An Introduction to Design for Six Sigma concepts

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Product Excellence using 6 Sigma Module

Objectives of the session

• History of Six Sigma
• Describe the Six Sigma Philosophy
• Introduce DFSS
• Key points in DFSS
• DFSS background
• DFSS process
• Differences between DFSS and Six Sigma
Introduction to Six Sigma

• Six Sigma is:
  – A business process
  – Proactive approach to designing and monitoring key activities
  – Philosophy
  – Methodology
  – A process that is customer focussed and profit driven

• It works by:
  – Being adopted by the whole company;
  – Creating an internal infrastructure within the company;
  – Using metrics to measure processes and changes to processes
  – Using scientific methods, changing the working culture and introducing business process management
Six Sigma Background

- Motorola employee investigating variation in various processes
- Acted on results using tools to reduce variation
- Improved the effectiveness and efficiency of the processes
- Engaged CEO
- GE is the company that made SIX Sigma a management philosophy

What is six sigma performance?

Sigma ($\sigma$) is a statistical metric that corresponds to dpm (defectives per million)

- $2 \sigma$: 308,537 dpm
- $3 \sigma$: 66,807 dpm
- $4 \sigma$: 6,210 dpm
- $5 \sigma$: 233 dpm
- $6 \sigma$: 3.4 dpm
DMAIC

Define
- Define business objectives
- Set Up project team, establish the charter and develop project plan
- Review customer requirements
- Map process

Measure
- Data collection plan
- Confirm starting and targets
- Validate measurement system

Analyse
- Data analysis
- Root cause analysis
- Process analysis

Improve
- Solution generation, selection and implementation
- Launch new improvements
- Monitor controls and track defect reduction
- Design and implement audit plan

Control

Product life cycle

Disposal
Concept and definition
Operation and maintenance
Continuous assessment
Installation
Design and development
Manufacturing
Introduction to DFSS

- Systematic methodology for designing or redesigning products or services according to customer requirements and expectations.
- Optimises design process to achieve six sigma performance
- Get it ‘right first time’

What is Design For Six Sigma?

- Companies who had seen the success of Six Sigma for problem solving using DMAIC wanted to apply data driven tools and techniques to the design of new products, processes & services
- Typically, after 2 years of DMAIC, Design For Six Sigma programmes were launched
- Applied in both Manufacturing and Service industries in technical and non-technical environments
- Used to define and/or supplement the ‘design’ process
When to Use DFSS

- Creating a new product, process, or service
- Incremental improvement cannot close the gap between the current process capability and customer requirements
- Should spend time understanding the faults of existing systems before you embark on a redesign methodology

Generic ‘Design’ Process

- Requirements Flow down
- CTQ Flow up
The DFSS Opportunity

“Design in” quality when costs are lowest

Effect of design phases on life cycle

Potential is positive
Impact > cost

Potential is negative
Impact < cost

Cost vs impact
The Vision of DFSS

From
• Evolving design requirements
• Extensive design rework
• Product performance assessed by “build and test”
• Performance and producibility problems fixed after product in use
• Quality “tested in”

To
• Disciplined CTQ flow-down through requirements management
• Controlled design parameters
• Confidence in product performance
• Designed for robust performance and manufacture
• Quality “designed in”

DFSS Methodology

• DMADV
  – Define, Measure, Analyse, Design and Verify

• PIDOV
  – Plan, Identify, Design, Optimise and Validate.
### DFSS Process

#### Define
- Initiate, scope and plan the project

#### Measure
- Understand customer requirements and generate specification

#### Analyse
- Develop design concepts and high level design

#### Design
- Develop detailed design and verification plan

#### Verify
- Demonstrate compliance and launch product
Tollgates and phases

• Stopping point within the flow of phases
  – A thorough assessment of deliverables
  – A thorough review of the project management plans for the next phase
• Checklists
  – Summary statements of tools and best practices required to fulfil gate deliverable
• Scorecards
  – Summary statements from specific application of tools and best practice

DMADV

Define
DMADV - Define

Elements of a Charter

- Problem Statement
- Opportunity Statement
- Importance
- Expectations/Deliverables
- Scope
- Schedule
- Team Resources
Develop Project Plans

- Project schedule and milestones
- Organizational change plan
- Risk management plan
- Review schedule

Risk Management Plan

- 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
- In Define, the team should:
  – Identify known and potential risks for the project
  – Indicate when and how the risks will be addressed
Sources of risk

- External – legislation – outwith the control of the project team
- Internal – within control of project design, human factors and technology etc.
- Handle risk by taking action to avoid (mitigation)
- Build up reserves (contingency)

Spheres of Risk

- Risks *cannot be transferred* between disciplines
- Risks *must be translated* between disciplines
Project plan vs Risk plan

• **Project Plan**
  – Outlines what the project team *intend* to do
  – Supports the Project Management process

• **Risk Plan**
  – Covers how the project team *might* have to *change* the plan
  – Supports the Risk Management Process

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Risk Management Process

- Identify
- Quantify/Classify
- Analyse
- Get OWNERSHIP
- Provision
- Monitor
- Manage / Control
Systematic Risk Identification

• A structured approach that allows an organised critical analysis of risks of the system under consideration.
• All risks are reviewed systematically.
• Risks are addressed from the system level to the component level.
• Risks arising due to system functional, environmental profiles, implicit & explicit requirements, interaction of components/subassemblies, manufacturing/assembly processes & supply chain are considered.

Risk Categorisation

<table>
<thead>
<tr>
<th>Probability of occurrence</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>5</td>
</tr>
<tr>
<td>medium</td>
<td>3</td>
</tr>
<tr>
<td>low</td>
<td>1</td>
</tr>
</tbody>
</table>

Risk element scores = probability X impact
Categorizing Risks

- Risks are categorized by their probability of occurrence and their impact on the project.

<table>
<thead>
<tr>
<th>Probability of Occurrence</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow Light: Proceed with caution</td>
<td>Yellow Light: Proceed with caution</td>
<td>Yellow Light: Proceed with caution</td>
<td></td>
</tr>
<tr>
<td>Red Light: Address before proceeding</td>
<td>Red Light: Do not proceed</td>
<td>Red Light: Reassess project</td>
<td></td>
</tr>
<tr>
<td>Red Light: Do not proceed</td>
<td>Red Light: Do not proceed</td>
<td>Red Light: Do not proceed</td>
<td></td>
</tr>
</tbody>
</table>

Mitigation versus Contingency

- Mitigation involves *buying off* a problem in advance.
- Contingency means *being ready* to manage crises pro-actively.
Effect of mitigation and contingency on project plans

- Mitigation activity is entered directly into the project plan.
- Contingency plans and contingent mitigation plans are held in the Risk Plan.
- Implemented contingency becomes part of the project plan.
- When an impact occurs, contingency plans are moved.

Responsibility

- The Technical Manager or the Lead Engineer of the project
- He/She acts as, or alternatively, nominates a team leader.
- Responsible for organising Technical Risk Assessment sessions & maintaining the information and selecting a team.
- The team consists of at least one representative from:
  - Project Management; Stress/Integrity; Design Engineering; Development Testing; ILS; Quality; Manufacturing; Sourcing; Systems/Requirements
Example: Risk assessment/management process

1. **RISK IDENTIFICATION**
   - Identify risk

2. **RISK PRIORITISATION**
   - Assess magnitude of the risk

3. **RISK MANAGEMENT**
   - Develop plans to manage the risk

Example

In order to ensure that all possible risks are identified, the risk identification for a component/sub-assembly is carried out in three stages:

- Brainstorm all risks associated with the ‘FUNCTION’ of the component (or subassembly)
- Brainstorm all risks associated with the ‘REQUIREMENT’ of the component (or subassembly)
- Brainstorm all risks associated with the ‘MANUFACTURE/ASSEMBLY/SUPPLY’ of the component (or subassembly)
Example: Brainstorming risks

<table>
<thead>
<tr>
<th>Sub-assembly</th>
<th>Part</th>
<th>Type of risk</th>
<th>Description of risk</th>
<th>Who</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor Wound Main Assembly</td>
<td>Clam p Plate</td>
<td>Function - What does it do? (eg. Insulating, protecting)</td>
<td>Clamp plate is too weak to clamp the rotor windings axially – could cause windings to short against rotor framework.</td>
<td>Paul Harris</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Requirement - What does it have to cope with? (eg. CF loading, vibration, temp., oil)</td>
<td>Cannot withstand the high CF loads – could cause clamp plate to break &amp; thus, windings to short against rotor framework</td>
<td>Paul Harris</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manufacture - How do you make this or where did you buy it (supply chain)?</td>
<td>New manufacturing process to be used. This may cause porosity of the material.</td>
<td>Steve Robb</td>
</tr>
</tbody>
</table>

Remember all risks brainstormed must be considered & recorded!

Magnitude of risk

- After a risk has been identified, the next step is to assess the magnitude of the risk. This enables the prioritisation of all the risks identified & ensures that a concerted effort is made to mitigate the high scoring risks.

- The following factors are used to assess the magnitude of & prioritise technical risks:
  - Pedigree
  - Testing
  - Analysis
  - Severity
  - Probability
### Risk Prioritisation

**Factors Used for Prioritising Risks**

<table>
<thead>
<tr>
<th>PEDIGREE</th>
<th>TESTING</th>
<th>ANALYSIS</th>
<th>SEVERITY</th>
<th>PROBABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do we have any past experience (product/process) that can help us assess the magnitude of the risk?</td>
<td>Do we have any evidence from testing that can help us assess the magnitude of the risk?</td>
<td>Do we have any evidence from theoretical analysis that can help us assess the magnitude of the risk?</td>
<td>What impact can this risk have on the project or product?</td>
<td>What is the likelihood of the risk being realised?</td>
</tr>
<tr>
<td>Based on evidence</td>
<td>Based on evidence</td>
<td>Based on expert judgement</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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### Risk Prioritisation – Function/Requirement Risks

**Example: Scoring Function/Requirements Risks**

<table>
<thead>
<tr>
<th>Sub-assembly</th>
<th>Part</th>
<th>Type of risk</th>
<th>Description of risk</th>
<th>P</th>
<th>T</th>
<th>A</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor Wound Main Assembly</td>
<td>Clamp Plate</td>
<td>Function - What does it do? (eg. Insulating, protecting)</td>
<td>Clamp plate is too weak to clamp the rotor windings axially.</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>Stress Report 1234</td>
</tr>
</tbody>
</table>

**Pedigree**
- 1 Identical design in Long Field Service
- 3 Identical design in Development Units/ Similar design in long term service
- 9 New Design

If pedigree = 1, stop scoring, move onto next risk.

**Testing**
- 1 Full representative test
- 3 Read across tests with good sample size/ limited tests/ Verification
- 9 Zero testing/ small sample size

Preliminary analysis suggests design meets requirements. Therefore, Analysis = 3

**Analysis**
- 1 Full Capable Analysis
- 3 Preliminary Analysis
- 9 No Analysis/ not capable of analysis

**Stress Report**

Remember to record evidence used for scoring. This can be updated as Managements actions are completed.
Risk prioritisation – severity and probability

Example: Scoring Severity & Probability

<table>
<thead>
<tr>
<th>Sub-assembly</th>
<th>Part</th>
<th>Type of risk</th>
<th>Description of risk</th>
<th>P</th>
<th>T</th>
<th>A</th>
<th>RP N1</th>
<th>S</th>
<th>P</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor Wound</td>
<td>Clamp Plate</td>
<td>Function - What</td>
<td>Clamp plate is too weak to clamp</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>24</td>
<td>9</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Main Assembly</td>
<td></td>
<td>does it do? (eg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Insulating,</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td>protecting)</td>
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</tr>
</tbody>
</table>

The likelihood of the risk being realised is medium. Therefore, Probability = 3

The Clamp Plate is too weak to clamp the rotor windings axially. Therefore, Severity = 9

Risk prioritisation – project risk score

- The ‘Project Risk Score’ is calculated using the formula:
  Project Risk Score = S X PR
- The Project Risk Score is used by the project managers for the prioritisation of technical risks in the overall project risk management process.

Example: Calculating the ‘Project Risk Score’

<table>
<thead>
<tr>
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<th>P</th>
<th>R</th>
<th>Project Risk Score</th>
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<td>3</td>
<td>24</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>6561</td>
</tr>
<tr>
<td>Main Assembly</td>
<td></td>
<td>does it do? (eg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>Insulating,</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>protecting)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example: Managing Risk Management Actions

The project manager is responsible for managing the risk management actions and maintaining the risk curve.

<table>
<thead>
<tr>
<th>Management Action</th>
<th>Who</th>
<th>Planned Closure Date</th>
<th>Actual Closure Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carry out full stress analysis of clamp plate</td>
<td>David Bonniemaan</td>
<td>15/01/02</td>
<td></td>
<td>Open</td>
</tr>
<tr>
<td>Monitor performance of clamp plate when next five development units are tested</td>
<td>Peter Dunkz</td>
<td>15/01/02</td>
<td></td>
<td>Open</td>
</tr>
</tbody>
</table>

At early stages, more risks identified, total RPN2 rises.

Effective management of risks – RPN 2 falls.

### Risk Management

- Identify some risks for projects
- Estimate the probability of occurrence
- Estimate the effect/impact
- Identify mitigating actions for highest scoring risks.
Project Reviews

• Regular reviews are key for successful projects and should be included in the project schedule
• There are several levels of review:
  – Milestone or tollgate reviews; weekly reviews; daily reviews
• In addition, design projects have three unique reviews:
  – Concept review; High-level design review; Detailed design review

Key Outputs of DEFINE Phase

• Project team
• Project business case
• Project objective
• Project plan (GANNT chart)
• Document control systems
• Risk reduction plan
DMADV

Measure

DMADV - Measure

• **Goals:**
  – Collect Voice of the Customer data
  – Translate VOC into design requirements (CTQs)
  – Identify the most important CTQs
  – Develop the measurement system for each CTQ
  – Develop a design scorecard
  – Revise project objective if necessary

• **Output:**
  – Prioritized CTQs
Measure: Tools

- Data collection plan
- Customer segmentation
- Customer research
- Voice of Customer table
- Kano model
- Affinity diagram
- Benchmarking
- QFD (Quality Function Deployment)

Measure: Key Activities

Understand Voice of the Customer → Translate VOC Needs Into Requirements (CTQs) → Prioritize CTQs → Reassess Risk
What is the Voice of the Customer?

- The term Voice of the Customer (VOC) is used to describe customers’ needs and their perceptions of your product or service.
- It includes all forms of interaction between customers and your organization.

Use of Kano analysis

Critical to Quality Characteristics

- 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.
- Use QFD to transfer VOC data into CTQs.
Develop and Validate a measurement system

- Review data requirements
- Review how to capture data
- Review applicable analysis methods
  - e.g. compare voice of the process with voice of the customer – SPC and capability analysis
- Decision criteria to determine acceptance
- Establish validity of the measurement system

Develop a design scorecard

Used to help the team to:
- Establish nominal values and specification limits for each CTQ
- Predict output of the voice of the process with respect to stability (SPC)
- Highlight problems and risks of CTQs
- Track CTQs throughout the entire life of the product
Generic design scorecard

<table>
<thead>
<tr>
<th>Scorecard Part A (Voice of the customer)</th>
<th>Scorecard Part B (Predicted Voice of the process)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTQ</td>
<td>Target</td>
</tr>
</tbody>
</table>

Reassess Scope and Risk

- 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?
Measure: Tollgate Review

- This tollgate review 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 lead to the following steps:
  - Proceed to Analyse
  - Redo parts Measure
  - Stop the project

DMADV

Analyse
DMADV - Analyse: Key questions

- Important processes/functions that must be designed to meet the design requirements?
- Key inputs and outputs of each process?
- Processes for which innovative new designs are required to maintain a competitive advantage?
- Different solutions available for designing each process?
- What criteria do we use to evaluate these design alternatives?
- Collect information on these criteria for evaluation?

DMADV - Analyse

Identify Key Functions → Prioritize Functions → Generate Concepts → Evaluate and Analyze → Concept Review
Identify Key Functions

Identify Key Functions

WMG

Heat Water

Regulate Heat

Unite Tea and Water

Allow Infusion

Separate Tea and Leaves

Hot Tea

Tea Leaves (waste)

Energy

System Boundary
Generate Concepts

- 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

Design Review

- Process for objectively evaluating the quality of a design at various stages of the design process
- Opportunity for voices external to the design team to provide feedback on the design, as the product and service is being developed
- Helps to ensure that the design will satisfy customers, and that the design process will function effectively to produce a high quality product or service
When to conduct a design review

- **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.

Design for X

- Design for manufacture
- Design for assembly
- Design for reliability
- Design for testability
- Design for service
- Design for quality
- Design for reusability
- Design for environment
Analyse: Tollgate Review

• This tollgate review focuses on:
  – List of key functions
  – List of top concepts
  – Pugh Matrix
  – Concept review outputs
  – Risk analysis update

• This review can lead to the following steps:
  – Proceed to High Level Design
  – Redo work on concepts, concept review and tollgate review
  – Stop the project
DMADV - Design

From Concept to Design

- Less Detail / Many Alternatives
- More Detail / Few Alternatives
- Most Detail / Single Alternative

Redesign
Design: Goals and Outputs

• Goals:
  – Develop high level and detailed design
  – Test design components
  – Prepare for pilot and full scale deployment
• Outputs:
  – Tested high level design
  – Tested detailed design
  – Plans for process control
  – Completed design reviews

Design: Tools

• QFD
• Simulation
• Rapid prototyping
• Weibull analysis
• SPC and process capability
• Detailed design scorecards
• FMEA
• Reliability testing and qualification testing
• Design reviews
Tollgate review

The pre-pilot detailed design tollgate review focuses on:
• Developed design
• Completed FMEA/simulation analysis
• Design solutions for vulnerable elements
• Organizational Change Plan updates
• Process management system variables
• Process management system details

DMADV

Verify
Steps in the Verify phase

• Build a prototype
• Pilot test the prototype
• conduct design reviews using design scorecards
• Decide if the process is meeting business objectives
• Close DMADV project
• Transfer lessons learned from the project
Verify: Goals and Outputs

• Goals:
  – ‘Stress-testing’ and de-bugging of prototype
  – Implementation and team closure

• Outputs:
  – Working prototype with documentation
  – Plans for full implementation
  – Process owners using control plans to measure, monitor and maintain process capability
  – Project closure and documentation completed
  – Ownership transition from sponsor to operations management, and from design team to process management team(s)
  – Lessons learned

Completion Checklist

• Completed project documentation that summarizes results and learnings
• Recommendations (supported by updated information, if possible) for the next generation of this design
• Plans for (or results from) communicating your achievements to the rest of the organization
• Plans for celebrating your success
Advantages of DFSS

- Provide structure to development process
- Anticipate problems and avoid them
- Reduce life cycle cost
- Improve product quality, reliability and durability
- Cultural change
- Minimise design changes
- Improve communication between functions

Difference between SS and DFSS

<table>
<thead>
<tr>
<th>DMAIC</th>
<th>DFSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>reactionary</td>
<td>proactive</td>
</tr>
<tr>
<td>detecting and resolving problems</td>
<td>preventing problems</td>
</tr>
<tr>
<td>Existing products or services</td>
<td>Design of new products, services or processes;</td>
</tr>
<tr>
<td>Financial benefits quantified quickly</td>
<td>Financial benefits long-term</td>
</tr>
<tr>
<td>Mainly manufacturing processes</td>
<td>Marketing R&amp;D and design</td>
</tr>
<tr>
<td></td>
<td>DFSS team cross-functional</td>
</tr>
</tbody>
</table>
DFSS Summary

• Rigorous approach to design
• Primarily used for new product design
• Structured approach
• DMADV and PIDOV
• Tailored for each company
• In conjunction with product introduction
• Pushes key issues up front – design for reliability and design for manufacture