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Abstract: This project examines the concept of concurrent engineering and specifically deal with issues in the implementation and management of a concurrent engineering program. Why must CE be considered by US companies, its definition, conversion to CE environment, barriers to the implementation of CE, communication in teams are discussed. Also, some cases of companies are described briefly.

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ABSTRACT

This paper examines the concept of concurrent engineering and will specifically deal with issues in the implementation and management of a concurrent engineering program.

The paper begins by discussing why concurrent engineering is a philosophy that companies, specifically in the U.S. must consider to regain the competitive edge to become leaders in the present day global economic market. Concurrent engineering is then defined and explained. Managing the conversion from a traditional engineering process to a concurrent engineering environment is then examined.

Barriers in the implementation of concurrent engineering are then dealt with. First the seven organizational barriers and some possible solutions are discussed followed by what are termed as common failure modes and their possible solutions.

The next section deals with interpersonal communication in multifunctional teams and methods of quantifying opinions to optimize communication is discussed. A methodology to enhance team dynamics CEMET is then defined and explained in detail. As part of team issues, the role of the team leader and his responsibilites are briefly discussed.

Some cases of companies that have had significant success in implementing concurrent engineering are described briefly. In conclusion the importance of concurrent engineering and its tremendous potential is again stressed.

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INTRODUCTION - THE NEED FOR CHANGE

Concurrent Engineering is a buzzword in the industry today. But is it just that or is it a philosophy that could actually produce results. This is a question that companies, big and small are asking themselves before having to commit large amounts of capital to revamp their engineering and management approach to embrace a philosophy that is totally different from the traditional system.

Global economic conditions have resulted in competition for manufactured goods being extremely stiff. Japanese companies have absorbed the increased value of the yen and are making a comeback from setbacks of the past two years. Companies from the newly industrialized countries of south-east Asia are attempting with significant success to raise quality to compete on equal terms with American and European manufacturers. Eastern Europe and China are on the road to becoming serious players in the global manufacturing market. To add to this keen competition, massive federal budget deficits and inequities in the balance of trade have meant that exporting is no longer an option for American manufacturers, it is a necessity.

According to C.Fred Bergsten, director of the Institute of International Economics, to cover the large external deficit, the U.S. Government will have to borrow about $10 billion every month in new money from the rest of the world and avoid any net withdrawals from the $1.5 trillion stock of liquid foreign assets already in America. He goes on to say that the only long term solution is for American industry to export more. If the deficit is to be turned around, not only must more corporations export more products, but must also produce products that will prove to be import substitutions (*Hartley, 1993*).

So, there is an immediate need for change. Progress has been made and is continuing to be made. A significant helping hand has been the declining value of the U.S. dollar. U.S. manufacturers have increased their share of the world's export market by about 0.6% annually between 1987 and 1990. Some sectors of industry have achieved dramatic results, notably semiconductor makers who have improved their share of the world market from 34.9% to 36.5% and have increased their share of the Japanese market from 3% in 1986 13% in 1990. However, this must be tempered by the fact that it was political

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pressure from the U.S. Government that played a significant role in persuading the Japanese to buy American made semiconductors by imposing punitive sanctions on imports of electronic goods made with Japanese semiconductors. Other sectors of American industry have not been so successful, in particular the auto industry. In 1990, General Motors, Ford and Chrysler posted sales losses of 4%, 11% and 15% respectively, while Japanese auto companies, Toyota and Honda increased their U.S.. sales by upto 15%. The position has only got worse, with the big three posting record losses in the fiscal years 1992-93 *(Hartley, 1993)*.

Obviously, tremendous efforts are needed to combat this flood of imports. The answer lies in increasing exports, but that is not the whole picture. The answer lies in producing better products that meet the requirements of customers. When NTT, the Japanese telecommunications monopoly first opened its doors to American-made products, its executives complained that the American phone sets were not as good and easy to use as comparable Japanese products.

To meet these goals, manufacturers not only need to improve their performance continuously but to ensure they can make better products with shorter lead times and with improved inherent quality. It is no longer a question of simply cutting manufacturing costs - itself a major challenge - but of refocusing the direction of business so that it responds to the needs of customers.

It is clear that Japanese companies are able to develop products much more quickly than their American competitors and with higher quality. This is the key to being dominant in the present day market. This competitiveness results from a number of factors, one of them being the use of improved methods of product development. Time to develop products from the concept stage to manufacturing are about half for Japanese companies compared to U.S... manufacturers. The number of defects per unit in Japanese goods are about half those in American goods. Ramp up to full production is much quicker and the number of engineering changes at later stages in the process considerably lower. What is the solution ? It is essential to return to the roots of business to examine and re-examine priorities and goals. An improvement of every aspect of the product from the beginning of design to the end of its service life is absolutely imperative. Without the product there is no business.

Unless the right product is available when the market wants it, profitability will be poor. 60% to 80% of the eventual cost of developing the product is committed at the design stage, so more funds have to be invested earlier to improve results. Any attempt to sharpen the company's performance must start with the product. Cost cutting, asset stripping and improving manufacturing efficiency are worthless unless the product meets the customer's needs and is available when there is demand for it and has "world class" reliability and marketability.

In such a situation, a management and engineering technique practiced widely in Japan and by some corporations in the U.S. may supply at least part of the answer. It is called Concurrent Engineering. Implementation and management of this program is the central focus of this paper.

CONCURRENT ENGINEERING - THE CONCEPT, THE DEFINITION

The traditional approach to product design has been serial or sequential in nature, with little or no interaction between the various departments involved in the process of product development. This lack of communication manifests itself in poor quality products, long development times, extensive redesign and large scale budget overshoots. In such an environment, design is often done in a relative vacuum. Manufacturing, testing, marketing and service departments may not see a design until it is virtually completed. At this stage, any alterations suggested by these departments, if implemented, cause significant delays in time to market and if not implemented result in poor quality. Either way, a bad situation.

The central principle of concurrent engineering is to replace this serial process by a parallel one. Instead of allowing design groups to develop products that must be force fitted into existing manufacturing, test and service processes, with no forethought to such product attributes such as manufacturability, testability or serviceability, smart managers are converting to a design team concept that moves previously "downstream" product considerations "up front" (i.e. right from the start of the product development effort). This approach provides early visibility for any changes to manufacturing, test or support processes that may be required in order to handle new product design, fabrication, packaging or test technology features that will make the product itself more competitive. The technique also ensures that the voice of the customer is heard throughout the development processes, both directly and through the marketing department, which channels the feedback (*Turino, 1993*).

Concurrent engineering integrates expertise from all of the various engineering disciplines during the actual design phase. Tradeoffs regarding producibility, testability and serviceability are made in real time. Thus, when a design is verified it is already manufacturable, testable, serviceable and is what the customer wants. The whole focus is on a "right the first time" process, rather than on the typical "redo until right" process that is so common in the serial engineering mode of operation. This is achieved by the formation of multi-disciplinary teams which is a central feature of the CE philosophy. These teams, their composition and method of operation will be discussed in detail in a later section.

Although concurrent engineering has been and will continue to be defined in a whole variety of words and phrases, the following definition sums up its basic principles fairly well.

> "Concurrent Engineering is a systematic approach to the integrated, simultaneous design of both products and their related processes, including manufacturing, test and support. It is a concerted corporate effort to achieve maximum efficiency, economy and quality throughout the total business cycle (*Turino, 1993*)."

It is also important to recognize what Concurrent Engineering is not. It is not an attempt to restrict design innovations or to criticize the ability of a design (or a designer) to perform the required functions in terms of creativity or innovation. It is also not the universal panacea to the problems of the entire corporation. If other areas like inventory control, manufacturing efficiency, production scheduling are ignored then concurrent engineering, even if implemented perfectly will not result in any improvement.

Concurrent Engineering is made up of a minimum of six specific design activities that go on in parallel. They are:

Design for Performance (DFP) - ensure that all customer requirements are implemented, human factors accounted for and safety built in.

Design for Manufacturability (DFM) - includes using minimum number of parts, facilitating error free assembly and using standard components.

Design for Testability (DFT) - provides for partitioning, control and visibility to facilitate testing.

Design for Serviceability (DFS) - includes features like making replaceable items accessible, partitioning designs into modular functions and including built-in test and remote diagnostics.

Design for Compliance (DFC) - compliance with appropriate regulatory agencies around the world.

Design for Quality (DFQ) - includes the basics of meeting customer quality expectations and ensure reliability and ruggedness.

Concurrent engineering is a culture change for most organizations. It thus has a big impact on the whole organization, but especially so on the designer. It is intended to cause designers, from the very beginning of a design activity to consider all elements of the product life cycle, from product concept through design, manufacture, service, disposal, quality, overall business costs, time to market and customer needs (*Kosuke, 1993*).

It is also intended to foster team leadership, in addition to functional management, in order to provide the right resources and expertise at the right time and in the right place, on a project and process oriented basis.

Inspite of the obvious benefits of CE, making the change in a corporate climate and culture has most often turned out to be much more difficult than expected. This, often painful and frustrating process is the subject of the next few sections of this paper.

ARE COMPANIES READY FOR CONCURRENT ENGINEERING?

Now that we are aware of the need for companies to embrace the philosophy of concurrent engineering, we need to concentrate on the suitability of concurrent engineering for companies which have been following traditional philosophies of management for long. It has now been repeatedly asserted that any process of change is a frustrating process as it goes against the basic principles of inertia. The following are some of the main factors that need to be considered by the top management before giving the go-ahead for the change to concurrent engineering.

- What is the present state of communication in the company?
- What type of organization does the company have?
- Does the organizational environment foster openness, candor, and respect?
- Are employees comfortable with working in cross-functional teams.
- Does the organization work closely with vendors and suppliers?

In addition to the above factors, there are numerous other forces that affect the suitability of a company to concurrent engineering. These forces, if considered properly right from the start make the change easy for the management as well as the employees.

Some of the major hindrances to the change to concurrent engineering occur at the organization level. The present state of team integration in an organization has to be clearly understood before making any changes. The management has to assess whether individuals in the organization have necessary training and knowledge to complete tasks, whether they clearly understand about the information needs of their tasks and what information they need to develop,and whether they try to gain knowledge about up-stream and down-stream tasks and their information needs and results.

Furthermore, care has to be taken to make sure that project team members have the skills needed to fulfill the project goals. The management should also ensure that the project environment fosters openness, candor, and respect. The organization should strive to achieve a common vocabulary across all projects in the program to support schedule and technical discussion. Every project manager should know the basic principle in managing projects, viz., the project teams should work effectively, meeting cost, time, and quality goals. This is one of the considerations that affects team dynamics. The means for resolving conflicts needs to be clearly outlined during the team integration stage.

Of late, the customer's importance is being recognized by most of the companies and efforts are being made to integrate the customer with the organizational functioning. The team integration process also should contain provisions for having the customers as members of the enterprise teams. With the principles of JIT, MRP, etc., coming into play, the suppliers and vendors also need to play an important role on the multi-functional teams. They should readily share the risks and rewards offered by this whole new philosophy of managing things.

Once the management looks into the present state of affairs with regards to the above factors, it needs to highlight areas where the present configuration is sufficient and areas that need improvement. As computers will play a major role in the near future, electronic datalink facilities have to be established with the suppliers and vendors. Teams need to be created only when it makes sense to create them. All teams need to be disbanded after their useful service life ends. Also, as we will observe later, one of the organizational factors that adversely affects team integration is the physical distance separating team members. So, as far as possible the management has to make sure that all team members are colocated.

For an effective concurrent outlook, teams should have the authority to make decisions about tasks. Individual team members must be made aware of the rewards before, during and after tasks are completed and should be made to accept responsibility for their actions. There should be a clear demarcation of the domain of a team's authority vis-a-vis other teams. The management contribution at this stage would be to build a reward system based on team results as well as individual performance on tasks. Cross-discipline on-the-job training should be initiated throughout the enterprise and support must be provided for teams to learn from earlier successes and failures.

Communication plays a very important role in the success of any organization. In order for the management to realize its goals, an effective two-way communication between the employees and the managers needs to be present in the enterprise. As observed from the case study of "The SNC Group" for the Suncor project, a task that looks impossible can be made possible by establishing a good rapport with the employees. The management can improve communications by arranging shop tours and co-locating project team members. They should treat vendors as partners in the enterprise and utilize them to improve communications and their products.

Once team integration is achieve, the focus shifts to the management of data generated by these teams. The questions that need to be raised at this stage are the number of times that the data is generated and the availability of this data to all team members. All project teams should make an effort to identify needed software and hardware resources up-front and the responsibility for data management should be clear. Once the data information is determined and if it is found that data is generated multiple times, the management should identify if the problem is in data format, robustness, availability or communication. In this age of information super-highway, it is but a logical step to develop electronic mail and file sharing throughout the enterprise.

At this stage of the process, all team members should clearly understand who the customer is and what the customer requirements are. The individual should also understand the mechanism for reporting status and progress. Methods such as QFD must be used to develop customer requirements.

Next important area of focus is the planning methodology used by the enterprise. All tasks should be parallel with estimated inputs which are continuously refined as knowledge is gained. Task performance on time/cost/quality scale should be continuously tracked for future purposes. The parallel nature of tasks forces inter-dependency among them and this task inter-dependency should be understood by the teams. The planning methodology for each project should be managed at the enterprise level and if the current planning method leads to unrealistic/unachievable plans, the managers should institute a study to find out what is actually happening. If tasks are late, over budget or result in decisions that are reconsidered later, then review task input and measurability of expected result. Relevant standards must be made known and individuals must be enforced to adhere to these standards. It is always good to have a documented standard process for projects and the management should monitor the strict adherence to these processes. Encouragement should be provided for individuals to develop multiple concepts for each task and methods should be made available for concept development and evaluation. The role of management here is to establish a culture that encourages multiple concept development and also to provide communication and training methods to support concept development. Technology readiness should be ensured and critical parameters for each concept must be known before commitment to a particular concept.

The teams must plan for evaluation support like simulation, prototype testing etc, before hand and the tools and facilities for evaluation must be continuously improved. Decisions must be made on the results of evaluations and meeting the schedule should not be the sole driving factor during this process.

Concurrent engineering being a relatively new field, the research going on currently is of an empirical nature and based on this, it is now a well established fact that many of the above factors come into play during the process of conversion to concurrent engineering. Any company that is seriously considering a change of its management philosophy needs to assess its current state and capability with respect to these factors. Once the improvements as suggested by this assessment are completed, the company should not face any problem in starting the conversion to concurrent engineering and adjusting to this whole new idea of better management.

MANAGING THE CONVERSION TO CONCURRRENT ENGINEERING

Concurrent engineering is an ongoing process, not an instant fix program. It is also a continuos improvement process, very much like Total Quality Management. Managing the change to CE takes several factors, among them the following.

Top-down specifications
Bottom-up design activities
Management involvement and commitment
Common language at all levels

Creating top down specifications will get easier the more often people do it and see the benefits of doing it. Designers will implement the concurrent engineering guidelines more often when they realize it doesn't have to take a lot of time or cost a lot of money, and that doing so will shorten time to market and simplify design verification tasks.

Management must be both committed and involved and this happens only by setting an example and promoting constant communication by all those involved.

CE emphasizes communication between all entities within the company and for effective communication, a common language in terms of objectives, methodology and tools must be developed.

The evolution of an organization from a serial (or sequential) design culture to a concurrent design culture is very similar in many ways to the evolution of an organization toward total quality mangement. It can be divided into five specific phases, based on a model developed in Sematech's Partnering for Total Quality series (*Turino, 1993*).

Phase 1: Short Term Focus This phase is the unfortunate stage that too many companies find themselves in today. In such a situation, revenues and budgets are a higher priority than CE, the sales department is the only customer contact, design practices entirely intuitive and a high incidence of rework and scrap exists. Organizations in this phase have no mission statement and no management vision beyond the short term "bottom line". R&D is often starved to shore up quarterly profit statements, mortgaging the company's future. Little or no manufacturing data exists and if it does it has not been analyzed or utilized properly.

The emphasis on budgets above all else means that professional training of employess is minimal to nonexistent. Managers in such companies are too busy fighting fires to practice fire prevention by eliminating the arsonists.

Phase 2: The Product Focus In this phase companies have recognized the peril of the short term focus mentality and have moved toward a product focus mentality in an attempt to regain lost market share and become competitive again. Here, design quality is viewed as meeting specifications, no more,no less. Data is applied to factory improvements only. Consistent design methods are lacking and moderate to high scrap and rework costs exist. In the people area, development personnel are insulated from customers and training is limited to skills-oriented training. Fire fighting is still prevalent. A lot of managers find themselves enmeshed in this stage, where they acknowledge that the system has to be changed, but support from the top is not forthcoming.

Phase 3: Product and Service Focus. Companies in this stage view design quality as including DFM (Manufacture), DFT (Testability) and DFS (Service). These activities are at least minimally supported by data collection and analysis activities that are in place and functioning in support of statitistical process control and factory TQM efforts. As a result of these investments in both money and people, these companies are seeing reduced scrap and rework costs. The CE program is an executive priority and this results in periodic customer surveys to determine customer expectations and the design process is carried out by multidisciplinary teams to ensure true concurrency of effort.

Phase 4: Process or System Focus. Senior managers have now recognized the value of cross-functional teams and as a result of the vision and efforts of typically one senior manager, concurrent design methods are used for all products. The process is more streamlined with the effective maagement or elimination of bottlenecks in the manufacturing environment. The company sees its manufacturing, test and service costs going down and a considerable reduction in its time to market new products. Product quality begins to improve and sales begin to increase.

Phase 5: Continuos Improvement Focus. This is the phase where products can be customized rapidly to meet more frequent customer requirement changes through the reuse of engineering investments, where order and factory cycle times have been cut significantly, up-front planning has replaced back-end redesign, reaction and rework. In the personnel area morale is high and people are proud and motivated about their jobs. There is an expanded partnering that exists with both customers and suppliers. Design methods are benchmarked against the best competitors.

All these factors have resulted in substantial benefit to the organization in terms of lower capital equipment cost, greater and more effective use of automation, minimal redesign, improved design quality, improved organizational motivation and morale and a process of continuos improvement that is built in place.

As explored in more detail the next few sections making the transformation to the CE philosophy is not an easy one. The first problem to combat is changing the existing culture. To begin a cultural change it is critical to acknowledge the realities of the people, the products and the organization. A key to this is **open book management**, where employees are encouraged to become part of the process of improvement and change. It can also relieve significant burdens from top management by driving decision making to the lowest levels. Reporting product profitablity, company performance and division revenues (where applicable) can foster both internal (healthy) competition and company-wide cooperation.

While trying to change the existing culture, it **should not be attacked head on** - there is too much history and inertia. Gradual change is the way to go. Processes have to be examined as a whole and small changes have to be engineered constantly.

An important factor is a focus on **retaining existing customers** versus acquiring new ones. Studies of the market have shown that given a difficulty factor of one for selling additional products to existing customers, it is three times more difficult to sell an existing customer a new product. That difficulty factor can considerably be reduced if the customer feels he has contributed to the design of the product. For new customers, the difficulty is even greater. The old marketing axiom " your best saleman is an existing customer" sums it up nicely. If existing customers are not satisfied with a product, it is impossible to build a stable clientele and subsequently expand market share.

Another part of staying more competitive is to **get closer to the customer.** Involving them in the design from the earliest stage is a key factor. Customers with technical questions about products should be able to access technically competent personnel for guidance. Customer directed R&D can pay big dividends.

Suppliers can also be valuable members of the product development team. It is almost always less expensive in the long run to buy something from someone who already makes it to than it is to develop the designs, tooling and manufacturing expertise to make it in-house. Partnering with suppliers adds their expertise to that of the product development teams at virtually no cost. Suppliers often suggest better, less expensive ways to do things. Reliance on a few reliable, efficient and flexible suppliers is recomended. Reducing the overall number of suppliers also reduces the overhead cost of purchasing, inspection and record keeping.

Finally **price (or cost) is not the driver** in a CE environment. Higher quality, even if the it costs more initially can result in lower costs at the next levels of assembly, due to increased leads. So quality and on-time delivery are more important than price alone.

The following principles, which have either been mentioned before or will be in the future have been set down here to place everything in a nutshell and serve as a convenient source of reference.

The Ten Commandments of Concurrent Engineering

Create Multifunctional (or Multidisciplinary) Design teams.
Improve Communication with the Customer/User
Design Processes Concurrently with the Product
Involve Suppliers (or Vendors) Early
Simulate Product Performance
Simulate Process Performance
Integrate Technical Reviews
Incorporate "Lessons Learned"
Integrate CAE Tools with the Product Model
Continuosly Improve the Design Process

Reference?

THE SEVEN ORGANIZATIONAL BARRIERS IN THE IMPLEMENTATION OF CE AND SOME GUIDELINES TO OVERCOME THEM.

Implementation refers to the planning, organization and delivery of change. The change is in the process used to deliver new products. It is this process of change that is the cause of so much resistance to implementing anything new - in this case CE.

The remarkable success of companies that use the concurrent engineering process is well documented. Improvements in quality, cost, development times and delivery are phenomenal. However, converting to a CE environment is not without considerable effort.

The experience of many companies indicate that the quality of the CE implementation plan is more important than any other factor in the success of a CE program. The vast array of tools and methods available to implement the program have the appearance of a catalog selection process - choose the right ones to install in a specific situation. Studies of CE implementations demonstrate that in practice, the implementation of each individual tool can vary enormously in the benefits achieved. The selection of CE tools is a concern for most companies but, with the exception of team working, it is not a significant cause of low or high achievement in product development. The ability of most companies to deal with this technical issue is standardly high, but it is with behavioral and organizational issues that most companies are traditionally weak. Yet, these areas are consistently ignored and under-performance continues. Understanding these problem areas and developing techniques to overcome them will move companies rapidly upward from standard performance.

The seven barriers discussed in this section are the most common that are found in almost all companies that are switching to the CE mode. Some ways to overcome them have been examined. The incidence and effects of such barriers were clearly dramatized in a recent study of approximately 300 randomly selected industrial new product developments (*Souder, 1987*). The effective use of CE was made difficult by the unwillingness and psychological inabilities of R&D, manufacturing and marketing personnel to collaborate. Nearly 60% of the projects had some incidence of disruptive harmony that stood in the way inter-departmental collaboration. It further showed that the lack of collaboration and concurrent engineering correlated with the failure of the projects. This set of seven barriers is by no means comprehensive and other barriers called Common Failure Modes are discussed in the next section.

Organizational barriers relate to management style, organizational policies, organization cultures, personnel behavior, risk taking propensities and accustomed ways of functioning. These barriers are imposing to overcome, since they involve deep-seated and well-entrenched ways of doing things and behaving. Moreover, they are likely to be complex and interrelated. For example, a change in top management style can directly affect risk taking propensities.

Lack of clear commitment and support from **senior management** is a key barrier that has to be overcome. If CE is truly important and company-wide then all of senior management should be a part of the planning and ensure support. Implementation should begin in the board room. To quote Marion Wade the founder of Service Master," If you don't live it, you don't believe it" (*Belohav, 1990*). Philosophical shift must be initiated at the top of the organization, then wash down to the next layer of management. This effectively touches all levels of management with each layer being brought on board before the next is asked to sign on. This technique mandates that the executive level understand

and embrace the concepts before attempting to sell them to subordinate levels. This is called the "waterfall effect" of top management support that is necessary for organizational change (*Harrington, 1987*). Clarifying business benefits and plotting a non-CE scenario (i.e. what if CE is not implemented) is part of the process and this is where the upper levels of management could play an important part. Without first creating sufficient top management priority for CE it is unreasonable to move out of the getting started phase. Planning where to go and how to get there must follow from direction from top management to ensure that the effects are felt company-wide. Another requirement is for top management to allow sufficient time for the new philosophy to generate benefits. It takes time to get departments that have never been required to work together to cooperate on optimizing a design.

Inadequate organizational climates have been blamed most often for stunting the growth of a CE program. A climate is an organization's prevailing attitude, atmosphere and orientation. An empirical study of 52 firms found that three major factors controlled by top management were responsible for stimulating inter-functional cooperation, inter-departmental cooperation and the adoption of new techniques. They are the degree of uncertainty in task assignments, amount of role flexibility and the level of perceived openness and trust (*Souder, 1987*). It should be the endeavor of management to promote these three factors, in particular to ensure the success of a program.

Since CE emphasizes multi-disciplinary teams, a key to its success is **cooperation** between the various staff functions. There has to be willingness among the various entities to share information and insights about the product. An impediment to this requirement is a manager who is overly protective of his area. This is usually out of fear and insecurity, rather than a blatant disregard for the organization's objectives. This fear can be motivated by a lack of confidence in the individual's own talents, talents of the staff, or the fear of being shown up by one's colleagues. Regardless of the stimulus, fear must be eliminated to in order to implement any organizational improvement philosophy. Open exchange of ideas and information must be conducted in a non-threatening environment.

Inadequate reward systems that fail to motivate performance is a significant issue. The traditional reward system employed by many organizations can be a significant barrier to achieving the cooperation required. Reward systems based on departmental goals rather than organization-wide objectives can lead to sub-optimization of the organization's performance. If a department head perceives himself in an adversarial role with his organizational counterparts, he is less likely to share information needed for a successful product design. The organization must therefore ensure that its employee reward system is not contradictory to the co-operative efforts required of CE.

Lack of customer involvement has historically led to widespread failures in design, from consumer products to computer systems. The most important factor for determining the success or failure of a product is the user. This is a fact that is often forgotten in the product development process. It is the voice of the customer that has to guide the design effort at every stage. However, it must be kept in mind that customers vary in their level of sophistication. Some know exactly what they need, others are vague and yet others can make erroneous assumptions. Thus the customer's specifications have to be analyzed carefully, refined and then implemented.

The requirement of **supplier involvement** in the design process is described as "Co-makership". In the partner -supplier relationship, the supplier is integrated in operations of the client company (*Merli, 1991*). This requires a number of changes in the operating environment of the client company. First, the suppliers chosen should be kept to a minimum and there must be open information exchange and cooperation between the client and the supplier. Examples of the successful implementation of this practice include both Xerox and Ford (*Dertouzos, 1989*).

The last of the seven barriers is a **fear of the loss of creativity** of the design engineer. While the design engineer is somewhat restricted to using proven techniques and accepting advice of others involved, the benefits of improved design far exceed the restrictions on creativity.

Apart from the seven barriers discussed in this section there are a large number of other issues that managers have to face. Some of the more common ones are examined in the next section and are termed Common Failure Modes.

COMMON FAILURE MODES IN THE IMPLEMENTATION OF CE AND THEIR SOLUTIONS

Common Failure Modes (CFM) occur throughout the organization, from senior management to staff. Over the implementation time frame, the majority of the activity passes from management to staff, with early failings mainly occurring within management. The pattern of CFM's illustrates that the early phases of the product development process contain the most failings. This reiterates the fact that right-the-first-time design is equally relevant whether designing a CE implementation program or a product *(Evans, 1993)*.

The first and possibly the most important CFM is the **cost to benefit ratio**. Before commitment to CE is sought, the management must believe there is significant benefit to be gained. Senior executives must convey this to everyone involved in the program. If CE is viewed with uncertainty, this translates into a lack of commitment and ultimate failure. Costs of a CE program are difficult to predict. Return on investment of team training, building and developing, for example are more difficult to calculate than, say a CAD system. This makes it susceptible to cost cutting. If a CE implementation is viewed as a once only activity with a calculable low risk return, the money may become available, but permanently improved performance is unlikely. If it is viewed as a infrastructure project without financial focus it may never be approved or more likely, will never gain enough urgency to be implemented. The solution is to combine the two arguments to produce a program that delivers specific financial returns in the long term.

Middle management is the usual location of the initial CE implementation activities. But this level of management can never support a full implementation. A solution is to involve a member of upper echelons of management, who acts as the **champion of the program** and can lobby other members of the policy making levels of management.

Most CE programs have been victim to **poor vision**. What is it that is to be achieved ? The goal of the entire exercise seems to get lost during the process. Performance targets have to be clearly specified to provide clarity of vision. Short term targets are of special value here.

Lack of **CE experience** is another factor that plagues companies in the early stages of implementing a program. Flying by the seat of the pants is the most common approach. The solution to this is two fold. One is to recognize the lack of experience and the other is to look to your own experiences and plan to maximize their effect. Internal experience needs to be incorporated into the implementation plan quickly and effectively and this means a willingness to change the plan and the inclusion of a learning system within the plan.

CE is an enormous change from the traditional form of management that most companies are used to. Making the transformation is a long and painful process. The term used to describe this barrier to the implementation of CE is called **Culture Paralysis**. A culture change is required at every level of the company to redefine roles of individuals, departments and company policy makers. This is a massive undertaking if tackled in a top-down manner where everyone is instructed what to do and when. It is far less daunting if organized from bottom up; help individuals begin to change some of the things they do and the way they do it and grow from there. The sum of the changed individual behaviors eventually becomes a noticeable change in company culture. Changing individual behavior is primarily achieved by changing how the individual is measured and rewarded. Team supporting behavior comes from a common goal and common measurement and is complemented by lack of external interference.

The **variety of tools** available to implement CE is at times bewildering to companies that are exploring the CE option. The best way to solve this problem is allow the actual users to choose what they think is most appropriate. Assuming a team approach, team members should identify what tools are to be used and how. Guidance can be provided by the CE planning group.

Fear of the large change that CE will bring makes all CE implementation planners wary of starting the actual implementation. The desire to plan more carefully and in more detail, to win more support, etc. acts as a brake. This fear of the unknown can be overcome if senior management set specific and aggressive targets, acknowledge that the pace is deliberately high, that mistakes will be made and openly discussed and any lessons learned will be incorporated.

Most CE implementations are designed assuming a **product design specification** is in place. The implementation therefore fails to address the weaknesses already built in. Product specifications are typically lacking in sufficient content to guide design decisions or detailed to the point of describing how the product will work. By including the product specification in the analysis phase the CE planning team will inevitably tackle the weakness identified. The product specification should describe in customer terms what the customer wants in sufficient detail to identify tradeoff issues. This ensures best targeting of product characteristics.

Middle Management Hijack is a common problem in companies that are in the early (the most important) stages of a CE program. When multi-disciplinary teams are being used, the position of functional managers alter dramatically. They are likely to recall the resource from the team to solve short term problems, to require the individual to report back on their work and to alter that work as they see fit. This removes real responsibility from the team and slows the process, as well as re-emphasizing the functional alignment of team members. The eventual result is failure or reduced ability to meet project and product goals. The solution is to clarify and agree with the roles and responsibilities of management and the teams. This can only be achieved if the individuals involved understand and believe the principles of CE and education in the philosophy is a pre-requisite for this.

Team members allocated to a **CE team** for the first time find the new role disorienting. Even if management does not interfere, the individual team members will often revert to their previous way of working. In this situation the opportunity is being lost to bring all of the team resources together to ensure the product design progresses with all constraints being considered. This is often caused by middle management hijack and/or unclear roles and responsibilities. The solution in these cases is a refocus and introspective session to determine some role re-definition..

CE planning groups expend enormous amounts of energy identifying all possible problems and designing a solution that meets them. As each problem is analyzed further, more detailed concerns are raised which the solution must address. This is a form of paralysis as real change does not happen and the longer the delay continues, less likely that change occurs. Companies must accept that it is impossible to design a **perfect CE**

implementation and then stop the process. The ethos of continuos improvement must be accepted and the aim should be to implement a program that can quickly identify problems and opportunities from the implementation and incorporate the lessons into the plan.

The effort in all concurrent engineering implementation is initially based in management and it is no surprise that the majority of early common failure modes are caused by management. During the preparation and planning phase a lack of targeting is felt strongly and leads to confusion about what is acceptable and which tools to use.. This typically leads to a planning phase which concentrates on technology and avoids non-technical issues. The power of multi-disciplinary teams, for example cannot be ignored. The tendency to leave problems to be solved at some unspecified, later point and to divert energy to topics that are easier to solve is another big concern. To avoid these problems it must be absolutely clear that the implementation of concurrent engineering is a major challenge for management and the challenge, however daunting must be accepted. Most importantly, CE is based on the principle of common sense. This gives CE implementation a robustness that is difficult to shake; even poor implementation can be an improvement on existing product development performance.

We have discussed a number of obstacles that CE implementation has to face and some of the solutions that are applicable. To summarize some actions that can be taken, it has priority-wise narrowed down to five major actions that definitely need to be tackled.

Making the Cultural Transformation
Effecting Organizational Change
Concurrent Engineering Team Building
Providing Adequate Support Technologies
Fostering Role Definition and Interaction

The first two have been discussed at length in this section and the previous one. The third and fifth will be explored in detail in the next sections. The fourth is a technical barrier that has not been addressed and is beyond the domain of this report.

MULTIFUNCTIONAL TEAMS - INTERPERSONAL COMMUNICATION

In order to deal with the complexity inherent in modern product development there has been an increasing degree of specialization. Some engineers specialize in the design function, others in the manufacturing function, still others in reliability etc.. These specialists are then put together as a multifunctional team to develop a product. While there is an obvious advantage to having teams composed of well-trained, experienced specialists there can be considerable interpersonal communication problems within such teams. This is due to the fact that the previous training and individual experience which each specialist brings to the team leads to terminology and the use of that terminology particular to the individual's specialty. In other words, each specialist has their own viewpoint of product development *(Fotta & Daley, 1993).*

This is obviously a complex communication process. If each specialists' viewpoint is put into a concrete communicable form, compared with others viewpoints and demonstrated and explained to the teams then interpersonal communication could be enhanced.

Concrete representations of viewpoints are expressed very well using the **Personal Construct Theory**. This is a theory that has been applied in a variety of domains including clinical psychology, market research, knowledge acquisition for expert systems and management team development. PCT is based on the premise that everyone develops constructs (ways of thinking) about a domain based on differences they perceive between entities (objects, people, design alternatives, etc.) in that domain. For example, a group of design alternatives may be seen as varying in cost. An individual would then have a construct concerning this variation in cost about the design alternatives. The alternatives are the entities in this case.

PCT further assumes that people can name these constructs and tend to use bipolar dimensions when they do so, (e.g., friendly-unfriendly, quality-no quality, fast-slow). In the example just given a likely name is 'high cost-low cost'. This is referred to as the terminology used to verbally explain a construct.

According to PCT, people develop sets of constructs (construct systems) for each of the domains of their experience. An individual's construct system for a particular domain establishes a personal model of that domain for the individual. This is basically a person's viewpoint of the domain. Based on this viewpoint one anticipates the domain and acts on the basis of these anticipations.

Since a person's construct system is largely determined by past experience, the construct systems of team members with differing specialization will reflect their personal viewpoint. If these different construct systems could be determined and then communicated to the others then they could be used as the basis for improving team members' understanding of one another's viewpoints.

There are a number of techniques available to quantify viewpoints, but the most well known is the one developed by Shaw and Gaines in 1989. It is called **entity-attribute grids**. It provides a way to elicit and view a person's construct system for a particular domain. First of all, a set of entities are chosen within the domain that are items of interest. The entities are compared and will fall along a dimension extending from the positive aspect of this construct to the negative aspect of the same construct. Furthermore, one could quantify this construct by letting one end of the dimensions be a low number and the other end be a higher number. A person could think of different entities and construct similar scales and end up with a personal construct system (viewpoint) of approaching some task. The grids would be developed by describing the constructs along the rows and plugging in quantified scores in the columns. An individual's entity attribute grid (the patterns of ratings over all the constructs and the terminology used) provides a construct system or personal viewpoint of this domain.

The entity attribute grids supply a method to quantify viewpoints. The next step is to come up with a framework within which to compare these viewpoints. This framework is created using a communication classification scheme.

Viewpoints of experts in the same domain can be categorized in four ways - consensus, correspondence, conflict and contrast.

Consensus exists if two specialists use the same terminology to describe the same concept. There is no communication problem here. The specialists are thinking about the same thing in the same terms. If two specialists use different terminology to describe the same concept **correspondence** occurs. There is a communication problem here because they use different words to mean the same thing. Since the specialists have an underlying understanding of the same concept the problem should not be too severe if it is identified and communicated to the specialists as early as possible.

Communication problems become severe when the specialists have different concepts but use the same terminology to describe them. This is referred to as **conflict**. Finally, a potentially severe communication problem exists when specialists have different concepts and use different terminology. This is referred to as **contrast** and often indicates different areas of expertise. These last two categories are what happen most often in multi-disciplinary teams.

Developing entity-attribute grids for each specialist on a team provides the terminology used by each specialist to describe a construct. The pattern of ratings over a construct represents quantitative information about a concept. Thus entity-attribute grids can provide terminology and concept information. Using the scheme outlined above, the grids can then be compared to identify probable communication problems between specialists on multifunctional teams. These potential communication problems are then used as the basis for team discusssions to reduce communication problems on multi-functional teams.

CONCURRENT ENGINEERING METHODOLOGY FOR ENHANCING TEAMS (CEMET)

This is a methodology that is used to build on the theories and techniques developed in the previous section. It is divided into five phases.

Phase 1: This phase is problem identification and evaluation. In this phase opportunity for the application of CEMET is first identified and the appropriateness of using CEMET is considered. Information sources include documentation about the product under development, the project manager and the team itself.

Phase 2: This phase discusses how to develop data collection materials for the problem at hand. There are two basic choices - collect data by hand or use a software tool. The choice really depends on the resources and the size of the project. The crucial procedure in this phase is the development of a set of entities. The entities will be a short list of items drawn from a domain in which the entire team is working. Once the entities are chosen triads must be formed. A triad is a group of three entities. For example 'structure, supportability and acquisition' could be one triad. The objective is to try to elicit different constructs for each triad by asking each person to describe how two of them are similar and the other different.

Phase 3: In this phase team members' viewpoints are developed. Team members are interviewed to elicit constructs and ratings for the entities chosen. Each team member is interviewed individually. Triads are analyzed in detail by each member and their opinions are quantified on a scale.

Phase 4: At this stage team member's viewpoints are compared. The responses of all team members to the same triad are compared. The reasoning behind using each triad for this analysis is as follows. In considering the same triad each specialist has started with the same stimulus. Comparison of these samples should provide us with insight into classifying interpersonal communication.

Phase 5: The last phase involves the discussion of comparison of viewpoints. The first meeting should be with the entire team. Follow-up meetings may focus on certain groups or even pairs of individuals. This phase of CEMET technology is largely subjective. CEMET uses the communication classification scheme to evaluate team member constructs in order to identify possible communication problems. This information is used to focus team discussion.

The CEMET methodology proposed here can help each specialist in getting a better understanding of the viewpoint of the other specialists on a multi-functional team. Futhermore, use of CEMET can help to identify and work through the source of much dissension in these teams - viewpoints which are not communicated and terminology that is used in different ways by different team members.

One crucial area in which CEMET could be applied is in helping each team member better understand how other members view the goals of the team. Actually such an application will also likely help each team member to better grasp their own understanding of the goals.

ROLE OF THE TEAM LEADER

An effective product development team is a synergistic group of engineers who are committed to achieving common objectives: working well together; sharing resources; information and skill sets and producing high quality results. The key to the success of any team effort is the leader and this section discusses his role and reponsibilities within the framework of the CE program.

The leader is the representative of the team to the management. He has to act as a conduit by which the project team continues to receive proper resources of people, equipment, material, training and support from the organization (*Shina, 1991*).

Some of his responsibilities are to select and recruit a well balanced team in terms of technical knowledge, skills and experience. Time and resources for team development should be made available.

Assign responsibilities that match team members' capabilities. Allow each member to exploit his potential by giving them free rein in their areas of expertise.

Keep the team well informed on the perspective of management and the state of the project and the company in general. Reorganize the team to meet changes in project goals and technical needs.

Acts as the team's point person in recognizing and removing obstacles using directive management techniques to get the project back on track.

Project leaders are developed not born. With the correct mix of leadership, delegation and technical knowledge, project leaders can complete their projects successfully.

THE ECONOMIC COSTS AND BENEFITS OF CONCURRENT ENGINEERING AND HOW TO MEASURE THEM.

The benefits of concurrent engineering when concerned with the overall engineering design process is well documented. When properly employed, concurrent engineering techniques can dramatically reduce product development time, improve quality, and in theory, lower overall design cost. The questions that must be answered are how much does implementing concurrent design procedures save the organization financially, and how do we measure such a benefit.

According to Julius P. Wong, previous cost estimating systems used to evaluate the amount of financial capital involved in implementing a concurrent design are outdated and inappropriate. These estimates are based on three classes: screening estimates, budget estimates, and a definitive estimate. A screening estimate enables the organization to perform a preliminary fiscal examination of the project to determine whether such a project should be rendered. Budget estimates, close but more detailed cousins of the screening estimate, are utilized for budgetary purposes. The definitive estimate is the most detailed cost estimate employed but requires substantial time to complete.

Traditional engineering cost estimating systems place the cost estimation phase of the process at the end. Essentially, the design, analysis, prototype testing, and process planning phases are calculated before a cost estimate is made. This is obviously an inaccurate method for estimating the cost of a project based on a concurrent philosophy.

Wong and his associates have developed an integrated cost estimating system for the concurrent engineering environment. This process utilizes a new concurrently based cost estimating structure that develops a cost estimate in conjunction with the design and process planning activities. This procedure fosters a designer to generate cost estimates that reflect a products entire life cycle cost.

The ICESCE consists of four separate modules. A database module, an interface module, and a utility and central processing module. Seven modules comprise the database: the custom, labor, materials, operation, overhead, product, and support databases. The central processing module and the interface module are responsible for system calculations and input/output file managers respectfully. A set of utility programs comprise the utility module. Programs like the ICESCE, in the academic world, are facilitating the development of suitable cost estimating systems for concurrent engineering projects. Numerous studies have been performed in the private sector to analyze how the economic benefits of concurrent engineering can be measured. A study conducted by the space and defense company TRW is a good example of these efforts.

TRW performed an economic analysis based on the economic benefits of employing concurrent engineering techniques for several space and defense related projects. The projects included a low band sensor (project 1), a microwave circuit (project 2), a defensive satellite kinetic energy weapon (project 3), and a command center processing and display system (project 4).

To better understand the effects of concurrent engineering and discern associated costs, TRW investigated the direct and indirect labor and capital costs associated with a CE program. One important aspect of the study noted that the cost involved in implementing concurrent engineering programs should decrease as previously developed tools were re-used. This included both capital expenditures as well as domain expertise.

The results of the implementation of concurrent engineering techniques for each project was evaluated using a benefit/cost ratio. Estimated economic benefits of CE were weighed against the associated costs. The higher the B/C ratio, the larger the estimated savings, and if the ratio was less than one obviously the implementation of CE techniques cost (at least for the present term) are more than they are worth.

Previously completed similar projects were used as a basis for comparison. Therefore, the cost of a similar project using concurrent engineering techniques were compared directly to an earlier, conventionally managed program.

Project 1 was completed a month ahead of scheduled saving approximately 50,000 dollars in labor costs and while increasing base expenditures by $11,000. Therefore, the B/C ratio equals 50/11, or 4.5:1. Likewise, the use of CE produced a B/C ratio of 2.8:1 for project 2, 3.3:1 for project 3, and an astounding 17.3:1 for project 4.

Clearly, at least with the aforementioned defense and space related projects, the utilization of concurrent engineering methods saved the organization money. It should be noted that some of the savings were attributed to the increase in major design errors discovered early (for example: during project 3 manufacturing uncovered four major design flaws saving three weeks). Savings that were not calculated included benefits such as a potential increase in future business due to higher customer satisfaction. Although these measures were not computed due to a lack of accurate measuring techniques, their potential benefits are easily implied. More research needs to be done in the field of concurrent engineering project cost estimating and benefit analysis, since previously mentioned research suggests a wide array of potential savings.

BENEFITS OF CONCURRENT ENGINEERING - CASE STUDIES

There are many well documented examples that prove how powerful the CE process and culture can be in reducing time to market, improving design and product quality, reducing the number of design iterations, speeding the manufacturing process and lowering product costs. This section discusses some examples *(Turino, 1993)*.

AT & T made several organizational and process changes in the design of the "circuit pack" for its 3B series computer. The "model shop" where prototypes were fabricated for laboratory testing was completed eliminated. Initial units were built using the equipment that would be used in actual high volume production. Yields improved from 50% to 90% and design iterations were reduced by 33%. Achieving these results required actually doubling the size of the up-front circuit design staff. The resulting shortened time to complete each new design however, coupled with the savings due to improved yields and fewer design changes easily paid for the increased up-front costs.

Boeing's Ballistic Systems Division implemented a number of CE features that included using Product Development Teams (PDT's) that comprised of members from engineering, logistics (test and support), material (purchasing), manufacturing and quality assurance. The results were spectacular. Manufacturing costs down by 46%, inspection costs down by a factor of three, material shortages reduced from 12% to 1%. This was achieved by empowering the PDT's and holding them completely responsible. Each PDT "owns" its product and each PDT representative has the authority to commit his or her functional organization. Each member also participates in and authorizes release of drawings, requests for purchases and other design and implementation documents.

Burr-Brown chose a CE team approach, with excellent results in the design of digital-to-analog and analog-to-digital converters for digital signal processor applications. Personal interaction between the team members yielded better and more manufacturable designs. The process was started by encouraging inputs during the final revisions of product proposals from marketing and not during final revisions of the product designs themselves. The primary team consisted of members from design, test, manufacturing and marketing, led by a product manager, all dedicated to the product. Other personnel with additional expertise were called upon as needed during the product design. The result: time to market cut down by six to nine months.

Codex uses electronic integration of the design process to facilitate the CE process. Each engineering discipline has simultaneous access to the design representation data base and can thus participate in the design process in real time via his workstation. The investment has cut time to market by more than 33%.

Hewlett-Packard implemented a TQC program, which included CE and its features were management commitment, customer focus, statistical process control, systematic problem solving and total participation. The results: scrap and rework cots cut by 80-95%, manufacturing costs reduced by 42%, parts inventories cut by upto 70%.

CONCLUSIONS

Concurrent engineering is the way to go. The end of the global recession is hopefully in sight. Economic indicators are swinging upwards and that trend is likely to continue. Companies that have survived the recession should look at changing with the times and be better prepared for the next downswing in the economy. Increasing one's competitive edge is the only way to survive. The benefits of concurrent engineering are well documented and there is no doubt it pays off. But the question is - is it worth all the effort in terms of time, money and other resources to make that, as expressed in this paper, painful cultural and organizational change ? The answer is an absolute YES.

Quality and time to market are probably the most important aspects that define the competitive edge of a company and concurrent engineering makes the most significant difference in precisely these two areas. The benefits of concurrent engineering are both measurable and non-measurable.

The measurable ones are lower time to market, lower scrap rates, lower design changes etc. The non-measurable ones are probably the ones that make the biggest difference in the long term interests of the company. These include morale of the work force, self confidence of middle management, "ownership" and responsibility on the part of middle to higher management. These are values that are often hidden since they cannot be quantified and do not appear on financial statements. But they are what keep a company going and separate the leader from the rest of the herd.

Making the change is painful and it may not seem worth it in the beginning, but it the effort is worth it.

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