COMPUTER INTEGRATED MANUFACTURING SYSTEMS: *SELECTED READINGS*

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PREFACE

As early as 1981 the Institute of Industrial Engineers began to anticipate the need to provide its members with information on the subject of computer integrated manufacturing systems (CIMS). In order to educate the industrial engineer on CIMS, three divisions within the Institute, Computer and Information Systems, Manufacturing Systems, and Production and Inventory Control, joined forces. This cooperative effort has resulted in three tangible products to date: the two-year CIMS series published in *Industrial Engineering* magazine, the co-sponsorship of technical sessions at the 1984 Fall IIE Conference, and this collection of readings. All three efforts have taken a substantial amount of planning and coordination by members of the three divisions. We hope the results have been worth the effort and will help the practicing IE stay current with today's technology.

CIMS has been defined as the ability to control all phases of the manufacturing system using computers, from planning—through design—to shipping. CIMS also implies the ability to take each system and subsystem that presently operates independently and create a single system which integrates all operations. This integration means that information could be shared by each area, thus making planning and control easier and more efficient. Rather than optimizing individual components, which often results in "islands of automation," the ultimate CIMS will optimize the operation as a whole.

While it is generally accepted that no true CIMS are in existence today, there are systems which already have in place many of the components required for CIMS. The ideal CIMS will consist of a careful integration of hardware, software, and human resources. The hardware is clearly in the most advanced state. This is evident by the abundance of highly sophisticated, computer-controlled machine tools, sensors, and material handling equipment. The continued advancement of the state-of-the-art in computers is also contributing to the development of CIMS by offering faster, cheaper, smaller, and more powerful computing capabilities. These two factors are the primary reasons for the development of flexible manufacturing systems (FMS). Much of the required software also exists, although there is much disagreement as to how it should be linked and which tools are best. The existence of FMS demonstrates the ability of the software to successfully link multiple elements into complex systems. Although the increasing sophistication of FMS is aiding the development of CIMS, several vital pieces of CIMS are still missing. The ability to directly link CAD and CAM systems relies on the development of computer-aided process planning (CAPP). CAPP is still in the research stage, except in a few isolated cases. Effective resource planning which would allow the development of a practical shop floor scheduling capability is a topic of great discussion, but little progress has been made in recent years toward achieving this goal.

In establishing the guidelines for the selection of papers to be included in this volume, the editors first divided the areas of CIMS to be treated into four main sections. The first section develops an historical perspective on computer integrated manufacturing systems and provides a glimpse into their future. The use of CIMS as an operating philosophy, as well as the economic and social impact of CIMS use is also discussed in this section.

The second section covers the area of manufacturing components, structure, and technologies.

The articles and conference papers selected for the third section address many of the issues and factors which affect the development and implementation of CIMS. Both technical issues and management concerns are discussed.

The final section focuses on the planning aspects and applications of computer integrated manufacturing systems. It covers the basic building blocks required for the development of CIMS and suggests methods for implementation. Five case studies of systems in use today are also included.

During the paper selection process we became very conscious of the fact that many aspects of CIMS have not been covered and need to be addressed in future articles. We hope that you, the readers of this collection, will research and write papers and articles on the topics that still need to be examined.

John W. Nazemetz
William E. Hammer, Jr.
Randall P. Sadowski

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EDITORIAL OVERVIEW of Section I

Comprehension and appreciation of the major trends that are transforming our society is essential for the professional who aspires to prosper in these turbulent times. During the next few years we will witness fundamental structural changes in the way we carry out our manufacturing activities. We will begin to realize the integration of our design, process planning, scheduling, and control functions using computer technology. The readings in this section were selected to provide perspective on the trends that have taken us to the present state of the manufacturing art, as well as to raise some of the questions that must be answered as we proceed.

In the first subsection, Randall Sadowski and Mikell Groover provide a brief history of recent developments in the integration of manufacturing functions. They discuss developments from the precomputer control era through computerization and development of a classification for the major trends in fixed and flexible automation. These papers provide an historical anchor for evaluation of the techniques and applications that will be discussed in later sections.

The second subsection builds on this background and tries to forecast the future. During almost any discussion on the future of CIMS, questions are raised regarding vendors' plans, capabilities, and concepts. Cincinnati Milacron is always included among the vendors driving CIMS technology and Karl Schultz provides a summary of what this manufacturer sees as the future of CIMS. William Welter also provides his view of the "factory of the future" and includes in his discussion the implications of the use of this technology for the industrial engineering profession.

In the third subsection Hal Mather and Jason Smith raise some questions as to the validity of and prerequisites for CIMS implementation. Both authors discuss the necessity of getting a production system under control before attempting to integrate manufacturing functions, noting that substantial benefits can be obtained from these efforts. Roger Willis, Kevin Sullivan, and Jack Meredith look at the economics of a true CIMS and the problems of justifying and assessing the synergistic effect of interlocking subsystems.

As a fitting finale to this first section, the social implications of CIMS implementation are discussed. Since industrial engineering is the only engineering discipline to specifically consider the human being in the workplace, our displacement of him/her must be considered and assessed.

This section is intended as a brief overview and, as such, all aspects and issues cannot be raised and examined in-depth. The most notable omission is a discussion of systems which represent the culmination of efforts to integrate our manufacturing systems. As will be seen in the remaining sections, the subsystems are in various stages of development and integration.

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History Of Computer Use In Manufacturing Shows Major Need Now Is For Integration

By Randall P. Sadowski
Purdue University

The earliest applications of computers in industry and manufacturing-related activities were primarily in the administrative and finance areas. These initial applications were learning experiences which required projects that involved easily identifiable and tangible savings.

Administrative cost reduction or cost avoidance systems provided such projects. They also provided relatively straightforward applications of well documented procedures. In the manufacturing area, on the other hand, procedures were not clearly developed or documented.

These administrative applications also required calculations which were consistent and compatible with then-available hardware and software capabilities. Administrative calculations such as payroll, general ledger, etc., provided well defined, repetitive computations that were relatively trivial and lent themselves directly to serial or sequential processing. This serial processing was a key attribute, since the early computers were incapable of totally random access of large volumes of data.

Before computers could be successfully applied in the manufacturing area, technical capabilities would have to advance to a stage at which computers could handle large volumes of data in a non-sequential fashion, and the disciplines and approaches of manufacturing would have to become much better defined.

Operationally, it made sense that initial applications would be in the administrative area, with its well defined, sequential disciplines. These applications were often in small departments and were initially not integrated together. The computers of the 1950s were relatively slow and expensive, and the cost of using a computer in these early stages of development limited its use in most business environments.

Organizationally, it was natural that the newly created data processing and systems departments would report directly to finance or administration in the early days when applications were limited to the business areas. However, this structure has caused much grief in recent years in many industries trying to implement successful computer-integrated manufacturing systems. Fundamentally, it became apparent in the early use of computers that it was much easier to succeed in administrative applications than it was in the ill-defined manufacturing area.

The punched card era

The punched card provided a reusable form of data which could be analyzed and manipulated with unit record equipment (counting machines, collators, sorters, key punches, etc.). It became widely accepted and used in administrative and financial applications during the 1950s and '60s. Although these bear little resemblance to computer implementations as we think of them today, they represent the origins of today's computer systems.

The early use of punched cards in manufacturing was predominantly seen in their inclusion in job or order packets for material requisition, labor reporting and job tracking. These cards were often key punched from manufacturing paper documents such as routings and parts listings. The punched cards were also used for simple inventory accounting systems.

Limited attempts were made to use punched cards for bill of material explosions. However, by and large this proved to be technically infeasible from a time and effort standpoint.

During the same time, computers were being introduced into the engineering areas of manufacturing for companies with heavy engineering requirements. This was partially due to the introduction of FORTRAN and the availability of lower-priced engineering computers. A mainstay of that period was the classic IBM 1620.

Although the computers available at that time were compatible with engineering activities, the evolution of computers discouraged their use in the logistics side of manufacturing. The available computers were principally binary word machines with limited input/output capabilities. They were primarily interfaced with printers, card readers and magnetic tapes, which were ideally suited for the sequential-type operations previously mentioned. In addition, the languages available at that time were simply not suitable for the types of tasks required in the manufacturing environment.

The production and inventory control environment at that time required large data processing type jobs, not engineering oriented jobs. Thus the primary obstacles to successful implementation of manufacturing systems were the hardware technology, inadequate languages and the inability to perform random access of data.

Pre-computer controls

Gradually the early manual data collection systems evolved to allow for numeric data entry devices in production control or dispatching departments. This was achieved by linking key punch output devices in these areas to the centralized facility. Although such systems were not truly utilizing the computer, they did prove beneficial in dynamic job tracking and centralized dispatching activities.

There were even attempts by some facilities, primarily long lead-time build-to-order durable goods manufacturers, to manually explode engineering bills of materials for component manufacturing and purchasing requirements. The result was often called the "quarterly schedule" because the time required to manually explode the bill of materials precluded the possibility of doing it more often.

Some companies utilized non-computer punched card equipment to develop an alternative approach to exploding bills of materials by simply calculating the gross requirements. The level-by-level approach which resulted in the total netting of requirements was not practical on this non-computer type equipment.

During this time, the initial concepts for manufacturing systems were being developed by long-lead-time type users. Unfortunately, short-lead-time manufacturers didn't have the time or computation capability to produce the required manufacturing control information. Such manufacturers often utilized manual order point or min/max systems to replenish individual components rather than utilizing the bill of material relationship requirements.

One successful early computer approach to inventory management grew out of techniques developed by distribution companies to control distribution of finished goods inventories. Such inventories were being effectively managed using statistical inventory control or scientific order-point concepts.

> **"There is a distinct lack of executive leadership which has the foresight to look beyond a CIMS as a purely technical challenge and view it as the management challenge that it really is."**

Inventory and management replenishment systems were developed which utilized ABC analysis, EOQs, order-point concepts, forecasting with exponential smoothing and statistical techniques for dealing with safety stocks. Such systems were readily adaptable to the period's computers and provided an exciting new use in inventory management which actually worked for finished goods or distribution inventories.

Unfortunately, the technique was so desirable that many consultants and manufacturers attempted to apply it to discrete component manufacturing inventories, with often disastrous results. It became apparent that although a technique was needed, it was simply the wrong tool for these kinds of environments.

Early computerized systems

The late fifties and early sixties provided, for the first time, relatively low-cost computing capabilities which allowed the concepts of data processing to emerge. These new systems arrived with extremely fast and capable input/output devices and commercially oriented or non-engineering programming languages. No longer limited to sequential processing, they opened the field for computerized manufacturing applications.

The first manufacturing application that evolved was the preparation of shop documents and paperwork on pre-punched cards for job, labor and material reporting. During this time a limited number of companies were performing an explosion of the bill of materials using sequential tape systems. This frequently required many, many passes of reading the tape.

With the development of direct access storage, such systems were often converted to take advantage of this capability to perform a direct explosion of the bill of materials. The addition of this new direct access storage device suddenly brought adequate and reasonably priced data processing equipment to a large number of manufacturers.

Although the power of the computer had finally arrived at the point at which it could be used in the manufacturing environment, there was little, if any, software available.

The late sixties saw the emergence of the minicomputer, produced by manufacturers such as Digital Equipment and Hewlett-Packard. Although the minicomputers lacked applications software, they were widely accepted by the engineering and technical community for their computing capability and were quickly adopted for a wide range of engineering and process monitoring and control applications.

These were predominantly standalone and well justified islands of automation that emerged in factories nationwide. They were predominantly in the process and flow manufacturing industries (petroleum, chemicals, pharmaceuticals, consumer goods, etc.).

During this phase, the computerization of manufacturing systems was slow primarily because of the lack of software. Many companies attempted to write their own software and proceeded to implement such systems. The primary application areas were inventory accounting, requirements planning (subsequently called MRP), and in some advanced systems, operations scheduling and capacity requirements planning.

The COPICS concept

During the 1960s, IBM undertook the development of an overall concept for a production and inventory control system. This concept was announced in the late 1960s and subsequently published by the company in the early 1970s in eight paperback volumes.

It is important to recognize that the development of the communications oriented production information and Control System (COPICS) concept involved no software. However, it did provide a rather detailed view of the data flow in a manufacturing organization with an integrated system consisting of sales forecasting, engineering data control, inventory control, requirements planning, purchasing, operations scheduling, shop floor control, etc. In this sense it made a major contribution to the subsequent development of computer-integrated manufacturing systems.

This concept provided the outline and defined the boundaries which allowed the intelligent development of software for the control of manufacturing systems. The actual software that emerged over the next couple of years included the bill-of-materials processor program (BOMP), inventory control, requirements planning systems and rudimentary capacity planning systems.

The BOMP was a breakthrough in data storage and access concepts (it used a chain file technique). Although this concept represented a significant breakthrough for dealing with the bill of materials, it is definitely not a data base system by today's standards.

These software systems gained immediate acceptance and subsequent widespread use in many types of manufacturing operations. Although the requirements planning system was only one section of the original COPICS concept, the systems being implemented were referred to as MRP (material requirements planning) systems.

The decade of the seventies saw the emergence of the COBOL language and an explosion of knowledge of MRP systems, fueled by some successful systems and a cadre of manufacturing consultants. Many of these consultants were prominent in the MRP crusade which occurred during the 1970s.

This crusade resulted in a large number of actual implementations of MRP systems and a vast amount of experience being gained, primarily through failures. The age of the computer had arrived, and manufacturers were rushing to take advantage of its capability. Unfortunately, many of these MRP implementations were subsequently determined to be failures.

During this same period, the growth of the minicomputer was exponential. However, it was primarily in stand-alone islands of automation which would ultimately have to be incorporated together in order to achieve a truly functional computer-integrated manufacturing system.

The initial computerization of production and inventory control systems consisted of limited application software offerings by only a relatively small number of vendors. Many companies based their systems on available BOMP or BOMP-like software, utilizing some of the inventory accounting and requirements planning software available, and then developed and wrote a significant amount of home-grown or in-house software to supplement that which was available. The COPICS concept was widely used as a blueprint or architecture for what was now being called manufacturing systems.

At this stage, manufacturing systems for most companies did not include design engineering functions or plant automation. The few exceptions tended to occur in a small number of leading edge manufacturing companies and in highly automated process plants which were very flow shop oriented.

Explosion of computerization

The second half of the 1970s and the early 1980s saw a truly dramatic increase in the development, acceptance and implementation of computerized production and inventory control systems. Unfortunately, not all of these systems ultimately proved to be successful.

This sudden explosion of computerized manufacturing systems can be traced directly to the development of new technology (hardware and software) and a recognition by industry that such systems were vital to the success of their companies. Computers were now easily affordable by most manufacturing companies. The price/performance curve of components was experiencing approximately a 20% annual improvement, which was compounding over time.

Computer hardware and software vendors recognized and targeted manufacturing as a significant marketing opportunity for subsequent sales. Simultaneously, the consulting community and selected computer vendors were beginning to spread the gospel of manufacturing systems. This consisted of a rather intense phase of teaching, telling, selling, consulting and publishing of the benefits of computerized manufacturing systems.

The number of commercially available computerized systems in-