Introduction

Computer Integrated Manufacturing (CIM) is the integration of all the processes necessary to manufacture a product through the use of computer technology. In manufacturing, CIM is integration through the centralization of knowledge (Thompson and Graef). In its fullest implementation, CIM integrates all manufacturing information, not just the manufacturing data for products, but also the business procedures, corporate goals, and management structure of a manufacturing enterprise.

An approach to the organization and management of a firm, in which the functions of design, manufacturing, and production management are mutually rationalized and completely coordinated, through the use of appropriate levels of computer and information/communication technologies.

Computer Integrated Manufacturing (CIM) is a much broader concept than any of the previously mentioned support technologies (i.e., CAD, CAM, CAPP) and that, in fact, encompasses and integrates all of them. Unfortunately, there is still considerable confusion about what CIM involves and what it means. Many CIM proponents focus on the creation and use of a company-wide integrated database and network.

While these are important aspects of a CIM system, having them does not mean that a firm is integrated. Mize's definition takes a very broad view of CIM with the primary focus being the rationalization and integration of all aspects of the manufacturing organization. If we accept this view, then an organization desiring to implement CIM must concentrate on rationalizing their production system, their information system, and their managerial/control system. In this regard IPD is a mechanism for rationalizing the design process. That is, IPD's use of multi-functional teams forces us to breakdown functional barriers within the organization (i.e., integrate the managerial system). IPD also provides the motivation and necessity for integration of the information system in order to more effectively communicate and share data among team members and teams. In a CIM system, as illustrated in the following figure, an IPT would utilize an integrated CAD, CAE, CAPP, and CAM system in the development and production of new products.
CIM is a conceptual approach to helping manufacturing organizations respond to the difficult environment in which they operate. CIM is not a product that can be purchased and installed. CIM is a way of thinking about and solving problems. The emphasis is on understanding how to create effective manufacturing enterprises. The determination to apply this understanding must come from personal commitment. CIM is thus taken here to involve the design or redesign of an entire manufacturing enterprise, so that all aspects of the system work together effectively. In most of the cases of interest, integrated information flow, the widespread application of computers, and high levels of automation result from such design efforts. However, these technologies are identified here as a means to an end; the emphasis is on understanding how to most appropriately use all available resources to achieve enterprise objectives.

The advantages of conversion to CIM-oriented operations for companies were found as:

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<tr>
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<th>Reduction in engineering design cost</th>
<th>25 - 30 percent</th>
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<tr>
<td>2</td>
<td>Reduction in overall lead time</td>
<td>30 - 60 percent</td>
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<tr>
<td>3</td>
<td>Increase in product quality</td>
<td>2 - 5 times</td>
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<tr>
<td>4</td>
<td>Increase in capability of engineers</td>
<td>3 - 35 times</td>
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<tr>
<td>5</td>
<td>Increase in productivity of production operations</td>
<td>40 - 70 percent</td>
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<td>6</td>
<td>Increase in productivity of capital equipment</td>
<td>2 - 3 times</td>
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<tr>
<td>7</td>
<td>Reduction in work-in-progress</td>
<td>30 - 60 percent</td>
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Toward Competitive Manufacturing Systems:

The management of a manufacturing system to best use all resources, and the management of technology to best achieve system objective, are both essential aspects of problem solving. Skilled management is required to make the best use of available resources. In today's manufacturing setting, technology must be viewed as a potential resource. Thus, the management of technology including selection of the most appropriate technology for use and its optimum application is an essential management task.

Strategy Development For CIM Implementation

The implementation of CIM would result in getting all "islands of automation" in the factory to work together as one functioning unit. The range of benefits includes:

- Inventory reduction
- Manufacturing cost reduction
- Product quality improvement
- Increased manufacturing flexibility
- Improved On-time delivery
- Allowance for dynamic market management

Typical problems in CIM strategy development include:

Lack of management commitment
The driving force must come from a top management committed to this new way of doing business is necessary.

Lack of knowledge of long term business goals
All levels of management and workers should involve, otherwise the wrong type of process being implemented or the wrong type of process being installed

Lack of in-house expertise of current systems
Multi-background teams with many skills, ranging from software, hardware, to business management expertise are needed.

Methodology
Phase I: Concept Development

- Company goals and objectives
- Commitment

Justification

Phase II: Concept Design and Integration

- Project team
- Requirements
- User involvement and vendor support
- Design/Implementation
Phase III: Proof of Concept

New Manufacturing Enterprise Wheel
- Customer, is the primary target for all marketing, design, manufacturing, and support efforts in the enterprise. Only with a clear understanding of the marketplace and the customer can the enterprise be successful.

- The 2nd layer on the wheel focuses on the means of organizing, hiring, and training, motivating, measuring, and communicating to ensure teamwork and cooperation in the enterprise. The techniques used to achieve this goal include self-directed teams, teams of teams, organizational learning, leadership, standards, rewards, quality circles, and a corporate culture.

- The section 3 focuses on the shared corporate knowledge, systems, and common data used to support people and processes. The resources used include manual and computer tools to aid research, analysis, innovation, documentation, decision making, and control of every process in the enterprise.

- The 4th layer, three main categories of processes, product/process definition, manufacturing and customer support, make up this section of the wheel. Included in this group are fifteen key processes that form the product life cycle.

- The 5th layer, enterprise has resources that include capital, people, materials, management, information, technology, and suppliers. It also has responsibilities to employees, investors, and the community, as well as regulatory, ethical, and environmental obligations.

- The final part of the wheel is the manufacturing infrastructure. This infrastructure include customers and their needs, suppliers, competitors, prospective workers, distributors,
natural resources, financial markets, communities, governments, and educational and research institutions.

The three major CIM components

- Production management,
- Data management, and
- Communications management

The three major CIM components production management, data management, and communications management -- are described in terms of software available today and future software based on emerging international standards. Key standards efforts such as product data exchange, open systems interfaces, database systems frameworks, and CIM frameworks are described. Achieving an integrated manufacturing environment depends upon the design and implementation of system architecture for CIM. Within this architecture computer software systems can be developed to drive the processes defined by CIM. The system architecture includes three separate but related architectures. These are production management, data management and communications (Jones, et al). Production management includes all of the functions related to the customer order, design, fabrication (e.g., machining), inspection, and customer support of products. Data management includes all functions related to the delivery of accurate and timely information to the production management processes. Communication management includes all functions required for the reliable transmission of messages among all of the computer systems in the enterprise.

The present state of software associated with the implementation of CIM architecture is explained here. Emphasis is placed on the need for the implementation of standards that will facilitate the integration of the software into a cost-effective CIM environment.

Production Management Systems

Production management systems can be divided into three major areas: manufacturing data preparation, shop-floor control, and administrative management. Manufacturing data preparation includes all the functions required to generate the data needed to manufacture a product capable of meeting a particular customer’s requirements. Shop-floor control includes all the processes involved in manufacturing a particular product. Administrative management includes all the functions required to manage the overall enterprise, independent of any single product requirement.

Manufacturing data preparation software systems include Computer Aided Design (CAD), Computer Aided Processing Planning (CAPP), and Computer Aided Manufacturing (CAM) systems. CAD systems are used to take user product requirements and generate product
designs which include geometry data, tolerances, materials, and other required manufacturing specifications. CAPP systems can be used to take the output of a CAD system and generate a process plan that is a complete list of raw materials, tools, machines, fixtures, and machining instructions to be used during the fabrication process. CAM systems starting with the output of the CAD system (and CAPP system) can be used to generate the Numerical Control (NC) code for machine tools. In some cases "CAM" can mean also the inspection code for coordinate measuring machines or the robot commands for controlling an industrial robot. For most CAM applications, the user must interact with the system in generating the final NC code for a given machine.

At the present time, there is a broad range of software products that provide capabilities usually as a function of the product type. The CAD system used for mechanical design is usually quite different than the system used for electronic design and relies on different analysis tools to generate an efficient product design. This is mainly due to the inherent 2-D nature of electronics and the 3-D nature of mechanical parts. CAPP systems are mostly interactive with the user participating in the generation of the plans. There are several programs presently available that employ "expert systems" that allow for the automatic generation of process plans, but these programs usually require an intensive initial effort to identify the rules that will be used for specific part families. Although CAD and CAPP systems were originally mainly available on mainframes, today they are almost exclusively implemented on either engineering work stations or personal computers (except in industries such as aerospace where large mainframes are a way of life).

Today's data preparation systems will be changing rapidly as the emerging standard, STEP (Standard for the Exchange of Product Model Data), becomes mature (Smith, et al). This standard will have the capability of defining all the information about a product needed for its entire life cycle. STEP will also specify the database environment in which the product data will be accessed. Finally STEP will have a set of "application protocols" which will specify both the information itself as well as how it is used for specific CIM applications.

Shop-floor control systems are usually hierarchical. One such system is a five level structure containing facility, shop, cell, workstation, and equipment (Bloom and McLean). The facility level performs the functions as defined for manufacturing data preparation and administrative management. The other four levels are responsible for driving the equipment on the shop floor based on the production schedule and products to be manufactured. At the present time there are many programs available for performing job scheduling and controlling the shop operations. However, there is not an effective link between shop-floor control and administrative management systems.
This has resulted in the need to have software translators to convert the output of process planning systems and NC programming systems into the actual input used to drive the machines on the shop floor. Research efforts have been involved in developing a true "data driven" production environment, but this will ultimately require changes in the machine control architectures (as in the Next Generation Controller Project underway by the U.S. Air Force Manufacturing Technology Program.) In fact, future shop floor control systems will be driven by product data (e.g. STEP) that will eliminate the need for much of the intermediate software translations that are presently required.

Administrative management systems include marketing information, sales/order processing, production program planning, purchasing, sales/dispatch, accounts payable, requirement planning, capacity management, material flow, cost accounting, payroll accounting, personnel information, accounts receivable, and financial accounting. These systems have been automated long before the manufacturing-related systems. The computer programs are usually developed for large mainframe computers (although today these systems are available on personal computers). They are often obtained as an integrated set from a single software vendor where the database integration comes with the programs. Historically there has been little interaction between the manufacturing software developers and the business systems developers. It is for this reason that CIM has been very difficult to implement (Fossum and Ettlie).

**Data Management**

There are two major issues related to data management: data modeling and data administration. Data modeling involves the development of a conceptual model of all the information involved in the CIM environment. There are several modeling techniques now available (as software products) that allow the representation of the real-world objects, as well as the information units that describe and distinguish them. An example of a public domain modeling technique is IDEF1, which has been used both in the manufacturing database environment, as well as in the standards community for STEP (IDEF1 1981). It is an extremely complex effort to integrate all the information used by CIM applications (Scheer), but a necessity, if an enterprise wants a successful CIM environment.

The second data management issue, data administration, is the data services that control access to all data in an enterprise. This includes "query processing", "transaction management", and "data manipulation" (Jones, et al). There are many software database systems available today, some that allow only for a centralized access to shared data among the CIM processes and some that allow for a distributed access to the CIM data. Some of the database systems allow the applications that access the database to interact through a "data dictionary" which defines all the data and their
interrelationships. In most cases, this means that the CIM database can be restructured without all the applications being revised.

The critical issue is how to integrate database systems from different vendors that are implemented on different computer platforms. This is the heterogeneous distributed systems environment that is the reality in the CIM world. An example of the system architecture required for implementing this environment is the Integrated Manufacturing Data Administration System (Libes and Barkmeyer). Today’s software systems are already making use of such standards as SQL (Standard Query Language), IRDS (Information Resource Dictionary System), and RDA (Remote Data Access) in order to offer complete data administration capability for CIM (Bloom, et. al. 1988). By using this open database architecture approach, the CIM application software vendors can produce software independent of the actual physical means of accessing the information that is required by the application.

Communication Management

The communications system provides the functions needed to transmit messages among computer programs executing production and data management tasks. There are three key concepts that facilitate effective CIM networks (Jones et al):

1. CIM programs use one common connection for communications with other programs, regardless of function or location,
2. Physical networks are transparently interconnected, and
3. Technology and topology of sub networks are chosen to provide optimal communications responsiveness.

The communications software that is available today falls into two categories: closed system and open systems. The closed systems are those which rely only on products from a specific computer vendor. The open systems are those that adhere to the Open Systems Interconnection (OSI) network architecture (Weston et al). Specific applications within the OSI framework include the Manufacturing Automation Protocols (MAP) concept of one physical bus connecting all factory-floor stations, and the Technical Office Protocols (TOP) used for connecting engineering work stations. In particular, there is the Manufacturing Message Specification (MMS) which provides the level of message handling support required at the specific device to be connected to the network.

Standards Issues

At the present time, implementing CIM in a company (or an enterprise that involves an industrial network of partners and subcontractors) requires a tremendous effort to develop software translators for the
different applications and databases. If CIM is to be effective, internationally agreed-upon interface standards are necessary to avoid huge translation costs. The European Economic Community produced a Directory of European Standardization Requirements for Advanced Manufacturing Technology (Directory 1990) that lists the required standards in terms of seven classifications:

**Interworking** covers the general framework for CIM architecture and communications (such as OSI).

**Data** covers the definition of information and related application data (such as STEP).

**Processing** covers the open systems framework for database systems and operating systems (such as IRDS).

**Control Equipment** covers the interfaces to manufacturing systems (such as NC controller codes).

**Human Aspects** covers the integration of human operators into a manufacturing environment.

**Mechanical Aspects** covers the standards needed for different classes of machines (such as turning centers).

**General Aspects** covers a set of methods of analysis and representation of enterprises.

Perhaps the most important standards activity at this time is the work by the International Organization for Standardization (ISO) Technical Committee on Industrial Automation (TC184) Subcommittee on Architecture and Communications (SC5) Working Group on CIM Architecture (WG1) on a framework for modeling CIM (ISO 1990). This work is based on the CIM-OSA (CIM Open Systems Architecture) project (ESPRIT 1989) which could revolutionize the development of CIM software systems.

CIM software systems of the future will be "plug compatible" with any system in an enterprise based on the emerging standards described in this paper. Applications will have standard interfaces to database systems through standard communication protocols. All applications will be able to exchange product data through the use of a standard product data exchange structure. Software systems will be written using programming languages that exist in a standard operating systems framework (such as POSIX, an emerging international standard based on UNIX) that allows for total portability of applications and data among computer systems.

Perhaps the most exciting effort under way is the increased use by companies of "concurrent engineering" methodologies (Winner). The research and development now proceeding in design theory and methodology will lead to new ways of integrating the processes that make up a part of the product’s life cycle.

**Key challenges**

There are three major challenges to development of a smoothly
operating computer-integrated manufacturing system:

- Integration of components from different suppliers: When different machines, such as CNC, conveyors and robots, are using different communications protocols. In the case of AGVs, even differing lengths of time for charging the batteries may cause problems.

- Data integrity: The higher the degree of automation, the more critical is the integrity of the data used to control the machines. While the CIM system saves on labor of operating the machines, it requires extra human labor in ensuring that there are proper safeguards for the data signals that are used to control the machines.

- Process control: Computers may be used to assist the human operators of the manufacturing facility, but there must always be a competent engineer on hand to handle circumstances which could not be foreseen by the designers of the control software.

Pragmatic Applications

It might be more prudent for a company to begin the process of computer integration with CAD/CAM and an integrated business data base. There are many reliable and proven CAD/CAM software packages available, as there are integrated business software systems. Taking small steps instead of a wholesale CIM approach is advisable.

Advantages

CIM combines development policy competence with a thorough knowledge of the labour market. Our organisation and the managers and technical specialists we place are integrated into numerous networks and partnerships that span the globe. You, as employer, stand to profit from these connections.

Example:

The following example of a manufacturing DVD / CD Storage unit factory. The computer system is in control of every stage from design and the ordering of materials to the manufacturing processes and distribution to customers.

This is the complete automation of a manufacturing facility such as a factory. All functions are under computer control. This starts with computer aided design, followed by computer aided manufacture, followed by automated storage and distribution. One integrated computer system controls all that happens.
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**Stage One** - Computer Aided Design. A product is designed totally on computer. When complete it is tested or its functions simulated on screen before even a prototype is made. If a circuit is involved it is designed by using software and tested on screen. Improvements / alterations are made to the design using the same CAD software.

**Stage Two** - Prototype Manufacture. Prototypes are manufactured on machines such as 3D printers which produce an accurate 3D model. CNC routers and laser cutters may also be used to produce a realistic model. Sometimes working models are manufactured.

**Stage Three** - The computer system controlling the plant works out the most efficient method of manufacture. It calculates costs, production methods, numbers to be manufactured, storage and distribution.

**Stage Four** - The computer system orders the necessary materials to manufacture the product. Keeping costs to a minimum. The “just in time” philosophy is applied. This means that materials/components are ordered as needed. Very little is stored at the factory. Usually only enough materials are stored to keeps the factory going for a small number of days. Materials are automatically reordered when required, to keep the factory working smoothly and continuously.

**Stage Five** - Manufacturing begins with the product being made using CAM (Computer Aided Manufacture). Computers control CNC machines such as laser cutters, CNC routers and CNC lathes.

**Stage Six** - Quality control is applied at every stage. The product is tested using computer control inspections. For instance, the accuracy of manufacture is tested automatically. This ensures that the product is manufactured to the correct sizes.
Stage Seven - The product is assembled by robots. This is automated (controlled) by the computer system.

Stage Eight. The product is quality checked before being stored for distribution to the customer. All storage is automated. This means that computer controlled vehicles move the finished product from the manufacturing area to storage. The computer systems keep track of every individual product. Products are bar coded which are constantly scanned and recorded by the computer system.

Stage Nine - The product is automatically moved from store to awaiting lorries/trucks for distribution to the customer.

Stage Ten - Financial accounts are updated, bills chased up and paid by the computer system.