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**Integration of Engineering  
Systems**

**by**

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I N T E G R A T I O N   O F   E N G I N E E R I N G  
S Y S T E M S

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## INTEGRATION OF ENGINEERING SYSTEMS

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### ABSTRACT

Systems integration is recognized as a key to improving efficiency and productivity in an engineering and manufacturing environment. The ultimate goal is to provide engineering management with improved systems efficiency, control, and monitoring capabilities, and to allow for consistent, accurate, and real-time sharing of data between related functions which now rely on manual procedures for communication between standalone applications.

Because of the technical and organizational issues involved, systems integration will occur in a gradual, modular fashion, and will require considerable management effort and support. The proposed starting point for this process is the integration of Manufacturing Resource Planning, (MRP II) and Computer Aided Design, (CAD). MRP II, being an engineering and manufacturing systems controller, will serve as the central coordinator of this and future integrated systems. MRP II includes such functions as engineering data maintenance, shop floor control, purchasing, accounting, material requirements planning, and inventory control. CAD, as the first system to be integrated into MRP II, will link the design and drafting processes with these functions.

Given the large number, variety, and complexity of systems available commercially, the most practical approach to integrating MRP II and CAD is to establish an interface between existing systems, in order to communicate common information. The theory of data base interoperability is being developed to provide these links at the data base level, allowing for both the exchange and updating of information in any given data base consistently. The first data sets to be communicated within the MRP II/CAD system include Part Master Records, Bill of Materials, and Engineering Changes.

The ongoing research in this field is discussed and two case studies of pertinent industrial applications are also presented.

### INTRODUCTION

Under pressure to remain efficient and competitive in today's market, many engineering executives feel compelled to implement one or more of the vast array of new technologies and techniques which are being presented and promoted as a means to the development of the factory of the future. These include Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Flexible Manufacturing Systems (FMS), Manufacturing Resource Planning (MRP II), Group Technology (GT), Just In Time Inventory Control (JIT), Automated Materials Handling (AMH), Computer Aided Process Planning (CAPP), and Artificial Intelligence (AI), to name only a few. Too often, however, this approach, in which individual technologies are implemented independently, results in "islands of automation", in which individual tasks are automated without any communication or interfacing with other related activities.

Instead of firms independently automating as many as 50 different functional areas (1) often using unique hardware and software for each, it is time for managers to adopt a systematic approach to implementing and then integrating the various technologies as a means for achieving the productivity gains required (2).

The ultimate goal of this implementation and integration process, commonly referred to as Computer Integrated Manufacturing (CIM), is to use both hardware and software to provide effective and economical interaction between every business activity using information as the ingredient to hold it all together. Frequently, CIM is defined simply as the integration of CAD and CAM; in reality, however, CIM must include all of the techniques mentioned above, and others, each of which has a role in the planning, monitoring, control, and execution of the various production functions.

Today, CIM is only a dream; it cannot be purchased as a turn-key system, and no one has yet created a comprehensive CIM system in industry. The barriers to CIM are numerous and include not only technological difficulties, but organizational issues as well. For CIM to be successful, management will have to take the leadership role in coordinating the gradual implementation of CIM components and most importantly, prepare

the members of the organization for the drastic changes that will accompany CIM development.

This paper describes the current status of CIM and discusses some of the problems faced by developers of CIM, including the lack of communications standards, the creation of an organizational model for CIM, and the technical difficulties of integrating heterogeneous equipment. A general strategy for modular implementation of CIM is presented and, finally, two case studies of firms heading in the direction of CIM are discussed.

#### WHAT IS CIM?

Computer Integrated Manufacturing is the use of integrated computerized tools to plan, design, develop, manufacture, sell, and service products. By coordinating all these functions and sharing common data, CIM will improve productivity and delivery performance, and facilitate better and faster product design. In a typical CIM environment, an engineer will use a Computer Aided Design system to design a product based on the requirements set forth by marketing surveys and research. During the design stage, the system will facilitate such things as stress-strain analysis, thermal analysis, vibrational analysis and so on, without the need for prototypes. When the design is finalized, it will be passed to both the Manufacturing Resource Planning system for recording product structure information and the Computer Aided Process Planning system, where, using Artificial Intelligence and Group Technology, process plans will be developed. Once the process plans are complete, these will be downloaded to the Manufacturing Resource Planning system, which serves to execute them. MRP II coordinates the scheduling of shop floor activities and machines, and the gathering of materials and other resources (i.e., purchasing and inventory control), based on the process plans and the production schedule established by master scheduling.

In its execution role, MRP II is assisted by Artificial Intelligence, Automated Materials Handling, Computer Aided Manufacturing, Group Technology, and other tools. MRP II will also coordinate the distribution of the finished products. By coordinating all of these activities, MRP II effectively serves as the "hub" of the CIM system, as depicted in Figure 1, the functional model of CIM. The links between the systems are determined by the common information required by each.

#### BARRIERS TO CIM

There are many problems and issues that must be resolved before CIM is possible. These include not only technical concerns, but organizational issues as well. The primary restriction is that much of the technology necessary for CIM has yet to be developed. Though some systems such as CAD and MRP II have been in existence in one form or another for many years, they are still not fully mature. Other technologies, such as CAPP, AI and GT, are really still in their infancies. In fact, the whole science of manufacturing could be considered to be in its infancy (3) given how far we are from realizing the theoretical limits of efficiency. Revolutionary changes are required in product design, materials handling, processing, assembly, and management. Fundamental research in the areas of machine tool technology, programming languages, hardware and software architectures, robotics, and geometric modeling is also essential.

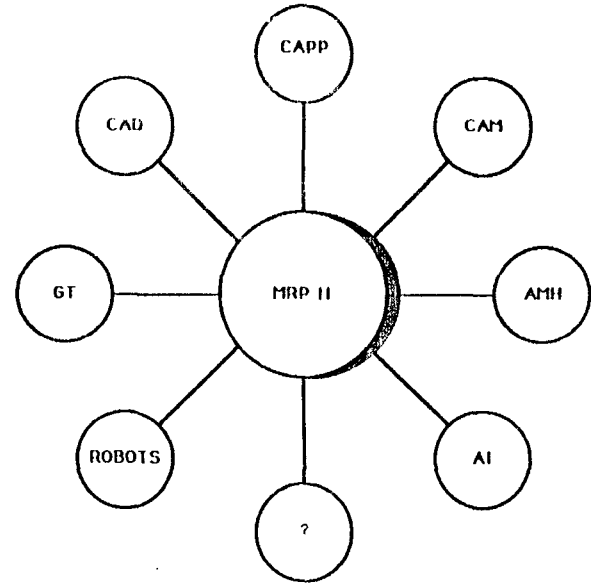


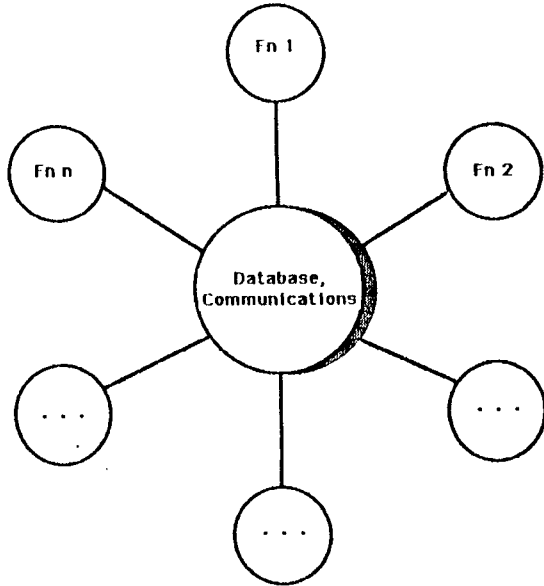
Figure 1. Functional CIM Model with MRP II as the Hub

Besides the fundamental research necessary for CIM development, there are a number of other major technical concerns. One of the most crucial is the question of the physical construction of a CIM system. Given the functional model of CIM shown in Figure 1, how is the actual system to be constructed? There are two primary schools of thought in this area. The first is that a single database, accessible to all system functions and maintaining all system data, should be constructed as shown in Figure 2a. The second alternative is that separate databases be maintained as needed for each function, with interoperational capabilities to provide for the creation, access, and updating of data from any appropriate system. This concept is presented in Figure 2b.

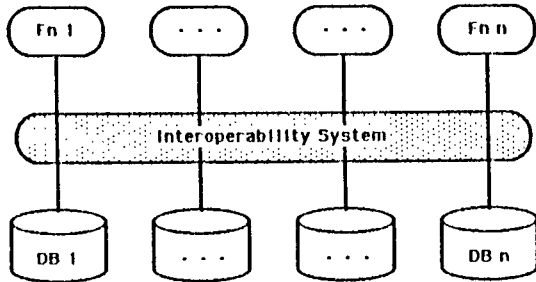
The idea of a single database may appear to be the more efficient choice, since each piece of data is maintained in one single place. But it is possible that the size of the database required by a typical manufacturer would reduce the system performance (eg., access time) below that considered acceptable (4), not to mention the effort required to maintain such a large system. Further, a single database system would require CIM to be developed from the "ground" or database upwards, a monumental task for any single developer.

Using multiple databases is less efficient than a single database in that the same piece of data may be maintained in several data bases around a facility. Further, the interoperability functions between the various databases would have to be extensive and carefully controlled to ensure that all users of a common piece of data are in fact sharing the proper information at all times. But a major advantage of using multiple databases is that it allows for the integration of separate systems, which offers two distinct benefits. The first is that it would then be possible to build CIM gradually, beginning with several "seed" systems and building onto this nucleus as technology

and capital constraints allow. Given the potential impact a CIM system may have on an organization, gradual development is perhaps the only way CIM will succeed. The second advantage of integrating systems is that users are free to choose any particular system to handle a given function; a single vendor need not be chosen for the entire range of systems. In the near future at least, it appears that the multiple database concept is the only practical solution. The idea of integrating systems from different manufacturers brings



a. Single Database Approach to CIM



b. Multiple Database Approach to CIM

Figure 2. Single and Multiple Database Concepts

to light one of the most significant issues in CIM development: communication standards. With the myriad of software and hardware developers, each with their

own communications format, the prospect of easily integrating these systems becomes bleak at best, requiring great customization and expense. Significant and widespread progress can be made toward CIM only when certain standards for communications have been adopted.

Efforts in this direction have been made, for example the Initial Graphics Exchange Specification (IGES) (5) designed to standardize the transfer of graphical information, and Manufacturing Automation Protocol (MAP) for local area networking.

Perhaps the biggest stumbling block to CIM is the lack of commitment by management. If it ever becomes a reality in its envisioned form, CIM will result in changes in virtually every aspect of a company's operation. Communication and cooperation between departments must be improved and the whole business must learn to function as a team, instead of separate, antagonistic groups. Only management can lead a company in this direction. The aim is to create a company structure paralleling the structure of CIM: a collection of diverse functional areas held together by the communication of the information needed to achieve their common goals.

AN APPROACH TO CIM DEVELOPMENT

Currently, the only practical approach to CIM development is to implement functional areas gradually, with each retaining its own individual database. Implementation will begin with a nucleus of functions, which will be expanded as appropriate. The first systems to be integrated should be relatively mature, and more importantly, should have a well defined interaction.

The proposed candidates meeting these requirements are Computer Aided Design and Manufacturing Resource Planning. While neither of these can be called fully mature, their overlap is well established: product definition. CAD facilitates the creation and design of parts and assemblies, where assemblies are really just arrangements of component parts. MRP II has the role of cataloging each part by number and description, and of defining the product structure (i.e. where each part is used).

More specifically, the elements common to MRP II and CAD to be shared by the integration are as follows:

- Bills of Material
- Engineering Changes

This overlap is depicted in Figure 3.

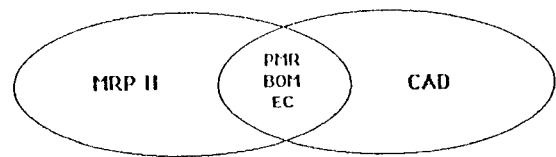


Figure 3. The Intersection of CAD and MRPII

These elements serve different purposes in CAD and MRP II. To the designer, they represent the documentation of the part or assembly created and its manufacturing processes. To the users of MRP II, the

production control and materials department, they serve as the guide to production activities and material purchases. Thus an integrated MRP II/CAD system would cross the boundary between design and production and make the first step towards true CIM. Designers working at CAD stations could create and then release new parts to the system, at which time part master record information would be automatically generated in the MRP II system. For each end product designed and released, a bill of materials defining the product structure would also be generated. At the time of creation, additional data required only by MRP II could be added by that system's users.

The authors are currently developing the functional specifications for the combined MRP II/CAD system, which will eventually lead to a working model derived from commercially available systems. Integration will be achieved by a multidatabase interoperability system, also currently under development, which will allow the use of a high level language (PROLOG) to define the update and retrieval dependencies of the systems to be integrated. Communication between the databases is then established through inter-database operation "calls", and each operation followed by a return message indicating the success or failure of that operation.

This approach is designed to provide maximum flexibility for expansion. As other systems are added, the interoperability system can be reprogrammed for the specific interactions required. Because the interoperability system is external to all of the databases, it can be tailored to operate with the various communication formats used by manufacturers, minimizing the impact of the lack of standards.

Beyond the MRP II/CAD nucleus, it is next planned to add Computer Aided Process Planning, which will be designed to determine the process routings of components designed by CAD with the aid of Group Technology and Artificial Intelligence. The routings will then be passed to MRP II for scheduling.

#### THE ROLE OF MANAGEMENT IN CIM DEVELOPMENT

Given the technical complexities, high price tag, and long term nature of CIM development, it is no wonder that management often takes a "wait and see" attitude. As long as there is no fully operational CIM system to demonstrate its benefits, it will be difficult to convince these companies to proceed with integration.

Alternately, management may seek quick solutions to its production problems, embracing the ideas of MRP II, CAD, CAM, and CIM, but may be unwilling to provide the necessary time and resources, both financial and human, to see projects to their completion. Too often, there are unreasonable expectations of the quantitative benefits, and the amount of time, education, and change to company procedure is not recognized. As a result, millions of dollars may be spent on a project such as MRP II, which is then abandoned when it is discovered that the performance measures the system should have improved have actually worsened.

For successful CIM implementation, management must remain committed to the project from its inception and recognize the difficulties involved. The importance of short term return on investment must be reduced when compared to the long term, hard to quantify benefits of integration (6) including responsiveness, productivity, quality, lead time, design excellence, flexibility, and work-in-process inventories. And, most importantly, management must be willing to involve all affected levels of personnel in all stages of the process

including planning, design, implementation, testing, and training.

Planning for integration is crucial to success. Analyzing needs, arriving at a conceptual model of information flow through the organization, and developing an implementation plan may take anywhere from four to 20 months (4). French (7) provides a list of various considerations to be explored during this phase; some of the most important are:

- First, the potential impact on every functional area of the organization should be examined and likely problems, penalties, and benefits, both short-term and long-term, should be identified.
- Second, the leaders of each functional area should be allowed to share their concerns and ideas with those in charge of planning, so that a consensus can be reached as to why the project should proceed from the viewpoint of a given function.
- Third, company-wide concerns and opportunities should be identified, and a single list made of these, as well as those specific to each functional area.

With the list just described, a plan can be developed to include funding needs, manpower, and time requirements; inevitable delays and mistakes should be allowed for. Once generated, it is important that the development and implementation plans be discussed with each of the areas so that their involvement can be made clear.

The actual implementation of the plan may again extend from several months to several years. The most important factor for success is that implementation be done gradually with minimal disturbance of existing operations. For those areas to be altered drastically, the current system should be maintained until trouble-free operation has been attained by the new system.

As portions of the system become operational, continual evaluations should be made to uncover any problems and determine the effectiveness of the system. Potential changes should be carefully studied before any alterations are made.

#### CASE STUDIES

A few of the attempts at integrating manufacturing systems are worth noting at this point. Most of those receiving attention in the literature have involved large firms with enough capital to invest in large-scale projects taking many years to complete. The thrust of these projects tends to be toward integrating CAD and CAM; some MRP II functions are occasionally accommodated, albeit not integrated.

##### Ingersoll Milling Machine

Probably the most comprehensive and most often cited example of an integrated system currently in use is at Ingersoll Milling Machine Company of Rockford Illinois (8), winner of the 1982 LEAD award from the Computer and Automated Systems Association of the Society of Manufacturing Engineers (CASA/SME). Ingersoll produces large milling machinery, customized for each customer's application, with lot sizes averaging less than three units. The plant uses 25,000 different parts each year, of which 70% are in lots of one, and 50% are never made again. Most engineering

efforts therefore cannot be reused and there are no provisions for prototypes or models. In 1979, Ingersoll decided to integrate when they realized the trouble they were headed for with 1300 different computerized applications and 225 master files with redundant and uncoordinated data.

Ingersoll's system encompasses, in one form or another, the following functions:

- Master Scheduling
- Engineering Design
  - Assembly and Piece Part Drawing
  - Bills of Material
- Production Planning and Control
- Inventory Control
- Purchasing and Accounts Payable
- Routings and Process Planning
- Numerically Controlled Programming and Post Processing
- Flexible Machining System
  - Parts Storage and Retrieval
  - Automatic Transportation
  - Part Identification and Tracking
  - Direct Numerical Control (DNC)
  - Automatic Inspection (QNC)
  - Tool and Fixture Management
  - Process Data Management and Support
- Assembly
- Job Cost and Management Reports

Integration is achieved through two data bases, one alphanumeric and the other geometric, which Ingersoll hopes to eventually combine. In order to reduce the previously chaotic data bulk to only two databases, considerable rewriting of software was necessary and a moratorium was placed on all new software development.

The major integration successes at Ingersoll are in the area of flexible machining. The CAD/CAM geometrical database and NC programming capabilities have allowed Ingersoll to use six machine set-ups to replace 17 old machines. A second set of six machines will replace 23 more. Drawings created with the CAD system are the driving force for not only NC programming, but also for routing and quality control inspection.

Ingersoll's use of MRP II is also impressive, incorporating purchasing activities, shop floor control, material needs, and scheduling, all in real time.

In the area of MRP II/CAD interaction, Ingersoll has achieved a limited interface between the two systems. When an assembly is drawn on the CAD system, its component parts are found in the bills of material file, and their part numbers and descriptions are retrieved. When the assembly drawing is completed, the component data is downloaded to the bills of material, where it drives the rest of the manufacturing process. The CAD module, as of yet, cannot automatically generate a bill of material for a new part, nor does the interface handle engineering changes.

Ingersoll considers its system a great success and plans to continue on the road to complete integration. George Hess, Vice President of Systems and Planning, credits the commitment of management and their willingness to be a leader in automation instead of a follower. Each system, such as CAD and CAM, was developed as soon as it was available.

#### Boeing

Another example of integrated systems can be found at the Boeing Commercial Airplane Company of

Washington, currently implementing their second such system. Their first system, the CAD/CAM Integrated Information Network, or CIIN, was used in the design of the 757 and 767, and is still in use today. Because of CIIN, both planes were delivered ahead of schedule and under budget.

CIIN is used to provide communication between the various databases and applications that already existed at Boeing; the concept is demonstrated in Figure 4. The primary goal, according to Beeby (9), was to interface the key geometry and graphics systems, including several Boeing lofting programs (which generate descriptions of lines and contours of an airplane). These functions were interfaced via translators to and from a "neutral" database format, and the data stored in a geometric database, as shown in Figure 5 (10). The network allows, for example, lines to be extracted from master models, translated to a graphics system, stored, and then retrieved by manufacturing for use in tool design and part manufacture.

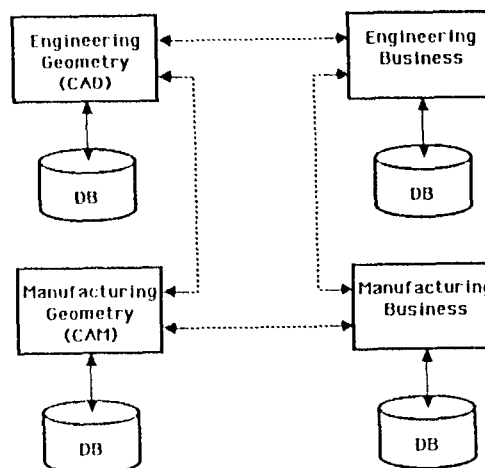


Figure 4. The Current CIIN System at Boeing

While the geometric functions at Boeing are well interfaced, if not integrated, non-geometric functions do not fare as well. The geometric database management system of CIIN does have access to other databases, such as marketing and manufacturing, but not in an integrated sense; only certain information processes are interfaced, and those only at the data level.

Though it has been instrumental in saving time and money, Beeby (9) points out several shortcomings of CIIN, such as its complexity, lack of user-friendliness, and its high price tag. The use of so many heterogeneous hardware and software systems, each with different user interfaces and a unique set of translators, makes the system large and inefficient and makes it difficult for people to move around the organization without being restrained.

With the problems of CIIN surfacing, Boeing began planning their next system, hoping to achieve the integration that CIIN did not. The new system, which took four years to plan and will take 10 years to implement (1985-1995), is centered around the Boeing

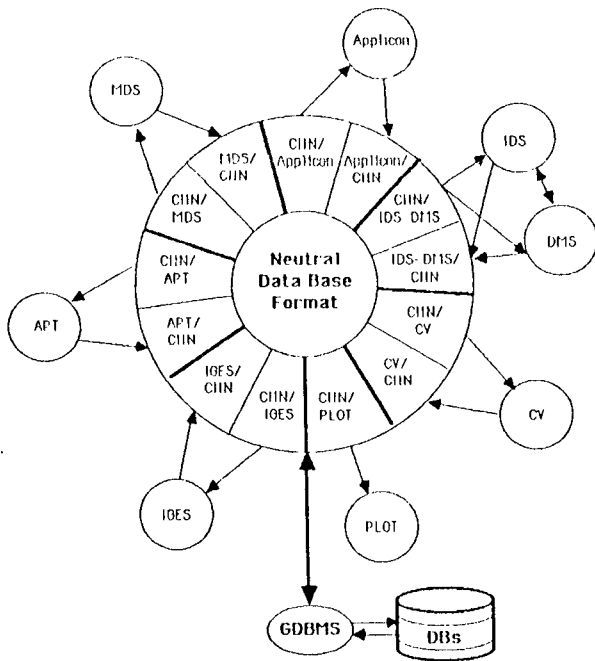


Figure 5. The Physical Arrangement of Boeing's CIIN

Computer Support System (BCSS). The goal is a single database handling all engineering and manufacturing functions, as well as finance, sales, marketing, and customer support. Instead of translators customized for each function, a single data structure will be used for all product data. A special core data manager will be designed to verify and enforce all of the database system constraints. Boeing is likely to find the development of this single database to be its most difficult, if not impossible, chore.

According to Beeby (9), BCSS will use a structure emphasizing the logical relationships between functions corresponding to the structure of product development. Therefore high on Boeing's priorities is the integration of product definition data (e.g. geometry, analysis data, bills of material) and planning and control data (e.g. inventory management, production, and scheduling). Development will occur gradually, with applications being integrated one at a time.

When completed, the functions of BCSS will cover the entire spectrum of manufacturing activities, serving everyone from designers to process planners to financial personnel. Boeing has committed the full-time efforts of 100 professionals to the development effort, a promising sign for success.

#### CONCLUSIONS

There is no doubt: Computer Integrated Manufacturing is coming. It is the role of management, and engineering management in particular, to guide industry through the both revolutionary and evolutionary changes that will accompany its implementation. Full commitment is essential; planning is a must.

The model for CIM should be based on the flow of information among the various departments and functions of the company. Manufacturing Resource Planning will

serve as the central "hub" of the system, coordinating and controlling the information and activities needed to plan, design, test, manufacture, market, distribute, and service products.

Implementation would occur gradually, but always with the vision of the complete system in mind. The proposed starting point of MRP II/CAD integration establishes the foundation of the total system and will link the design function to the product structure records. A separate interoperability system will be used to define the relationships and update constraints between the two systems and will be automatically executed as required to maintain consistent, up-to-date information in both systems. Additional system tools can be integrated with the nucleus system by simply redefining the constraints in the interoperability model.

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