
Research Papers

KEY DRIVERS FOR BUILDING QUALITY IN DESIGN PHASE

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Abstract

In today's business environment quality became key-factor in addition to Technology and Innovation. Fortunately, BEL has identified these parameters as key parameters long back for its business growth. Today, Quality became part of our life and spreading every sphere of the life including non priority activities. More so for industries, Quality became key parameter to be considered every phase of the products including design. Few decades back, quality was limited to the restricted areas like various manufacturing processes & today it became mandatory to add quality element in every sphere of products. Thus quality has gained importance in design phase also in recent times. Hence, it is time for us to identify key drivers for building the quality in design phase of our products and services. In light of this, I would like to bring out various drivers that imbibe the quality at early stage of products (design stage). This enhances the product quality and reduces costs, improves profits & derives customer delight. Specifically, how experimental designs, Systematic learning, ruggedness can be used in design, test and improve the quality of products, thus, reduces cycle time and ensures sustainability in the growth. Few case studies are also presented to emphasize the requirement of quality in design phase.

KEYWORDS:

Robust Product Design, Cycle Time Reduction, Development Cycle Time, Quality Enhancement, Response Surface Methodology

INTRODUCTION

Quality is part of every product in today's competitive markets, for sustaining business growth. Quality in design is a future investment for long term business survival. Competition and Quality leads to product innovation and reduces product cost and delivers many products in short time. In fact this reduces the life time of the products. To achieve low cost & ruggedness in the products, quality shall be considered at product design stage and amortize the costs in products that are developed. The success secret of long-live companies like Boeing (more than 100 years company), is maintaining quality in every phase of their activities (Products & Services). The surveys in the past brought out that, closer to 70% of quality & cost issues arise, could be solved, during the design phase. And the fact is that most quality issues / cost drivers can be solved in the design phase & not the manufacturing phase. Quality emerges from innovation and Innovation improves Quality. Thus Quality & innovation can't be separated from each other. Various studies emphasizes that the quality shall be imbibed at Design stage and in fact physical development of products consumes most of the Development Cycle Time (DCT). It is also identified that experimentation takes larger time than product manufacturing. Hence special focus has to be made during design phase to improve the quality. Therefore an effective method for

innovation is experimentation, which form key activity to product quality and reduces DCT for new products. Therefore it is necessary to understand that what are the tools, how to use and what role these tools play in product development process. Therefore it is important activity to use effective tools by design engineers to reduce DCT and provide quality designs. Experimentation, Systematic Approach, Simulation & Analysis tools, Robustness, Documentation at design stages leads to better quality products during manufacturing. The team identified these drivers are important for building quality in products at design stages. These issues are presented in this paper.

II PRODUCT DEVELOPMENT CYCLE

A typical product development process is shown at Figure 1.

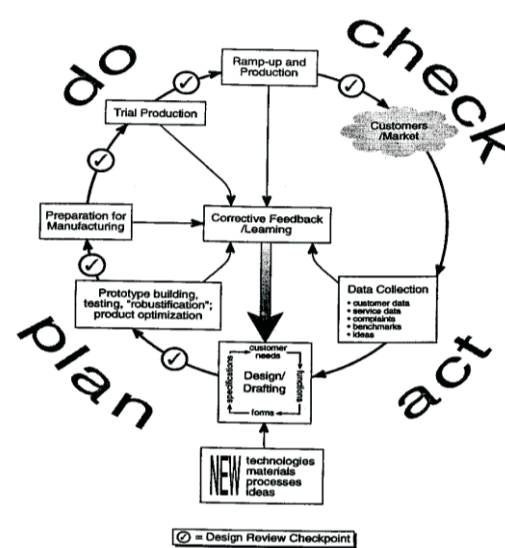


Figure 1. The product development process conceptualized as a cyclic learning process.

The development cycle shown above is commonly used by many people and is used as on-going cyclic learning process. This helps in continuous learning and improving the processes which is suitable for modern scenario of continuous improvement. Most of the new products are derivatives of the old products with various improvements / upgradations. For example Samsung Galaxy Note III is an upgraded version of Samsung Galaxy series of smart phones, Swift Dzire 2012 car is upgraded version of Swift Dezire 2010, Laptop manufacturers have many upgrades, Windows software has many upgrades and so on. Although some new products are really new, but majority of new products are improved versions of the old products. Therefore, we can assume that the cycling process of product development use the product knowledge of previous generations and forms basis for the new product development. Therefore this development cycle is called as Plan-Do-Check-Act (PDCA) cycle. Though the development cycle shown above is broader version, one has to go in deep and generate finer version of PDCA. Systematic approach at design stages to these finer issues yields better products to customers and likely to prevent low level of quality, costly recalls, reliability problems & high rate of failures. The study found that approximately 44% of the quality problems that are led to voluntary recalls were attributed to poor design drivers that could have been prevented by adequate design controls for critical and noncritical products. Thus Systematic learning is important process in experimentation / design of a new product. It is virtually important to get the design right at the first time. The results of study are shown at Figure 2.

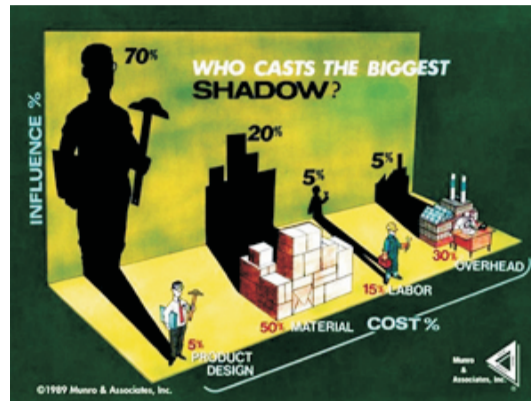


Figure 2 Up to 70% of quality and cost issues arise, or could be solved, during the design phase.

III EXPERIMENTATION

Designing and developing products that meet customers' expectations is a complex task. It is to be noted that the multitude of variables in various tasks, influence the product's quality characteristics. These complex interrelationships are often not understood and not documented. This leads to uncertainties about product performance. Lack of knowledge leads to bad decisions, and may cause quality and reliability problems. The problem is further compounded by the very nature of product development. Due to insufficient knowledge, the decisions could not be taken, specifications could not be written properly. To avoid making decisions based on the guesswork, one has to conduct many experiments to provide the necessary decision making support information.

It is a common misconception that experimentation only plays a role in the prototype testing phase. Many researchers found that product developers frequently use experiments in all phases of the development process. Figure 3 shows experimental objectives at different stages of the product development process.

Concept development	Prototype development	Preparing for manufacture and trial production	Ramp-up and production
<ul style="list-style-type: none"> • Test existing theories and concepts • Establish new theories and concepts • Proof of principle • What happens if.... • Generating new ideas 	<ul style="list-style-type: none"> • Choice of materials • Product performance • Specifications • Robustness and reliability • Sensitivity to component variation • Simplicity • Trouble shooting 	<ul style="list-style-type: none"> • Product manufacturability • Simplicity • Sensitivity to component variation • Tolerancing • Reliability • Cost • Trouble shooting 	<ul style="list-style-type: none"> • Process yield • Product and process quality • Product and process reliability • Process simplicity • Cost • Trouble shooting

Figure 3 Examples of possible objectives of experiments at different phases of the product development process

1 Experimental design in product development

We will illustrate an example (Case study-1) how experimentation will help in product design / development and improve the quality. This case study related to a project which has been just concluded. A system uses radome to protect the electronics in the unit from external environment like weather, salt, temperature, dust etc.,. Thus the radome in addition to these protections, in this application should also provide RF transparency over wide frequency range in Azimuth and Elevation directions.

The application is very critical and we should produce the item with the required electrical and environmental specifications. Various suppliers were contacted and there is no positive solution.

A cross functional team was formed to address this issue. After a few initial meetings / discussions, the team has made many experiments and suggested an alternative solution, to manufacture the radome with various layers of honeycomb structure (the raw material for radome) on single radome with 12 sectors covering each 30° sector and prototype testing is done on composite radome and experimentation is done for the performance of the radome at all these sectors. The best sector material composition of honeycomb structure was selected for manufacturing of the complete radome. The radome was well suited for the application and repeat production became very easy and these radomes are produced in large numbers today. Thus a low cost, high performance radome could be made successful with the concept of experimentation in product development. Thus one of the key drivers for quality in design phase is experimentation.

After looking over the results from this first experiment, the engineers gained confidence due to the fact that the results are consistent and decided to use this method as repeat exercises during prototype development phase of radome for future applications which saves time and cost.

It is learnt from this example that several critical technical issues are often solved quickly, systematically and cost effectively by performing experiments in the early stages of the design process. Often well designed experiments will allow a project to go forward, rather than becoming bogged down in endless discussions. Good experiments at the early stages of the design / development of a product, as illustrated here, often shorten the development cycle time, reduce the risk of making design decision on a shaky foundation, and reduce the likelihood of quality problems emerging later when the product is manufactured, or worse, is on the market and in the customers' hands.



Figure 3(a) Radome developed through experimentation.

2 Indirect benefits from experimental designs

During the development of a product, there are many different reasons for performing the experiments, and a wide variety of experimental designs are available specialized for these different needs. The above experimentation case study helped in analyzing / understanding large number of factors like, the selection of number of combinations, cost and time etc.,. These type of experimentations incur huge costs in initial phase and the experiments become prohibitively expensive. We may instead use a factorial fractional design. Such designs consist of a carefully selected fraction of all combinations. This approach is particularly useful in screening situations, when the investigators are interested in finding out which out of a large number of potentially important factors have the biggest effects on certain quality characteristics. It is also provides indirect knowledge about how other layers of honeycomb structure can be useful for different types of radomes in future applications.

3 Screening experiments

To illustrate the usefulness of screening experiments, let us consider the following example (Case study-2, Source open paper from internet) from a company that develops ingredients for food products. The company was in the process of developing a new emulgator. To bench mark they wanted to compare the new product with another that was frequently used by their customers. From previous work, the development knew that several factors might have an effect on the stability of the emulgator, and wanted to test it in as broad an environment as possible. The eight factors and their levels are shown in Figure 3(b).

Factors	Level	s
A. Emulgator concentration	0.5%	1%
B. Protein type	1	2
C. Fat concentration	40%	60%
D. Fat type	1	2
E. Protein concentration	0%	10%
F. Temperature	40°C	50°C
G. NaCl	0%	1.2%
H. Emulgator type	New	Commercial

Figure 3(b) Eight factors investigated in the emulgator experiment.

A full factorial experiment for eight factors would require 256 individual trials. That many tests were clearly out of question. It was therefore decided to run only a 16th fraction of the full factorial requiring 16 trials. From it, it is possible to estimate the effect of the 8 factors and a number of interaction effects. The consequence of not executing all the possible combination is, however, that it gets confounding; several interaction effects will be mixed up and can only jointly be estimated as a group.

Without going into further details, this experiment showed that the stability seemed to increase with increasing fat concentration (C) and protein concentration (E). However, the key finding was that there did not seem to be any difference in stability between theirs and the competitor's emulgator (H).

This experiment demonstrates the potential of using fractional factorial experiments to screen a large number of factors in few trials. In this specific case the screening experiment was used to evaluate eight different factors in only 16 trials and it was found that only two had a large effect. Moreover, it showed that the product appeared to be insensitive or robust to all the factors that did not have an effect. With such experiments, products can be tested and the most robust and reliable prototype design selected.

The insight gained from the experiment can often be used to suggest modifications of the product that go beyond any of the tested variants and hence provide genuine quality breakthroughs, further details can be learnt from Juran (1964). Frequently, experiments are used to optimize product characteristics. Experiments for that purpose are called optimization or response surface experiments.

4 Optimization of experiments

Response Surface Methodology (RSM) was introduced by Box and Wilson (1951) as a method for experimental optimization of industrial products and processes; for a modern exposition refer Box and Draper (1987). The basic concepts of RSM can be understood by looking at the six pictures in Figure 4 (Case study-3).

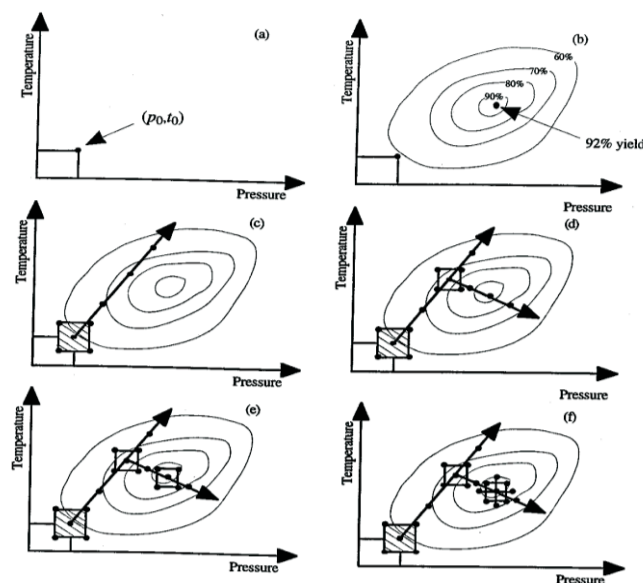


Figure 4. (a) to (f) show the phases of a response surface study.

For simplicity, suppose two factors, pressure and temperature, are believed to have an impact on the yield of a chemical process, currently run at pressure p_0 and temperature t_0 as shown in Figure 4a. Suppose further that the yield is much lower than expected, but the challenge facing the experimenter is how to reach the "mountain top" in as few trials as possible without knowing where it is located.

RSM consists of essentially three phases: initial exploration, exploration along the direction of steepest ascent, and exploration of near optimal conditions. The initial phase involves the use of a relatively small inexpensive two-level factorial or fractional factorial designs. The four trials plus a center point shown in Figure 4c will allow the experimenter to estimate locally the direction of steepest ascent. The next phase of the RSM strategy involves trying out, step – by – step, factor combinations along the path of steepest ascent as indicated in Figure 4c. As long as this step-wise strategy yields increasing results, the experimenter will continue. However, when the yield no longer increases another two- level factorial experiment is performed around the current best factor combination, (Figure 4d). From this two- level design the direction of steepest ascent is reevaluated and the process continued. The process will eventually bring the experimenter close to an optimum, or more precisely, a stationary point as in Figure 4e. At that point the experimenter might stop. But it is often advantageous to explore the near stationary conditions in detail. To do so, we typically use a central composite design as exemplified in Figure 4f. Such designs allow us to determine the shape of the response surface near the stationary point to indicate whether it is a peaked or flat maximum or minimum, a ridge, or a saddle point, all important issues for the product's robustness.

An example of the development of a new type of paper used for printing currency will illustrate the idea. A major problem with aging currency bills is the tendency of the ink to fade and wear off. A key quality characteristic for paper used for printing currency is its ability to absorb and hold ink measured by the contact angle. In preliminary studies it was found that the surface of paper when treated in plasma better absorbs and holds ink. It was, however, not known precisely how the paper needed to be treated to obtain the best results. Using an RSM approach, a half fraction of a two-level factorial design for three processing variables plus a center point was first performed. This experiment indicated some curvature in the response surface. A second experiment was then performed consisting of the complementary fraction and the data from both were analyzed showing near optimum conditions. The team then proceeded to add six star points completing a central composite design. A second-order Response - Surface Model was then fit to the data as shown in Figure 5.

Response Surface of Contact Angle

Contour plot and response surface of contact angle for SiCl₄ plasma treatment. Factor time is fixed at 0 level.

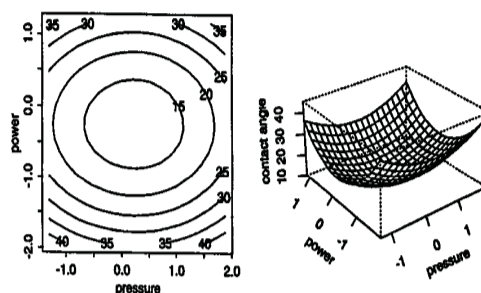


Figure 5 Response Surface study of plasma treatment of currency paper

From it we see that a minimum contact angle was achieved at a pressure of about 80 and a power about 70. However, changes in pressure between 70 & 90 and in power between 60 and 80 seem to a minimal effect on the quality of the paper.

Besides showing the use of RSM for optimization in product development work, this example also illustrates the usefulness of RSM in identifying how sensitive the optimum results are to variation in processing conditions around the optimum. A pointed response surface near the optimum implies that the processing conditions must be carefully controlled. However, a rather flat response surface indicates that the process can tolerate variation without a serious drop in the quality characteristics. In other words, the process is relatively robust around the optimum.

5 Robustness in experiments

The objective of another category of experiments is to discover design parameter combinations for which the product is robust to changes in factors that are uncontrollable outside the product development laboratory. For example, when designing an automobile engine, it is important that its performance is insensitive to changes in ambient temperature and humidity. Experiments with the purpose of discovering factor combinations that are robust to variation in environmental factors are often called Robustness Experiments.

The original application of the robustness concept was by Gosset (1931), although not explicitly promoted as such. Later, the idea was pursued explicitly by Michaels (1964), involved in developing detergents robust to changes in water temperature, water hardness, etc. More recently the concept has been pursued and raised to prominence by Kacker (1985), Taguchi (1987), Box, Bisgaard and Fung (1989), Box and Jones (1992), and Bisgaard (1992b).

Ideally robustness experiments should be performed during the early design phases to prevent costly changes later. During prototyping several different prototypes ought to be evaluated for robustness, not just a single prototype. This is emphasized by Bisgaard and Steinberg (1997). The prototype that is most reliable and robust can then be chosen for further development. In practice, however, it is not unusual that robustness experiments are run when problems emerge later in the development process.

The following example illustrates the use of robust design for achieving the quality. Log Periodic Antenna (LPA) is developed during 2001 for specific requirement. This antenna is supposed to be used in ships where the vibration levels are very severe. During initial experimentation, LPA was evaluated and is well suited for the product in terms of electrical performance and required quality checks were carried out, but, the LPA was failed during the simultaneous influencing of vibration levels in x, y & z directions. This problem was due to the failure of LPA for higher levels of vibration and hence there was need to relook into the mechanical design. The failure resulted in withdrawal few modules from the customer, thus delay in handing over the system to the user. A cross functional team ruggedized the design and a syntactic foam was used on the tip of the LPA, which was the main source of failure. Various experiments have been carried on few samples and finally achieved the robustness to

the unit through improved design. The pictures of the items are shown below at Figure 6.

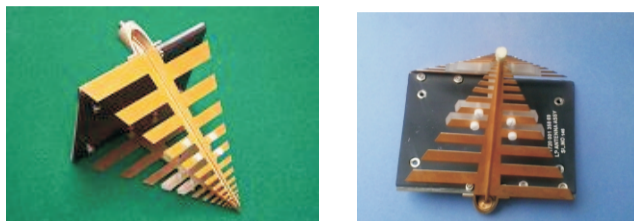


Figure 6 Picture of LPA without & with rigid syntactic foam

IV USE OF SIMULATION & ANALYSIS TOOLS

The objective of the analysis tools is to reduce the design time and ensure the reliable design at first time which reduces time and cost. The tools help in simulation of complex designs and identify the break even points which are away from the specified limits. Iterative developmental activities of the products have been carried out using the simulation tools and hence the first prototype model itself will emerge as closer to the required item. These tools gain importance as experiments become easier to conduct in simulation, and competitive benchmarking of the results are more rapidly analyzed, disseminated, and integrated into the overall product planning.

In addition to usage of these tools for product development, quality tools like FMEA, DFSS, etc. may be used during prototype design and validation processes. Out of these tools, DFSS (Design for Six Sigma) is popular tool. It is a systematic and structured approach to new products or processes design that focuses on “problem prevention”. This is done with the aim of meeting or exceeding all the needs of the customer and the CTQ (critical to quality) output requirements when the product is first released. The major objective of DFSS is to “Design things right the first time”.

Today many design simulation tools like Ansys, NX 7 are used to carry out FEM and thermal analysis during the design phase to achieve the product reliability and enhances the quality. This enhances the ruggedness in the product quality. This process also reduces huge amount of time and cost required to many numbers samples. Hence, it is desired to use best suitable simulation and analysis tools to produce results closer to realistic models. The prototype manufacturing and testing for ruggedness is mandatory in such cases to avoid the failures in the production phases of the product.

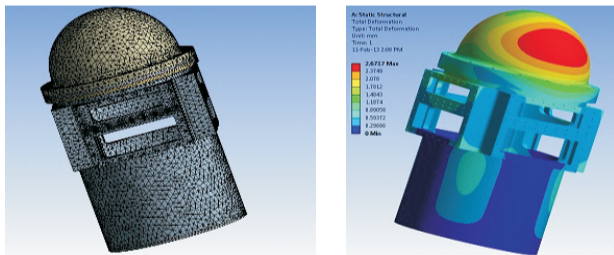


Figure 7 FEM of High pressure frame & deformation plot

V DOCUMENTATION

Documentation of earlier successful designs help in gaining knowledge and shall be used in the new product designs to reduce the product development cycle time and to reduce the design cost. Thus design documentation plays major role in improvements in product designs (new versions) and thus improves the quality. The documentation of successful designs will reduce production times and repeatability of the performance. Today, there many ways of data storage, format and access of these designs in a systematic way. Companies use many tools for this purpose and Knowledge Management Systems like Virtual libraries; Web-seminars, etc are the sources of the common documents.

VI CONCLUSIONS

There are many drivers that are to be considered during the design phase of a product to achieve the highest level of quality. Experimentation, Systematic Approach, Documentation, Robustness, Experience gained over past products, Design and Simulation tools etc plays major role in deciding the quality at design stage. Poor design may recall the products from the customer which is very costly in today's competitive business scenario. There are many benefits of the use of experimental design in product development. Most importantly, design of experiments provides an efficient and effective way for product development teams to generate information critically needed for quality product development in the design process. With this information, uncertainty about future performance of the product can be removed, and optimal and robust design solutions can be found. Experimental design can greatly increase the efficiency of the large amount of experimentation and troubleshooting that inevitably will take place during the development of any product whether statistical principles are used or not. The use of statistically designed experiments, however, can greatly reduce the number of tests needed and thus decrease the cost, ensure rapid data collection, and reveal important interaction effects.

Another benefit of experimental design is that simultaneous cost reduction and quality improvement is often achieved; it is sometimes possible to select combinations of processing variables or design parameters that will not only improve the quality of the product, but also reduce the cost of making it. Even an experiment that shows that a given factor has no influence on quality is useful. Such results will allow the product developers to choose the option that cost the least. Products can also frequently be made robust to variation in uncontrollable (environmental) variables. The difference between success and failure for a product may often be determined by the way the development team deals with variables they cannot control in the field. One of the major strengths of robust design is its ability to deal with uncontrollable environmental variables such that the quality of the product is reasonably constant even when the environmental variables vary as they inevitably will in use.

Carefully designed experiments provide a systematic approach for problem solving and troubleshooting during the development process. Product developers do not as easily get confused when trying to identify variables with large effects on the quality of the end product, and in determining optimum conditions for those variables. All this sums up to better, more robust products, in shorter time, with less effort.

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