ERP—A Manufacturing Perspective

INTRODUCTION

The manufacturing segment accounts for nearly 25% of the total IT spending in the country, which makes it the largest segment. According to an IDC study, the manufacturing IT spending in the Asia/ Pacific (excluding Japan) or APEJ region, will reach US$22 billion in 2010. The APEJ region will continue to be a fast-growing regional economic block, powered by the emerging economic engines of China and India. The number of organizations that have reported a close alignment of business goals with IT is increasing. 44% of the organizations in manufacturing and engineering/ auto segment have aligned their business goals very closely with IT.

The process manufacturing sector traditionally spends more on IT because of the larger population of companies engaged in this activity as well as their scale of operations. In general, the business and IT priorities of both process and discrete manufacturing are the same—controlling inventory, production costs, marketing costs, and improving supplier and delivery channel relationships on the business front; and improving IT infrastructure, automating internal and external processes, and better decision-making using IT. At the same time there are differences in the emphases that are given to the various aspects of IT usage. In this analysis, we take the segments together when discussing areas where they exhibit similarity and separately when we discuss areas that distinguish them from each other.

IT investments by large manufacturing organizations were on the decline last year, with many industries like automobiles, steel, cement and others facing a downturn in their business. Overall, many of the smaller manufacturing organizations, which have been traditionally poor in IT usage turned towards IT. Traditional large buyers like Bajaj Auto, Ashok Leyland, and TISCO, to name a few did not have any major IT project underway. Public sector steel companies slowed down the IT investments, whereas their counterparts in the private sector spent on ERP and plant automation. In the pharmaceuticals industry, the WTO agreement on patents has forced companies to get patents on their formulations. Clinical trials, a very data-intensive area, are fast emerging as an application in the pharmaceutical industry.

The major investment heads for manufacturing companies are:

- Infrastructure (systems, network components, messaging systems and so on)
- Software design and application development
- Software packages (word processors, spreadsheets, databases and so on)
- Enterprise resource planning (ERP) packages
- Packaged application implementation services
- Consulting services
- External connectivity i.e. connecting to dealers and suppliers (supply chain)

- Data warehousing
- E-commerce

Many manufacturing organizations, especially in the private sector have messaging and groupware in place for intra-organizational communication. Network-centric applications continue to be developed. Maruti Udyog is moving from its e-mail based messaging with dealers to an Internet-based one. A Kolkotta based manufacturing organization is setting up a sophisticated intranet with countrywide fax routing capabilities. Companies like IBM and Digital, which have a portfolio of solutions for the manufacturing industry through years of global experience, are bringing out newer application areas like e-commerce for Indian manufacturing organizations.

ERP

ERP is the watchword in the manufacturing industry and more and more companies are turning to ERP solutions. With almost all the global players present in the country, the stage is set for the launch of Indian manufacturing sector into the age of integrated applications. ERP is a high impact area because it leads to a bottom-up change in the organization i.e., it is by no means an incremental technology. While many companies do not even understand the full implications of using an ERP, they are nevertheless enchanted by the concept of integrated applications. But a mad rush into ERP without the necessary business process discipline will lead to more flops than hits.

The move to ERP is a high investment proposition with accompanying investments in hardware, connectivity and implementation services, apart from a lot of invisible costs involved in process change, change management and training. There are more than 130 ERP implementations underway in the country presently. SAP, the largest ERP vendor has around 75 customers in the country of which 52 are in the manufacturing industry, with a dominance of the discrete manufacturing companies. Most of these are first generation ERP, which addresses the area of integration of financials with logistics. These companies are looking at the first phase of integrating financials with logistics using a packaged application. The next phase taken up is either sales and distribution or production, depending upon the priority of the company. Demand driven industries like the automotive sector, consumer goods, processed foods and the like would take up sales and distribution. There are presently around 40 companies, which are in the process of implementing solutions in this area. Possibly, an equal number of companies are looking actively at production as the next application to be integrated. But it has been observed in the last one year that companies are willing to take up both the phases together right in the beginning. This is due to the fact that there is a lower perceived risk in implementation because of codeless implementation becoming the order of the day, thereby leading to better implementation maturity. Another reason is that there are enough process models available now in the country itself. Considered together, the total time taken for rollout is shortened.

The process industry focus is on integrating business applications with the plant floor. The major areas under consideration are finance, materials, and sales and distribution. Since production in the case of the process industry is plant-oriented, it falls within the realm of distributed digital control systems. Further, there are no multi-stage assemblies as in discrete manufacturing. The most important area after this is the maintenance function.

Selection of the proper ERP package is based solely on the business needs and the fit that the product offers. An interesting example is that of L&T, which uses two ERP solutions from SAP and Baan for two of its divisions. One of these, the unit equipment division, uses Baan ERP solution with the finance, manufacturing, distribution, shop floor scheduling, and budgeting modules. It helps the company gain competitiveness in global deals.

ERP presently is restricted to being a transaction-oriented operations system in the country. As of now, there are few examples in the country of strategic information systems built around an ERP solution. There are quite a few areas of refinement to ERP that are being actively looked at by some of the progressive companies. Termed, 'extended ERP' it seeks to encompass the suppliers and delivery channel partners into the organization's enterprise information system. Companies that operate in specific markets are actively looking at constraint based planning tools for supply chain planning and demand-chain planning.

CAD/CAM

CAD/ CAM is the other major focus area for the manufacturing sector. Traditionally, the automotive and aerospace industries are the largest consumers of CAD/ CAM. With the automotive sector in the doldrums, vendors were not able to meet their expectations from this industry. On the other hand, the farm auto sector did better in comparison. Mahindra & Mahindra (Tractor Division) has grown considerably in the last three years and their manufacturing capacity has doubled. This is accompanied with significant enhancement in design capacity. Increasing design capacity is also a competitive edge for a company. For example Tata Johnson Controls, which makes seating systems started off by designing seats solely for Ford and then with increased design capacity using advanced CAD/ CAM, went on to supply seating systems to many other auto majors. The major focus area in CAD/ CAM is on design analysis, development and manufacturing. Styling and ergonomics are the refinement areas to achieve design excellence. There were only marginal investments in modeling. There is also a trend towards reverse engineering, especially in the engineering and appliances industry. Many companies in the BPL Group have taken up reverse engineering.

Product data management (PDM) is another leading edge CAD/ CAM philosophy. TELCO and Mahindra Ford have integrated many of their suppliers. For the supplier it means enhanced competence and improved competitiveness. Many of these suppliers with their improved design capacity and integration with OEMs have also started exporting. Brakes India is supplying brakes to many of the European auto manufacturers.

Another reason, which prompts a company to make design an imperative is the improved alignment that many manufacturing organizations have acquired due to business process reengineering. An important trend is the integration of tier 1 and tier 2 suppliers with OEMs for standard product information.

In the heavy engineering sector, many companies have signed up multi-year contracts with global majors like SDRC and PTC. BHEL has a five-year CAD/CAM contract across all units with SDRC. Similarly Siemens, L&T, and Lakshmi Machine Works are investing in CAD/CAM to beef up their research capability.

MATERIALS REQUIREMENT PLANNING (MRP)

Initially manufacturers viewed MRP as a better method for ordering components than the independent demand inventory models they had been using during the 1950s and 1960s. However, it has evolved into a comprehensive priority planning system. MRP provides a method that helps keep order due dates valid even after the orders have been released to the shop floor or outside vendor.

MRP systems can detect when the due date of an order i.e. the date the order is scheduled to arrive, is out of alignment with its need date i.e. the date the order is actually required.

During the 1970s and 1980s techniques for helping to plan capacity requirements were tied up with MRP. Tools were developed to support the planning of aggregate production levels and the development of anticipated production schedules. Systems to aid in executing the plans were incorporated: shop floor control for the 'in-house factory' and vendor scheduling for the 'outside factories'. The expanded MRP system become known as closed-loop MRP because it provided feedback from the execution function to the planning functions, so manufacturers could change plans when necessary. Eventually practitioners expanded closed-loop MRP to provide the ability to translate the operating plan—expressed in manufacturing terms such as units and kilograms, into financial terms i.e. rupees, and the capability to simulate the effects of various plans in terms of both units and rupees. The new system, which was called manufacturing resource planning (MRP II), was a comprehensive approach for the effective planning of all the resources of a manufacturing organization.

Production and materials planning is critical to the success of a manufacturing company. A company can have the best product design, the newest manufacturing facilities, the latest equipment and all the latest production technologies like CAD/CAM, robotics, automated guided vehicles (AGVs), etc., but not the ability to compete. MRP has proved to be an effective production and inventory planning system in a wide variety of environments.

An MRP system requires 3 types of information:

- Master production schedule (MPS)
- Bill of material (BOM)
- Inventory records (IR)

The MPS is a detailed production schedule for finished goods or end items that provides the major input to the materials requirement planning process. Associated with each finished product is a BOM, which describes the dependent demand relationships that exist among the various components—raw materials, parts, sub-assemblies, etc.—comprising the finished product. The entire set of BOMs for the company's finished products is called the BOM file. Inventory status data for each product or component such as stock-on-hand, stock-on-order, etc. are provided by the inventory records, which also contain planning factors like lead-time, safety stock, re-order level and so on.

MRP logic uses the MPS, the BOM file and the inventory records to determine the following for all components:

- Planned order quantities
- Planned order release dates (to shop floor/ suppliers)
- Planned order due dates

The MRP system calculates the release dates and the due dates taking into consideration the lead-times required to produce or procure the components and recognizing the order, which are assembled into the finished product. If the MRP process is done in conjunction with capacity planning, the production facility should have the capacity to complete the orders on-time.

BILL OF MATERIAL (BOM)

A BOM defines the relationship of components to end items. The BOM identifies all components used in the production of an end item, the quantity required and the order in which the components are assembled. For example, consider an office chair. The chair is composed of a seat cushion, back cushion, adjuster mechanism, base unit, wheels and fasteners. To manufacture the chair the wheels, base unit, and adjuster mechanism are assembled into a chair frame, to which the base cushion and back cushion are attached. All the fasteners are identical; there are 11 of them for this chair.

Figure C.1 shows a BOM for this chair. To simplify the discussion this BOM does not show all purchased raw material (paint, steel tubing and so on). This form of the BOM is frequently called a product structure diagram.

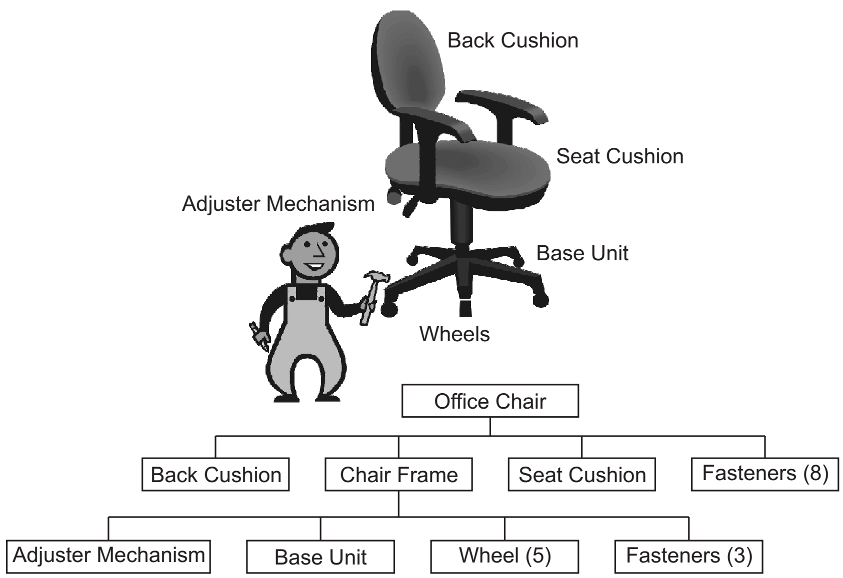

Fig. C.1 *Bill of Material for the Office Chair*

All items appearing below the final product (office chair in this case) in a BOM are referred to as components, whether they are raw materials or component parts or sub-assemblies. In the above figure all items with the exception of the 'office chair' are components. The term parent component describes a component at one level in the BOM that is composed of components from the next lower level in the BOM. The lower level components are called child components.

The key to MRP is time phasing of requirements for components based upon the structure of the BOM. If the time required to either manufacture or purchase components (lead-time) is known, we can determine when orders should be released to the shop floor or outside suppliers to ensure that the required components will be available when needed.

CLOSED-LOOP MRP

For an MRP system to be useful the production system must be able to complete component orders on-time. Closed-loop MRP uses capacity planning and feedback to improve the ability of the production system to complete work as planned. Capacity planning tools allow the operations manager to adjust the MPS and/ or planned order release dates or obtain additional capacity so that shop orders can be completed by their due dates. MRP planners use a number of planning factors (capacity planning factors, lead-time estimates, safety stocks, safety lead-time, etc.) and tools (capacity planning, frozen time horizons, firm planned orders, etc.) to improve the quality of the materials schedules generated by the MRP system. To determine how well the planning factors and tools are working; MRP planners need feedback from the shop floor and the purchasing department. With effective feedback the MRP planner can revise the planning factors and techniques so that better materials schedules can be developed in the future.

Feedback is also important when suppliers or the shop floor cannot meet order due dates. Timely feedback to MRP planners allows them to develop alternatives or at least to minimize the effect of the problem. For example, production of a batch of a component may not be completed on-time, but enough components may be available in on-hand inventory and safety stock to allow the production of a smaller quantity of the parent item to satisfy the MPS until production of the component is completed.

MANUFACTURING RESOURCE PLANNING (MRP II)

MRP was originally developed as a computer system that was limited to materials planning. As computer technology and MRP systems developed, it became clear that MRP systems maintain extensive information that can be used for other company functions. For example, MRP systems maintain accurate inventory information. Combining this information with cost data allows accounting personnel to have accurate inventory information in meaningful financial terms. Rather than having separate production and accounting systems, a company can expand MRP to meet the requirements of both the systems.

MRP II is an expansion of closed-loop MRP for managing an entire manufacturing company. MRP II systems provide information that is useful to all functional areas and encourage cross-functional interaction. MRP II supports sales and marketing by providing an order promising capability. Order promising is a method of tying customers' orders to finished goods in the MPS. This allows sales personnel to have accurate information on product availability and gives them the ability to give customers accurate delivery dates. MRP II supports financial planning by converting materials schedules into capital requirements. A company can use MRP II to simulate the effects of different master production schedules on material usage, labor and capital requirements. MRP II provides the purchasing department with more than just purchase requisitions. The long-range planned order release schedules can be used to provide purchasing with information for developing long-range buying plans. It is now common for suppliers to directly access a customer's MRP II system to receive up-to-date information on the customer's planned material needs. Information in the MRP II system is used to provide accounting with information on material receipts to determine accounts payable. Shop floor control information is used to track workers' hours for payroll purposes.

Manufacturing is the central function in a manufacturing company. The information required to successfully plan and schedule production is valuable to the other (supporting) functions in the company. MRP II systems increase a company's efficiency by providing a central source of management information.

DISTRIBUTION REQUIREMENTS PLANNING (DRP)

DRP extends the logic of MRP into the physical distribution system. It provides a mechanism for integrating the physical distribution system with the production planning and scheduling system. DRP assists companies that maintain distribution inventories in field warehouses, distribution centers and so forth, by improving the linkage between marketplace requirements and manufacturing activities. A DRP system helps management to anticipate future requirements in the field, closely match the supply of products to the demand for them, effectively deploy inventories to satisfy customer requirements, and rapidly adjust to changes in the marketplace. A DRP system also engenders significant logistics saving through improved planning of transportation capacity needs, vehicle loading, vehicle dispatching and warehouse receipt planning.

DRP has a central coordinating role in the physical distribution system similar to MRP's role in coordinating materials in the manufacturing system. DRP provides the necessary data for matching customer demand with the supply of products at various stages in the physical distribution system, and products being produced by manufacturing. The DRP record is similar to an MRP record. For example for a distribution center, forecasts requirements for a product replace gross requirements and are used in conjunction with information concerning inventory on-hand at the distribution center, inventory in transit to the distribution center (analogous to scheduled receipts in MRP), transportation lead-time, safety stock requirements and standard shipping quantities to determine time phased planned shipments to the distribution center (analogous to time phased planned orders in MRP).

In addition to determining time phased planned shipment quantities DRP provides a company with access to all the detailed local information for managing physical distribution and for coordinating with manufacturing. Because customer demand is independent, each distribution center for example, needs detailed forecasts of n-item demand. Careful attention to actual customer demand patterns may allow forecasts generated by a standard forecasting method to be tailored to local conditions, resulting in improved accuracy and inventory savings. As actual field demands vary around the forecasts, adjustments to plans are made by DRP. DRP makes continual adjustments, sending inventories from the central warehouse or manufacturing facility to those distribution centers where they are most needed. In a case when the total inventory is insufficient to satisfy requirements DRP provides the basis for accurately stating when delivery can be expected and for deciding allocations, such as favoring the best customers or providing inventory to last the same amount of time at each distribution center. In short, DRP is a critical link between the marketplace, demand forecasting and master production scheduling.

JIT (JUST-IN-TIME) AND KANBAN

Basically JIT means to produce goods and services when needed, not too early and not late. It is time based and often has quality and efficiency targets. JIT is a production philosophy and not a technology. This is due to the fact that it looks at the whole of the production system and goes far past inventory control. The JIT system has been called numerous names from zero defects and synchronous production to stockless production at Hewlett Packard. The JIT system also uses the pull method of scheduling material flow (Kanban). A JIT system aims to make goods available just in time, and these can be parts, products or sub-assemblies. It achieves some of the following benefits:

- Increased flexibility
- Parts reduction
- Increased quality
- Simplicity of system

The increased flexibility allows a company the ability to react to changing events i.e. change in customer orders, or design modifications. Increased productivity means that the shortest time and minimum of resources are needed to make a product. The overall objective of JIT is to produce parts in lot sizes of one, but this is not economically feasible due to setup cost compared to carrying cost.

At the heart of JIT is a set of tools and techniques. To achieve the aims of JIT then, a disciplined approach is needed which incorporates three principles applied to the organization:

- Elimination of waste
- Total quality management (TQM)
- Total employee involvement

Elimination of Waste

Waste elimination is basically removal of any activity that is not value-added, but first you have to recognize it. These activities do not increase product-value and are costly to the company. Examples of non-value-adding activities include traditional production methods i.e. inspection of parts, holding stock, inventories, time, etc. Waste can be eliminated from these activities by removal of defects and not over producing hence, make-to-order.

Total Quality Management

TQM eliminates waste by eliminating defects. In a JIT environment the aim is to prevent defects occurring, and this is achieved by detecting problems at their source. The whole of an organization are involved from manufacturing to product development and purchasing. Manufacturing uses statistical process control (SPC) and in-process testing (to allow detection at source) while product development ensures that new products can be manufactured to specification. Purchasing makes sure that the parts that are bought are of the required quality.

Total Employee Involvement

Total employee involvement has management providing the leadership and results in employees wanting to be involved in the processes. Opportunity is provided through education and training, and work teams.

Kanban

Most manufacturing companies view the making of a product as continuous—from design, manufacture and distribution, to sales and customer service. For many companies the heart of this process is the Kanban, a Japanese term for 'visual record', which directly or indirectly drives much of the manufacturing organization. It was originally developed at Toyota in the 1950s as a way of managing material flow on the assembly line. Over the past three decades the Kanban process, which is a highly efficient and effective factory production system has developed into an optimum, manufacturing environment leading to global competitiveness.

The Kanban process of production is sometimes incorrectly described as a simple just-in-time management technique, a concept that attempts to maintain minimum inventory. The Kanban process involves more than fine-tuning production and supplier scheduling systems, whereby supplying these when needed in production minimizes inventories and work in progress in closely monitored. It also encourages industrial reengineering such as a 'module and cellular production' system and group production techniques, where team members are responsible for specific work elements and employees are encouraged to effectively participate in continuously improving Kanban processes within the Kaizen (continuous improvement) concept.

The Japanese refer to Kanban as a simple parts movement system that depends on cards and boxes/ containers to take parts from one workstation to another on a production line. Kanban stands for Kan or card, and Ban or signal. The essence of the Kanban concept is that a supplier or the warehouse should only deliver components to the production line as and when they are needed so that there is no storage in the production area. Within this system workstations located along production lines only produce/ deliver desired components when they receive a card and an empty container, indicating that more parts will be needed in production. In case of line interruptions, each workstation will only produce enough components to fill the container and then stop. In addition, Kanban limits the amount of inventory in the process by acting as an authorization to produce more inventory. Since Kanban is a chain process in which orders flow from one process to another, the production or delivery of components is pulled to the production line. In contrast to the traditional forecast oriented method where parts are pushed to the line. The advantages of Kanban over the traditional push system are:

- A simple and understandable process
- Provides quick and precise information
- Low-costs associated with the transfer of information
- Provides quick response to changes
- Limit of over-capacity in-processes
- Avoids overproduction
- Minimizes waste
- Maintains control
- Delegates responsibility to line workers

Benefits of JIT

JIT is continuously seeking to reduce inventory levels of work in-process (WIP), raw materials and finished goods. Therefore less space is required with lower inventories, so there is less chance of the product becoming damaged, spoiled or obsolete. Material handling of lots can be automated and operations can be placed closer together enhancing communication and teamwork. The following are some of the benefits of a properly implemented JIT system:

- **Increased flexibility**—This can be done through small batch sizes, which achieves faster throughput. Flexibility is a pre-requisite if small batch sizes are to be kept. A flexible workforce means that the operators must be multi-skilled which is done through training. The worker should also be free to move from low demand to high demand areas.
- **Parts reduction**—JIT continuously seeks to reduce inventory levels of raw materials, work in-process and finished goods. Lower inventory means less space, less chance of obsolescence, damage or spoiling. Work in-process inventories are reduced as a company implements the "pull system". Raw material reduction is a key part of the JIT system and requires a sound relationship with the suppliers. Inventories can be reduced if products are produced, purchased and delivered in small lots. To avoid unnecessary production delays, raw materials must arrive just before they are needed and, they must be the correct material and must satisfy the quality specifications.
- **Increased quality**—When operating a JIT system disruption has a major impact, so quality problems need eliminating. Benchmarking, quality function deployment and service design

can be used for service operations. Service employees need to learn the value of providing defect free services.

- **Simplicity of system**—Product mix or volume changes planned by the master production schedule (MPS) can be accomplished by adjusting the number of cards in the system. Production orders are prioritized according to the cards on a post. Production orders for parts that are running low are moved in front of parts that have more supply.

Potential Pitfalls of JIT

Many companies fail to understand what JIT is and what it can mean to them because they fail to implement it properly. Most importantly they need to be aware of the tasks, resources, timescale and costs. For this, the system will need the full backing of top management. The JIT system will also fail if an adequate education program is not provided. If careful planning of process and control improvements is not strictly followed, this will result in JIT not being realized. The planning stage will require dedication and time and may also require the assistance of an external consultant(s). All the above must be integrated with moves towards JIT purchasing or again true JIT will not be achieved. The JIT system should not be viewed as a one-off scheme but as an ongoing continuous process.

COMPUTER-AIDED DESIGN/COMPUTER-AIDED MANUFACTURING (CAD/CAM)

An increasingly popular tool for product design is computer-aided design (CAD). CAD systems are computer programs or integrated packages for workstation hardware and software that allow the user to draw and easily modify product designs on a computer screen. Advanced CAD systems provide designers with at least 3 major benefits.

- **Graphics capabilities**—CAD systems allow the designer to view a product from different perspectives, including three-dimensional rotations and various cross-sections. The designer can also make proportional changes in scale, or change the angle of an arc with the click of a computer mouse rather than having to re-draw the entire product.
- **Design, storage and retrieval**—Some CAD systems can store the design characteristics of existing products and components. Then for example, if a company needs a gear for a new product, the designer can enter the relevant information about the gear such as its diameter, tooth pattern and required hardness into the CAD system. The CAD system determines whether the company is already using an identical or sufficiently similar gear, in which case a new one is unnecessary. If not, a gear that has similar properties may exist. The designer can then use the design of this similar gear as a starting point for the new gear. This capability not only promotes the use of common components but also reduces design time.
- **Automatic evaluation of specifications**—One of the most time-consuming aspects of design for highly technical products is calculating whether or not product specifications such as strength, heat resistance or aerodynamic drag are satisfied. These calculations can be programmed into some CAD systems so that whenever the designer changes the design (by altering the shape or material to be used), these performance characteristics are re-calculated automatically and compared to the product requirements. This is sometimes called computer-aided engineering (CAE).

The overall benefits of CAD systems can be substantial. The features described above reduce development time and cost, and they improve product quality because more design options can be evaluated in greater detail more quickly. For example, Motorola used three-dimensional CAD to produce its award winning MicroTac pocket-sized cellular phone two years ahead of the competition. It is not uncommon for CAD systems to reduce product cycle times by 10–50 %.

Even greater time and cost reductions have resulted from recent advances whereby CAD engineered designs are converted automatically into software programs for computerized production machines. These are called computer-aided design/computer-assisted manufacturing (CAD/CAM) systems. This automatic conversion eliminates the costly and time-consuming steps of having a person convert design drawings into a computer program for computer-controlled production equipment, such as robots or machine tools. Large automotive or electronics companies alone do not use CAD and CAD/CAM systems. Future Enterprises, the largest maker of wedding jewelry in the United States reported that its CAD/CAM system reduces the time required to design and make jewelry from five months to one week.

PRODUCT DATA MANAGEMENT (PDM)

One of the major manufacturing challenges is to maximize the time-to-market benefits of concurrent engineering while maintaining control of your data and distributing it automatically to the people who need it, when they need it. The way PDM systems cope with this challenge is that master-data is held only once in a secure 'vault' where its integrity can be assured and all changes to it monitored, controlled and recorded.

Duplicate reference copies of the master-data, on the other hand, can be distributed freely to users in various departments for design, analysis and approval. The new data is then released back into the vault. When a 'change' is made to data, what actually happens is that a modified copy of the data, signed and dated is stored in the vault alongside the old data, which remains in its original form as a permanent record.

This is the simple principle behind more advanced PDM systems. To understand it more fully let us look separately at how these systems control raw product data (data management and process management).

Data Management

Manufacturing companies are usually good at systematically recording component and assembly drawings but often do not keep comprehensive records of attributes such as size, weight, where-used, etc. As a result, engineers often have problems accessing the information they need. This leaves an unfortunate gap in their ability to manage their product data effectively. Data management systems should be able to manage both, attribute and documentary product data, as well as relationships between them, through a relational database system. With so much data being generated a technique to classify this information easily and quickly needs to be established.

Classification should be a fundamental capability of a PDM system. Information of similar types should be capable of being grouped together in named classes. More detailed classification would be possible by using 'attributes' to describe the essential characteristics of each component in a given class.

Classification of Components

Components will be entered in the database under a variety of classes, which suit your business needs. Classes themselves can be grouped together under convenient broad headings. This allows all your company's working stock of components to be organized in an easily traceable hierarchical network structure. Each part can be given its own set of attributes. Additionally, some systems allow you to register that certain components are available with specific 'optional' attributes. This can be invaluable in controlling bills of materials (BOMs).

Classification of Documents

Documents relating to components and assemblies can be similarly classified; for example, classes might be 'drawings', '3D models', 'Technical publications', 'Spreadsheet Files', etc. Each document can have its set of attributes—part, number, author, date entered. At the same time relationships between documents and the components themselves can be maintained. So for example, a dossier for a specific 'bearing assembly' could be extracted, containing 2D drawings, solid models and FEA files. PDM systems vary greatly in their classification capability. Some have none. Others support the ability to define a classification only at the time when the database is implemented. More recent PDM systems have provided a capability that can be defined and modified at will as the demands of the organization change.

Product Structure

The third way product data can be accessed is by product structure. For any selected product, the relationship between its component assemblies and between the parts that make up these assemblies should be maintained. This would mean that you could open a complete bill of materials including documents and parts, either for the entire product or selected assemblies. One distinct advantage is the ability to hold not just the physical relationships between parts in an assembly but also other kinds of structures for instance, manufacturing, financial, maintenance or document relationships. So, it is possible for specialist team members to see the product structured from their point of view.

Querying the Data

As you can imagine, you need to be able to 'get at' the components and assembly data by a variety of routes. You could move up and down a classification tree, pick your way through a product structure, simply call-up the data you want by searching for it by name or part number, or search for groups of data by specifying an attribute or combination of attributes. For example, you could ask to see all stainless steel rivets with anodized shanks less than 10mm long.

Process Management

So far we have dealt only with organizing data so that it is easy to access, refer to and cross-reference; basically passive procedures. Process management on the other hand, is about controlling the way people create and modify data—active procedures. This may sound like just a new name for 'project management'. It is not. Project management concerns itself only with the delegation of tasks; process management addresses the impact of tasks on data. Process management systems normally have three broad functions:

1. They manage what happens to the data when someone works on it (work management).

2. They manage the flow of data between people (workflow management).
3. They keep track of all the events and movements that happen in functions 1 and 2 during the history of a project (work history management).

PDM systems vary widely in how they perform these functions. The following is a broad overview:

Work Management

Engineers create and change data for a living. The act of designing something is exactly that. A solid model for example, may go through hundreds of design changes during the course of development, each involving far-reaching modifications to the underlying engineering data. Often the engineer will wish simply to explore a particular approach, later abandoning it in favor of a previous version.

A PDM system offers a solution by acting as the engineer's working environment, meticulously capturing all new and changed data as it is generated, maintaining a record of which version it is, recalling it on-demand and effectively keeping track of the engineer's every move.

Of course, when an engineer is asked to carry out a design modification, he or she will normally require more than just the original design and the engineering change order (ECO). Many documents, files and forms may need to be referred to and other members of the design team involved too. In a traditional design environment you would compile a project folder or dossier, which the team could refer to as needed.

Current PDM systems cope with this requirement with varying degrees of success. One approach is that which emulates paper-based processes by using what are known as 'user packets'. The packet allows the engineer to manage and modify several different master documents simultaneously as well as providing various supporting documents for reference. This approach also supports the concurrent engineering principle. For example, although only one user can be working on a 'master' design, colleagues working on the same project can be instantly notified that there is an updated master design and reference copies of it will be made available to them in their own packets. Only the user to whom it is logged out can work on a given packet, but its contents can be looked at and copied by everybody with the necessary access permissions.

Workflow Management

Packets have the advantage of making it easy for team members to share meaningful groups of documents but they are useful for another reason too. They make it possible to move work around from department to department, or from individual to individual in logically organized bundles. During the development of a product many thousands of parts may need to be designed. For each part files need to be created, modified, viewed, checked and approved by many different people, perhaps several times over. What's more, each part will call for different development techniques and different types of data—solid models for some, circuit diagrams for others, FEA (functional economic analysis) data for others.

As if this is not confusing enough, work on any of these master files will have a potential impact on other related files. So there needs to be continuous cross checking, modification, re-submission and re-checking. With all these overlapping changes, it is all too easy for an engineer in one discipline to be investing considerable time and effort in pursuing a design which has already been invalidated by the work someone else has done in another part of the project. Bringing order to this highly complex workflow is what product data management systems do best. In particular they keep track of the thousands of individual decisions that determine who does what next.

Most PDM systems allow the project leader to control the progress of the project via 'states' using pre-determined 'triggers' and a routing list, which may vary according to what type of organization or development project is involved. The way systems differ is in how much flexibility they permit within the framework discipline. The most rigid systems are based on procedures. Every individual or group of individuals is made to represent a state in a procedure—'Initiated', 'Submitted', 'Checked', 'Approved', 'Released'; a file or record cannot move from one individual or group to the next without changing states. Some systems make it possible to give the task an identity of its own, separate from the people working on it.

For example, suppose an engineer working on a design wants to confer with colleagues as to the best way to approach the design. So long as the master model and all the associated reference files are contained in and controlled by a packet, then it is simple to pass the entire job across to any number of other people without triggering a change of state. The formal workflow procedure is not compromised by this informal re-routing, because the authority to change the file's state does not move around with the packet. It remains with the designated individual.

Communication within the development team is enhanced too. When packets of data and files are passed around instructions, notes and comments can accompany them. Some systems have 'redlining' capability; others even have provision for informally annotating files with the electronic equivalent of 'post-it' notes.

In other words, a process management system could be seen as a way of 'loosening up' your working environment instead of constraining it. The challenge is how far you can allow informal teamwork and cross-fertilization to carry on and still keep overall management control of project costs and deadlines? Most systems allow the up-to-date status of the entire task with all supporting data, to be tracked and viewed by authorized individuals at all times.

Of course, a packet represents one task in a product development project, which may consist of many thousands. Each packet follows its own route through the system but the relationship between packets also needs to be controlled.

To coordinate such a complex workflow effectively you need to be able to define the interdependence of tasks so as to match the way your individual project is structured. Not all systems are easy to customize in this way. The ones that are, have the ability to create a hierarchical relationship between files. For example, you could instruct the system to prevent an engineer from signing off an assembly for release until all its parts have been individually released.

Work History Management

As we have seen, product data management systems should not just keep comprehensive database records of the current state of the project; they should also record the states the project has been through. This means that they are a potentially valuable source of audit trail data. The ability to perform regular process audits is a fundamental requirement for conformance to international quality management standards such as ISO9000, EN29000 and BS5750. But project history management is also important to allow you to back-track to specific points in a project's development where a problem arose, or from which you may wish to now start a new line of development.

What specific development milestones the system records, is important. Some systems record only the changes in ownership of documents. So ownership can be traced at a specific point in time, but not the modification itself. Others have the ability to record changes but may do so as a series of snap-shots taken only when a file changes 'state'. This can leave large gaps in workflow history as a user may have been making modifications to a design for several weeks without any change to its state. Some systems provide an historic record, which is like a moving picture, allowing you to record changes to any system defined level you choose for example, every time a modified file is saved. This level of historical tracking, as well as providing comprehensive auditing, also permits the active monitoring of individual performance—and is invaluable during time-critical projects.

Benefits of PDM

The following are some of the benefits of the PDM system.

Reduced Time-to-Market

This is the major benefit of a PDM system. Three factors serve to place limits on the speed with which you can bring a product to market. One is the time it takes to perform tasks such as engineering design and tooling. Another is the time wasted between tasks as when a released design sits in a production engineer's in-tray waiting its turn to be dealt with. And the third is time lost in re-work. A PDM system can do much to reduce all these time limitations.

- It can speed up tasks by making data instantly available, as it is needed
- It supports concurrent task management
- It allows authorized team members access to all relevant data, all the time with the assurance that it is always the latest version

Improved Design Productivity

Product data management systems when driving the appropriate tools can significantly increase the productivity of your engineers. With a PDM system providing them with the correct tools to access this data efficiently the design process itself can be dramatically shortened.

Another factor is that designers should spend more time actually designing. Historically, a design engineer would spend as much as 25–30% of his time simply handling information; looking for it, retrieving it, waiting for copies of drawings, archiving new data, etc. PDM removes this dead time almost entirely. The designer no longer needs to know where to look for released designs or other data; it is all there on-demand.

A third major time saver is the elimination of the 're-invented wheel' syndrome. The amount of time designers spend solving problems that have probably been solved before is notorious. It is often considered quicker to do it again than to track down design elements that could be re-used. With a PDM system however, the identification, re-use and modification of existing similar designs should become routine.

Improved Design and Manufacturing Accuracy

An important benefit of PDM systems is that everyone involved in a project is operating on the same set of data, which is always up-to-date. If you are working on a master file you know it is the only one; if you are viewing a reference copy, you know it is a replica of the latest master. So overlapping or inconsistent designs are eliminated even when people are operating concurrently. Naturally, this leads to far fewer instances of design problems that only emerge at manufacturing or QA, fewer engineering change orders (ECOs), more right-the-first-time designs and once again, a faster path to the marketplace.

Better use of Creative Team Skills

Designers are often conservative in their approach to problem solving for no other reason than the time penalties for exploring alternative solutions are so high. The risks of spending excessive time on a radically new design approach, which may not work, would be unacceptable. PDM opens up the creative process in three important ways.

First, it keeps track of all the documents and test results relating to a given product change, minimizing design re-work and potential design mistakes. Second, it reduces the risk of failure by sharing the risk with others and by making the data available to the right people fast. Third, it encourages team problem solving by allowing individuals to bounce ideas off each other using the packet transfer facility, knowing that all of them are looking at the same problem.

Comfortable to Use

Although PDM systems vary widely in their levels of user-friendliness, most set out to operate within the existing organizational structure of a product engineering operation without major disruption. The system should in fact, make familiar tasks much more user-oriented than before. When users wish to view information on a PDM system the application is loaded automatically and then the document is loaded. In a conventional working environment users would either have to be much more skilled at accessing the information or be prepared to accept it in a much less flexible form.

Data Integrity Safeguarded

The single central vault concept ensures that while data is immediately accessible to those who need it, all master documents and records of historical change remain absolutely accurate and secure.

Better Control of Projects

The reason that product development projects are almost invariably late is not that they are badly planned in the first place but that they routinely go out of control. Why? Because the immense volume of data generated by the project rapidly snowballs beyond the scope of traditional project management techniques. The greater the competitive time pressures, the greater the scope for inconsistency and likelihood of re-work. PDM systems enable you to retain control of the project by ensuring that the data on which it is based is firmly controlled.

Product structure, change management, configuration control and traceability are key benefits. Control can also be enhanced by automatic data release and electronic sign-off procedures. As a result, it is impossible for a scheduled task to be ignored, buried or forgotten.

Better Management of Engineering Change

A PDM system must allow you to create and maintain multiple revisions and versions of any design in the database. This means that iterations on a design can be created without the worry that previous versions will be lost or accidentally erased. Every version and revision has to be signed and dated removing any ambiguity about current designs and providing a complete audit trail of changes.

A Major Step toward Total Quality Management

By introducing a coherent set of audited processes to the product development cycle, a PDM system should go a long way towards establishing an environment for ISO9000 compliance and total quality management (TQM). Many of the fundamental principals of TQM, such as empowerment of the individual to identify and solve problems are inherent in the PDM structure. The formal controls, checks, change management processes and defined responsibilities should also ensure that the PDM system you select contributes to your conformance with international quality standards.

MAKE-TO-ORDER (MTO) & MAKE-TO-STOCK (MTS)

One way to classify the manufacturing operations is by the amount of processing the product requires after the company receives an order from a customer. At one end of the processing spectrum is the make-to-order (MTO) company. This company does not begin processing the material for the component or product until it has received an order from the customer. In some cases the company may not even procure the material and components until after it receives the order. This type of manufacturing operations is practiced when the company competes on the basis of product customization and serves its customer base by providing unique and/ or highly specialized items. An MTO company also bases its production planning on firm customer orders.

At the opposite end of the spectrum is the make-to-stock (MTS) company, which manufactures products and places them in inventory before it receives customers' orders. Either the customer purchases the products directly from the inventory at a retail outlet or the company ships the product off-the-shelf from the finished goods inventory at the factory or at a distribution center. MTS companies rely heavily on market analysis and demand forecasting in planning the production of their products with respect to the product mix and volume.

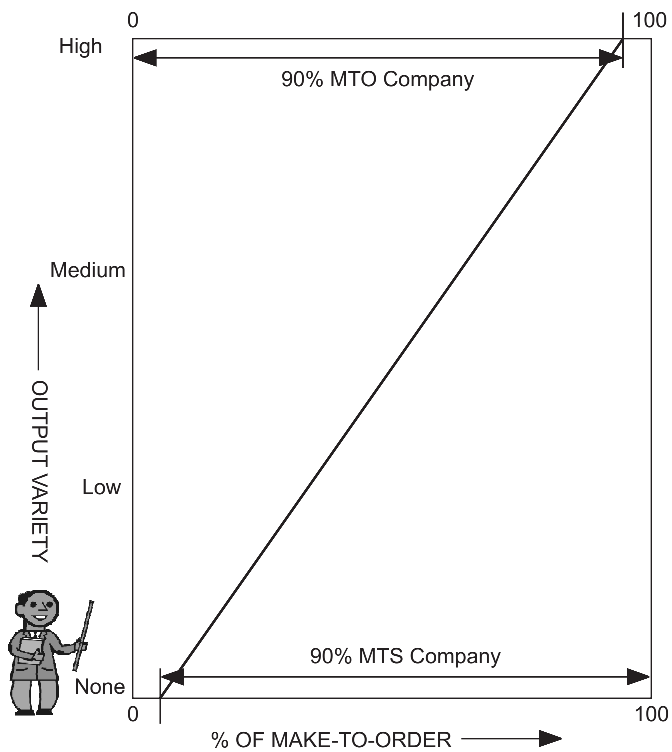

Fig. C.2 *Make-to-Order*

Figure C.2 shows the relation between the output variety (degree of customization) and the type of manufacturing operation. As it is evident from the graph, the output variety is highest when the company is operating in the make-to-order mode as the companies can serve each and every individual customer in the way he/ she wants. However, the cycle time will be more and the cost of the product also will be more. In the case of an MTS company the products are already made and kept in the inventory for the customer to pick up. Here the customer will not get any individual attention or customization; he can buy what is available with the company. Since an MTS company will be making products in lots and the cost of the products will be less as the economies of scale will be at work there will not be any waiting period for the customer after placing the order.

ASSEMBLE-TO-ORDER (ATO)

Another variation of the manufacturing operations is the assemble-to-order (ATO) company. The assemble-to-order company manufactures standardized option modules according to the forecasts it has made and then assembles a specific combination or package of modules after receiving the customer's order. A classic example is the automobile manufacturer. After receiving orders from a host of dealers, the manufacturer specifies the exact production schedule for the automobiles. The schedule is based on the options ordered by the customers—automatic transmission or manual transmission, air- conditioning, standard or digital control panel, leather, cloth or vinyl seating and so on. Many components for assembling the automobiles would have been ordered or started into production before receiving the customer's order based upon-demand forecasts. Thus, the major processing that remains when the orders come in is assembly. This approach shortens the time between placement of the order and delivery of the product-cycle time.

ENGINEER-TO-ORDER (ETO)

Yet another variation of the manufacturing operations is the engineer-to-order (ETO) company. The engineer-to-order company is the ultimate in product variety, product customization and flexibility. In this mode of operation anything will be manufactured as per order—but at a price. The expensive clothing of the 'bold and beautiful' is an example of this kind of production. Products are made for each customer and even the minute details for example, the texture and feel of the cloth, the color of the threads, the size of the collar and so on will differ from one customer to another depending upon the customer's preferences. So the manufacturer cannot keep anything in inventory; he will have to order only after the customer has given his/ her specifications. Obviously the cost of production will be highest in this mode of production.

CONFIGURE-TO-ORDER (CTO)

Along the broad spectrum of make-to-order manufacturing there is a growing convergence between strictly assemble-to-order (limited options and features) and completely engineer-to-order (just about anything goes, at a cost) environments. This evolving environment is often referred to as configure-to-order. Using a rules-based product configuration system, configure-to-order (CTO) manufacturers are able to simplify the order entry process and retain engineer-to-order (ETO) flexibility without maintaining bills of materials for every possible combination of product options.

MANUFACTURING PLANNING AND CONTROL

Manufacturing planning and control is broadly categorized as either make-to-order (MTO) or make-to-stock (MTS). The material and production planners within these communities confront unique challenges in the face of demand management. MTS manufacturers produce end items that are stocked and ordinarily available prior to receipt of a customer order. For MTO manufacturers the identity of the end item is often unknown until the receipt of a customer order. As a result, a certain level of standard sub-assemblies is typically inventoried to expedite delivery of the finished product.

Traditionally, MTO manufacturers have had to choose between ATO and ETO. ATO suppliers face the need to extend product lines, add features and increase flexibility to meet customer demands. ETO manufacturers feel pressure to standardize at least some of their product lines to reduce costs and remain competitive. Today, the CTO environment has emerged in response to customers' demands for individualized products with shortened lead-times, improved quality and competitive prices. Virtually any manufacturer that uses features, options or variable dimensions is a candidate for entering the CTO environment.

Transitioning to a CTO environment requires an evolution of the core planning tools that support the business. Traditional MRP tools rely on pre-defined bills of material and routings to support the planning process. For those moving from an ATO environment, existing bills and routings no longer represent the increasing end item availability and complexity. For material and production planners the transition to CTO combines the challenges of planning in ATO and ETO environments. Planners are responsible for determining material and sub-assembly quantities at the right time. Faced with the lengthy new product introduction process, planners have virtually no advance information. The new or modified manufacturing bill is not available until after the customer order is received. Until a sales history is accrued for the newly introduced features and options, planners are not able to monitor and improve forecasts.

Without software support tools planners have few alternatives in developing a planning platform. Generally, bills and routings are constructed to reflect the manufacturing process. Each level of the bill and associated routing steps represent individual shop orders. Planners work with a different set of bills and routings that are structured to represent demand percentages and load consumption of various options and defined common sub-assemblies. When customers request either a subtle change to a previous order or a complete new design, new part numbers have to be created, bills and routings developed or copied and modified, and costs assigned and rolled up. Finally, accounting can calculate if there is any profit margin. By the time planners have access to the final bill and routing, material requirements planning (MRP) and capacity planning (CP) have nothing to say except "expedite" and "overload.'

One option is to pre-define all possible combinations of options and features even if many will never be sold. However, this approach creates an engineering maintenance nightmare and does nothing to facilitate forecasting. Another option is to manually create part numbers, bills and routings on an "as needed" basis. Not only is this a time-consuming process but is also prone to errors. The only other option is to develop cumbersome combinations of "special" sales orders and phantom part numbers, creating an enterprise-wide nightmare.

In response to the need for an accurate planning platform several manufacturing software packages are now available with powerful 'configurators.' The configuration process allows orders to be taken by answering questions with pre-defined rules that reduce order and entry errors. Many configurators also support the entry of a specific code string that allows customers to order "just like the last time" or "just like the last time but make these yellow instead of red." The configurator then populates the attributes of the newly configured item, tests for configuration conflicts and generates the appropriate bill of material, routing and price, based on rules and calculations.

The part number assigned to the new item can be formatted as an intelligent part number or simply given the next sequential assignment. The end item description and operation text in the routing reflects the result of the entry selections or text keyed directly by the operator. Setup and run times in the routing and quantity per assembly in the bills can be calculated based on selections or user inputs.

The key component of a configurator is the blueprint of valid combinations of features and options. This blueprint, or "CTO model," uses a traditional bill of material model with parent and component relationships. Rules and calculations then ensure that the resulting configuration can be built, define how to build it and establish a selling price. The flexibility of establishing this CTO model is clearly an important aspect of selecting the best configuration software for your business. Few functional areas are exempt from the impact of transitioning to a new way of entering sales orders; automatically generating new part numbers, bills and routings; building and shipping products; and recording the financial results of doing business. The design of the CTO model must support:

- Ease of quoting and order entry
- Accurate pricing, discounting and commissioning
- Essential customer documents such as packing lists and invoices, required shop paper and applicable financial records

Input from product data management, sales and marketing, manufacturing and finance is required to develop a CTO model that supports the integrated environment. It is important to understand how the configurator generates the "appropriate" bill of material and routing because they are at the core of the planning process. Typically, a CTO model represents a translation of product engineering rules that define relationships among product options, materials and manufacturing processes. Multiple CTO models differentiate different sets of valid relationships and required processes.

The CTO model presents valid options within a model and applies rules or calculations based on selections. For example, a CTO model of a personal computer would have a set of component options such as case styles (slim line or tower), CPUs (66 or 100 MHz), hard drives (520MB or 1.2GB) and monitors (VGA or SVGA). Structured beneath the options would be the real item part numbers. (There could be several levels of options before the real part number level.)

Key considerations for material and production planners are the modularity of the real bills of material that will be combined in the configured end item and the level at which sales analysis records will be stored. In many instances, the structure (if bills and routings exist at all) needs to be re-examined in light of how it will support the CTO model.

With the introduction of configurators the lengthy process of product introduction is greatly reduced by the ability of the configurator to automatically create new part numbers, generate bills and routings, and assign prices. However, unless the manufacturing bills have been reviewed and contoured to a CTO model, the result is often inaccurate/ inadequate information, faster!

With the architecture of the CTO model and the ability to capture sales analysis information at the option level, planners have a tool to improve their planning models. The ability to capture sales analysis records on the options provides the ability to accrue data for use in forecasting software. For example, within the accessories option each occurrence of a mouse, modem, NIC, sound card and

CD-ROM selection is captured as a sales analysis record. This information is available for summarization at month or year-end. The data can be reviewed and massaged and then input to the forecasting algorithms. Instead of forecasting at the accessory level with the use of percentage bills of material, information is automatically monitored and maintained at the detail level.

The considerable power of configuration software provides the means to quickly develop accurate part, bill and routing information. In addition to maintaining sales analysis information at the configured item level, detail information by option is also available. This provides a powerful database for the dissection of market data. It also becomes the foundation for improved forecasting and planning capabilities.