to be exchanged. The various layers and most important standards of the OSI reference model are discussed in relation to manufacturing applications. Of specific interest are the FTAM (File Transfer, Access and Management) and MMS (Manufacturing Message Specification) standards. Examples show how these standard are applied. Other subjects of interest are MAP (Manufacturing Automation Protocol), TOP (Technical and Office Protocol), CNMA (Communication Network for

Manufacturing Applications) and the fieldbus. Examples are given to show their application.

Chapter 7 gives an overview on new developments in computer-aided design and their impact on manufacturing. It starts with an explanation of the product model as the basic source of engineering and manufacturing documents. Second, the most important features of the various CAM standards and interfaces of interest to engineering and manufacturing are discussed. Third, thought is given to design for manufacturing, assembly, inspection and testability. This chapter does not go into the details of CAD. The reader interested in this topic should become familiar with books on basic CAD practices.

Chapter 8 discusses planning and scheduling of manufacturing operations. When a production lot is prepared for manufacturing, parts are grouped to facilitate setup for machining and assembly; thereafter, process planning determines the production processes and their sequence; as the next step, the tools and fixtures are selected; and finally, machining data and programs are generated. For ongoing production, the machines and assembly lines are selected and a load balance is done. Material requirements planning initiates the ordering, purchasing and distribution of parts and raw materials. When everything is ready for production, the orders are released to manufacturing.

Chapter 9 gives an overview on the basics of robotics. The different types of robot design are explained, together with the mathematics needed to describe robot motions. The topic of robot programming is divided into explicit and implicit programming. Whereas most presentday robots are programmed by explicit languages, in the future the implicit method will gain importance. However, the final language for programming robots will be based on a hybrid approach using implicit and interactive graphic features.

Chapter 10 gives an introduction to material handling. The distribution of parts, raw material, tools and manufacturing accessories is vital to ascertain an uninterrupted production. The principles of logistics and supporting computer structures for material handling are explained. In material handling, the identification of parts and their tracking through production is essential to assure that the right parts are at the right time at the right station. An overview is given on material transportation and storage systems and the role of the computer in their control. Topics like push-and-pull production principles are also part of this chapter.

Chapter 11 concludes the book with a presentation of computer-aided quality control (CAQ) methods. Quality assurance comprises the quality that is engineered into a product, the quality of parts manufacture, and the post-auditing of quality at the customer's site. All quality problems must be observed, analyzed and corrected by an integrated quality control system. The chapter discusses computer-aided quality planning, testing and evaluation. The operation of computer-controlled tests in ongoing production is discussed and it is shown how computers can be programmed to learn their own test limits. Particular attention is paid to the operation of coordinate measuring machines. The chapter concludes with a discussion on programming languages for test applications.

This work was conceived, structured and written by three authors who have factory and university experience. An effort was made to write the book in a coherent way so that the reader will be obtaining an overall concept of CIM.

We believe that we reached this goal in most aspects. For the structuring of the book we had many meetings to coordinate its contents. The material was carefully discussed and edited several times. Various manufacturers helped to structure the outline of the book. We are indebted to the former Dean of Engineering of the University of Massachusetts at Amherst, Dr James E.A. John, and his successor Dr Keith R. Carver as well as Ministiralrat Karl-Heinz Kammerlohr of the Ministry of Science and Art of the state of Baden-Württemberg, for the encouragement and help they gave us to realize this book. There are many people who contributed to the success of this work. We are thankful to Manfred Gärtner, Ulrich Hänerle, Wolfgang Sperling, Dr Manfred Härdtner (Universität Stuttgart), Georg Näger, Bärbel Seufert (Universität Karlsruhe), Dr Klaus Linke (Deutsches Institut für Fernstudien, Tübingen), Mehren Kamran, Jyh-Haw Kang, T.S. Lang, Hsu-Shang Liu, Jennifer Savickis and Pam Stephan (University of Massachusetts at Amherst). Tim Pitts of Addison-Wesley also deserves our thanks for his help and patience.

The authors hope that the work will help the reader to get an insight into the general philosophy and concepts of CIM and the operation of the basic building blocks of the business function of the factory. We wish our readers much luck with their studies.

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Introduction

This book is concerned with the application of the computer to the support of manufacturing. The computer has only recently been introduced to the performance of planning and control tasks in manufacturing systems. Before the advent of the computer, many other types of control aids and methods were used. Originally, the artifacts that mankind used in daily life and work were handmade by skillful craftsmen. These craftsmen often had a great dexterity and ingenuity, and were capable of making extremely complex devices such as the movement of a watch or the mechanisms of astronomical instruments. Many of our present-day manufacturing methods date back to the time when man started to use tools: for example, turning and drilling are basic machining operations that have been simplifying the work of craftsmen for over 6 millennia. The first known turning machine for wood was drawn on an inside wall of an Egyptian pyramid. Typically, with this type of machine, man was responsible for controlling and powering it. The skills of the operator were essential in controlling the machine; he was responsible for generating the desired workpiece contour and also for controlling the feed and speed of the cutting tool. As objects became increasingly complex to manufacture, the control of the machining operation became increasingly difficult. When man started to use metals, then other means of power had to be found. New sources of power were water and, later on, steam. To make machine tools more adaptable to different metals and workpiece sizes, they were equipped with reduction gears to control speed and torque. A further improvement was the invention of the lead screw to drive the machining tables at different speeds. All these improvements entailed the incorporation of manufacturing know-how into machine control, and it relieved the craftsman from performing some of the control tasks. With the introduction of tracing templates, master cams and linkages, it was even possible to produce automatically predefined workpiece contours and shapes. In other words, the control devices were components with memory, and they were capable of reproducing a predetermined operation consistently. However, they had a severe problem; for new types of contours and shapes new gears, cams, linkages and templates had to be produced, which usually was very expensive. Thus, this type of automation was not very flexible.

Until almost the middle of the Nineteenth century, all artifacts were custom-made. The increasing wealth of the population stimulated the demand for conventional and new products, thus it became more and more difficult to satisfy the market. It needed figures like Frederick Taylor and Henry Ford to invent the division of labor and to define the principles of mass production before manufacturing could be revolutionized at the end of the last and the beginning of this century. With their ideas, many machine tools were tied together to form a flow-line manufacturing concept. The power was supplied by central power sources, and often it was very difficult to arrange the machines in an optimal way. The early machining and assembly lines used for mass production were rigid and expensive, and they only could serve the market as long as there was a need for uniform products. As soon as a market was saturated, customers changed their desire for products where there was a choice of designs and features. Conventional mass production methods could not handle this variation in product type, since it was virtually impossible to alter the rigid machine setup.

The repetitive machining and assembly lines had process knowledge incorporated in them in a rather permanent way. First, cams, linkages and templates had insufficient memory capacity. Second, there was a limit to the control mechanisms that could be built on mechanical principles. Third, the control of the power supply imposed severe restrictions on the configurability of the production system.

The invention of the electric motor and electric switching and control devices started a new era of machine control. These devices led to the conception of individual powered and controlled machine tools and production machines. Thus, manufacturing facilities could be configured toward the requirements of making a given product.

With the greater number of product variants, new problems arose like time scheduling and full utilization of manufacturing resources. To solve these organizational tasks, graphical, mathematical and heuristic planning and control methods were introduced. It turned out that, for a large workpiece spectrum which needed the use of many different machine tools, good planning and control became extremely difficult – the manufacturing engineer was quite happy if the production run never had to be changed. The required organizational flexibility could only be improved with the introduction of the computer in the manufacturing system. However, the computer underwent its own evolution. The first computers using vacuum tube technology had little impact on improving the organizational control of manufacturing systems. The invention of the transistor led to the development of complex computers and large-capacity memories, which are the basis for computer-integrated manufacturing (CIM) systems. The first computer-operated controllers were numerical controllers (NC) and programmable logical controllers (PLC). Both were very successful in controlling the making of the product on the manufacturing level. An efficient organization control, however, was only possible with the introduction of distributed computer systems and communication buses suitable for operating in a noisy manufacturing environment. One of the great challenges in conceiving and building CIM systems became the construction of software.

When we look at the emergence of the first computer-controlled factory and observe the developments which will lead into the next millennium, it is surprising how fast future CIM concepts have been evolving. With the computer-controlled manufacturing concept of the Seventies, standalone NC machines or conventional machine tools typically were employed, and material movement was done with simple transportation means. The organizational planning and control was performed with the help of a centralized computer system. For communication with the factory floor and the feedback from the process, manufacturing documents in the form of written reports, tapes and punched cards were used. This type of operation was very slow, and reactions to market or production changes often imposed severe bottlenecks. The incorporation of the computer into the manufacturing equipment controllers simplified standalone control of machine tools and provided an improved utilization of resources.

However, a real CIM system can only be engineered when all activities which contribute to the making and shaping of the product are integrated within the factory concept of the Nineties. Engineering, process planning, manufacturing scheduling, order release and control, material movement and quality control must all be interconnected and the total system must operate as one unit.

The new CIM systems are being constructed with the help of standardized machine interfaces, communication buses, computers and software. The greatest challenge of the control system will be the conception and production of modular software which can be used for various applications. Today, the software often amounts to 50–60% of the total installation cost of a CIM component. This cost increases when whole CIM systems are implemented. The future of successful CIM applications will greatly depend on the availability of standardized hardware and software components and on configuration tools with which these components can be assembled into manufacturing systems.

CIM can be considered as a philosophy in which the computer plays a central role for planning and controlling the manufacturing process. However, the manufacturing systems and processes are in general of great complexity and have evolved using experience gathered over many years. For this reason, it is virtually impossible to configure, build and run a completely automatic factory in which the computer contains all the manufacturing knowledge needed to guide the whole plant. The computer can take on routine work in a plant under normal working conditions. Strategic planning and control, as well as handling of disturbances, however, have to be done by well trained and experienced managers who know how to use the computer as a supporting tool for achieving the goals of the manufacturing system. The success of a company in its marketing environment depends on how well a CIM system is used and operated. CIM is not a cure-all for every manufacturing problem; it must be applicable and justifiable. thus, in many factory situations CIM will only solve problems in parts of the overall function; an attempt must be made to integrate these parts into an operable manufacturing system.

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