Effective Use of Concurrent Engineering Tools in Engineering Education

R. Radharamanan, Angela P. Ansuj
Mercer University/Federal University of Santa Maria, Brazil

Abstract

In this paper, the concurrent engineering design concepts, the tools that are used to achieve the concept of design for manufacturability, and the benefits one can expect by integrating the best practices for their process improvement are applied in an engineering education environment. The students are trained to use the concurrent engineering tools in their engineering courses such as use of design of experiments and Taguchi methods in conducting experiments to improve the product quality by controlling the process variables; and the use of design for manufacture, computer aided design, and value analysis in their multidisciplinary senior design projects in improving the product design, meeting the time schedule (project completion time), and providing customer satisfaction (client) with high quality and minimum cost. The results obtained through laboratory experiments and design projects are presented and discussed.

I. Introduction

Concurrent Engineering (CE) is defined as the earliest possible integration of overall company's knowledge, resources, and experience in design, development, marketing, manufacturing, and sales into creating successful new products, with high quality and low cost, while meeting customer expectations. The most important result of applying CE is the shortening of the product concept, design, and development process from a serial to a parallel one. The general concepts when applied in an integrated manner are very powerful and can be applied in any type of organization [1, 3].

The basic purpose of CE is to be more effective by means of cooperation among all departments involved in the creation of a product [2]. The CE design process in its simplest form is the integrated execution of basic principles, such as process management, design, manufacturability, and automated infrastructure support. Process management is probably the most important of the four principles, since it coordinates and facilitates the CE design process [7]. The design phase is the execution of the design process for developing a product and its manufacture, and many different people that are involved in the project execute this phase. Manufacturability involves the interaction of the people involved in the actual production of the product with its designers, so that different parameters of the product can be reviewed and discussed and any problems quickly identified and solved. Finally, automated infrastructure support provides all the processes that facilitate all the other processes, such as computers, data transfer and retrieval systems, and the like [3, 7]. A very basic and important ingredient of CE is Design for Manufacture (DFM). DFM is the practice of designing products with manufacturing in mind so that they can

be designed in the least time with the least cost. Also, DFM allows a smoother transition from the design of a product into its production as well as minimizing the cost of assembling and testing the product. Quality and reliability are also affected by DFM in a positive way, and therefore the needs and satisfaction of the customers are met and the product automatically becomes more competitive in the market [4, 6].

II. Concurrent Engineering Design Process

The design process of CE has many objectives, the most important being the completion of the actual design of the product. This process begins with a mental idea of a product, and then it proceeds to mature into a more defined concept that can be engineered in many ways to come up with a finished product, taking full advantage of the other CE processes. An interesting aspect of the CE design process is the need to develop a model of the design process to complete a product design. Such a model begins with an intellectual process that is usually carried out in a team or a group of teams. Each team works individually and together to achieve the common goal of putting out a competitive product. The ultimate goal of CE is to integrate the different group's concepts and ideas smoothly and without conflicts, so that the final goal can be achieved in the most efficient way possible. There are many different design approaches that can be taken by the CE design team, such as stepwise refinement, group technology, and DFM. Of all three, DFM deserves the most study, since it relates directly the skills of CE's design and development with the industrial processes of production and manufacturing.

III. Design for Manufacture – DFM

A simple definition of DFM is the comprehension and optimization of interactions between different facets of the complex manufacturing systems for effective quality, cost and delivery, with the ultimate aims of producing products with better quality, lower cost, and a reduced time-to-market [2]. There are different stages when implementing DFM in any type of endeavor or industry. The first is the optimization of the design process, in which the actual process, and not the product, is optimized. The second stage is the optimization of the physical design or the actual product. Once a product is chosen that will be easy to manufacture, the product should be designed so as to ease its assembly. A comprehensive planning, research and development reduces the amount of iteration and makes any engineering change possible at a reduced cost in the event that a product is being revised and redesigned [2, 4]. As a result the quality, cost and delivery of the product are greatly improved thanks to early design decisions and increased communication among all members involved in the design, production, and marketing of the product.

The DFM design team should consider all the alternatives possible to come up with the optimal design, which is most of the time, a challenging task to undertake. The key to reduce costs is a synergism between cost, productivity and quality. If right from the beginning the DFM design team comes up with an optimal design that makes full use of production and materials, manufacturing costs will be reduced and there will be less quality risks involved. Also, the product's variability will be decreased, making a more desirable product with probable increase in sales and market share. A typical product design cycle for manufacture is shown in Figure 1.

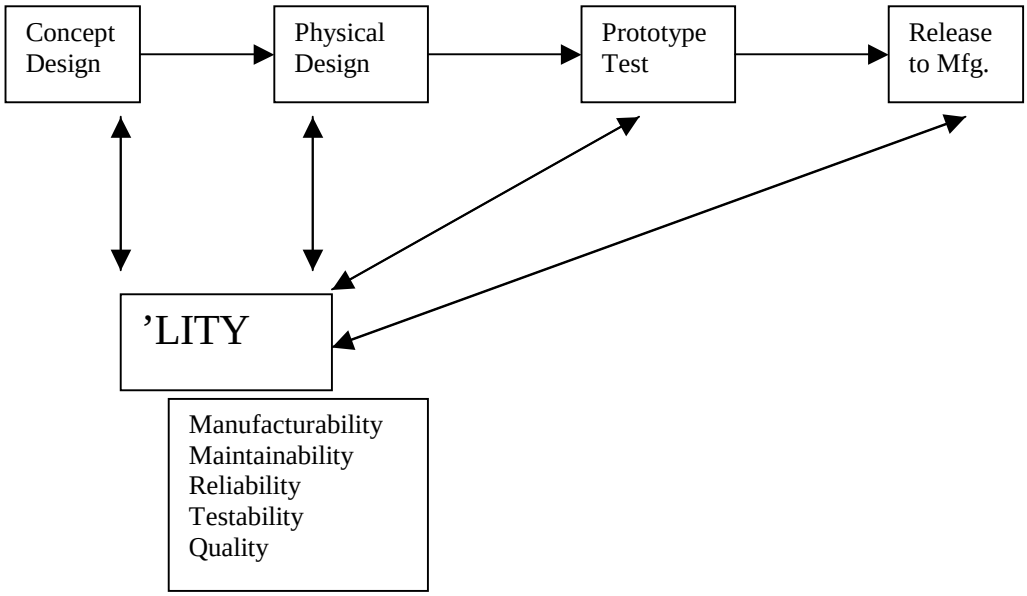

Figure 1. Product design cycle.

IV. DFM Tools

The commonly used DFM tools and what they can achieve when applied in a design process is given in Table 1 [6, 9]. The DFM strategies can provide success only when the various components of DFM are applied as a complete package. DFM in a general sense relies on a closer working relationship between the product design activity and manufacturing activity with the aim of improving manufacturing performance [8, 9].

Table 1: DFM tools and what they can achieve

DFM Tools	DFM activity			
	Optimize concept	Simplify	Ensure process conformance	Optimize product function
Design axioms	*	*	*	*
DFM guidelines	*	*		
Taguchi method	*	*	*	*
Robustness assessment	*	*	*	*
Mfg. process design rules		*	*	
Designer's tool kit			*	
Computer-aided DFM	*	*	*	*
Group technology	*	*	*	*
FMEA	*			*
Value analysis				*

V. Concurrent Engineering Concepts in Engineering Education

A. Design of Experiments and Taguchi Methods [10]

Use of experimental design and Taguchi methods in engineering education is illustrated by the term project during a period of one semester carried out by a team of senior engineering students at the Federal University of Santa Maria, Brazil. The students are asked to conduct experiments and use Taguchi methods in verifying the quality of incoming raw material received from small and medium producers who supply raw milk to the milk processing cooperative center. The parameters that need to be controlled on the incoming raw material from the vendors are:

- The acidity level is expected to vary between 14 and 18 degree Dornic;
- The density of the milk can vary from 1.028 gm/cm^3 to 1.032 gm/cm^3;
- The fat content can vary between 3% and 3.2%.

In this section, the selection of factors and levels for controlling the quality of milk received from small and medium producers using the design of experiment and Taguchi methods is illustrated. Based on brainstorming and group discussion, 3 factors with 2 levels are chosen for illustrating the process of optimization. These factors are regarded as control factors (factors that can be freely specified) and have effects on the quality of milk received from vendors. The factors and the levels are listed in Table 2. There are three factors each with two levels. There are a total of 4 degrees of freedom - one for the overall mean, and 3 for the three 2-level factors. This requires at least 4 experiments to be able to estimate the effect of each factor. Therefore, an orthogonal array of $L_4(2^3)$ has been chosen [10]. In this case, the interaction between the factors is not considered; and only three replications are considered to minimize the cost related to experimental design and analysis.

Table 2 - Factors and levels

Label	Factor	Levels	
		Low	High
A	Acidity (^{o} Dornic)	14.000	18.000
B	Density (gm/cm^3)	1.028	1.032
C	Fat (%)	3.000	3.200

Table 3 shows the experimental design for the milk received from the vendors. The columns under factor levels list process control factors and rows represent different setting combination of each factor. The factor values columns show the values of acidity, density, and fat chosen for each experiment. The response values columns show replications of percentage rejection of milk received from vendors for each factor level combination obtained from the experiments conducted by the students in the available lab facility at the cooperative milk-processing center. The last two columns represent the mean response and the standard deviation for each combination of factor levels. The sample mean is calculated from the response values:

$$\bar{Y} = \sum_{i=1}^{n} Y_i / n \qquad (1)$$

where Y_i is the sample value and n is the number of replications. The standard deviation is calculated using the relation:

$$S = \sqrt{\sum_{i=1}^{n} (Y_i - \bar{Y})^2 / (n-1)} \qquad (2)$$

According to statistical theory, the sample means are approximately normally distributed, but the sample standard deviations are not. To solve this problem, often sample standard deviations are transformed by taking their logarithms. The logarithms of the standard deviations are found much closer to being normally distributed.

Table 4 shows the results of the experiments based on the mean of the replication samples. Table 5 presents the averaging of all the experimental values of the percentage rejection of milk received from the vendors. From table 5, the chosen factor levels based on the minimum percentage rejections are A_1, B_2, and C_1. These correspond to setting acidity at 14° Dornic, density at 1.032 gm/cm^3, and fat at 3.0%. These levels are not in the orthogonal array $L_4(2^3)$. They are in the 8 full experiments. The contribution for the chosen factor levels is additive yielding. The expected value (EV) is given by:

$$EV = \text{Average} + (A_1 + B_2 + C_1)\ \text{Contribution} \qquad (3)$$
$$= 11.5 + (10.5 - 11.5) + (11-11.5) + (9.5 - 11.5) = 8.0\%$$

Table 3 - Experimental design for milk received from Vendors

Expt. No.	Factor Levels			Factor Values			Response Values			Mean Response	Standard Deviation
	A	B	C	A	B	C	1	2	3		
1	1	1	1	14	1.028	3.0	8.9	9.3	8.8	9.0	0.2645
2	1	2	2	14	1.032	3.2	11.4	12.5	12.1	12.0	0.5568
3	2	1	2	18	1.028	3.2	15.3	14.7	15.0	15.0	0.3000
4	2	2	1	18	1.032	3.0	10.2	10.3	9.5	10.0	0.4359

Table 4 - Experimental results based on sample mean

	A	B	C
Level 1	21	24	19
Level 2	25	22	27

Table 5 - Averaging of experimental values

	A	B	C	Average
Level 1	10.5	12.0	9.5	10.67
Level 2	12.5	11.0	13.5	12.33
Average	11.5	11.5	11.5	11.5

Thus, the expected optimum value for the combination A_1, B_2, C_1 is 8%. In this project the students are trained in teamwork, customer focus, product quality, process focus, leadership, communication, brainstorming, conduct experiments, analyze and interpret data, and optimization.

B. Senior Design Project at Mercer University

At Mercer University School of Engineering, senior design projects are multidisciplinary in nature with duration of two semesters. During the first semester, a team consisting of three students is expected to work on a project proposed by the client and come up with a preliminary design acceptable to the client. They work closely with the client and the technical advisors to accomplish this task. Once the preliminary design is approved, during the second semester, the students' team will build, test, and install the design to the satisfaction of the client and the technical advisors. It is very common that three students from three engineering disciplines sign up for a design project involving knowledge and skills from different engineering disciplines.

One such project is given to a design team consisting of three students. The task is to integrate a CRS-A255 robot arm with a Fadal VMC 15 CNC machining center [5]. The team should design an automatic clamping device to hold the part that is being machined. They also should design a control system to operate the automatic clamping device. They are expected to consider the safety issues while operating the system, as well as learn to program the robot arm and the CNC machining center. The summary of the work accomplished by the team is presented and discussed below.

The Clamping Device [5]: Three different alternatives proposed, for the clamping device, are: 1. Use a pneumatic vise. 2. Use two air cylinders and a permanently mounted piece of L-shaped metal. 3. Use one air cylinder and a permanently mounted piece of V-shaped metal. The feasibility criteria considered for the clamping device are: to produce a clamping force from 10 to 150 psi; to fit onto a 16"x 29" CNC machining center table; capable of opening and closing automatically; and to hold a 3"x 3" part. The merit criteria considered for the clamping device are: cost, centering ability, and safety.

Based on the feasibility criteria, merit criteria, cycle time analysis, force analysis, robot work envelop, robot control program capability, and sensitivity analysis, the third design alternative

has been chosen. This includes an air cylinder with a V-block attached to the end of the shaft, and a V-block that will be mounted on the CNC machining center table.

Control System Design [5]: Three different alternatives proposed, for the control system design, are: 1. Write a computer program for the CRS-A255 robot arm to control the air solenoid. This will be accomplished through an integrated relay switch in the robot's general-purpose input/ output port on the back of the C500C robot control unit. The relay switch will be normally open and supply the 120-volt AC to the solenoid so that it will stay closed thereby keeping the clamping device open. When the computer activates the relay switch, the switch will open removing the 120-volt AC from the solenoid so that the solenoid will open. This will allow the air pressure through to close the clamping device. 2. Use the manual approach, in which the human user will flip a switch and the clamping device will either open or close. Similar to the design alternative 1, when the switch is flipped, the current will flow through the solenoid and close it thereby opening the clamping device. When the current is cut off, the solenoid will open and allow the air pressure to close the clamping device. 3. Use the combination of alternatives 1 and 2. In this, the user will select whether the clamping device should operate in automatic or manual control mode.

The feasibility criteria considered for the control system design are that it should fit on or around the table to which the robot arm is attached to, the table should fit securely inside the CNC machining center opening, and the robot arm should not make contact with the CNC machining center while loading or unloading a part. The merit criteria considered for the control system are: cost, easy use, safety, constructability, and client preference.

The third alternative with a dual control system in which the user may select either automatic (computer control) or manual (user control) mode has been selected. The overall project cost is estimated to be $150 considering only the material cost for building the clamping device and the control system.

During the second semester, the students' team will build, test, and install the clamping device and the control system. This set up will form an integral part of the CNC machining cell with robot interface for loading, unloading, and automatic actuation of the clamping device.

VI. Conclusions

In this paper, many concepts have been listed that when properly applied will lead a design team to an optimal design of any product or service. Only by the skillful integration of design, manufacturing, and marketing an industry today can survive in this highly competitive world where cost, time-to-market, and good quality are imperative for survival. The effective use of some of the concurrent engineering tools in engineering education presented and discussed in this paper will certainly prepare the engineering graduates to meet the above challenges. The students are trained in most of the concurrent engineering tools during their senior design projects which include team building, customer focus, customer satisfaction, leadership, product and process focus (cost, time-to-market, and quality), design for manufacture and assembly, computer aided design and manufacturing, design of experiments and Taguchi methods, and selection of design alternatives using value analysis.

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R. RADHARAMANAN
Dr. R. Radharamanan is the Professor of Industrial and Systems Engineering at Mercer University in Macon, Georgia. His primary research and teaching interests are in the areas of manufacturing systems, quality engineering, and product and process development. His former positions include: President of ISPE; Director of Advanced Manufacturing Center; Acting Director of Industrial Engineering; and Research Director CAM and Robotics Center. His professional affiliations include ASEE, IIE, ASQ, SME, ASME, and ISPE.

ANGELA P. ANSUJ
Dr. Angela P. Ansuj is the Associate Professor of Statistics at Federal University of Santa Maria, Brazil. She received her B. S. in Accounting, M. S. and Ph. D. in Production Engineering from the Federal University of Santa Maria. Her primary research and teaching interests are in the areas of quality and productivity, and applied statistics. Her former positions include: Chairman of the Department of Statistics and Coordinator of the Graduate Program in Quantitative Methods. Her professional affiliations include Brazilian Societies for Operations Research, Production Engineering, and Quantitative Methods.