99A0091

99A009I

Project Number IQP-MQF9811

The Role of Concurrent Engineering in Product Realization

An

Interactive Qualifying Project Report

Submitted to the Faculty

of the

Worcester Polytechnic Institute

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

Cem Oflaz

Cem Oflaz

Date: August 19, 1999,

Approved:

M. Fofana

Advisor: Professor Mustapha S. Fofana

ABSTRACT

For a company to survive in today's competitive world, it should constantly reduce product costs, improve quality and also shorten the time to market. This brought along the shift from the traditional linear management of product realization activities to nonlinear or concurrent engineering (CE) management. The objective of this project is to become familiar with the needs of concurrent engineering approach and its impacts in industry. Using the typical tools of CE, such as computer-aided-design and computer-aided-manufacturing (CAD/CAM), quality function deployment, DesignQA, we have demonstrated how product realization activities are simultaneously managed. The benefits of CE are illustrated by considering a case study for the product realization of the MDX Helicopters at McDonnell Douglas Helicopter Company.

TABLE OF CONTENTS

GOAL STATEMENT

The goal of this project is to explore the importance of concurrent engineering in product realization process.

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to thank the Prescient Technologies, Inc. for providing me numerous materials and publications on my research for this project, and also giving me an internship opportunity, where I gained significant experience with CAD systems.

I would also like to thank Professor Mustapha Fofana for his guidance through out this project. It's been a tremendous experience working with him. This project would not have been possible without his support.

Mostly, I would like to thank my family for their support in making my education possible. It has been a stressful and enlightening journey, which has become my most valuable asset.

Chapter I. The Need for Concurrent Engineering

1. Introduction

For more than ten years, the globalization of manufacturing has been proceeding at a frantic pace. At the same time, the competitive environment also reached a serious and sustained high level of intensity. In order to be able compete in this environment, every manufacturing organization now must:

- Constantly reduce product costs
- Substantially shorten time to market and response to customer demands
- Constantly improve product quality

In order to achieve these goals successfully, a company must understand the importance of product realization process. Product realization is briefly the entire activities needed to produce a product. Product realization combines market requirements, technological capabilities, and resources to define new product designs and requisite manufacturing and field support processes [12]. Concurrent Engineering (CE) is a manufacturing methodology that is used in product realization process. The goal of CE methodology is to rapidly and simultaneously make a product with less cost and better quality. Concurrent literally means a case of existing or happening at the same time. CE can be defined as an integration of product and process design activities for production. CE provides an environment, where product realization activities are performed in parallel rather than sequential in order to reduce the cycle time and improve quality of the product. Before companies adopted CE, a product was first designed, modeled, tested during the design process and then sent to the manufacturing engineer to be manufactured, where most of the problems were usually uncovered. Because of the lack of communication between the design and manufacturing engineers, many designs would not fit in the manufacturing process, thus bad quality products were produced or the cycle time to produce a product increased dramatically. However, using CE tools such as CAD/CAM minimizes the lack of communication between the design and manufacturing engineers. In fact, the designs can be taken to the CAM environment (CNC machines) directly from the CAD environment without making any prototypes or blueprints for manufacturing. Since the engineers perform concurrently, any problem that may occur can be solved rapidly without reducing the cycle time. As a result of using CE in product realization, companies can reduce cycle time, constantly improve quality, reduce production cost by reducing waste and eliminating re-iterations of the product.

The term concurrent engineering, also called simultaneous engineering, was used the first time in the US in 1989 [1]. It is primarily a means to increase competitiveness by decreasing the lead-time and improving quality. The main methodology is to integrate the product development and the development of the product design and production processes. In this way concurrent engineering is a label for a development era of the manufacturing technology. To be successful CE must be based on relevant decisions; such as the use of efficient tools and is led by dedicated management. Education and the ability for teamwork are essential for the success of CE. More efficient software tools and manufacturing system principles are being developed in research projects. Today, CE is widely used in industry and expectations range from modest productivity improvement to a complete push-button type automation, depending on the views expressed [4].

The lack of communication between design and manufacturing engineers has been an issue that results in bad products and inefficient production methods. CAD/CAM systems are the best tools to provide communication between design and manufacturing departments in a company, and are also the best tools for concurrent engineering. Using computers in design process allows the designer to design without constructing a prototype, instead modeling, analyzing and testing on the computer. CAD also provides fast data transfer to manufacturing department that can be used in CAM systems. Another tool for concurrent engineering is the quality function deployment (QFD), which is a method for decision making during product realization process before marketing the product. CE in product realization process is explained in detail in chapter two. Chapter three discusses the role of concurrent engineering tools such as CAD/CAM and QFD in product realization process with a case study at McDonnell Douglas Helicopter Company. Methods to improve product quality with DesignQA are also introduced in this chapter.

Chapter II. The Role of Concurrent Engineering in Product Realization Process

2.1 Product Realization Process

Making a useful product is not only composed of design and manufacturing processes, but it also involves activities such as material selection, cost, quality, time-to-market and customer support. Product realization process involves all these activities that are required for a successful product. Successful product must meet fast changing customer's needs in order to be a marketable product. This can be accomplished by rapid production and better product quality. Rapid production produces high production cost and may also bring along more defective products if not managed well.

A good product realization process begins with an exploration of business, marketing and technical opportunities, followed by a firm definition of customer need and product performance requirements including quality, reliability, durability, and other important factors such as aesthetics [3].

Many improved methods have been introduced in product realization process. These methods are Concurrent Engineering (CE), Design For Manufacture (DFM), Design For X (DFX), Life Cycle Engineering, Lean Manufacturing, Agile Manufacturing and Integrated Product and Process Design and Development Method (IP^2D^2). All these methods have the same goal that is, rapid production with less cost and better product quality. In the following section Concurrent Engineering tools will be explored and how these improved Product Realization Process will be discussed.

2.2 Concurrent Engineering in Product Realization Process

Modern manufacturing industries are facing many challenges, such as global competition and fast-changing consumer-demands. In order to meet these challenges, there is a need for rapid production with less cost and constant product quality improvement. These and other challenges can successfully be met by adopting CE methodology. CE tools such as CAD/CAM is used in many industries such as automotive and aerospace, for geometric modeling of conceptual designs, design testing, drafting, documentation, machining, inspection and assembly of complex parts. Using CAD/CAM results in cost and time savings in every step of the product realization, which makes it an important tool for automation. The savings of CAD/CAM method over Manual method can be seen in Figure 1 [14].

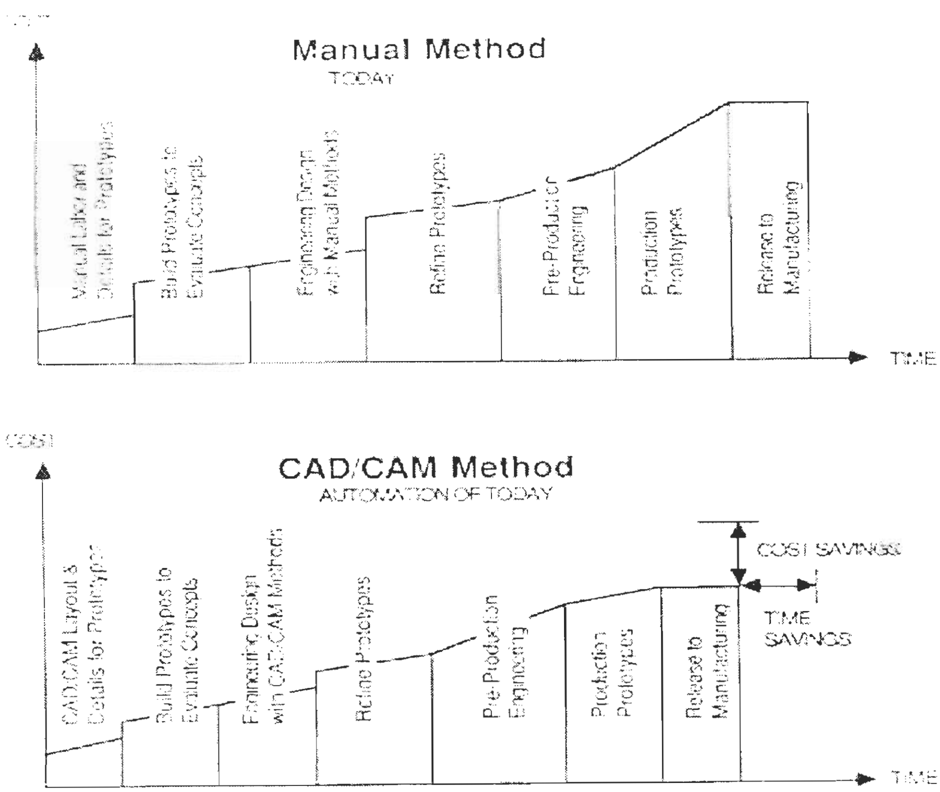


Figure 1: Comparison of Manual Method and CAD/CAM Method in today's Automation.

2.2.1 Components of Concurrent Engineering

According to B. Prasad "Concurrent Engineering Fundamentals Vol. 1&2" [4], CE approach to product design and development has two major themes. The first is establishing a concurrent product and process organization. The second theme is applying this methodology to design and develop the total production system. He defined CE system as a set of two synchronized wheels that represent the two themes with inner working of its elements (see figure 2). CE is " integrating product and process design over the enterprise" [4], meaning the activities in product realization process acting together to produce a product. The first theme of CE approach is establishing a ***concurrent product and process organization***. The second theme is applying this methodology to design and develop the total product system. This is referred as ***integrated product development*** (IPD) [4]. In Concurrent Engineering system, each modification of the product represents a transformation relationship between specifications (inputs, requirements and constraints) outputs, and the concept the modification represents. At the beginning of the transformation, the specifications are generally in abstract forms. As more and more of the specifications are satisfied, the product begins to evolve into physical form. The two wheels together harmonize the interests of the customers and development of CE organization (frequently referred as an enterprise).

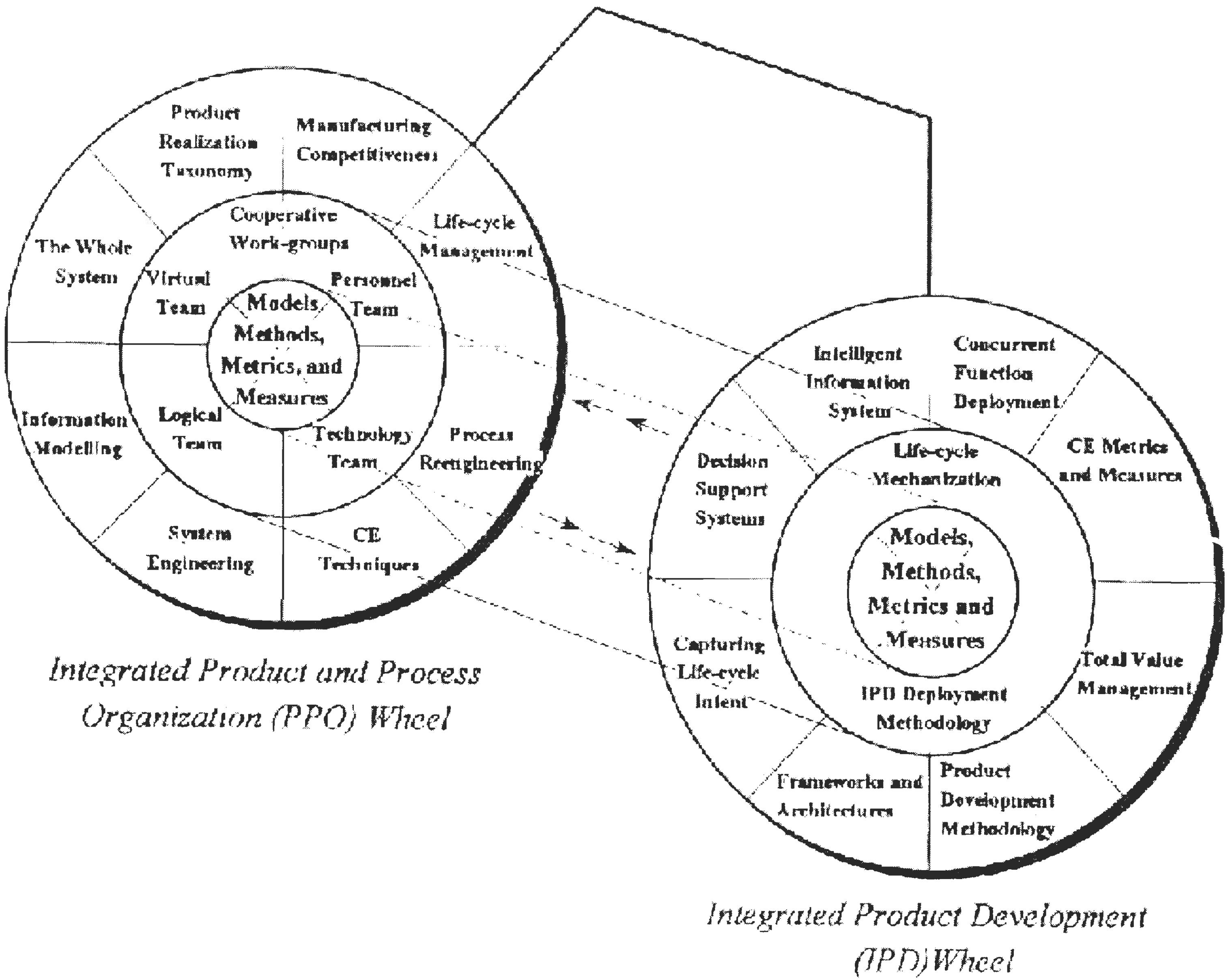


Figure 2: A Synchronized Set of CE Wheels.

CE is a people and communication issue whose goal is to design and manufacture a product in such way that the product will meet the customer's requirements to the fullest extent. It has been the challenge for the design and manufacturing engineers to work together as teams to improve quality while reducing costs, weight, and lead-time. A single person, or a team of persons, seems to be not enough to provide the links between, human knowledge and skills, organization and technology. Thus number of supporting teams are needed [4]. The communication between these teams such as, design and manufacturing engineers are crucial in order to satisfy the customer's requirements.

The preliminary design of the product is first established by the design engineers, manufacturing engineers identify manufacturing processes that are suitable for the product. Management team analyzes the cost, market and management of the product. These activities are carried out concurrently during the integrated product and process organization wheel. The supporting teams such as concurrent function deployment and decision support groups should provide the engineers with more information about the customer's requirements and the most efficient way to satisfy these requirements.

The benefits of adopting concurrent engineering are numerous and positively affect the various activities in a corporation. Some of these benefits include the following:

1. Because the consumer is consulted during the early product development process, the product will appear on the market with a high level of quality and will meet the expectations of the customer. For example, customer support provides the communication between the customers and the designer such that the customer can discuss with the designer the likes and the dislikes on the previous product. Thus the

engineers can eliminate the unwanted features on the product and can concentrate more on the customer requirements.

2. Adopting concurrent engineering will result in improved design quality, which is measured by the number of design changes made during the first six months after releasing a new product to the market. These design changes are extremely expensive unless caught early during the product development process. The lower the number of these changes, the more robust the design of the product is. In a concurrent engineering environment, these design changes would evidently be minimal. Using the CE tools such as CAD/CAM can translate the designer's ideas to the manufacturing engineer in a fashionable way that minimum design changes would take place. If design is not compatible with the manufacturing process, then the problem could be recovered immediately in the product realization process.
3. Reduced production cost is a consequence of the reduction in the number of design changes after releasing the product and the reduction in the time of the product development process. Reduced cost of course, provides a manufacturing company with a real advantage in meeting global competitive pressures and an ability to eliminate the worry from other competitor's prizes.
4. As a result of reduced design time and effort, new products will be pumped into the market more frequently. This is an advantage that Japanese automakers have over their American counterpart [4]. They can produce more different models, with smaller production volumes and shorter life cycles.
5. Increased reliability and customer satisfaction will result from delivering the product "right the first time" and will also enhance the credibility of the manufacturing

company. Strong interface with the customer provides to understand the needs and the requirements of the customer, which results in making the product right the first time.

2.3 Tools for Concurrent Engineering in Product Realization Process

Concurrent Engineering is largely an organizational and managerial challenge. Communication between the different parties involved in the product realization process, early design reviews by the development team, and applying value engineering/quality function deployment are some of the challenges that management has to face. However, the rapidly advancing field of computer aided engineering and design opens an opportunity to promote concurrent engineering effectively. Most of the existing computer programs for life cycle design typically apply to detailed stages of design. Their aim is to provide feedback to the product design as opposed to process design. Although it is widely recognized that engineers need to look at early designs in order to make a significant impact, many manufacturing issues cannot be answered without the details of the design.

Over the last decade advances in product design and development, including manufacturing technologies have been revolutionary. Computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), computer-aided process planning (CAPP), computer-integrated manufacturing (CIM), and computer-aided testing (CAT) have helped cut down product development cycles and further reduce the variability inherent to the manufacturing processes. These and other advances in automation and system integration have helped reduce costs that were traditionally associated with mass manufacturing [6].

2.3.1 Computer-Aided-Design and Computer-Aided-Manufacturing

Applying the capabilities of the computer to assist in the preparation of a graphical representation of a product offers many advantages such as the ability to design and manufacture complex features within limited time and better dimensional accuracy. Dimensions can be stated in the units desired and the drawing will be a very accurate representation. In addition, it is easy to imagine the productivity gains that are available if one can simply recall an existing drawing and modify it, compared to the laborious task of recreating the entire drawing from scratch.

The modern CAD systems represent the physical characteristics of the object in mathematical form [10]. The mathematical representations can be used to develop what the properties of the product would be if it were to be built, and to test (simulate) its behavior under different conditions. The imaging process serves time and labor. The resulting mathematical descriptions open the door to an ever-increasing range of engineering capabilities such as (CAE) and (CAM).

Geometric modeling is one of the most widely utilized tools of CAD. The principle packages that are most often available in CAD software are geometric modeling, geometric graphics, design, manufacturing and programming software. A well design CAD system should allow ease of repetition of detail, rapid modification of entities and modification and the reuse of existing models. For this to be achieved effectively, the CAD user has to be provided with a rich set of facilities for entity manipulation. The system also has to be based on storage of the model in a computer data structure that facilitates inactive modification. CAD is used during the design cycle in both analysis and the redesign. CAD is most useful during the redesign process, because it allows the designer to make changes very easily by a simple sequence of commands. One of the major advantages of CAD is that it allows the designer to exercise creativity, which could be very important at critical moments of the design cycle. With the development of three-dimensional CAD systems, CAD models contained enough information for NC cutter-path programming. The link between CAD and NC began with the so-called turnkey CAD/CAM systems, which were developed in the 1970s and 1980s Many manufacturers of discrete products have employed NC machine tools for decades [7]. For a machine tool such as a mill or lathe, the part program describes the path that the cutter will follow, as well as the direction of rotation, rate of travel, and various auxiliary functions such as coolant flow. Whether it is a simple two-axes drill or a complex five-axes machining center, all NC machines require part programming. The preparation of paper tapes or tape images for NC machine tools is complex and time consuming. It often takes several hours or days to program and prepare a paper tape for a part on a machine tool. Since part programmer have difficulty keeping up with the demand for new part programs, there is a strong incentive to develop efficient procedures capable of replicating the human part programming process and install these procedures on a CAD/CAM system. An example of how the use of CAD has improved productivity at McDonnell Douglas Helicopter Company is illustrated in Chapter Three with a case study [6].

2.3.2 Numerical Control Machines and Computerized Numerical Control Machines

One of the most important developments in manufacturing automation is numerical control (NC). NC has been defined by the Electronics Industries Association (EIA) as " a system in which actions are controlled by direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data." The data required to produce a part is called a part program. The focus of NC machines has traditionally been on the manufacturing of complex parts in large volumes. However, because of the development of more efficient programming languages NC is now employed for smaller volume sizes. A numerical-control machine tool system includes the machine-control unit (MCU). The MCU is further divided into two elements: the data processing unit (DPU) and control-loops unit (CLU). The DPU processes the coded data read from the tape or other media and passes information on the position of each axis, its direction of motion, feed and auxiliary function controls signals to the CLU. The CLU operates the drive mechanisms of the machine, receives feedback signals about the actual position and velocity of each axes, and indicates when an operation has been completed. The DPU sequentially reads the data when each line has completed execution as noted by the CLU.

The motion control of NC machine tools is completed by translating NC codes into machine commands. The NC codes can be broadly classified into two groups.

(1) Command for controlling individual machine components such as motor on/off control, selection of spindle speed, tool change, and coolant on/off control. These tasks are accomplished by sending electric pulses to the relay system or logic control network.

(2) Commands for controlling the relative movement of the workpiece and the tools.

These commands consist of such information as axes and distances to be moved at each specific time. They are translated into machine-executable motion-control commands that are then carried out by the Electro-mechanical control system. Currently, NC controllers are built using microcomputer technology. Such controllers are called CNC (computer numerical control). CNC systems are more flexible than their NC counterparts because they allow programs to be edited, stored in memory and recalled instantly. CNC machines can generally machine more complex shapes than NC machines and also provide circular interpolation and canned programming cycles. CNC controllers have been applied to nearly every kind of machine tools namely, lathes, milling machines, drill presses, grinders, etc. Features available to modern machines include tool, pallet, and workpiece changers. Controller features include interpolators, graphics interfaces, interactive operator programming, and data communication.

Creation of NC programs from CAD files allows a part programmer to access the computer's computational capabilities via an interactive graphics display console. The part-programming operations typically start with a design in the form of a CAD drawing or a model. After a review by a production planner, the tool design/selection process is completed, often with the assistance of the CAD system. Part programming through CAD allows the part geometry to be described in the form of points, lines, curves, etc., just as it is on an engineering drawing, rather than requiring a translation to a text-oriented notation. CAD/CAM system allow the user rapidly define the geometry and as well as to use powerful graphics display capabilities to quickly define, verify, and edit the actual cutter motion.

2.3.3 Quality Function Deployment

Quality function deployment was developed in Japan during the seventies and now is being used extensively in many companies around the world. QFD is another tool for concurrent engineering, which identifies the customer's needs and translates them into a set of design parameters that can be deployed vertically top-down through a serial four-phase process [4]. The four phases are:

1. **Product planing:** This matrix constructs the frame for the product, driven by what the customer wants. More effort is involved getting the information necessary for determining what the customer truly wants. This might seem to increase the initial planning time in the product definition phase, but it reduces the overall cycle time in bringing a product to market. Customer requirements are basically the needs of the customers. For instance customer needs for a car might be a V-6 engine, fast acceleration from 0 to 60 mph, lightweight, low fuel usage and serviceability. These are the row elements of the matrix. Design requirements that are defined by the manufacturer constitute the column elements of the product-planning matrix. They are a set of quality characteristics through which a set of customer requirements can be realized. For instance power, crashworthiness and weight might be design characteristics for a car. Feedback from an old product defines the needs, what's for a future product. Thus the interface with the customers are very important. This can also be accomplished by conducting surveys for customers or even to the current market.

2. **Parts deployment:** This process identifies the characteristics of the design such as the material, dimensions and other properties. These are the technical features of the selected design. This matrix contains the part requirements (rows) and the design parameters (columns).
3. **Process planing:** The manufacturing processes are defined in this matrix depending on the characteristics of the part. Here the design is tested if it is compatible with the manufacturing processes without manufacturing it. If any problem occurs immediate change can take place because of the concurrency of the product realization process.
4. **Production planning:** Here the decisions are made for how to go about the production process, marketing, serviceability, and support of the design. This planning helps to make the realization process more efficient. The manufacturer will have the opportunity to discover and correct the problems before they occur during the production process.

QFD provides decisions for all these concepts before making and marketing the product. It is the most efficient way of improving quality continuously during the realization process. QFD is basically the framework of the product, likened to the framework of a house. The foundation is customer requirements. The frame consists of the planning matrix, which includes items such as the importance rating, customer-perceived benchmarking and sales point. The second floor of the house includes the technical features. The walls are the interrelationship matrix between the customer requirements and the technical characteristics [11].

Chapter III. The Role of CAD/CAM in Concurrent Engineering

3.1 Applications of Concurrent Engineering Tools

CAD/CAM systems are implemented in many manufacturing companies that are making complex products, especially in automotive and aerospace industries in order to reduce design and production time, cost and also increase quality. CAD is used to design complex parts on the computer both geometrically and analytically such that there will be no need to physically build prototypes or models. And also to prevent complex engineering analysis such as material strength, stress, aerodynamics, heat transfer and vibration, which take the most time in the design process.

CAM has done for manufacturing process, what CAD did for design process. Simply reduces production time, improves quality and also reduces cost by eliminating waste material. Another important advantage of CAD/CAM systems are to make the data re-usable for other design and manufacturing processes in order to reduce the time when a product change is introduced. Examples of how concurrent engineering tools such as CAD/CAM and QFD are implemented in the industry are shown in the following sections with a case study at McDonnell Douglas Helicopter Company [6].

3.2 Preliminary Design of a Light Commercial Utility Helicopter

McDonnell Douglas Helicopter Company (MDHC) is developing the MDX helicopter in direct response to stated customer needs for a flexible, light twin helicopter with significantly reduced life cycle cost [6]. The Company uses MDX as a pilot project for its integrated product definition process, which is the company's version of concurrent engineering. The company has changed their linear traditional design process to a more concurrent approach, which includes early emphasis and treatment of manufacturing, supportability, and business requirements. This integrated product definition process is illustrated in Figure 3.

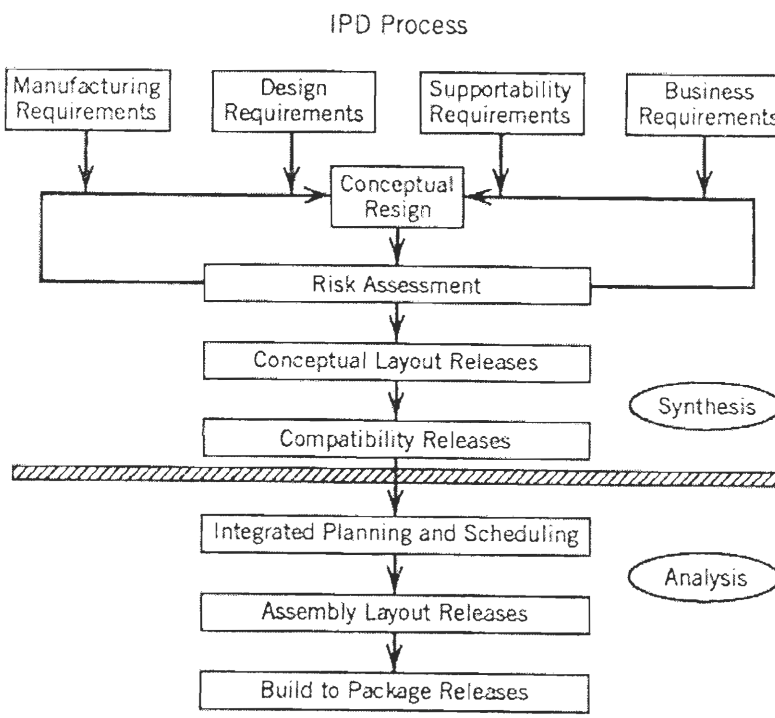


Figure 3: Integrated Product Definition Process at MDHC [6].

3.2.1 Implementation of QFD for MDX Helicopter Design

One of the key characteristics of this new implementation is the strong interface with the customers. It is essential to understand who the customer is and what the customer's requirements are. In order to achieve this, MDHC decided to use quality function deployment method with the concurrent engineering concepts. Customer requirements are identified by a worldwide market survey and also using the feedback at the conferences and meetings. Using the results from the market survey and feedback, customer requirements QFD matrix is constructed as shown in Figure 4 [6].

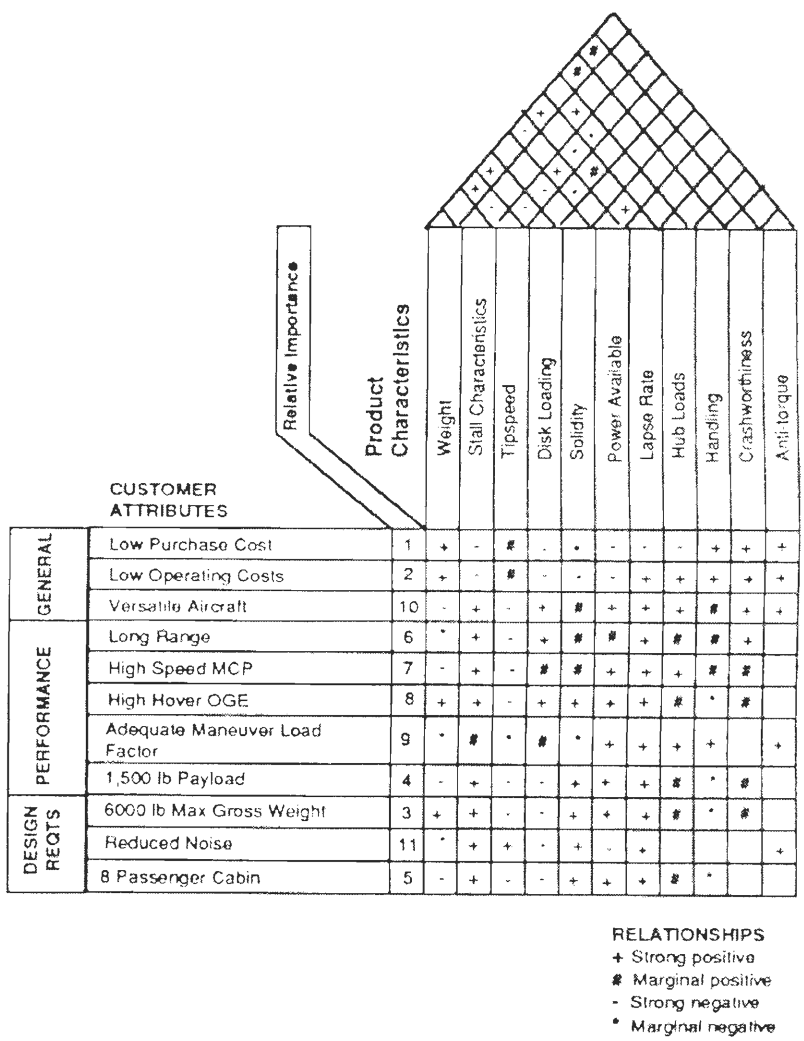


Figure 4: Customer Requirements QFD Matrix for MDX Helicopters.

Engineers and operators from different areas work on the QFD matrixes as a team and construct the four phases of QFD as illustrated in figures 5, 6 and 7 [6].

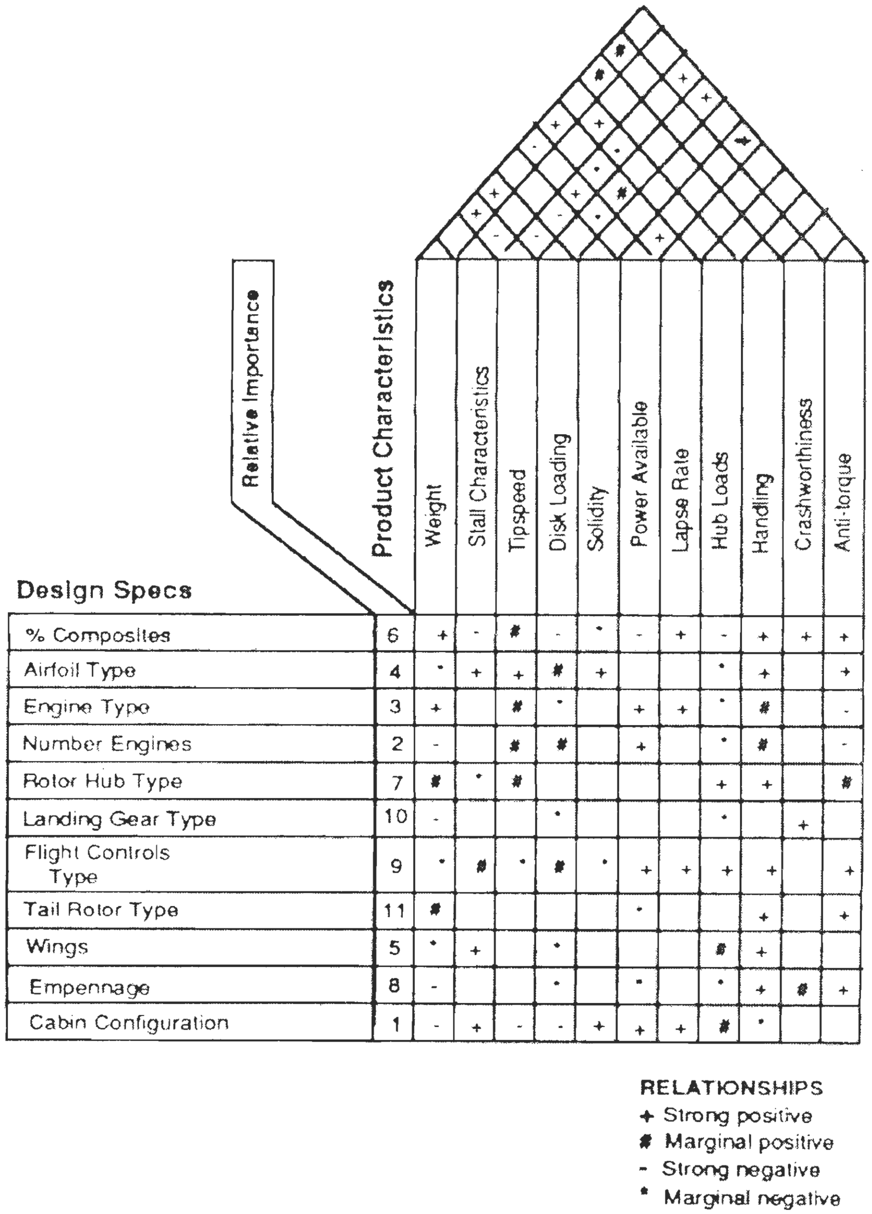
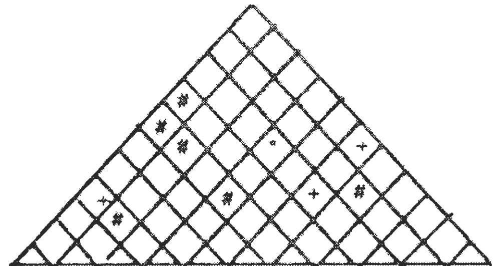


Figure 5: Design Specs QFD Matrix.

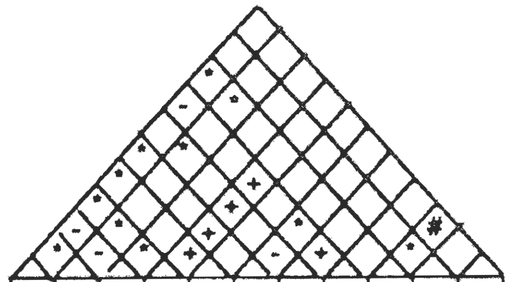


Design Specs	Relative Importance	Skin Tolerance	Rotor Balance	Fasteners	Finish Application	Bearing Tolerances	Instrument Calibration	Machine Retooling	Material Strengths	Shape Variance	Gearing Tolerances	Electronics Integration
% Composites	6	#	#	+	+			-	+	+	#	
Airfoil Type	4	+	+		#			*	#	#		
Engine Type	3					#					#	
Number Engines	2					#					+	
Rotor Hub Type	7		+			#		*	+			
Landing Gear Type	10								#			
Flight Controls Type	9						#					#
Tail Rotor Type	11	#	#		#	#		*	#		#	
Wings	5								#			
Empennage	8	#		#	#			*	#			
Cabin Configuration	1								#	*		

Production Controls

RELATIONSHIPS
+ Strong positive
# Marginal positive
- Strong negative
* Marginal negative

Figure 6: Production QFD Matrix.



Design Specs

Design Specs	Relative Importance	De-Icing	Skin Repairs	Painting	Time between Services	Replacement Part Quality	Tool Calibration	Mechanic Training	Fluid Level Tolerance	Component Accessibility	Part Commonality	Tool Commonality
% Composites	6	#	*	-	+	+	-	-		+	-	-
Airfoil Type	4	+			#							
Engine Type	3				+	+	*	*	-	+	+	+
Number Engines	2				-	+		*	-	-	#	#
Rotor Hub Type	7	#			+	+	-	-	*	+	-	-
Landing Gear Type	10				#	#			*	*		
Flight Controls Type	9				+	+	-	-	-	*	+	+
Tail Rotor Type	11	+			#	+	*	*	-	+	-	-
Wings	5	+		+						*		
Empennage	8		+	+						-		
Cabin Configuration	1			#						+		

RELATIONSHIPS
+ Strong positive
# Marginal positive
- Strong negative
* Marginal negative

Figure 7: Support QFD Matrix.

3.2.2 Implementation of CAD for MDX Helicopter Design

In addition to low purchase and operating costs, the other general customer requirements must be satisfied to provide a flexible product such as, low payload, 8 passenger cabin, high speed, etc. After the QFD matrix is constructed and the needs are established, the actual design of the helicopter can take place. The Company used Catia, a 3-D CAD software for designing and testing of the helicopter. For instance, one of the critical customer requirements is the 8-passenger cabin space. First, the minimum dimensions of the cabin are determined in Catia as shown in Figure 8 [6]. Then adding more parameters to the design cabin design is finalized. These are illustrated in Figures 9 and 10.

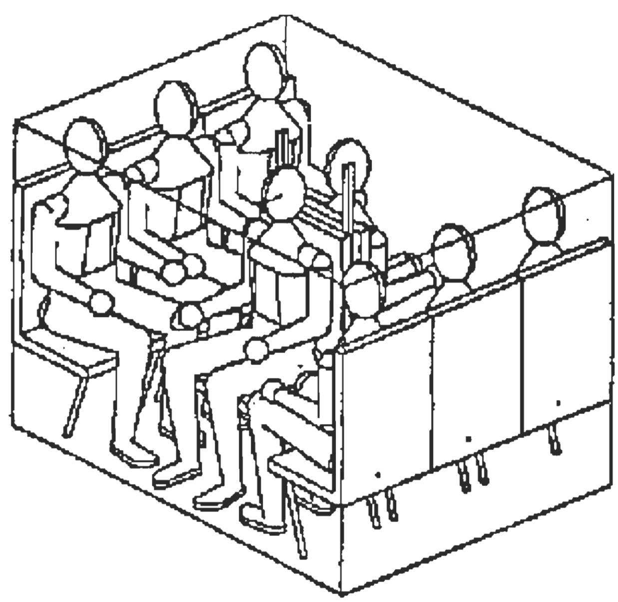


Figure 8: Catia Model for Minimum Dimensions of Cabin with Passengers.

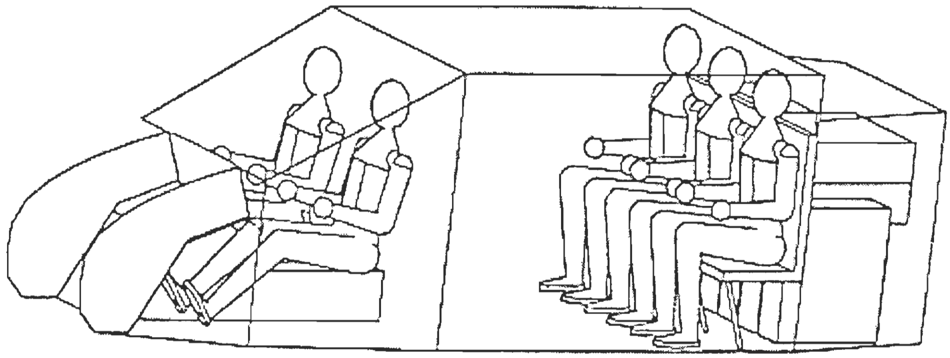


Figure 9: Catia Model of Cabin with Fuselage, Cockpit and Baggage.

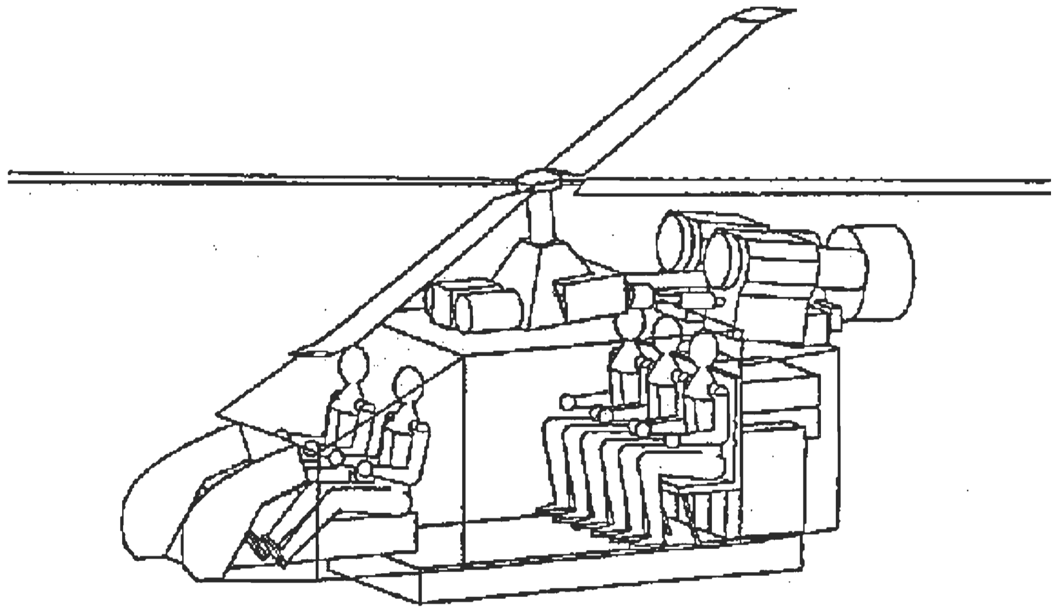


Figure 10: Catia Model of Final Cabin Design.

3.2.3 Improvements to the Design Process

Concurrent design process not only helps to understand the customer's needs and turn them into a well-made product, but also continuously improves the quality of the design by carrying all the product realization processes concurrently. For instance during the design of the MDX helicopter, cabin design was improved in order to make it compatible with the manufacturing processes. Since the design changes are introduced during the preliminary design process, product cycle time decreases dramatically.

Chapter IV. DesignQA

4.1 Improving Model Quality

The benefits of dimension-driven solid models of the sort pioneered by Pro/Engineer have been well advertised. The parametric approach makes it easier to change models, to develop new variants of existing designs, and to automate drawing production. Features can be suppressed to facilitate analysis or intermediate manufacturing process [8].

Yet the benefits of feature-based models don't come automatically. If models aren't crafted carefully, making changes becomes frustrating and difficult.

- A change to a variable may cause features to move about in ways the designer didn't anticipate.
- Parts may fail to regenerate completely, leaving failed features in the model.
- Features that become very small or disappear completely can play hob with manufacturing, analysis, or data-translation programs.
- Designers can modify model tolerances in order to make shapes regenerate, but these modified tolerances may cause numerically controlled tool programs, finite element mesh-generation routines, or rapid prototyping output to fail.
- Improper use of dimensional constraints can cause errors in new designs, leading to manufacturing defects, rework, or product failures.

As long as a CAD model is under the control of the engineer who created it, sloppy modeling practices don't seem to cause many harms. When a change to a model produces unintended results, the designer can usually spot the errors and take steps to fix them.

But the quality of feature-based models becomes much more important when models are released in larger organizations for use by analysts, planners, machinists, and other designers. Poorly built models can be almost impossible for others to modify. Even worse, changes made by people less familiar with the design's intent can produce bad products. Poorly crafted models are nearly useless for creating new designs or variants of existing designs. Chaos can become nearly total when numbers of workers collaborate on a large product, each with his or her own notions of how parametric models should be made.

3.4 The Need for Checking

No reputable manufacturing firm would issue a drawing without having it checked. Three-dimensional CAD models can be thought of as design documents that are even more valuable than drawings. They, too, should be checked before release. Like a drawing with errors, a poorly crafted CAD model can cause mistakes in dozens of manufacturing processes that rely on its data. Several types of checking that can be preformed on CAD models are as follows [8]:

- Models should be checked to assure that they convey the proper design intent
- They should be checked for good modeling practices
- Files should be reviewed for conformance to company standards
- Drawings associated with models should be checked for proper drafting practices

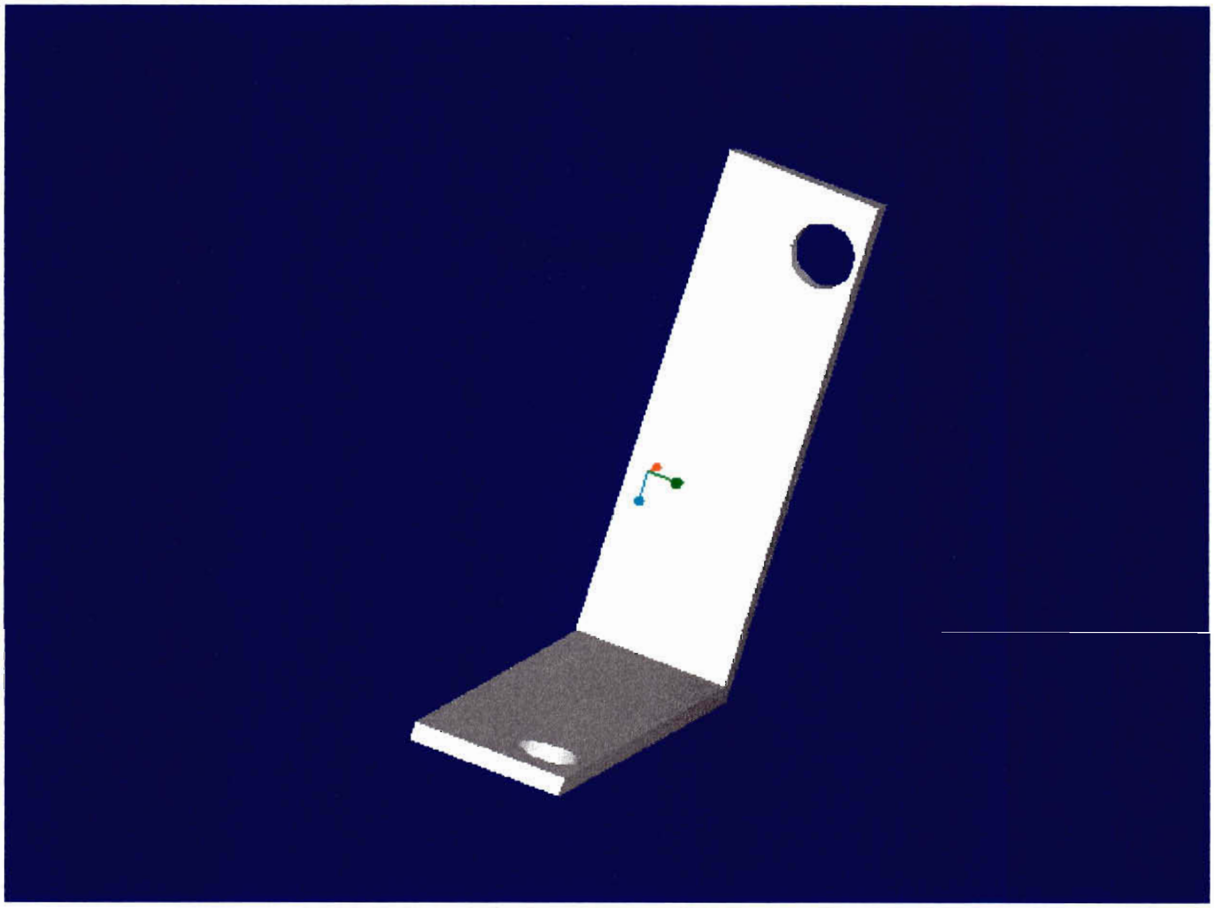
4.2.1 Design Intent

The most powerful capability of feature-based modelers is their ability to capture the designer's intent. Embedding this intelligence in a model allows workers who are not thoroughly familiar with a product to make changes to existing designs or new variants of them.

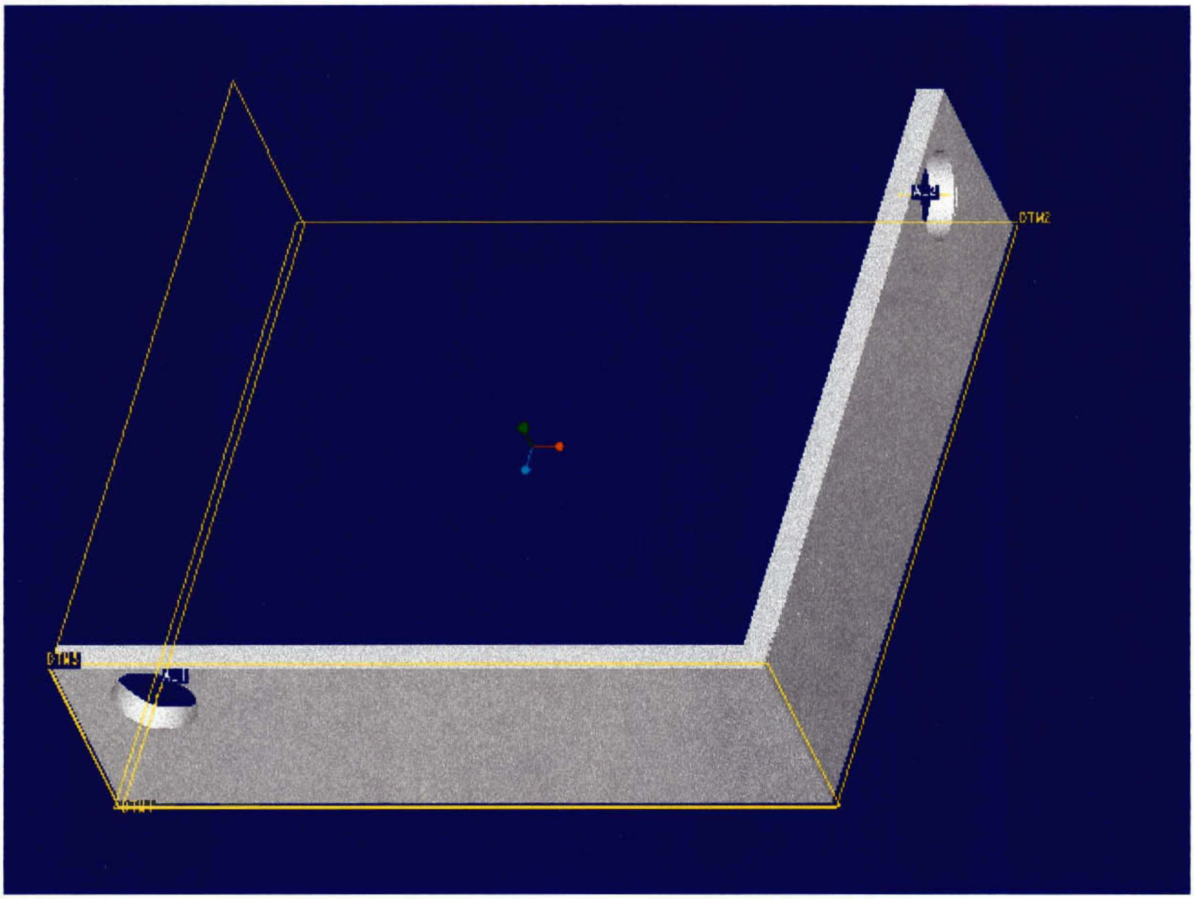
A simple example of embedding design intent is the angle bracket model illustrated in Figure 11. A simple example of preserving design intent is illustrated by the angle bracket model in the upper left. When relationships between features such as the through hole and chamfer are properly defined, a change to the bracket's width and length produces a bracket with equal legs and holes that remain centered as shown in the upper right. On the other hand when the design intent is not captured, the holes do not remain centered when the width is changed, and the legs will be unequal unless the width and the length are individually set equal as shown in the middle in Figure 11.

In real life, designs are much more complicated than this simple example. So it isn't always obvious what the design rules should be. But whenever possible, relationships between dimensional values should capture the important rules that govern the design. A good design checker is one, who knows how a product family should be designed. He or she can review a dimensional-driven model and suggest changes for better capturing design intent. It's important for parametric models to be checked in this way before they are released for manufacture.

Figure 11



Part 1 for IQP with out datums



Part 1 for IQP with datums

4.2.2 Good Modeling Practices

A second importan' set of modeling checks has to do with what might be termed "good CAD modeling practices." For example, it is generally a bad practice to create features that are children of rounds, fillets, or chamfers. That's because it may be desirable to suppress fillets or chamfers, but if there are features dependent upon them, these, too, will be suppressed. Other examples of bad practices include:

- Cuts or holes that lie outside the part model.
- Features buried within the model that are not visible.
- Very small features or surfaces that have no purpose.
- Excessively deep parent-child relationships
- Too many driven dimensions
- Mathematical relationships in part-models without comments or notes to explain them.
- Tolerances below corporate standards

Checking for these types of errors is routine and does not necessarily require deep understanding of a product design. Such checks can be done automatically with proper software.

4.2.3 Conformance to Conventions

Most companies have conventions that should be adhered to before models are released. Such conventions include appropriate file, layer, and drawing view names, limits on file sizes, approved drawing scales, and inclusion of data such as part numbers, release dates, revision numbers, and the name of the person who has created the part model. While checking the accuracy of such data is not easy, it is possible to check automatically that, at a minimum, legitimate values have been entered for the appropriate processes.

4.2.4 Drawing Quality

All engineering drawings should conform to good drafting practices and to company standards. But drawings associated with parametric solid models should adhere to additional rules if the associative benefits are to be fully realized [8]. For instance, it is a bad practice to employ 2D geometric entities on an associated drawing. Part lines should be projected in drawings from solid models. When drawings are done this way, changes to models are reflected automatically in the drawings. 2D geometry that appears only in a drawing view won't update when the model is changed. The use of 2D geometry should be minimized, but it can't always be eliminated. In some cases, solid-modeling programs won't create certain types of geometry, so the designer has to fake missing lines on the drawing [8]. In other cases, the geometry might not project properly from the solid. 2D entities were created to work around shortcomings in the CAD software. But excessive use of 2D entities should be corrected before a drawing is released.

Drawings should also be checked to ensure that the appropriate drawing template has been used, that views don't overlap or lie outside of drawing boundaries, and that out-of-scale dimensions have not been used except when absolutely necessary.

4.3 DesignQA

Today's CAD/CAM solid modeling tools provide engineers and designers the power to fully specify the products before they are manufactured. From geometry to material properties and to non-geometric engineering data, the engineering model is a virtual product definition. With a well-designed product development process, the CAD model itself is a product. The quality of the CAD model directly affects the quality of the finished product. DesignQA is the answer to the improving model quality, catching the design intent and drawing quality concepts that were discussed in the previous section.

DesignQA is a software product of Prescient Technologies that works as a module in CAD software such as PRO/Engineer, CATIA and UNIGRAPHICS. DesignQA is an interactive CAD model quality assurance tool, which helps to ensure that the design models:

- Are reusable by other CAD users
- Incorporate data requirements of downstream applications
- Can be used by analysis, manufacturing and rapid prototyping systems

DesignQA is the only quality assurance application that works to prevent problems before they occur. DesignQA allows early problem solving and decision making, which are the key concepts of CE. Pre-configured for immediate use, DesignQA comes with standard modeling practices defined by a consortium of Pro/Engineer users representing the Pro/User modeling standards group. DesignQA operates seamlessly within Pro/Engineer environment and is designed to be easily customized with a corporate and project design standards. Some essential features of DesignQA include:

- Flexible and extensible modeling standards support diverse requirements

- Out of the box standards provide a jumpstart for implementing good practices
- Easy to use and powerful browser-based application requires little end-user training
- Operation from within Pro/Engineer using native CAD geometry and menus to ensure consistency and accuracy of data
- Quality metrics help guide process improvements

DesignQA improves Design Quality in the following ways [13]:

Best Practices: Integrate design guidelines such as appropriate materials and bend radii. Validate that the design model incorporates clear and reusable modeling techniques. Check drafting characteristics such as layer and view management. Incorporate non-geometric release requirements at design time with the engineering checklist.

Data Management: Verify the integrity of the design database before 'vaulting' it. Ensure that models incorporate non-geometric data (e.g. parameters and materials), naming conventions and other requirements of downstream applications. Eliminate extraneous geometry and external references, which expand and complicate database entries.

Measurement and Feedback: Pinpoint product development issues with DesignQA's Quality Monitoring System (QMS), which allows the user to measure the quality of the engineering process. Reveal where in the design process problems occur and what problems are the most common so that resources can be focused on addressing the most critical issues.

Integrated Design: Avoid non-value added modeling rework and costly manufacturing errors by detecting modeling issues like small faces, edges and gaps, buried (filled) features, tangent and geometric inconsistencies with the use of geometry quality module.

Implementation: Employ an extensive out of the box-modeling standard. Apply unique build on the fly functionality to reflect and prioritize company specific design guidelines. Standardized configurations to reflect diverse design groups.

Continuous Learning: Infuse company specific and general industry design and modeling expertise with DesignQA's expert advise, customized HTML reports and direct links to online reference and training materials.

4.4 Benefits of DesignQA

- Distribute effective, consistent modeling techniques to facilitate sharing design models across CAD users, suppliers and customers.
- Eliminate data exchange bottlenecks by considering the requirements of downstream systems at design time.
- Encapsulate data required for PDM and other downstream systems.
- Enable efficient model use by analysis users by pinpointing modeling and geometry challenges up front.
- Reduce production delays by embedding manufacturing requirements into the design process.
- Identify and minimize design and manufacturing bottlenecks by quantifying specific model quality defects and addressing the causes.
- Eradicate non-value-added rework and clean-up tasks by applying consistent design techniques.

4.5 Implementing DesignQA:

A step-by-step Process for improving The Quality of the Engineering Product by Prescient Technologies.

Several essential guidelines govern the strategy of the DesignQA implementation process [9]:

- Implementation is Not Limited to Software Installation: Expectations are set at the beginning of the implementation process that the goal of implementation is not merely the successful operation of the software and training of the users. The goal, rather, is the successful integration of the software in the design/model release and approval cycle.
- The Process Must be Scaleable: The DesignQA implementation process will work for a wide range of installations. It is designed to be sized, staffed, and timed according to the number of CAD users, number of design model, design/program model release rate, and complexity of the design release process;
- The Process Must be Incremental: By starting with small pieces of the overall problem, the implementation program progresses through several manageable steps-each of which can be accomplished in a very short period. The increments are often chosen based on a project/program focus.
- The Process Must Make Efficient Use of Resources: Rather than requiring a dedicated team of full-time technical staff, the implementation plan is based on the participation of only those individuals who play a role in the process. Since implementation focuses on success in the design process, the schedules and work

environment of engineering managers, designers and CAD support personnel are often considered.

- The Process Must Produce Verifiable Results: A successful implementation program must include a means of verifying results. Metrics is established early on, which serve as guides in the process. The results are quantifiable and verifiable.

4.5.1 The Implementation Process of DesignQA

To be successful, a plan must be laid out which describes a "sequence of events" that offers a roadmap not only of what to expect next, but what the objectives are for each step.

There are eleven major steps in the implementation process [9]:

1. Establish Short-Term and Long Term Goals: Begin by establishing the short-term and long-term goals for the implementation of DesignQA. These are typically a reduction in the amount of time spent by designers to rework models and drawings to correct specific types of problems. It is often best to be specific on the problems to be solved. For example, a short-term goal may be to eliminate the manual checking of drawings for documentation-related items (layers, naming, conventions, parameter values, views, etc). A short-term goal may also be a reduction in the amount of time to evaluate models for a specific design project.
2. Identify Metrics: Without identifying specific metrics, there will be no way to tell if the program is successful. Begin by establishing metrics that are meaningful to the organization. These can include high-level measures, such as time (hours per design release), cost number of engineering changes, etc. The metrics can also be quite

specific, such as types of quality standards to be tracked (model naming convention) and quality ratings, or scores for each design model.

3. Develop the Standards: For each quality standard within the group of metrics currently being addressed, the standards are configured to meet the needs of the specific group or organization. These configurations should be validated not only with management but also with end-user personnel, in order to verify the practicality and usability of the standards.

4. Assess Current Status/Performance: The second step in the process is to identify the "as-is" condition, or the current level of performance of the organization with respect to the previously identified metrics. This set of measures then forms the baseline against which future performance standards are measured, and a determination as to any improvement can be made. This can be accomplished by running DesignQA against a set of representative models from the existing database of released or on-process designs. This step is also known as a "condition assessment."

5. Establish Objectives: In order to be successful, it is necessary to build into the process some targets for improvement. For each of the identified metrics, a set of objectives is established, showing a measure of improvement over the baseline conditions. This set of objectives can be updated from time to time, in order to reflect past improvements and changes in the environment such as, new types of projects, new features in the CAD/CAM systems, etc.

6. Build an Incremental Implementation Plan: It is more advisable to take a subset of the issues identified as quality metrics, and to begin attacking that subset first. This first subset can be made as small as five quality standards, and should be highly focused.

At the time that the first subset is identified, it is also advisable to plan the follow-on steps of addressing each following subset of the total picture. Associated with each group of quality standards, a short time period for production implementation should be formulated.

7. Create the "Directions for Production Use": This step begins with an understanding of how DesignQA is to fit within the design/model release process. It is necessary to identify to users, managers, and administrators exactly what guidelines govern the use of DesignQA, and the standards in question. For example, it may be decided that the first set of quality standards is absolutely necessary in order to release a design model. Such, a mechanism must be developed within the release process to verify that a DesignQA "stamp" has been placed in the model, and that the stamp corresponds to the most recent version of the saved model. Conversely, it may be that the first set of standards is developed as recommendations, or guidelines, rather than hard-and-fast rules. Regardless of the specific directions for use, these guidelines must be made known to all affected people, and the necessary infrastructure to support the methods of use must be built.

8. Test the Quality Standards: Prior to releasing the application into production, verification of the configuration of the quality standards is a prudent measure. This can be accomplished by applying the quality standards to some or the entire group of models used in the condition assessment phase. Any necessary modifications identified through this testing are made at this time.

9. Train the End-Users: Although DesignQA is directly integrated within the CAD/CAM system, and is easy to use, it is necessary to spend a brief amount of time,

typically one to two hours with end-users (design engineers) instructing them on the philosophy and mechanics of using DesignQA. It is necessary to identify and explain how these quality standards are intended to be implemented.

10. Place DesignQA and the Quality Standards in Production: By placing the system in a production environment, under the governing conditions established in the "Directions for Production Use" step, the system essentially "goes live." Close monitoring of how users are using the system is highly desirable.

11. Collect and Analyze Measurements: It is advisable to collect data not only on the quality standards (the metrics) but also on the frequency of the use of DesignQA. On a periodic basis (weekly, for example) an analysis of the data should be performed to determine what kind of quality measures are being identified and addressed, and to validate the goals and assumptions made at the time that the initial quality standards and objectives were established. Any modifications to the quality standards configurations can be made at these intervals.

12. Expand The Breadth and Depth of Implemented Quality Standards: Based on the incremental implementation plan, repeat steps 5 through 11 for each of the new groups or subsets of quality standards identified in the plan.

4.5.2 Establishing Standards

Establishing the guidelines that are applied to Pro/Engineer models simplifies which DesignQA features to use to accurately reflect production installation needs. This also insures that only applicable guidelines are applied during model quality review process. DesignQA has standard files (check files) that contain specific guidelines including custom feedback. Multiple standard files can be created or copied to meet the company, division, or project's specific needs. One way of managing the standard files is to create a separate standard file for each company, division, or project. These files can be run individually or combines into a single combination standard file.

Categories are a DesignQA feature that enables to group together standards within a standard file. Categories are defined at the organizational/ installation level. By categorizing or grouping standards together, the user can quickly select which standards are applicable at that point of the design process. One way of managing the categories is to create a separate category for each step of design process, conceptual, detailed, and final design. This feature prevents standards that are not appropriate from running (see Table 1: Standard Templates Grouped by Categories).

Table 1

Category	Generic Standard Types			
Features	External References	Early Features	Insert Modem	Incomplete Features
	Burned Features	Features With Geometry Checks	Number of Features	
	Children of Default Datums	Feature Creation Attributes	Starting Features	
	Average Parent Child Death	Features With Children	UDF Usage	
	Direct Children Of Specified Features	Features With No Children		
Dimensions				
	Created vs. Shown Dimensions	Dimension References	Dimensioning	
Drawing				
	Drawing Accuracy	Erased Views	Restricted Drawing Text	Unused Models
	Drawing Format	Number of Notes	Spelling	
	Drawing Setup File	Number of Sheets	Start Drawing	
	Drawing Table Parameters	Number of 2-D Draft Entities	Symbol Usage	
	Drawing View Scales	Overlapping Views	Title Block Cell Contents	
	Entities Outside Drawing Border	Required Drawing Text	Title Block Cell Length	
Family Table				
	Family Table Exists	Instance Naming Convention	Family Table column Names	
	Family Table (Nested) Exists	Family Table Parameter Constraints	Instance Default Values	
Geometry				
	Model Envelope	Small Faces	Small Radii Faces	
	Sharp Edges	SLA Chord Height		
	Instance Naming Convention	Short Edges		
Material/Mass Properties				
	Appropriate Material	Mass Properties	Material Assigned	Material Properties Defined
Layers				
	Components on Layers	Layer Status	Non Standard Items on Layers	
	Empty Non-Standard Layer Names		Layer Names	
		Legacy LAYERS		
Naming Convention				
	Model Envelope	Model Naming Convention	Model Name Length	Simplified Rep Naming Convention
Standards	Assembly Constraints	File Size Individual	Regeneration Test	
	Declared Layouts	Number of Components	Relations Without Comment	
	Engineering Checklist	Parameter Constraints	Relation Errors	
	File Size All Inclusive	Parameter Names	Regeneration Warnings	View Names
	Number of Simplified Representations	Part Accuracy	Start Model	
External				
	External Custom Checks	External Programs Check		

Table 1: Standards Templates Grouped by Categories.

4.5.3 How to Make Use of DesignQA Standards File

The standards file (checks file) can be created to analyze if the models (parts, drawings or assemblies) created in Pro/Engineer are compatible with good modeling practices of a company's design process. The good modeling practices listed in section 4.2.2 can be checked by DesignQA standards file. Bad modeling practices such as features buried within the model that are not visible, very small features or surfaces that have no purpose, deep parent-child relationships, too many driven dimensions, etc. can be checked by DesignQA's same name standard checks and can also be corrected in a session.

For example, "sample.chk" as shown in Figure 12 was created and checks were configured in order to test Pro/Engineer models for the following bad-modeling practices:

- Cuts or holes that lie outside the part model
- Features buried within the model that is not visible
- Excessively deep parent-child relationships
- Inappropriate drawing or model names
- Inappropriate drawing formats
- Mathematical relationships in part-models without comments or notes to explain them
- Too many driven dimensions

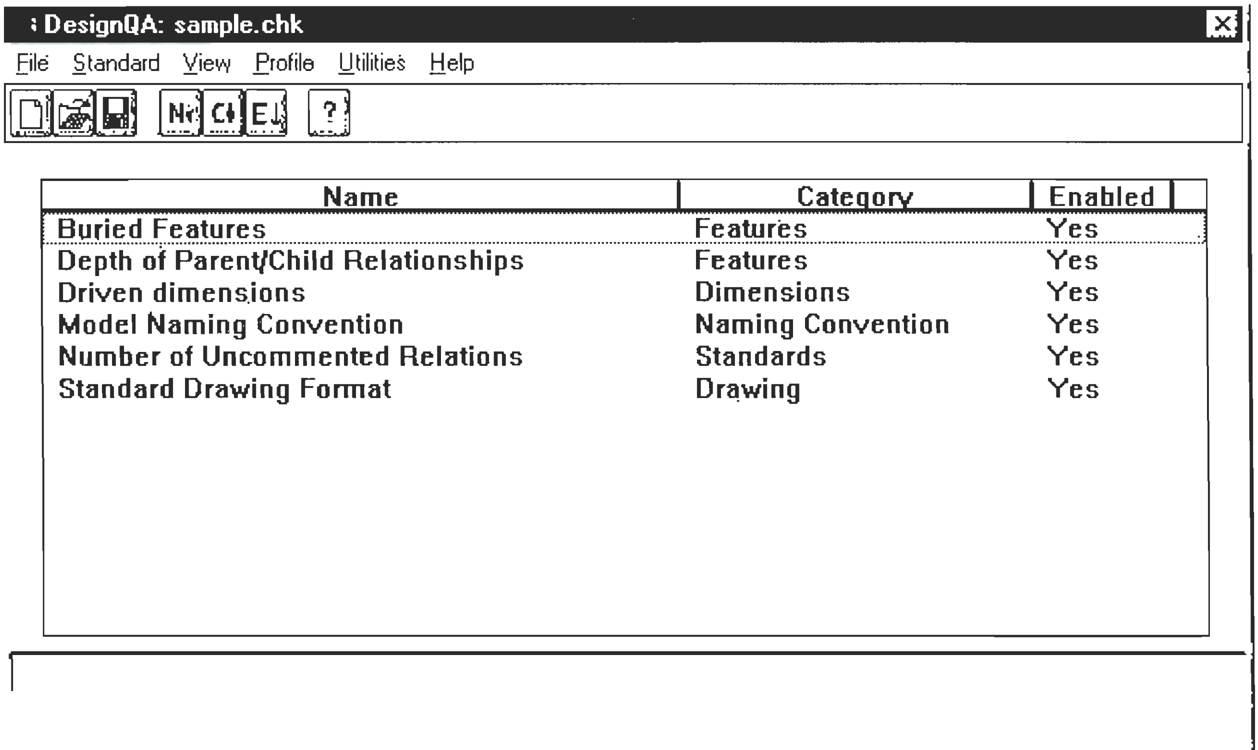


Figure 12: "Sample.chk" Check File

4.6 Application of DesignQA in Industry

DesignQA is used in companies as a quality improvement tool during the product realization process for reducing the cycle time, and improving the design quality.

Bell Helicopter Textron the V-22 Tiltrotor Team developed an automated wiring process that eliminated the need to build costly and schedule intensive mockup models. Cutting production costs was a primary goal of the V-22 development program. Bell's Integrated Wiring System (IWS) combined DesignQA capabilities with CATIA to create an interactive design environment that "has been one of the largest contributors in the V-22 subsystems cost reduction."

The results from this development program were:

- 70% Overall Cycle Time Reduction
- 77% Manufacturing Time Reduction
- 95% Engineering Time Reduction
- 100% Accuracy in Wire Harness Design & Installation

Chrysler's Fastener Engineering Department used a similar approach to Reduce Cycle Time. The objective was to reduce number of fasteners part types. The Results were:

- Variations Reduced from 35,000 fastener parts to 4,000 per year
- Savings were approximately 1 cent/fastener (1 Billion Parts/year)

Chapter V. Results and Conclusions

The term Concurrent Engineering (CE) has stimulated an industrial development towards shorter cycle times, lower production cost, improved quality in the product realization process which have resulted to more customer satisfaction. Leadership, development of teamwork and education have been important factors for implementing CE successfully. In this interactive qualifying project, the definitions and benefits of CE. have been presented. Furthermore, the role of the typical elements of CE, quality function deployment, DesignQA, and CAD/CAM in product realization process has been demonstrated. From this research project, it is obvious that design quality is important not only for designers, but also for the entire manufacturing enterprise. Improving design quality in the early stages of the design process brings a significant opportunity for organizations to dramatically lower production costs, eliminate unnecessary iterations in the design process and also reduce product cycle time. An organization that accomplishes all these improvements in its design and manufacturing processes can satisfy the fast changing customer needs with high quality and lower costs. These are the major reasons why CAD/CAM and DesignQA are the best tools for CE in product realization process.

It was my experience in this project that in order to use CE tools efficiently, it is crucial to be updated with the new developments in the technology. Because today I know more than I knew yesterday.

REFERENCES

[1] G. Sohlenius, Concurrent Engineering, Royal Institute of Technology, Stockholm, 1992.

[2] L. Miller, "Concurrent Engineering Design", Society of Manufacturing Engineers, Dearborn, Michigan, 1993.

[3] National Research Council (U.S.). Committee on Engineering Design Theory and Methodology, "Improving Engineering Design", National Academy Press, Washington, D.C., 1991.

[4] B. Prasad, "Concurrent Engineering Fundamentals", Vol. 1 & 2, Prentice Hall PTR, Uppersaddle, NJ, 1996.

[5] S. Wakil, "Processes and Design for Manufacturing", PWS publishing, Boston, MA, 1998.

[6] A. Kusiak, "Concurrent Engineering Automation, Tools and Techniques", John Wiley & Sons, INC., New York, NY, 1993.

[7] Dr. K. Taraman, "CAD/CAM: Meeting Today's Productivity Challenge", Computer and Automated Systems Association of SME, Dearborn, Michigan, 1980.

[8] J. Wyze, Computer Aided Design Report, CAD/CAM Publishing, Inc, San Diego, CA, January 98.

[9] G. A. Finn, M. Mason, J. Racine, Implementing DesignQA, Prescient Technologies, Boston, MA, August 1998.

[10] D. Turbide, "Computers in Manufacturing", Industrial Press, New York, N.Y, 1991.

[11] J. Bossert "Quality Function Deployment", Marcel Dekker, INC., New York, N.Y, 1991.

[12] National Research Council "The Competitive Edge", National Academy Press, Washington, D.C, 1991.

[13] "DesignQA User's Manual", Prescient Technologies, Boston, MA, 1998.

[14] W. Engelke, "How to integrate CAD/CAM systems", Marcel Dekker, INC., New York, NY, 1987.