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Abstract: We describe the concept and elements of Computer Integrated Manufacturing (CIM), then explore in more detail how CIM ties into efforts related to bringing a new product to market, sometimes called "concurrent engineering". Special attention is given to decreasing development time, increasing quality, and improving overall profitability by using an integrated business approach. Finally, we compare and contrast CIM with aspects of Total Quality Management.

COMPUTER INTEGRATED MANUFACTURING

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This paper describes the concept and elements of Computer Integrated Manufacturing (CIM) then explores in more detail how CIM ties into efforts related to bringing a new product to market, sometimes called "concurrent engineering". Special attention is given to decreasing development time, increasing quality, and improving overall profitability by using an integrated business approach.

Finally, this paper will compare and contrast CIM with aspects of Total Quality Management.

American businesses with manufacturing capability are having to become more competitive. Products have increasingly shorter life spans, customers expect higher quality for the money, and business climates are no longer supportive of companies who are not returning a handsome profit to shareholders. International trade complicates matters by expanding the requirement base of customers to satisfy and companies to compete with. Business decisions need to be made quickly and correctly. [18] Those succeeding in this competition are finding ways of attaining increased quality, shorter design cycles, increased levels of customer satisfaction, and higher profitability while being able to make decisions faster and with less waste in every sense. Many techniques have emerged as being helpful and popular towards meeting these goals. Those such as Taguchi Methods, Shainen Methods, Statistical Quality Control, and Six Sigma Design Methods offer companies tools to address specific issues. Others reach further, suggesting not only methods for solving specific problems, but describing cultural, philosophical, and organizational changes as being necessary for success. The concept of Computer Integrated Manufacturing (CIM) is one such approach, although the name might lead one to mistakenly conclude it provides for solutions just in manufacturing. As J. Tracy O'Rourke of Allen-Bradley puts it " too many people think of the factory floor when they think of CIM." [2] CIM, when applied properly, has ties into all functional areas of a manufacturing company and affects the nature in which business is done. Mr. O'Rourke considers CIM to be the "marketing machine of the future" allowing businesses to react to opportunities in less time and for less cost than was ever before achievable. [23]

To understand CIM, it is important to differentiate between CIM and what likely comes to mind when CIM is discussed - Computer-Aided Manufacturing (CAM). The differences appear to be trivial at first glance, but exploring the difference between CAM and CIM will reveal why CAM has helped to make CIM possible but more difficult to achieve at the same time.

CAM is essentially the automation of a variety manufacturing processes through the use of computers. [16] CIM really refers to the broad issue of the integrating of all functions related to producing a product into a computer integrated system capable of logically linking information from the discrete elements of the business . [2]

As computers that were powerful, affordable, programmable, and could be connected to manufacturing equipment became available the major focus was on automation for speed and economical reasons. No standards for those systems existed at the start, so any manufacturing area could easily end up (and generally did) with systems from different vendors which could not communicate one to the other. The ability to move information between systems became a large task, often error-prone and requiring programming expertise. Modern business pressures called out for the ability to control and observe processes quickly and in a closed-loop fashion, which suggested integrating individual processes from an information point of view. The growth of CIM has been stymied by the fact that the growth path of computers and software in manufacturing companies was not tailored for eventual smooth integration of separate operations. [9]

At the heart of CIM is information, and this poses the greatest challenge in making CIM work. [9] All functions within a business require information to do their task, and generate information as they do. Some information required by a function is resident within the function itself, while other information must be supplied from some other function. The ability to access, create and use information from across the business is key. The Society of Manufacturing Engineers offers the following five-dimension model to describe activities performed within CIM by use of their "CIM Wheel" : [9]

1) general business management
2) product and process definition
3) manufacturing planning and control
4) factory automation
5) information resource management

The CIM wheel points out that the integration of several functions within a manufacturing company must occur for CIM to be effective. This does not simply mean that the automated systems within those functions must be able to communicate, nor that the management structures for those functions simply be combined. It means that activities must occur with the organization operating as a whole, and not as a set of fragmented functions under one roof. [9]

To illustrate this point, let us look at the activities performed by all the functions within a business rather than activities performed by each functional area. C.H. Link offers the concept of a computer integrated enterprise, which focuses on the efforts of the whole manufacturing corporation and the tasks all functional areas need to perform. The seven sequential functions a manufacturing company does are: [14]

1) Decide - what will satisfy the requirement
2) Design - conception of end product for use
3) Plan - prepare for action
4) Acquire - get resources necessary to do the job
5) Make - match the resources to the task and produce desired result
6) Verify - compare result to designed concept
7) Deliver - send product to customer

To complete these seven steps successfully, all functional areas of the business must be actively involved. Marketing, design engineering, finance, production, planning, procurement, service, quality assurance, shipping, sales, management, and facilities must participate to varying degrees at different steps in the process. For the business to perform competitively, each function should be able to contribute in a timely manner using accurate information that is commonly available to all functions, and should be able to communicate its contributions in a manner that is directly usable to other functions. Any inability to do so invites barriers to goals of short development times, high profitability, and increased quality. [12] Even one error could result in a product being unfit for customers. One misunderstanding between design engineering and marketing on the height of a carry-on suitcase could render it too large to meet airline regulations once produced. Hence, the integration of data flows is necessary, but not sufficient for success. The integration must allow enough accessibility of information to encourage the organization to make the product be correct in all regards.

The idea of functional areas working together in an integrated fashion is nice in theory, but it is all too often the case that these functions represent individual dynasties with barriers around them. Will CIM work when information may be guarded within the walls of a function, or when willingness to change methods of operation does not exist? Dr. George Mendenhall of SBI Corporation stresses "enterprise-wide commitment" in making CIM work. He suggests that it is our politics that impede progress towards CIM, not technology. [21] To succeed, a corporation needs an understanding of what it needs to achieve in all respects, a set of disciplines in each functional area which ensures cooperation, support through times of change, and a plan that everyone can understand and identify with. Traditional barriers between marketing, engineering and manufacturing must be eradicated and even product specification and vendor interaction techniques changed. Dr. Mendenhall lists eight important items to consider when determining if an operation can be successful implementing CIM: [21]

1) product definition standards and engineering rules that are consistent with company objectives and acceptable to the market
2) manufacturing process standards and process rules that are appropriate to the product
3) marketing rules - including sales and forecasting rules - that are consistent with product and process rules and that allow for corrective feedback
4) a change-management approach that coordinates all the influences brought about by product or process changes
5) resource channels and resource commitment capable of supporting a CIM environment
6) an information network that interrelates all databases and processes
7) preventative maintenance procedures that maximize the probability that events will be carried out as the system anticipates
8) an exceptions management process to handle problems that require changes.

One additional element of general business management as defined in the CIM wheel is the role and activities of management and managers. Indeed, this may be the most important aspect of success or failure and it has many dimensions. In discussions about breaking down interfunctional barriers and encouraging global decision-making, what is really being discussed is interactions between people. It starts with an involved commitment from upper level management to foster change and provide the necessary resources to insure that the integration takes place. Middle managers must be included in both creating the vision for the future and planning for that vision to become a reality. [15] In many cases, the managers who must change the most are the first-level managers and supervisors. [8] They must become better coaches, leaders, and teachers. They must facilitate cooperation between functional areas and manage resources locally to achieve better global results. This often means they need to be working themselves out of a position of power and into a position of supporting coach. [1] Finally, attention must be paid to the fact that employees may be affected by automation in various ways. Jobs may be completely eliminated or redefined by the automation opportunities CIM can bring or by the elimination of data handling jobs resulting from correct system integration. Workers fear that they will either lose their jobs or not be smart enough to be retrained, especially if they haven't been continuously trained throughout their career. [15] Everyone is affected in some way, and management as whole must be prepared to work each employee through the change in a supportive manner.

Referring back to the "CIM wheel", the second dimension is product and process definition. The ability to integrate the creation of new products and processes with abilities available within reasonable reach of the manufacturing operation is critically important. For design engineers to abbreviate design cycles and reduce the number of prototype turns prior to production, a solid definition of the product must be completed and communicated to all functions which have impact on the design or choice of components and vendors. [6] Design simulations are suspect if not based upon real data from the production line and can easily result in a product that suffers from low yield, insufficient quality, or high manufacturing cost. The subject of concurrent engineering addresses modern approaches to this, and is covered in detail later in this paper.

The third dimension of the CIM wheel is manufacturing planning and control. Much information exists about this area of study, but a common thread with relation to CIM is the capture, integration, analysis and use of information. In his book on World Class Manufacturing, Schonberger uses chapter 1 as introduction then dives right to the heart of the matter in chapter 2, "Line Operators and Operating Data." He points out that jobs on the production floor must change to include data recording, data analysis and problem-solving. Although he suggests starting small and simple, the argument builds to have the analysis activities of the production people be linked to the operation of the business as a whole. [20] Throughout the book on Synchronous Manufacturing, the idea of careful control of processes, material, resources and disruptions is central. Furthermore, doing so in a global business sense is prescribed as necessary for success. The goals of CIM support such an operation. [24] Both stress the importance of being able to monitor quality and quickly react to statistical variations in process control, and the need to understand material flow and resource planning against production output needs. Implementing CIM correctly simply makes these tasks quicker, easier and more accurate to perform.

The fourth dimension to the CIM wheel is factory automation. The key linkage to CIM is the ability to extract data from the automated process, monitor the process and exert control over the process with a minimum of wasted effort or errors. Of additional value is the ability to specify the attributes of a part through the use of engineering tools and have that part produced on the production floor without intervening steps. As has been mentioned, factory automation began before business integration, so the task at present is as much to transition an installed base of automated processes as it is to define the interfaces. [9]

Information resource management is the area where most companies who have adopted a corporate acceptance of CIM are still facing the largest challenges. The problem is two-fold: first is to get hardware and software formats installed in all functional areas so that communication can occur and; once that is established, the second task becomes one of how to manage, control, protect, analyze and convey the huge amount of data. [18] Standards have been established for specific links, such as the Initial Graphics Exchange Specification (IGES) but address only portions of the total data flow needing to occur across the business. Implementation schemes range from distributed databases in many small desk-top computers linked by networks, to central computers with terminal access. System architectures for networks are many, each with their own set of positive and negative attributes. [18]

Figure 1 shows a model of the information linkages between functional areas of a typical manufacturing business. Realizing that each box in the figure could have local computing and storage capability that is unique to that function, and that it is possible that no two functions have identical hardware and software tools, it becomes evident how complex a problem this can be. The orderly implementation of CIM requires that all interfaces become essentially transparent, which often means changes to both functions attempting to exchange data. Ownership of data and definition of presentation formats may be at issue, as well as simply the difficulty of rationalizing computer and software expense in addition to the existing systems. When the interpretation of Figure 1 to having centralized databases with convenient and timely access to information as shown by arrows between functions is achieved, the business is meeting the technical requirements of CIM. [18]

Figure 1. [18]

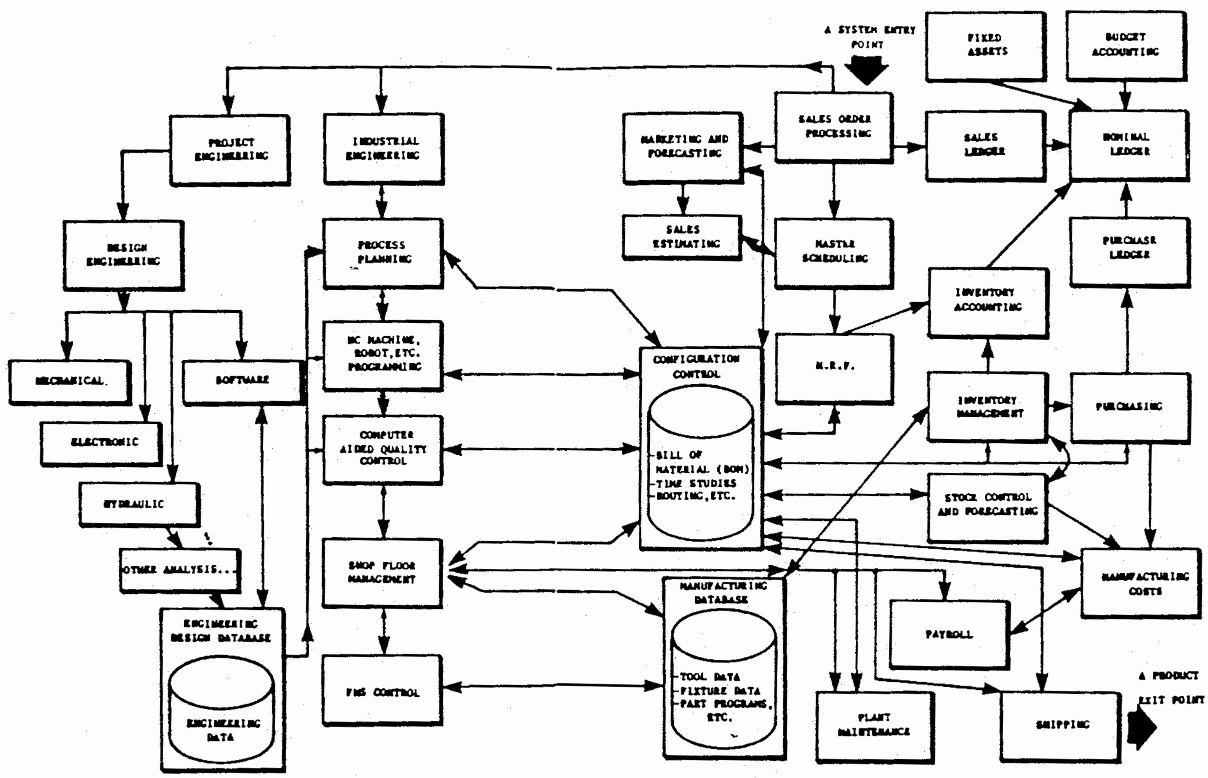

Figure 1.2 An overall CIM model integrating business data processing, Computer Aided Design (CAD), Computer Aided Manufacture (CAM) and Flexible Manufacturing Systems (FMS), incorporating machining, assembly, test and other processes.

Having discussed CIM and its application in modern business, attention will now be focused on the specific area of creating new products under an organization which employs CIM. Of critical importance to a business wishing to improve new product introduction times and minimize waste during these cycles is the linkage between the marketing, manufacturing and design engineering organizations. In the past, marketing would specify a product, design engineers created a prototype, then would hand it off to manufacturing to figure out how to mass produce it. This method is commonly referred to as the "relay race" method, or "throwing the product over the wall". [12] Many costly opportunities for problems exist within this approach, and in general the ability to correct these problems during the development phase is non-existent. [23] This approach causes products to undergo late design changes to correct for unmanufacturable designs or inherent quality problems, causes high development costs, alienation of workers who did not participate in the design, and continuous problems getting quality parts from vendors. The obvious solution was to have functions work together from day one of a product development cycle. This approach has been dubbed "concurrent engineering" and is yielding great gains in time-to-market, improved manufacturability and quality, and lower development costs. [12]

Concurrent engineering is supported by three trends of cross-functional coordination: organizational design issues, improved communication, and decision support systems/models. Indeed, what is being addressed here is simply partnering of the functions within a company. [10] Organizational design issues refer to the notion that for concurrent engineering to occur, the functions must be managed in such a way as to promote teamwork, avoid autonomy, and foster a better understanding of all of the issues each function faces. In most cases, this requires a concerted and participatory effort on the part of upper-level management to generate a model for operations under a concurrent approach. [22] Further changes in management are often necessary, such as removing layers of management, reducing the number of first- and second-level managers (where local kingdoms of optimization live), and even placing several functions for a project under a single manager. [8] All team members start working together for a common goal, and with the support of management to ensure resource availability. It is interesting to note that "throwing designs over the wall" actually encourages bureaucracy, since it spawns additional work and rework that must be managed. [12] Conversely, eliminating rework and waste reduces the need for many departments and managers. It should not be surprising that this also creates resistance to concurrent engineering from a human standpoint . [8]

On the surface, improved communication means making sure no barriers to communication exist between interfunctional and intrafunctional teams. Digging deeper, it means that people can gain access to information they need to make decisions even when that information is not within their functional area. When a design engineer is choosing a component, data indicating whether it is considered favorable to be used by the manufacturing team must be quickly available. Cost of the component, vendor history, second sourcing and parametric data must be available too, if the designer is to make the decision quickly and accurately. This topic has been called Engineering Data Management (EDM) and must be mastered to take advantage of the automation CIM has to offer. Data used in simulation of designs and processes must be based upon accurate and timely information from the actual production floor, when possible. [22]

Decision support systems/models tie closely to the communication and simulation aspects of concurrent engineering, but embody one key difference. That difference is the ability to link the activities of the new product design process to the needs of the customer. [5] The method most employed in making the linkages between customer and manufacturer is Quality Function Deployment (QFD), brought to the United States by Don Clausing. This technique employs a set of disciplines that require thorough research and understanding of customer needs, documenting those need in a format usable by all functions, determining the relative importance of those needs to the customer, and then using a team approach determine what action the company can take to best satisfy those needs. [6]

To illustrate the ties between concurrent engineering and CIM, an example of a product development will be useful. The process starts with the perception somewhere in the business of a market need. [23] Further study of the customers, marketplace and business climates by a team represented by marketing, sales, manufacturing and engineering results in a description of the customer's needs and prioritization of those needs. Those can be documented on a single sheet as a management tool, called the House of Quality [6]. This team must be willing to take a customer's unusual requests seriously and not try to force an existing product or service to fit. Such an approach stifles breakthroughs. [23] Once the team has an understanding of what the customer needs, attention can be given to ways of satisfying those needs. The team is important here for two reasons: the first is to be able to identify alternatives that would be difficult to design, produce, distribute, or market; the second is to form a team consensus to support interfunctional communication. [5] Proper application of CIM begins to play a major role here, as different alternatives need to be examined for technical feasibility, material cost, manufacturing implications, and design complexity. Having access to current operational data supports direct comparisons using those processes which exist and support the proposed product. In those cases where new processes would be required, existing processes may provide an adequate baseline from which to start.

During this evaluation phase, things such as quality, manufacturability, and cost are variables. Sales impacts to current products can be simulated, and rolled into production plans to show impacts on material volumes. As a result, the product incantation which supports the business goals best can be identified. As product development begins, all other functions are aware of issues that need to be solved in their respective areas and by what date.

As soon as an approach is chosen, these attributes are fixed for the lifetime of the product for all practical purposes, and the baseline established for the ultimate expectations for the product. [23] It should be noted that design engineers in this process generally have to give up some autonomy, as they normally have been the ones who determine all of these attributes with assistance from marketing and manufacturing to varying degrees. [8]

With an approach (agreed upon by the team) in hand, the task becomes that of turning it into a quality product in the shortest time with minimum waste. Integration of all areas of the business speed this process greatly. As an example, computer-aided design processes which feed directly into manufacturing systems can enable the first prototypes to be made on the production floor, greatly reducing the cost of the prototypes and speeding first prototype times. [23] This also helps support quality goals by allowing the team to ascertain the quality of the first products built on the production floor. [19] Rapid feedback to design engineering of production's ability to make the product as specified allows the correction times to be reduced. The ability to use computer-based analysis tools allows design and manufacturing engineers to base decisions upon statistically valid data, rather than upon observations which could be misleading. Design for assembly can be achieved prior to design start based on actual manufacturing process data, speeding assembly and service repair time and reducing product cost.

This concurrent engineering approach extends outside the walls of the company to vendors, suppliers, and distributors. Just as manufacturing needs to be brought into the process from the beginning to insure their buy-in and ability to succeed, vendors and suppliers of critical components need to be treated as partners in the business venture. [12] These components from vendors can greatly impact the development times and quality of the final product, therefore great clarity in communication to those partners is needed. CIM supports this communication by making data available to enable engineers and procurement agents to specify all attributes of purchased parts completely, based upon needs of the customer and production organization. Integration that allows direct communication to vendor processes shortens lead times for prototypes and helps to eliminate errors. [7]

As the product speeds towards completion, an effectively working CIM organization will be able to bring the product into manufacturing smoothly. Automated and integrated costing systems, material scheduling systems, purchasing systems, and production scheduling systems are likely to accommodate a new product and roll it into existing plans on an overnight basis. Disjointed systems would require a more manual, step-wise and perhaps error-prone process to be followed, lengthening time-to-market, cost of production, and life cycle costs.

Once in production, the ability to monitor output for sufficient quality in the CIM environment can help keep production and life cycle costs low. Component changes and modifications can be simulated against current manufacturing data to determine the effects of changes prior to implementation, reducing risk to the business and speeding transition times. Using automated processes combined with statistical process control will help eliminate poor quality goods being sent to customers and allow corrective actions to be taken before it is necessary to stop the flow of product to customers.

Finally, this paper will compare and contrast the concurrent engineering approach with the concept of Total Quality Management. TQM has to do with continuously improving the quality using business-wide commitment and participation. It has to do with building quality in from the beginning and making everyone in the organization responsible for maintaining and increasing quality. The key TQM concepts are: [17]

1) Long-term perspective
2) Upper management commitment
3) Employ a system approach
4) Training and tools
5) Participation by all
6) New measurement and reporting systems
7) Cross-organizational communication
8) Leadership

TQM is not a recipe or predefined program in itself. It is a philosophy of doing business that can be supported by many specialized efforts including CIM. Employee involvement, Juran techniques, Taguchi methods, statistical quality control - all are tools that can be useful in helping an organization reach TQM.

The above list has many items in common with the items discussed in connection to CIM. Upper management commitment, system approach, participation by all, cross-organizational communication, and leadership are in common with those items

In summary, the observation can be made that the need for such topics as CIM and TQM may well be the result of the habit of American business focusing on the short-term financial gain. There would be no need for large integration efforts to achieve CIM had manufacturing companies insisted on suppliers of automated equipment being compatible with each other before accepting that equipment into their place of business, with an eye towards the future. Instead, businesses were after the supposed short-term gain in productivity and attendant decrease in operating cost (which sometimes never came). Since no information communication standards were forced to exist from the start, vendors of automation were free to create their own formats, and did. Only after manufacturers saw the hodgepodge of equipment they owned that could not be linked even within a production function, let alone to other functions, did the issue of CIM become trendy.

Similarly, TQM need not have become an issue of major importance in the sense that it means a major change in the way businesses and employees operate. Had a commitment to quality existed all along in American business, papers on TQM would be explaining how most U.S. companies are, not how they are striving to be. Why would a corporation not strive to reach the highest possible levels of quality? One possible answer is that individuals who controlled every aspect of the business were not being rewarded for improving quality, but for meeting every other goal but quality. Quality was considered sufficient if sales continued and no groundswell of discontent from customers existed. Only after standards of quality were established in the marketplace by a few competitors did the inability for American business to attain such levels become apparent.

Another interesting observation is that articles on TQM, CIM and concurrent engineering have some discussion of financial analysis attached to them. Once you look at these concepts, they really appear to be nothing more than common sense and once practiced will have a net positive result in financial terms. Yet, in American business there appears to be the need to express that common sense in terms of financial justifications. It implies that choosing a strategy that does not strive for improvements in quality, etc., can somehow deliver higher profitability to the bottom line over time. This is short-term thinking at work.

The final observation of this paper is on leadership, or lack thereof. In each article on CIM, TQM, concurrent engineering, and even introducing robotics into production - there was a statement for the need of leadership. Note that the statement was not for the need of management, but of leadership. Kouzes and Pozner list what they believe to be the five practices common to successful leaders: [13]

1. Challenge the process.
2. Inspire a shared vision.
3. Enable others to act.
4. Model the way.
5. Encourage the heart.

Indeed, taking on the challenge of transforming a business from the "typical American" variety to an efficient TQM operation will not occur by commanding it be done. Even small details within the corporation which are barriers to progress must be dealt with and incorporated into the vision of growth and improvement. It takes the elements of leadership. In an interview by Bernard Avishai, J. Tracy O'Rourke of Allen-Bradley stated "If you can't understand the fundamentals of a technological decision, you're a figurehead. You're not the CEO." All too often in our business, the upper-level managers fail to pay attention to the fundamentals of the decisions they make and create impossible situations for the employees to respond to, let alone excel in. Inspiring a shared vision takes getting down to the roots of the organization and understanding what problems people are facing, and what effects a decision will have on them. Too few managers have the skills to do this.

The greatest barrier to success in the areas of CIM and TQM is not the average worker - by far most want to be an important part of a growing and successful company. It is not the technology - affordable technology exists in abundance today. It is simply the lack of educated, capable and energetic leaders who can facilitate the necessary revolution within the time and budgetary constraints that exist today. That shortage may well keep the success rate of CIM and TQM low for the foreseeable future.