CONCURRENT ENGINEERING AND THE ENVIRONMENT

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ABSTRACT
Concurrent engineering is a powerful design method which utilizes the input from people who aren’t included in traditional design practices. It is important for manufacturers to understand the factors that contribute to competitiveness in the global marketplace. Competitiveness now includes the environment as consumer attitudes and legislation change to favor environmentally conscious products and processes. This paper explains how concurrent engineering can be used to design green products while gaining a competitive edge. Several design tools which aid in developing green products are defined herein. Concurrent engineering provides a means for efficiently incorporating the environment and other important design guidelines into the design process.

INTRODUCTION
There are many successes attributed to the design method called concurrent engineering (CE). For example Mercury Computers Systems Inc. (Lowell, MA) introduced a new add-on processor board in only 90 days instead of the usual 125 days [12]. Also, Cisco Systems Inc. (CA), maker of multimedia and multiprotocol internetworking products, saw its revenues jump $63 million from 1989 to 1990 when they adopted CE [12]. The key to CE is teamwork and uninhibited communication between departments who are traditionally at odds with one another. CE typically begins with the formation of a team which cuts across the entire product development and design processes. The team members are design engineers, manufacturing engineers, purchasing representatives, marketing representatives, customer service representatives, and suppliers. By including all of the people who will play a role in getting the product to market, better decisions are made the first time, reducing the need for redesign.

Benefits common to CE projects include shorter product introduction cycles, improved quality, reduced design iterations, and shorter production time [12]. All this adds up to a better product at a lower cost and in less time than traditional “over the wall” design methods. The overall result is a very competitive product. Examples of competitiveness achieved through CE include the products of Saturn and Hewlett-Packard’s Colorado Springs Division [8, 12].

Another recent advance in design is Design for the Environment (DFE) or green design, which resulted from increasing environmental concerns of both the consumer and government. The sins of past manufacturing and disposal practices continue to cost the U.S. billions of dollars. Because of this we now look more closely at what we plan to do and estimate the effects the product will have throughout its life and “death”. DFE considers the product, the processes utilized in the manufacturing stages, how it will be used by consumers, and how the product will be handled after its service life. Green design incorporates environmental objectives with minimum loss to product performance, useful life or functionality [5].

The definition of competitiveness means producing goods of higher quality, lower cost and in shorter times as manufacturers produce for a global market. But competitiveness no longer stops with these traditional goals. We must also produce goods with the environment in mind. Issues such as recyclability, toxicity, and emissions are being regulated at an increasing rate in countries around the world. Products with green designs are popular with consumers, too. Manufacturers who want to remain competitive must recognize the enormous opportunities green design presents and utilize them to their advantage.

U.S. manufacturers can not afford to fall behind in adopting the DFE philosophy. Already, foreign corporations have taken the lead in some areas of DFE. In Europe, many retailers are taking back the packaging from the products they sell. After the surge of high quality, less expensive Japanese products flooded U.S. markets in the late 1970’s, caution should be exercised so as to avoid a similar mistake regarding DFE. Competitiveness, achieved through green design as well as quality, cost, and time to market, is efficiently accomplished through the use of CE. Not only can traditional competitiveness be achieved simultaneously with DFE, it is facilitated by DFE.

PROCESSES OF DFE
The Office of Technology Assessment (OTA) identified two major goals of green design: waste prevention and materials management. Waste prevention is the activities by manufacturers and consumers that avoid the generation of waste. Materials management focuses on making the most efficient use of existing materials. By green design, the manufacturer improves material use efficiency by designing into the product features for reuse and recycling.
These goals are complementary as the reduction of resources in use results in less waste generated [5].

Waste prevention involves numerous aspects of product and system design. From a product view, eliminating unnecessary packaging is a marketing strategy passing the savings on to the customer. From a system view, those processes which use less toxic and exotic materials require less support systems and simpler material handling systems. An example is fiber recovery in the pulp and paper industry. This cuts down on the amount of fiber that ends up being landfilled, as well as reduces the need for virgin fibers. Other examples of waste prevention include weight reductions, minimizing energy used and extending service lives [5].

There are varying levels of material recovery which can be used as seen in Figure 1. It is possible that a product or its components can be reincarnated a number of times depending on the state of the component when the manufacturer receives it. The following definitions attempt to explain each process.

**Product Reuse** is not a new concept as glass milk bottles have been around a long time [10]. This requires the least energy to renew the product before it is reintroduced to the customer.

**Remanufacturing** has been defined as “Building today’s machine on yesterday’s base and possibly preparing it to adapt later to tomorrow’s technology,” by Sprow [9]. Old parts which are worn will be replaced by new ones in the old base. Often these machines are sold at a lower price than brand new machines, even though they perform the function as good as a new machine.

**Demanufacturing** refers to the process of reducing a product only to a level necessary to revitalize its functionality. This may, but does not necessarily include, the removal of subassemblies or parts which may be refurbished and reused. If subassemblies or parts are beyond repair they will be recycled to recover the materials [11]. Figure 2 shows the demanufacturing of a washing machine and the varying levels of product breakdown possible. This process strives to minimize the reduction of parts to a lower level of the product.
hierarchy. Figure 3 shows the hierarchy of a generic product. By reducing the components only as much as is necessary to reuse them, the value-added during previous processes is retained and energy requirements for reprocessing are minimized. This keeps costs to a minimum and reduces the volume that must be handled. This differs from the other processes in that assemblies and parts may be reused in original manufacture. Note that in this context, 'component' does not necessarily refer to a single part. A component may well be the complete product or an assembly of the product [10].

Recycling reduces components to the materials which compose them. This material is used in the manufacture of new parts. This requires the most energy of all the processes, but still spares the energy which would be needed for processing virgin materials, as well as saving landfill cost and space.

Energy recovery is used to convert chemical energy to other forms to extract the last value from organic material before it is disposed.

Previously, products were not designed to facilitate these processes. One design philosophy that supports green design is Design for Disassembly (DFD). By using fasteners such as two-way snap fits, or even molding in a notch for a screw driver to pry apart the product, disassembly is less time consuming, and results in less damage to parts.

Decision Making Strategies

The various phases of a product are examined by Life Cycle Analysis (LCA). This is a very useful tool in CE. LCA considers a product to begin at the point when material is extracted from nature and ends with return of the material to nature [10]. The definition of CE provided by Cleetus, "... to consider all elements of the product life cycle from conception through disposal," clearly includes a life cycle approach to products [2]. The product life cycle may have several loops within the Nature-Use-Nature loop as shown in Figure 1. The incorporation of green design into products facilitates the many benefits of CE ranging from reduced energy requirements to cost competitiveness.

When CE design teams use LCA there is a greater chance that the product will be as close to the optimum green design as possible. For instance, the supplier may be able to provide a recycled material in place of a virgin material called out by a design created by traditional methods. Since the supplier and designer do not confer with each other in traditional methods, the designer was unaware of the potential of alternative materials. In CE teams, this is overcome by communication between all members of the team as critical design decisions are made. Everyone is encouraged to make suggestions and new ideas are welcomed to improve the design. LCA provides a tool to examine each stage including raw material extraction, material processing, manufacturing, distribution, use, disposal, and any renewing or reusing processes. By examining each step, the inputs and outputs can be quantified and options can be weighed against one another to come up with the best overall solution.

Another technique for selecting design features is Quality Function Deployment (QFD). QFD is known as the "house of quality" in Japan where it is successfully used by Toyota Motor Corp. and others [6]. The goal of QFD is to maximize customer satisfaction. The customers are more than just product consumers. They include manufacturing and assembly, marketing, finance, and the environment. Multiple QFD tables can be used at different levels of design selections, as well as several customers in each table. Customer desires are weighted by importance and linked to design features by a simple spreadsheet. Each design feature is evaluated as to how well it meets the customers’ desires, clearly indicating which features are most important to incorporate. A second part of the QFD table is a correlation matrix which shows how each design feature interacts with all the others, as some may be complementary and others incompatible. Figure 4 displays the general form of a QFD table. Lastly, QFD provides a vehicle to compare the design features against those of competitors.

Environmental aspects of a product may be included in the QFD matrix to enhance the design opportunities. It is inevitable that tradeoffs are made when designing a product and the consequences of these decisions can be easily seen in the QFD table. For example, when an automotive component is being designed, there may be a choice between using metal or plastic. Each material has advantages and disadvantages which are correlated to the customer desires and their relative weight of importance. For instance, weight reductions continue to be a big concern, favoring the use of plastic, but plastic parts aren't being recycled whereas metal parts are. Therefore, plastic parts may contribute to landfill volumes, whereas the metal parts may not.

QFD supports robust design as well. Robust design, also known as parameter design, strives to reduce the product's sensitivity to variation in operating conditions by the careful selection of design parameter values [6]. By bringing a greater pool of knowledge to the design table of a CE team, robust design is easier and quicker, leading to greater competitiveness. Robust design also contributes to DFE because the selection of the optimum values will likely lengthen the useful life of the product, result in less waste, and reduce material and energy requirements needed to create the product.

Every manufactured product has inherent benefits and losses. Taguchi has modeled the losses incurred by society when a part is
not at the target value. The loss function depicted in Figure 5 shows that the minimum loss is experienced when the performance of a quality characteristic is at the target value, \( m \). The distribution of a quality characteristic is specified by its mean and variation. The drift in the mean and increase in variation due to aging, wear, and other factors throughout the product’s life results in an increasing loss to society [13]. Figure 6 demonstrates the shift in the characteristic distribution of a part over time, assuming a normal frequency distribution continues to characterize the quality characteristic over time. Green design evaluates these factors resulting in design choices which incur less loss over time and provide improved material efficiencies through demanufacturing, remanufacturing and recycling.

Deming and others have demonstrated that by removing sources of waste, it is possible to improve quality and productivity [3]. The removal of waste improves competitiveness not only by avoiding solid waste generation and its associated costs, but also, by excelling in traditional areas of competitiveness. Through the use of statistical process control (SPC) and design of experiments (DOE), the sources of waste are identified and eliminated [3]. The concept of "on target with the smallest variation" is central to understanding the variation in quality characteristics and minimizing the losses associated with shifts in the mean and increases in variation [13].

The modified life cycle engineering depicted in Figure 7 shows how the design and product cycles relate when these are considered infinite events as opposed to the old view of finite events. Previ-
Conclusively, the product cycle was considered to begin with design and end with disposal, but demanufacturing completes the circle. This represents the continuing use of assemblies, parts, and materials which also changes the design cycle and manufacturing considerations to account for the new source of assemblies, parts, and materials [11].

CONCLUSION
The design of a modern product requires more knowledge and skills than can be provided by a single person. Obviously, there are more guidelines which designers must be aware of as design methods become more sophisticated and more information becomes accessible to them. Design for the environment, design for disassembly, and design for recycling join comparable techniques such as design for manufacturing and assembly. Utilizing all these guidelines is challenging, but can be accomplished successfully within a multidimensional CE team. The tools contributed by various disciplines are necessary to design products that will keep up with growing customer expectations.

Companies concerned with long-term success must think in terms of DFE by using CE. There are initial costs associated with the processes such as recycling, demanufacturing, and remanufacturing which may be amortized and recovered. Enormous opportunities exist for manufacturers to pull ahead of the competition with respect to green design. Those who move ahead first will have a large hand in establishing regulatory changes and their competitive position as was demonstrated with catalytic converters used on automobiles [7].

Products designed with the environment in mind appeal to many consumers which increases competitiveness from a marketing standpoint. Consumers in Europe faced with high disposal costs are especially concerned with the environmental aspects of the goods they buy. Already, automobile OEM’s in Europe are planning to take back their products, as well as ‘green TV’s’ which can be returned to the manufacturer to be remanufactured and recycled, as well as eliminating all toxic chemicals from the design [1, 4]. Also, Xerox Corp. remanufacturers some of its parts from copiers recycles other for and annual savings of about $200 million [1].

CE is a powerful tool for producing unparalleled successes while reducing costs. It includes using LCA, QFD, and statistical quality control methods to accomplish green design. Bringing more people into the design process from the start results in better, more innovative designs. The examples included in this paper attempt to provide the reader a sense of the potential CE holds and how it can be used to design products with the environment in mind. The environment must be viewed not as a design constraint, but as a choice for manufacturers to use the technologies available to excel and become more competitive while keeping the environment in mind.
References


