WARWICK MANUFACTURING GROUP

Product Excellence using 6 Sigma (PEUSS)

Design for Six Sigma
DESIGN FOR SIX SIGMA

Contents

1 Introduction 1
2 Design for Six Sigma (DFSS) 5
3 DFSS Methodology 9
4 Difference between Six Sigma DMAIC and DFSS 39
5 References 39
6 Appendix 1 40
DFSS

1 Introduction

1.1 Six Sigma basics

Six Sigma (SS) is a business process that allows companies to improve their bottom line by designing and monitoring everyday business activities in ways that minimise waste and resources while increasing customer satisfaction. In Six Sigma, the purpose of process improvement is to increase performance and decrease performance variation. This increase in performance and decrease in process variation will lead to defect reduction and improvement in profits, to employee morale and quality of product, and eventually to business excellence.

The name “Six Sigma” derives from statistical terminology; Sigma (σ) means standard deviation. For normal distribution, the probability of falling within a ±6 sigma range around the mean is 0.9999966. In a production process, the “Six Sigma standard” means that the defect rate of the process will be 3.4 defects per million units. Clearly Six Sigma indicates a degree of extremely high consistency and extremely low variability. In statistical terms, the purpose of Six Sigma is to reduce variation to achieve very small standard deviations.

Compared with other quality initiatives, the key difference of Six Sigma is that it applies not only to product quality but also to all aspects of business operation by improving key processes. For example, Six Sigma may help create well-designed, highly reliable, and consistent customer billing systems; cost control systems; and project management systems.

Six Sigma has a broad focus:

- It provides specific methods to re-create the process so that defects and errors never arise in the first place.

Many companies have adopted the Six Sigma philosophy including the following:

- AlliedSignal;
- General Electric;
- Sony;
- Honda;
- Maytag;
- Raytheon,
- Texas Instruments,
- Bombardier;
- Canon;
- Hitachi;
Lockheed Martin
• Polaroid

They have adopted the SS philosophy because they believe that it will help them increase market share, decrease costs, and grow profit margins. As a result they are attempting to tie quality to profit.

To increase profitability the SS philosophy is adopted by the whole company, that is, operators, designers, service providers and managers. An internal infrastructure is created to enable all employees to become aware of quality performance and how it affects profitability.

The philosophy encourages people to ask questions about every process and every step along the way to creating the final product. It is about asking tougher and tougher questions until quantifiable answer can be achieved that result in a change in behaviour. Such questions cannot be answered without a planned approach to solutions; the SS methodology is therefore designed to pave the way to find the right answers.

Organisations need ways of measuring what they claim to value. The foundation of SS uses metrics or measurements to calculate success; a company using the SS methodology must therefore measure all its processes and changes to its processes.

There are three components necessary to becoming more effective and efficient using SS, these are:

1. **Business Process Management.** This strategic component is the responsibility of executive management.

2. A **scientific method** used to define and measure problems, analyzing root causes, and testing theories of improvement. In essence, this is the methodology used in SS to improve effectiveness and efficiency and encompasses well known and successful statistical tools.

3. Another key component of SS is a **cultural** one. All employees within a company, from senior executives to operators, must embrace and apply the methodology to ensure a successful outcome.

### 1.2 Summary of the Six Sigma Methodology

Six Sigma is a process-focused approach to business improvement. The key feature is “improving one process at a time.” The process could be a production system, a customer billing system, or a product itself. A process can be defined as a series of activities that takes an input, adds value to it and produces an output for a customer. Processes can be modelled in many ways, for example: an input/output diagram or a supplier-input-process-output-customer (SIPOC) diagram.

**SIPOC Diagram**
A SIPOC diagram is one of the most useful models for business and service processes. It can also be used as a model for a manufacturing process. The acronym SIPOC derives from the five elements in the diagram Figure 1.1 below:

- **Supplier**: The person or group that provides key information, materials, and/or other resources to the process
- **Input**: The “thing” provided
- **Process**: The set of steps that transform and, ideally, add value to the input
- **Output**: The final product of the process
- **Customer**: The person, group, or process that received the output

![Figure 1.1: SIPOC diagram](image)

For example, a SIPOC diagram for an academic teaching programme could be draw as in figure 1.2 using the following information:

- **Suppliers**: Book publishers and bookstores, university administrators and facility support people, lab equipment suppliers, accreditation board, tuition payers, and so on.
- **Inputs**: Books, classrooms and facilities, labs and facilities, academic program standards, and tuition.
- **Process**: The academic program, includes the curriculum system, degree program setup, courses, professors, and counselors. The process transforms inputs to a system of courses, academic standards (quality control system), and academic records; under this system, incoming students are processed into graduating students in many steps (coursework).
- **Output**: Graduating students with degrees.
- **Customers**: Employers of future students and the students themselves.

**Key requirements for output**: Excellent combination of knowledge for future career, high and consistent learning qualities, and so on.

![Figure 1.2: Example of an Academic Teaching Program of a University Department](image)
There are also several other process modelling and analysis methods available, such as process mapping and value stream analysis, which are also widely used in Six Sigma projects.

A process map is a schematic model for a process. A process map is considered to be a visual aid for picturing work processes that show how inputs, outputs and tasks are linked. Process mapping can be used to develop a value stream map to analyze how well a process works. Once a process map is established at an appropriate level of detail, the flows of products/programs/services, material, information, money, and time can be mapped.

In a Six Sigma project, if the Six Sigma team selects the regular Six Sigma process improvement strategy, then a five-stage process will be used to improve an existing process. These five stages are:

- Define the problem and customer requirements
- Measure the defects and process operation
- Analyze the data and discover causes of the problem
- Improve the process to remove causes of defects
- Control the process to make sure defects don’t recur

This five-step strategy is also called DMAIC (define-measure-analyze-improve-control).

The DMAIC methodology is the focus of the six sigma principles however a successful six sigma project requires management commitment and good teamwork.

### 1.3 Why Six Sigma?

The goal of Six Sigma is not to achieve SS levels of quality but is about improving profitability. However, improved quality and efficiency are immediate by-products of SS.

While SS is a long-term, forward thinking initiative designed to fundamentally change the way companies do business, it is mainly designed to generate immediate improvements to profit margins.

Many large companies have implemented SS because of the focus of profitability improvement and also the claims made on the successes of using SS.

SS consultants claim:

If a company operating at the three sigma level introduces SS and makes a one sigma shift improvement each year the company will experience:

- 20% margin improvement
- 12-18% increase in capacity
- 12% reduction in the number of employees
- 10-30% capital reduction
It is also claimed that the profit margin increases from 3 sigma to 4.8 sigma are dramatic and that at 4.8 sigma companies requires a redesigning of processes, known as Design for Six Sigma (DFSS).

Design for Six Sigma is therefore recommended when:
- A business chooses to replace, rather than repair, one or more core processes
- A leadership or Six Sigma team discovers that simply improving an existing process will never deliver the level of quality customers are demanding
- The business identifies an opportunity to offer an entirely new product or services

DFSS is not a quick fix; it will take more effort in the beginning, but it will pay off better than the regular Six Sigma process improvement in the end.

**KEY POINTS**

Six Sigma is a methodology that provides businesses with the tools to improve the capabilities of their business processes.

Unlike other quality initiatives that focused just on tools, Six Sigma is based on the active involvement it generates from the management.

Using the Six Sigma methodology makes all parties aware of what effects profitability.

Six Sigma is concerned with measuring processes and changes to processes.

Process is the basic unit for a Six Sigma improvement project. Process could be a product itself, a service/manufacturing process, or an internal business process. Process mapping, value stream mapping, and process management are effective tools for improving overall performance.

Six Sigma process improvements strive to improve both process performance and process capability.

DFSS is recommended when a company wants to introduce a new product into the marketplace.

### 2 Design for Six Sigma (DFSS)

#### 2.1 Introduction

DFSS is a business process focussed on improving profitability by introducing a methodology that helps companies to generate the right product or service at the right time at the right cost. It is an enhancement to new product development processes and provides the tools and teamwork to develop a successful new product or service.

DFSS has its roots in systems engineering and so management of requirements guides and drives the entire lifecycle processes. Thus requirements capture, understanding and flow-down are key elements of DFSS.
Customer-oriented design is a development process of transforming customers’ wants into design solutions that are useful to the customer. This process is carried over several phases starting from a conceptual phase. Figure 2.1 shows the product development lifecycle and illustrates the different phases throughout product development.

![Product development life cycle diagram](image)

**Figure 2.1: Product development life cycle**

In the concept phase, conceiving, evaluating, and selecting good design solutions are difficult tasks with enormous consequences. Design and manufacturing companies usually operate in two modes:

- *fire prevention*, conceiving feasible and healthy conceptual entities;
- *firefighting*, problem solving such that the design entity can live up to its committed potentials.

Unfortunately, the latter mode consumes the largest portion of the organization’s human and non-human resources; the DFSS methodology therefore aims to encourage companies to focus on translating customer wants and needs into the design process early in the product development lifecycle to reduce the need for costly firefighting activities.

Figure 2.2 highlights when DFSS is conducted relative to the product lifecycle. It illustrates the cost impact of making changes throughout the product life cycle and emphasizes the point that making changes early is most cost effective.
The major objective of DFSS therefore is to “design it right the first time” to avoid painful downstream experiences. The term “Six Sigma” in the context of DFSS can be defined as the level at which design vulnerabilities are not effective or minimal. Generally, two major design vulnerabilities may affect the quality of a design entity:

- Conceptual vulnerabilities that are established because of the violation of design axioms and principles.
- Operational vulnerabilities due to the lack of robustness in the use environment.

The objective of DFSS when adopted upfront is to “design it right the first time” by anticipating the effect of both sources of design vulnerabilities. This requires that companies be provided with the analytical means to achieve this objective and sustain it.

Design for Six Sigma is thus a systematic methodology for designing or redesigning products or services according to customer requirements and expectations. DFSS project teams integrate characteristics of Six Sigma at the outset of development with a disciplined set of tools.

DFSS therefore focuses on providing a methodology that systematically integrates tools, methods and processes to:

- assess customer needs;
- perform functional analysis;
• identify CTQs
• select the concept design;
• enhance detailed design and processes; and
• produce control plans

2.2 Why DFSS?

It is said that only about 60% of new products launched in all industries are a success and about 45% of resources allocated to developing and commercialising new products go into products that are killed or fail to provide adequate financial return. Some companies gave the following reasons:

• Inadequate market analysis;
• Product problems or defects;
• Lack of effective marketing effort;
• Higher costs than anticipated;
• Competitive strength or reaction;
• Poor timing of introduction;
• Technical or production problems.

DFSS is a systematic methodology that optimises the design process to achieve Six Sigma performance and avoid some of the problems that cause new products to fail.

Operational vulnerabilities take variability reduction as an objective and are primarily the purpose of Six Sigma. On the contrary, the conceptual vulnerabilities are usually overlooked because of the following:

• lack of a compatible systemic approach to find ideal solutions;
• ignorance of the designer;
• the pressure of schedule deadlines; and
• budget limitations.

This is because traditional quality methods can be characterized as after-the-fact practices. Unfortunately, this practice drives design toward endless cycles of design-test-fix-retest, creating what is broadly known as the “firefighting” mode of operation. Companies who follow these practices usually suffer from high development costs, longer time to market, lower quality levels, and marginal competitive edge. In addition, corrective actions to improve the conceptual vulnerabilities via operational vulnerability improvement means are only marginally effective if at all useful as well as increasingly costly as design entity progresses in the development process. Therefore, implementing DFSS in the conceptual phase is a goal and can be achieved when systematic design methods are integrated with quality concepts and methods upfront, as illustrated in figure 2.2.
Currently, industries are being forced to shorten lead times, cut development and manufacturing costs and lower total life-cycle cost (LCC), and thus there is a drive to develop strategies that will ensure good quality designs at the right cost and in the right time frame and DFSS is one of the key strategies.

It is often claimed that up to 80 percent of the total cost is committed in the concept development phase as depicted in Fig. 2.3.

From figure 2.3 the potential is defined the difference between the impact, the influence, of the design activity at certain design phases and the total development cost up to that phase. The potential is positive, but decreases as design progresses, implying reduced design freedom over time. As financial resources are committed (e.g., buying production machines and facilities, hiring staff), the potential starts changing signs going from positive to negative. In the consumer’s hand, the potential is negative and the cost overcomes the impact tremendously. At this phase, design changes for corrective actions can be achieved only at high cost, including customer dissatisfaction, warranty, and marketing promotions, and in many cases under the scrutiny of the government (e.g., recall costs).

![Figure 2.3: cost vs. impact of new product development](image)

The DFSS methodology provides a strategy for businesses to follow that will lead them to “designing products and services right first time” and therefore introducing successful new product or services into the market.

3 **DFSS Methodology**

3.1 **DMADV**
The DFSS methodology begins by finding and analysing the gaps in processes that are negatively affecting new product performance. It also focuses on customer response to the product. Once this has been completed the project to tackle the problems can be established.

The process for solving problems is called DMADV i.e. Define, Measure, Analyse, Design and Verify or sometimes it is called PIDOV i.e. Plan, Identify, Design, Optimise and Validate. Other acronyms include: DMADOV; DMCDOV; DCOV; DCCDI; DMEDI; DMADIC; ICOV and RCI.

Although these approaches differ in some respects they all basically follow similar steps to achieve similar goals. Essentially they are approaches to designing products, services and processes to reduce delivery time and development costs, increase effectiveness and better satisfy customers.

The basic procedure is outlined as follows:

- Capture customer requirements;
- Analyse and prioritise requirements;
- Develop design;
- Flow down requirements from the system level to sub-systems, components and processes;
- Track the product capability at each step;
- Highlight any gaps between requirements and capabilities and make these actionable; and
- Establish a control plan.

The methodologies mentioned above have the same objectives and are both rigorous in nature; their only real difference is in terminology. Figure 3.1 shows a comparison of the PIDOV and DMADV methodologies highlighting that the differences are mainly in the terminology adopted. These lecture notes will concentrate on the DMADV approach to DFSS.
3.2 Phase 1: Define

The first step in a DFSS project is to establish and maintain a DFSS project team (for both product/service and process) with a shared vision. The purpose is to establish and maintain a motivated team. The success of development activities depends on the performance of this team, which is selected according to the project charter. The team should be fully integrated, including internal and external members (suppliers and customers). Special efforts may be necessary to create a multinational, multicultural team that collaborates to achieve a Six Sigma–level design. Roles, responsibilities, and resources are best defined upfront, collaboratively, by all team members. The black belt is the team leader.

Once the team has been established, it is just as important to the black belt to maintain the team so as to continuously improve its performance.

The DFSS teams emerge and grow through systematic efforts to foster continuous learning, shared direction, interrelationships, and a balance between intrinsic motivators (a desire which comes from within) and extrinsic motivators (a desire stimulated by external actions). Constant vigilance at improving and measuring team performance throughout a project life cycle will be rewarded with ever-increasing commitment and capability to deliver winning design entities.

Figure 3.2 below shows the main activities within the define phase of DMADV.
Project Charter

As in the Six Sigma methodology the establishment of the project charter is a key step in the formalisation of the DFSS project. It aims to capture the vision of the project, to set direction for the project team and to define the parameters of the project. A charter is an agreement between the leadership team and the project team about what is expected in the project. It clarifies what is expected of the team, keeps the team focused, transfers the project from the leadership team and sponsor(s) to the project team and keeps the team aligned with organizational priorities.

The main elements of the project charter include:

- Problem Statement - this describes the current situation. This can describe the problems or challenges that customers (internal and external) experience.
- Opportunity Statement – this describes the market opportunity that the new product/service/process would address and the potential financial opportunity to which it could lead.
- Importance – this explains why this project now
- Expectations/Deliverables - these define what needs to be designed, but does not specifically describe the product, process, or service which is yet to be developed.
- Scope - this defines the boundaries of the project.
- Schedule – this gives details of the timing of actions, milestones, deliverables and reviews as well as the start date and end date.
- Team Resources – this identifies team members and technical experts and describes roles and responsibilities on the project.
- Business case – this gives the financial justification for the project.

It is important to spend sufficient time discussing and clarifying these charter elements to ensure that all team members, sponsors, and stakeholders understand the project’s focus and scope. The initial charter should utilize whatever relevant data is available at the time. The charter is a living document and will need to be revised as new data is gathered and analyzed as the project progresses.

Project Plan

The project plan developed should include the usual important elements, such as:
• Project schedule and milestones
• Organizational change plan
• Risk management plan
• Review schedule

It is usually a good idea to use project management software such as Microsoft Project to help manage complex design projects.

Design projects often need to be integrated with other standard organizational processes (e.g. a new product development process, or a software development process). Spending time up front working with others in the organization to integrate the project plan into those existing systems is usually well worth the effort since additional tasks are often identified which need to be built into the project plan.

Project plans often start with identifying key milestones. Milestones represent important decision points. The completion of each step in the design process is usually one of the milestones. The whole team should participate in defining and establishing dates for milestones. Once milestones are defined they are grouped into logical sequences and tools such as GANTT charts, PERT charts, or Activity Network Diagrams are then used to show the relationship between milestones, define the critical path, and build the project schedule. After milestones are developed, more detailed task planning begins, including developing the list of activities that must be completed for the project. The list should include these types of activities:

• work tasks
• Coordination activities
• Communication activities
• Meetings
• Status reports and schedule management
• Design reviews
• Change management activities
• Risk management activities

Once the plan is developed it is important to consider how the project will be controlled. Project controls help ensure that planned events occur as planned, and unplanned events don’t occur. They are needed for all complex projects, but what they focus on varies with the project. For example, some projects may need safety and environmental controls while another needs controls for work practices and ethical conduct. The riskiest projects most in need of control mechanisms are those that are involve lots of people, over a long period of time, designing high reliability products or services.
Controls need to match project needs. They should be as simple and easy to use as possible. The benefits of the controls should be understood, so that team members will support their use.

An example of a control mechanism is an issues board. The board is updated regularly, often daily. The top ten to twenty issues or problems are listed and color coded (green = “under control,” yellow = “I need help,” and red = “emergency”). The person responsible for addressing the issue is listed and the number of days the item has been on the list is also included.

In addition, document control is often critical for design projects in order to control and manage design changes when sub-teams are working concurrently. Design teams need to develop a method for organizing project documents; usually some form of centralized repository is used. Moreover since design documents are changed many times during the project, version control is therefore an important issue to consider. Accessibility to the repository by the team members, sponsors, and sometimes stakeholders to locate the most current version of all documents must also be considered.

**Organizational Change Plan**

Project plans should include activities related to ensuring that the organization is prepared to support the project. Because design projects require significant organizational commitment and impact many jobs, a change management plan helps ensure resources will be available and willing to help when needed. The change management plan, communication plan, and project plan are clearly linked. The change management plan should think through who will be impacted at which points in the project. Then plan how to prepare people for change well before the dates when they will be impacted.

Change strategies for some people will centre primarily on communication. For others, the strategy may include involving them in some of the team’s activities and including them in key design decisions and reviews.

Change is difficult for people because the ‘way things are’ is comfortable, familiar, has a history, and often is part of people’s identity.

To help people let go of the ‘way things are’ and support change, it is important to

- Communicate vividly why things must change (customer demands and dissatisfactions; competitive pressures; technology changes; etc.)

- Allow people to express their fears and concerns. Provide mechanisms to solicit opinions and concerns, and to provide answers and address fears.

There are many tools that can be used for establishing a change management plan and these include:
• Critical constituencies map - identifies the extent to which various organizations are impacted by the change
• Organizational change readiness map - identifies the organizational approach to change
• Stakeholders support map - articulates key stakeholders’ attitudes towards change
• Root cause analysis - Typical analysis examines reasons for change resistance


**Risk Management**

A risk management plan is a key activity in controlling any project as all design projects face a number of risks. The team’s job is to anticipate where the key risks of failure are and to develop a plan to address those risks. During the Define phase, the team should:

- Identify known and potential risks for the project
- Indicate when and how the risks will be addressed

When the team is first established, many of the risks are not known because the specific design has not yet been chosen. At the outset of the project, the team should identify any known risks as well as potential risks which they anticipate. The team should also indicate when (at which point in the design process) they expect to have the data to identify the real risks in the project. The risk assessment should be updated as the project moves forward in the form of risk reviews.

Common potential risks include: inadequate customer or business information, inadequate measures for the design, rapidly changing environment, scope creep, changing resource availability, complexity, unproven or new technologies, etc.

The task of identifying known and potential risks and defining a plan to reduce, minimize or eliminate these is referred to as mitigating risks. When a member of the team identifies any risk a method for mitigating that risk must be sought and costed. During the risk reviews all risks are prioritized so that the mitigating actions can be programmed into the project plan.

To prioritize, risks are categorized by their probability of occurrence and their impact on the project. Figure 3.3, below, illustrates the ‘traffic light’ approach to identifying and prioritizing risks.
From figure 3.3, the probability of a risk impacting a project ranges from “Green Light” to “Red Light.” It is the team’s responsibility to identify and assess risks prior to the implementation of a project. Failure to recognize and address a significant risk could jeopardize an entire project.

Different responses are appropriate based on the perceived severity of the risk. Risks in the yellow category can be addressed further downstream in the design process. Risks in the red category need to be addressed before proceeding further. Not all risks in the red category result in termination of the project; however, some action must be taken now.

Further information on Risk management can be found in the risk management lecture notes.

**Tollgate review**

Having established the project charter and plan and reviewed the risks a final tollgate review is carried out before proceeding to the next phase. This review should consist of a meeting with all team members to review the charter, risks and update the project plan.

Because design projects are often complex, resource intensive, and linked to accomplishing key business objectives, leadership reviews at the end of each step or phase of work are critical. These milestone or tollgate reviews usually focus on updating everyone’s understanding of how project progress and new information affect the business case, the business strategy to which the design is linked, the schedule, the budget, and other resource needs. Key risk areas are reviewed and plans to eliminate or address the risks are discussed.
The importance of design efforts makes ongoing communication with leadership essential. These reviews help maintain communication linkages and leadership support.

In addition, the sponsor and project leader may meet weekly to discuss progress, changes, surprises, resource issues, etc. This is an opportunity for joint problem-solving. It is also an opportunity to enlist the sponsor’s help in addressing organizational barriers or change issues.

Project managers also often hold daily check-ins with team members. These might be 20 minute meetings whose purpose is to surface problems early, review priorities, and answer questions.

A tollgate review checklist is established so that checks can be made to ensure that all the relevant stages have bee completed before moving on to the next phase.

3.3 Phase 2: Measure

DFSS projects can be categorized as design or redesign of an entity. “Creative design” is the term that we will be using to indicate new design, design from scratch, and incremental design for redesign or design from a datum design. In the latter case, some data can be used to refine design requirements. The degree of deviation of the redesign from datum is the key factor on deciding on the usefulness of relative data.

In this phase, customers are fully identified and their needs collected and analyzed, with the help of quality function deployment (QFD) and Kano analysis. Then the most appropriate set of CTQs metrics are determined in order to measure and evaluate the design. Again, with the help of QFD and Kano analysis, the numerical limits and targets for each CTS are established.

Figure 3.3, illustrates the main activities in this phase of a DFSS project

![Figure 3.3: Measure Phase](image)

Essentially this phase is concerned with capturing customer requirements.

The DFSS tools used in this phase include:
- Data collection plan
- Customer research

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Voice of the customer

The term Voice of the Customer (VOC) is used to describe customers’ needs and their perceptions of a product or service and includes all forms of interaction between customers and an organization. The VOC data helps an organization to align design and improvement efforts with business strategy and decide what products, processes and services to offer or enhance. Additionally it helps to identify critical features/performance requirements for products, processes, and services as well identifying the key drivers of customer satisfaction.

Data collection and analysis is also a major aspect in collecting VOC data and more information on this can be found in the data collection notes.

Affinity diagrams and the Kano model are useful tools for collecting and analyzing VOC data.

Noriaki Kano is a renowned Japanese expert in total quality management. His practical experience with understanding customer requirements led him to define three categories of customer needs:

- **Must Be**: These needs are expected by the customer. If they are unfulfilled, the customer will be dissatisfied, and moreover even if they are completely fulfilled the customer would not be particularly satisfied (e.g., airline safety).

- **Satisfiers**: These needs have a linear effect on customer satisfaction—the more these needs are met, the more satisfied these customers are (e.g., cheap airline tickets).

- **Delighters**: These needs do not cause dissatisfaction when not present but satisfy the customer when they are (e.g., airline that serves hot chocolate chip cookies en route).

Use of the Kano model is to ensure that no critical needs have been omitted. For example:

- List all the needs and categorize them as must-be’s, satisfiers, or delighters
- Make sure that no must-be need has been inadvertently missed
- If delighters are few, try to identify others, or enhance the VOC study—competitive advantage is gained through delighters

Quality Function Deployment (QFD) is the formal tool used to prioritize requirements and uses quantitative importance ratings of needs. The richness of the QFD approach is lost if quantitative prioritization data is not available. Whenever possible, quantitative data should be collected through surveys. See lecture notes on QFD.

Once VOC data is collected and prioritized then it needs to be translated into requirements.
Translating VOC data into requirements

In most situations, the needs of the customers are expressed in normal, everyday language. On the other hand, the requirements to design a product, process, or service need to be expressed in precise, technical terms. A translation process is therefore required to convert the needs of the customers into the language of the design team. These translated requirements, expressed in business or engineering language are called “Critical to Quality” or CTQs.

A CTQ should have the following elements:

- A quality characteristic that specifies how the customer need will be met by the product/service to be designed
- A quantitative measure for the performance of the quality characteristic
- A target value that represents the desired level of performance that the characteristic should meet
- Specification limits that define the performance limits that will be tolerated by customers
- Several CTQs will exist for each need.

For example: Telecommunications:

- Need: “I want my service installed on time”
- Characteristic: Timeliness of installation
- Measure: Percent of orders installed by customer requested date
- Target: 98%
- Specification Limit: 95%

There is no magic formula for generating measures as they are based on the team’s knowledge, the data obtained from the VOC study, and discussions between team members. Often the first few measures take a long time to generate and the task becomes easier as the team gets a feel for the process.

In general, the more detailed the level of analysis, the more useful and relevant the measures. Typically, teams use third level needs to generate measures. If there are 30–60 needs at this level, the task of generating measures can be quite daunting. In this case, teams may elect to initially develop characteristics for the first or second level needs and use QFD to identify the most important characteristics. Measures are then generated using the third level needs only for the most important characteristic.

Determining targets and specification limits is not always easy. Target setting is both an art and a science. Targets are often set arbitrarily because of the lack of information on benchmarks and satisfaction/performance relationships. This ultimately impacts the quality of the design. Even if formal mathematical methods can be used, some thought and analysis is critical to setting good targets. The general concept behind setting targets is that, in the absence of unlimited resources, the highest performance targets should be set for those measures that have the potential of providing the highest rewards. Therefore, in general, targets must be set to exceed competitor benchmarks for the most important CTQs. This must be balanced against the costs of meeting a high performance target and the internal capabilities of the organization. If the organization is not capable of performing at that level without a significant cost investment, then the returns may not justify the costs.

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From Figure 3.4, for CTQ 1, the curve between satisfaction and performance is steep—so making the investment to set a higher performance target than the competition will produce greater rewards. On the other hand, failing to at least meet the competition’s level of performance will result in significant decrease in satisfaction. For CTQ 2, the risk/reward situation is not so dire. The relationship between performance and satisfaction is shallower. As a result, a “low investment” solution of setting the performance target at or even below the competition’s performance will not result in a large satisfaction impact. Satisfaction/Performance functions can either be developed from experience, or formally estimated using conjoint analysis techniques.

Conjoint Analysis Example:
Suppose a company wants to find the relative importance of three attributes of coffee makers: size (i.e. number of cups brewed), brew time, and cost. Suppose also that there are three levels tested for each attribute: 10, 12, and 15 cup sizes; 6, 8, and 10 minute brewing times, and $15, $20 and $25 costs. Clearly, it is possible to define 27 designs (3 x 3 x 3) based on all possible combinations of these attributes. Customers are presented these 27 or some subset, and are asked to rank or rate their satisfaction with each design. For example, three combinations might be:
15 cup, 10 minutes brew time, $25
10 cup, 6 minutes brew time, $15
12 cup, 8 minutes brew time, $20
……
……
and so on.
By studying their rank orderings, we can estimate the implied importance of the various attributes. This approach proves to get at design tradeoffs in a way that simply asking the customer which feature is more important to them cannot.

Other methods for setting performance targets include: Benchmarking and QFD

Prioritising CTQs

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The QFD matrix is based on the VOC work to identify customer needs and priorities. It also summarizes any benchmarking work to understand key competitive measures and relative performance on those measures among competitors. The majority of the work in developing a QFD is compiling information. The information is then organized into various “rooms” which make up the House of Quality. QFD is most useful when representatives of all functions that might be involved with the production, delivery, and management of the product or service are involved in discussing the information summarized by the tool.

See lecture notes on QFD.

Reassess risk

Once the CTQs are prioritized, the design team should discuss the following questions:

- How difficult do we predict it will be to meet all the target values of the most important CTQs?
- Is it necessary to adopt a phased approach to meet the target?
- What are the risks associated with not meeting the CTQs now?
- What are the risks associated with dropping some of the less important CTQs from consideration?

To answer these questions a CTQ risk matrix can be established. The CTQ risk matrix articulates the risk associated with not meeting the target performance requirements. The CTQ risk matrix should consider risk along the following three dimensions:

- **Inclusion**: Will the CTQ be included further in the design process?
- **Complexity**: Are the technology requirements too complex to develop all at once?
- **Reach**: Will the CTQs be met for all customer segments simultaneously?

If all included CTQs cannot be met immediately, then a *phased* or *platform* strategy is developed, i.e. each phase is a sequential time period for implementing the design. To do this a platform management matrix is used. This matrix has the phases on the vertical axis and the customer segments on the horizontal axis. The cells of the matrix describe the features of the design in each time period and for each customer segment. A platform matrix specifies the phases in which the product/service design will be implemented. Multiple phases are indicated by color coding and in each box the design features associated with each phase are described. It is important to keep the feature descriptions general and free of specific technologies—technology selection gets done in concept design. The Platform Management Matrix can be used both as a strategic planning tool and as a project scoping tool. In the former use, some of the design features may not be currently specified.

See risk management lecture notes.

To complete this phase of DMADV a tollgate review is conducted and focuses on:

- Customer segmentation strategy
- Top 10-15 customer needs
- Top 8-10 CTQs and targets
- Summarized benchmark information
- Platform management matrix
- CTQ achievement matrix
The review can result either in proceeding to the next phase or redoing parts of this phase.

3.4 Phase 3: Analyse

The previous phase established the performance requirements that the product or service to be designed should satisfy in order to meet the customer needs. In this phase, alternative solutions for designing a product or service that will perform to these requirements will be determined. Analysis of these solutions is conducted to select the best one or two for the next stage of the design process.

![Figure 3.5: Analyse phase](image)

Figure 3.5 above illustrates the main activities involved in the analyse phase of DMADV.

The following DFSS tools are used in this phase:
- QFD
- Robust design
- Design for X
- DFMEA and PFMEA (design and performance failure mode–effect analysis)
- Design review
- CAD/CAE (computer-aided design/engineering)
- Simulation
- Process management

Design for X includes the following:
- Design for manufacture/assembly
- Design for reliability
- Design for testability
- Design for quality
- Design for reusability
- Design for the environment
- Design for maintenance

**Identify key functions**

Functions are the activities that a process, product, or service should satisfy, no matter what technology is used for the design. A block diagram is a useful tool for illustrating key
functions. For example, figure 3.6, below shows an example of a tea brewing process and identifies the key functions.

![Figure 3.6: tea brewing process](image)

The main function from figure 3.6 is the brewing tea function and this can be broken down further as shown in Figure 3.7.

![Figure 3.7: detailed tea brewing process](image)

Prioritise functions

Once all the key functions have been generated, identification of those that are critical to the design is made so that the following can be determined:

- Which functions need the most resources
- Which functions need innovative designs
- Which functions can use existing designs
- Which functions can be copied from competitors or industry standards

To prioritize functions they are mapping to the CTQs using QFD.

Generate Concepts

It is important to understand that concept design is just one step on the way to building the product or service that is being designed. The objective of going step-by-step through the design process is to make sure that expensive, risky decisions are not made until the design has been analyzed in detail, and until there is a degree of confidence that the selected design will perform as required by the CTQs.

Note the 2-way interactions between the various levels of detail. This implies that design is not a linear process, where the preceding step has to be completed before the following step is reached. Rather, design is an iterative and controlled but chaotic process, where multiple decisions simultaneously take place at various levels of detail. For example, concept design is primarily a paper design; however, some promising alternatives may be “built-out” in greater detail in order to understand them during the concept analysis phase. Similarly, some portions of the design may already exist in detail while other parts are still being developed. It is therefore important to think of design as a growing, organic process, rather than as a rigid, linear one.

Figure 3.8, above shows the iterative nature of design.
After mapping customer requirements to product, service, or process functions, generation of as many alternate concepts for meeting customer requirements as possible is necessary. Two approaches for generating concepts are possible and include: Bottom-up and Top-down. The bottom–up approach involves generating concepts function by function and the top-down approach generates concepts across the functions. Unlike the bottom-up method, where concepts are assembled from functional alternatives, the top-down approach emphasizes a system view of the design problem. This approach is especially effective for new designs. The bottom-up approach works better for redesigning pieces of an existing product or service. Even in the top-down approach, it is important to make sure that all functions have been considered. Also, it is not necessary that the entire concept is new; some parts of the concept may include existing designs.

Concepts are generated using two approaches:

- Creative idea-generation techniques that focus on analogy, connections, extrapolations and creative visualization to develop new ideas
- Benchmarking techniques that study similar designs in competing and non-competing businesses

Clearly, the two methods are not mutually exclusive—most innovative teams use benchmarking as a starter to creative idea-generation.

References 9 and 10

**Evaluate and analyze**

After the determination of the functional requirements for the new design entity (product, service, or process), the design entities that will be able to deliver those functional requirements need to be developed. In general, there are two possibilities:

- The existing technology or known design concept is able to deliver all the requirements satisfactorily; this phase then becomes almost a trivial exercise.
- The existing technology or known design is not able to deliver all requirements satisfactorily; then a new design concept needs to be developed. This new design could be “creative” or “incremental,” reflecting the degree of deviation from the baseline design.

Several design alternatives might be generated and there is therefore a need to evaluate them and make a final determination on which concept will be used. Many methods can be used in design evaluation, including design reviews, design vulnerability analysis (El-Haik 1996, Yang and Trewn 1999), and FMEA. After design evaluation, a winning concept will be selected. During the evaluation, many weaknesses of the initial set of design concepts will be exposed and the concepts will be revised and improved.

Once a wide range of alternatives has been generated, how the list of potential concepts can be narrowed is then determined. A tool called the **Pugh Matrix** is very useful in determining the ‘best concept’. The Pugh Matrix is used to select the best design concepts from among alternatives. The Pugh matrix is used iteratively to help the team invent the best concepts. Concepts are represented in the columns of the matrix and criteria are represented in the rows.
Next, one of the concepts is selected as a baseline and then each of the other concepts is compared against the baseline.

After the first round of ranking, there is another round of concept generation where: the best features of the different alternatives are synthesized into new concepts; the strongest concepts are enhanced by adding features from the unselected concepts to address weak areas; this produces ‘super concepts’ where the best features of the initial concepts are combined. This is followed by another round of ranking using the Matrix.

This iterative discussion often leads to a final choice of one or two new concepts that emerged during this process.

For more information see *The Idea Edge: Transforming Creative Thought into Organizational Excellence*, Goal/QPC, 1998.

The Pugh concept selection procedure produces a small number of concepts (one or two) that are worthy of further study. The following are the next steps in the design process:

- Develop each concept in more detail to ensure its feasibility (beginning high level design)
- Conduct a “concept review” with feedback from customers and other interested parties to select the final concept
- Design all the major elements of the selected concept (complete high level design)
- Predict the ability of the design to meet the CTQs

The development of the concept into greater levels of detail is called the “high level design”. Note that these are arbitrary definitions to indicate various levels of detail; there is no specific rule that determines when one stage ends and the next begins. For example, some of the concepts may be developed further before the Pugh evaluation is performed; in this case, the high level design may begin before concept evaluation is complete.

Also note that design is an iterative process; at the end of the concept review (described in the following pages), if no suitable candidate is found, it may be necessary to return to the concept generation stage for some elements even though high level design may be completed for others.

A concept review is one type of design review and should be conducted at the end of this phase to ensure efficiency of the design process.

**Principles of design reviews**

Design reviews are quality control tools applied to the design process. They serve two purposes:

- To ensure effectiveness of the design: Do the features provided by the design meet customers’ aesthetic and performance needs?
To ensure efficiency of the design process: Are the teams responsible for the various elements of the design working in a coordinated fashion that minimizes rework and duplicated efforts?

The principles of design reviews include:

- Have a design review at every stage of the design process to test the quality of the design
- Ensure that the design review gets both external and internal input
- Focus on identifying and resolving problems during the reviews—use the feedback to make changes immediately to the design
- Have multiple design reviews at any stage if necessary to ensure quality before passing to the next stage

Design reviews need to be conducted at every stage of the design process. The following are the most important stages where design reviews are conducted:

- Concept Review: Conducted after two to three key concepts have been identified and their feasibility has been determined.
- High Level Design Review: Conducted after a selected concept has been designed to some level of detail and tested, and before detailed design begins.
- Pre-pilot Design Review: Conducted when the detailed design is complete and the product/service is ready to be piloted.

The concept review is intended to obtain feedback from customers and other interested parties (other organizational entities, suppliers etc.) about the concepts under consideration. Based on the feedback obtained from the customers, one of the concepts will be selected for further design.

The high level design review is intended to review the capability testing results to ensure that the design is expected to meet the CTQs.

The pre-pilot design review tests for completeness of the design (i.e. makes sure nothing is left out) and evaluates the results of any tests conducted in the detail design stage.

It is important to understand that these stages are just guidelines, and every project may have different places in the design process where a design review is needed. The rule of thumb is to organize a design review whenever external feedback appears appropriate or when there are coordination issues. Also, the design review process is cyclic, and multiple design reviews may be needed at each stage of the design process.

There are two kinds of design reviews:

- Formal design reviews: These are reviews for which companies have well-established procedures that are part of the project plan for every project. They involve external (to the organization, company, or design team depending on the circumstances) feedback,
the results of which are consistently and systematically reported in the design documentation.

- Informal design reviews: These are typically internal reviews conducted regularly or as needed to ensure that the project is on target and to resolve specific technical and coordination issues.

A concept review is evaluated by using the following criteria:

- **Completeness**: Which functions are included in the concept? Which functions are excluded?

- **Performance**: How does the concept perform against the most important CTQs?

- **Operating Details**: How will the customers/organization/suppliers interact with the product or service described in the concept? What do they need to do to receive or operate the product or service?

- **Aesthetics**: How does the product or service look and feel? How does the operating environment look and feel? How comfortable and safe do customers feel when using the product or service?

- **Cost**: What is the approximate cost of delivering the service? How much will customers be expected to pay?

A successful design review, concept or otherwise must be planned and have the following documentation available:

- **Review agenda and format**: This is a planning document that details how the review is going to be conducted and describes the important steps that must be covered. As with all events, the amount of planning and organization determine the success of the review.

- **Concept description**: The format of this documentation depends on the project. In addition to paper descriptions, this can include blueprints, photographs, prototypes, models, drawings, screen dumps, data, calculations and anything else that will help explain the concept to the participants.

- **Data collection checklist**: This document lists the data that needs to be collected for all the key aspects of the design and consists of sampling schemes, formats, surveys, questionnaires, guides and other documents that support data collection.

- **Improvement checklist**: Once the data analysis is complete, this checklist lists the findings in order of priority, lists actions that need to be taken to make corrections where needed, identifies owners for these actions and sets up times by which these actions need to be completed. This checklist becomes part of the design project plan.

- **Data analysis**: The results of the data analysis should point out the next steps in the design process. If a clearly preferred concept exists, but some issues need to be further researched or resolved before moving further in the design process, then these are
documented as part of the design project plan. In this case, there may be no need for another concept review. If no clearly preferred concept exists, then the team must decide if there is the possibility of combining some of the best aspects of the existing concepts to create a “super concept”. This concept needs to be tested for feasibility, and a more limited concept review may be conducted to validate that this new concept is superior to the ones presented at the previous review. In some cases, none of the concepts may be preferred because all of them have serious flaws. In this case it is necessary to redesign the product or service with new concept ideas. A complete formal concept review must be repeated in these circumstances.

Constructive criticism should be welcomed during the concept review because very little money has been spent at this stage. It is far better to have issues come up at this stage than to move forward and find that many unaddressed issues remain after the design is complete. Therefore, the design team should plan especially carefully to make this review a success. Companies that have experience with concept reviews should compile a set of case studies of successful and unsuccessful concept reviews. Teams must be encouraged to develop their own lists of concept review “dos and don’ts” based on past experience and use these as lessons-learnt while structuring their own reviews.

Before finishing off this phase of DMADV a tollgate review is necessary and will focus on:

- List of key functions
- List of top concepts
- Concept review outputs
- Risk analysis update

This review can lead to either High Level Design, redoing work on concepts, concept review and tollgate review or even cancellation of the project.

3.5 Phase 4: Design

The overall approach to developing both high level design and the detailed design is the same, only the level of specificity differs.

In the high level design, you want to develop enough details so that the design can be evaluated for performance and feasibility. Several high level design alternatives may be tested until a suitable design is selected. In detailed design, the selected high level design is developed further to enable implementation.

Benefits of this two-phased approach are:

- Decisions about the major design components and how they fit together are made before detailed decisions are made. This results in a more stable and robust design.
• Evaluating high level design for performance and feasibility before more resources are spent in detailed design is more cost effective and efficient.

Risks associated with the design are better understood.

Figure 3.9, below, illustrates the link between high level and detailed design. It also illustrates the flow of activities within each of these design phases.

Implicit in the design process is the notion of **choices**. During each step of the design process, there are many possible alternatives. The selection of each alternative has its own associated benefits, costs and risks. The challenge of the design process is to make, at various levels of detail, the choices that simultaneously balance the benefit, cost and risk elements, and are compatible with previous, high level decisions. This kind of decision making process is called **satisfying**. It is supported with tools such as simulation and FMEA.

The result of this phase is an optimized design entity with all functional requirements released at the Six Sigma performance level. As the concept design is finalized, there are still a lot of design parameters that can be adjusted and changed. With the help of computer simulation and/or hardware testing, DOE modelling, Taguchi’s robust design methods, and response surface methodology, the optimal parameter settings will be determined. Usually this
parameter optimization phase, in product DFSS projects, will be followed by a tolerance optimization step. The objective is to provide a logical and objective basis for setting manufacturing tolerances. If the design parameters are not controllable, which is usually the case on the DFSS product projects, phases 1 to 3 of DFSS may need to be repeated for manufacturing process design.

The following DFSS tools are used in this phase:

- Design/simulation tools
- Design of experiment including the Taguchi method, parameter design, tolerance design
- Scorecards
- FME(C)A
- Reliability testing and qualification testing
- Rapid prototyping
- QFD

The results of each of the tasks need to be analysed and changes made to the design in light of the findings.

**DFSS Scorecards**

The DFSS Product Scorecard is an approach for collecting, displaying, and analyzing the facts around a design in order to predict future performance and to improve upon the initial design. In a scorecard, a comparison is made between the voice of the customer and the voice of the process. The purpose of the scorecard is to help find design solutions to any problems, not culprits! A DFSS product scorecard facilitates bridging customer requirements with product and process performance at all stages of the design process. It is a living document and revised accordingly.

See Paul Roberts notes on balance scorecards for further information.

**Simulation**

Simulation is an activity that allows one to draw conclusions about the behaviour of a real (or proposed) process by studying the characteristics of a model. It is used for evaluating the trade-offs between performance and resource requirements and to determine the “optimal” design. It is used when the process or system is complex or when the risk of failure of the real system is high. Simulation models can also be physical, such as cockpit simulators for training airline pilots. These are physical “mock-ups” of a real airplane. There is also a computer component of the model which represents conditions and creates the “emergencies”. This type of model is also used for training plant operators.

Simulation models provide quantitative performance measures of a given system configuration. They allow us to see the gain in performance for each addition or reallocation of a resource.

Since a simulation model is a computer model, and not an actual trial with real life customers, bottlenecks and unforeseen failures that cause long delays, poor service, bad product, or even
dangerous conditions do not result in disappointed, disgruntled, or injured customers or employees. For example: If your one of your design alternatives is to build a 10,000 sq. ft. warehouse, you can “test” it out without ever hammering a single nail. No capital investment is required.

There is no shut down of production nor any use of raw material with a simulation model.

The turn around time from concept to results is a matter of minutes, whereas in real-life it could be months or years.

In most cases, simulation is the best way of testing a high level design at the system level. However, it may be necessary to test one or more elements in greater detail, possibly because these elements contribute to the risks and vulnerability of the design, or because the characteristics of performance are not easily quantifiable. In such cases, prototyping is a good approach to test a design before detailed decisions are made.

**Prototyping**

Prototyping helps with testing the design through customer feedback early in the development process, before changes become more expensive. When designing a new product, process, or service, risk is greatest in those areas where customers have trouble defining requirements. For example: What does it mean for a steering wheel to “feel comfortable?” or What does it mean for a computer screen to be “not too bright?”

Prototyping helps with management of risk and uncertainty particularly for high risk components or subsystems of a design. It is highly focused on specific questions or a limited number of technical issues and has a focus on key interfaces, i.e. customer to component; and critical component to component. It is believed that customers respond well to prototypes.

It is important to be clear about how to use prototyping for a design. It is not simply building a smaller version or working prototype of the end product. The purpose is to gain the maximum amount of information as early as possible in the design process. It is important to focus on key questions, unknowns or risk factors that need to be explored with a prototype.

Rapid prototyping simulates the end product without necessarily providing the actual functionality in order to generate design specifications. The key to rapid prototyping is to be able to make changes quickly, inexpensively, and “on the fly.” Rapid prototyping involves creating components that look and feel like the end product, but that can be modified easily and putting components together to simulate the product’s end function. Software developers often sit with customers to modify screen design in real time before creating the actual product. Architectural firms create virtual environments so clients can “walk through” the buildings, check out sight lines, etc., before the foundation is even dug.

Example: A company that was developing a product upgrade knew that it would be louder than its predecessor and that they would need to dampen the sound. But they didn’t know how much sound dampening they would need, and didn’t want to wait to test the finished product. So they simulated various sound levels with a tape recorder and got customer feedback.
Completion of high-level design

Have a design review at every stage of the design process to test the quality of the design (concept, high level and detailed). Ensure that the design review gets both external and internal input. Focus on identifying and resolving problems during the reviews—use the feedback to make changes immediately to the design. Have multiple design reviews at any stage if necessary to ensure quality before passing to the next stage. The high level design review is intended to review the capability testing results to ensure that the design is expected to meet the CTQs. Project management issues for detailed design and high-risk areas are also identified and discussed at this stage. Unlike the concept review, the high level design review is not a step where advance/withdraw decisions are typically made, by this stage the organization is committed to completing the design. The purpose of this review therefore is to identify the main sources of risk due to technical, regulatory and organizational factors, and to make plans to reduce the risks.

The high-level design tollgate review focuses on:

- List of prioritized high level design requirements
- Paper design of key elements
- Results from simulation/prototyping
- Cost/benefit analysis results
- Identification of high risk areas and risk mitigation plans

Tolerances

The following scenarios occur frequently in design situations:

- You must set specifications (tolerances) for parts that stack or fit inside each other. Example: Drive fits in laptop bay.

- You must set specification (tolerances) on the cycle time of steps of a process or of the overall cycle time.

In this step, the DFSS team determines the allowable deviations in design parameters and process variables, tightening tolerances and upgrading only where necessary to meet the functional requirements. Where possible, tolerances may also be loosened. In tolerance design, the purpose is to assign tolerances to the part, assembly, or process, identified in the physical and process structures, based on overall tolerable variation in the functional requirements, the relative influence of different sources of variation on the whole, and the cost-benefit trade-offs. The DFSS team should have a good understanding of (1) the product and process requirements and (2) their translation into product and process specifications using the QFD.

By definition, tolerance is the permissible deviation from a specified value or a standard.

Example: Power Supply Circuit The high-level functional requirement of a power supply circuit is to provide electrical power for small appliances; output voltage is one customer
requirement. Although few customers will bother to measure the output voltage, the excessive deviation of output voltage will affect the functional requirements of small appliances. The larger the deviation, the more customers will notice the requirement degradations of the appliances. Customer tolerance is usually defined as the tolerance limit such that 50 percent of customers will be unsatisfied. For example, the nominal value of a power supply circuit could be 6V, or $T=6$, but if we assume that when the actual output voltage $y$ is either $<5.5$ or $>6.5$ V, 50 percent of customers will be unsatisfied, then the customer tolerance will be $6 \pm 0.5$ V.

A power supply circuit consists of many components, such as resistors, transistors, and capacitors. Setting the nominal values for these component parameters are the tasks for parameter design, and setting the tolerance limits for those parameters are the tasks for the tolerance design at the development stage. For example, if a resistor’s nominal value is 1000 Ω, the tolerance of that resistor could be $\pm 10\Omega$, or $\pm 1$ percent of its nominal value. These are called component specifications. The company that makes the resistor will then have to set nominal values and tolerances for materials, process variables.

Most of the work in tolerance design involves determination of design parameter tolerances and process variable tolerances, given that the functional tolerances have already been determined. The term tolerance design in most industries actually means the determination of design parameter tolerances and process variable tolerances.

**DOE**

Design of Experiments (DOE) is a systematic method to aggressively learn about a product, process, or service. Designed experiments are being used by design teams to perform critical design functions such as:

- Identify factors that affect performance measures
- Understand relationships between design factors
- Test cause-and-effect theories
- Optimize product, process, and service designs
- Design robust products, processes, and services
- Improve the manufacturability of the design
- Improve the reliability of the design

Six sigma and psws modules.

**Completion of design phase**

When all the tests of the detailed design are complete, and the process management plans are in place, we conduct the last design review, called the pre-pilot review. Unlike the concept review, where all interested parties are allowed to comment on the design, the pre-pilot review is usually restricted to technical discussions. It is important to understand that the pre-
pilot review is the last of many technical reviews conducted during the detailed design phase. Sub-teams will meet formally or informally as the design progresses to make critical decisions, resolve technical difficulties and ensure that the project is moving on track.

- Concept Review: The concept review is used to test the feasibility of various concepts and to establish customer and stakeholder preferences for one or more concepts.

- High Level Design Review: The high level design review is used to verify that the design can meet its predicted capability, that risks have been identified and to confirm the project plan for detailed design.

- Pre-Pilot Detailed Design Review: The pre-pilot design review is used to ensure that all elements of the design are complete, and that the design is ready for pilot.

The following items should be the output of the pre-pilot design review:

- List of participants
- List of key issues raised, identifying who raised them
- List of proposed actions, including who is responsible
- List of changes to reviewed documentation
- Schedule of future meetings to assess completion of proposed actions
- Schedule of future design review meetings as appropriate

The pre-pilot detailed design tollgate review focuses on:

- Developed design
- Completed FMEA/EMEA/simulation analysis
- Design solutions for vulnerable elements
- Organizational Change Plan updates
- Process management system variables
- Process management system details

3.6 Phase 4: Verify

After the parameter and tolerance design is completed, the final phase involves verification and validation activities. Figure 3.10, below, shows the main steps in his phase.
The following DFSS tools are used in throughout this phase:

- Process capability modeling
- DOE
- Reliability testing
- Poka-yoke, errorproofing
- Confidence analysis
- Process control plan
- Training
- Planning tools
- Appropriate data analysis tools
- Control charts
- Pareto charts
- Standardization tools
- Flowcharts
- Checklists
- Process management tools
- Process management charts
- Project documentation

**Pilot testing and evaluation**

No product or service should go directly to market without first piloting and refining. Design FMEA can be used as well as pilot and small-scale implementations to test and evaluate real-life performance. A pilot is a test of the ‘whole system’ on a small scale and its main goals are: to collect data on results in order to evaluate the new product, service, or process; and to collect data on the pilot plan in order to make full-scale implementation more effective.

There are many ways to pilot, including: table-top models, scale models, or mock-ups; Beta testing; test market release; trial runs; limited time offers; rapid prototyping and early evaluation by end users; pilot plants; walk-throughs; dry runs; and limited implementation for one location, one customer, or one product line.

After the pilot is completed and the data analyzed, the results are reviewed with management. This review focuses on: reviewing analysis of pilot results (and repilot results as appropriate); discussion of problems identified during the pilot, causal analysis, and data on effectiveness of countermeasures taken; and a review of risk issues. The key output of the review is a decision about whether to move the design into full implementation.

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Implementation

As the design entity is validated and process control is established, the full-scale commercial rollout and the new product, together with the supporting processes, can be handed over to design and process owners, complete with requirements settings and control and monitoring systems.

A full-scale implementation should have been defined initially in the charter and the definition may have been refined in the multi-generational platform plan as the design evolved. Prior agreements about the boundaries of implementation should be revisited so that the team knows when its work is complete. At this stage an implementation strategy is selected resulting in an implementation plan.

The implementation strategy identifies how the design will be rolled out to different locations or areas. There are several approaches:

- Sequencing: The design is implemented in one location before the next location is started.
- Phasing: The design is partially implemented at one location and then the second location is started.
- All-at-Once: All locations start simultaneously.
- The approaches can also be combined.

From the strategy the plan can be developed and this will involve determining a work plan; a transition plan; process management plan; training plan and communication plan. In addition, documented standard operating procedures need to be updated based on the pilot and distributed. This documentation includes flowcharts, drawings, schematics, written instructions, and cautions. They may be written, photographed, illustrated, or on video or audio tape and should be simple enough for most people unfamiliar with the job, with the appropriate skills, to follow and produce the desired results. They should also record what to do and WHY. Standard operating procedures should be documented and stored so that:

- Everyone has easy access to the information
- They can be updated easily
- Versions can be easily controlled
- There can be links between documents such as flowcharts, instruction sheets, forms, and checklists
- People who are not fully trained can use them easily
- They are at an appropriate level of detail
- They describe how to prevent variation
- They focus on priorities

A plan for ongoing process management should be developed and could contain the following:

- A clarification of the process roles and a plan for who will fill those roles
- A working version of the Process Management Chart with the major process steps, measures, and response plans
- A working version of the dashboards that will be used to manage the process on an ongoing basis. What will be measured? How will it be tracked?
- A schedule for process reviews

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Process owners monitor key measures to ensure that the performance level continues to meet requirements. Control charts and pareto charts can be used to display and analyze this data.

When control charts are used for monitoring, you need to decide who will be responsible for their upkeep and for reacting to any signals, the following questions are useful to ask:

- Who will collect the data?
- Who will plot the data?
- Who will interpret the chart?
- What should they do if a signal of special cause appears?
- Where will the chart be posted?
- Will it be done by hand or on computer?

Everyone involved in using the chart ought to have been trained to collect and plot the data, and understands special and common cause variation.

Once responsibilities for implementation have been transitioned, the design team should go through a formal closure process that:

- Recognizes the considerable time and effort that went into the initiative
- Captures the learnings about the design process

At the end of the project capture all lessons learned and feedback to new design and development projects.

Project closure includes:

- Completed project documentation that summarizes results and learnings
- Recommendations (supported by updated information, if possible) for the next generation of this design

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• Plans for (or results from) communicating your achievements to the rest of the organization
• Plans for celebrating your success

4 Difference between Six Sigma DMAIC and DFSS

DFSS is said to be the logical extension of Six Sigma but their initiatives are different. Their differences include:

- DMAIC is more focused on reacting, on detecting and resolving problems, while DFSS tends to be more proactive, a means of preventing problems;
- DMAIC is for products or service that already exist, while DFSS is for the design of new products, services or processes;
- DMAIC is based on manufacturing processes and DFSS is focused on marketing, R&D and design.
- Financial benefits of DMAIC can be quantified more quickly with benefits from DFSS being more long-term.
- The DFSS team is almost always cross-functional so that the entire project team is involved in all aspects of the design process, from market research to project launch.

These notes have given a comprehensive discussion on the DFSS methodology, DMADV. Details on all the tools used in DMADV have also been given.

The deployment of DFSS is very similar to a six sigma project except that the project team members tend to be interdisciplinary i.e. design engineers, manufacturing engineers, test engineers, reliability engineers, maintenance engineers, components engineers, quality engineers etc. In addition the success of a DFSS project is mainly due to the commitment from top-level management to support the project team and follow-through on any recommendations. Adhering to the the DMADV process, conducting reviews at each phase and being proactive throughout project development are all factors that will affect the success of a new product being designed and developed.

5 References


6 Appendix 1

Six Sigma tables

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Warwick Manufacturing Group
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Warwick Manufacturing Group
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*Warwick Manufacturing Group*