Lecture 21: Variation Risk Management

Quality Types

Total Quality

- Human resources
- Organizing and operating
- Manufacturing
- Product and Services
- Design
What is variation?

• Variation = Deviation from nominal
  – variation: the extent to which or the range in which a thing varies
  – vary: to make differences between items
• All processes introduce variation into part dimensions
• Variation impacts performance
• Variation impacts cost

Nominal vs. Variation

• Nominal
  – Definition
    • the target value that the design tried to achieve
  – Quality of nominal design
    • Feature set
    • Look/feel
• Variation
  – Definition
    • Variation is the small deviation from nominal introduced by
      – the environment
      – manufacturing process
      – degradation
  – Quality of design for variation
    • Robust to internal variation
    • Robust to external variation
Why is this an interesting problem?

There are thousands of articles on variation and robust design

but....

Companies continue to struggle with variation and its effects

why?
Didn’t Taguchi solve this problem already?

- Design of Experiments is one tool of many used in the variation risk management process
- Tolerance design and parameter design methods are limited to single cause/effect methods
- Robust design methods can be used for single sub-systems

- Other researchers
  - Simulation tools to predict variation for particular problems
  - Robust concept design

What problems have not been solved

- Complexity
  - It is not enough to look at single cause and effect, the product (sub-assembly) must be evaluated as a system
- Prioritization
  - There are not enough resources to improve and control all processes
- Data supported processes
  - The data sources are limited
Source of Complexity

Complexity · Prioritization · Data Sources

- Process Variation
- Part Dimension Variation
- Sub-assembly dimensional variation
- Functional Variation
- Customer Dissatisfaction

- Stamping variation
- Door panel shape
- Gap between the door and frame
- Excess wind noise and leak
- Customer Dissatisfaction

- Locating system for k-holes
- Mis-located part
- Need for a custom shim
- Excess weight
- Customer Dissatisfaction

Complexity

Methods of Managing Data

Complexity · Prioritization · Data Sources

Key characteristics:

The set of small set of product features whose variation will create significant loss
**Key Characteristics Flowdown**

**Complexity** • Prioritization • Data Sources

*Characteristics of flowdown*

- Many layers deep
- Many contributors
- Cross coupled

**System**

- Contour
- Drag

**Assembly**

- Contour of the Main Torque Box
- Gap between the skins

**Feature**

- Height
- Angle of Front Spar
- Distance Between Spars
- Angle of Rear Spar

**Process**

- Fixture
- Extrusion

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**Example from a medical product**

**Complexity** • Prioritization • Data Sources
**Mathematical Model**

\[ x_{ij} = f(x_{1(i+1)}, x_{2(i+1)}, \ldots, x_{n(i+1)}) \]

**Variation Model**

\[ y_i = f(x_1, x_2, \ldots, x_n) \]
\[ \Delta y_i = \frac{\partial y_i}{\partial x_1} \Delta x_1 + \frac{\partial y_i}{\partial x_2} \Delta x_2 + \ldots + \frac{\partial y_i}{\partial x_n} \Delta x_n \]
\[ \sigma_i = \sqrt{\left( \frac{\partial y_i}{\partial x_1} \sigma_1 \right)^2 + \left( \frac{\partial y_i}{\partial x_2} \sigma_2 \right)^2 + \ldots + \left( \frac{\partial y_i}{\partial x_n} \sigma_n \right)^2} \]

- \( \frac{\partial y_i}{\partial x_n} \) determined using
  - VSA (variation systems analysis)
  - Design of Experiments
  - Product/process models
**Matrix Representation**

\[
\bar{a}_K = \begin{bmatrix}
\frac{\partial x_1}{\partial x_{1k}} & \frac{\partial x_1}{\partial x_{2k}} & \cdots & \frac{\partial x_1}{\partial x_{(k+1)k}} \\
\frac{\partial x_2}{\partial x_{1k}} & \frac{\partial x_2}{\partial x_{2k}} & \cdots & \frac{\partial x_2}{\partial x_{(k+1)k}} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{\partial x_n}{\partial x_{1k}} & \frac{\partial x_n}{\partial x_{2k}} & \cdots & \frac{\partial x_n}{\partial x_{(k+1)k}}
\end{bmatrix}
\]

\[
\delta_K = \begin{bmatrix}
\left(\frac{\partial x_1}{\partial x_{1k}}\right)^2 & \left(\frac{\partial x_1}{\partial x_{2k}}\right)^2 & \cdots & \left(\frac{\partial x_1}{\partial x_{(k+1)k}}\right)^2 \\
\left(\frac{\partial x_2}{\partial x_{1k}}\right)^2 & \left(\frac{\partial x_2}{\partial x_{2k}}\right)^2 & \cdots & \left(\frac{\partial x_2}{\partial x_{(k+1)k}}\right)^2 \\
\vdots & \vdots & \ddots & \vdots \\
\left(\frac{\partial x_n}{\partial x_{1k}}\right)^2 & \left(\frac{\partial x_n}{\partial x_{2k}}\right)^2 & \cdots & \left(\frac{\partial x_n}{\partial x_{(k+1)k}}\right)^2
\end{bmatrix}
\]

\[
D = \bar{a}_1 \bar{a}_2 \bar{a}_3 \ldots \bar{a}_{(\ell-1)}
\]

\[
T = \delta_1 \delta_2 \delta_3 \ldots \delta_{(\ell-1)}
\]

\[
b_f = Db_\ell \quad \text{and} \quad \delta_f^2 = T\delta_\ell^2
\]

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**Debate**

**Deming:**

- Zero Defects are best
- Any attempt to reduce variation and its impact will have a positive return

**Juran:**

- Need to balance the cost of variation against the cost of extra precision
Problem definition

“Quality is Free”, but

Quality requires an investment of resources

and there are limited resources in a company.

Why is prioritization non-trivial?

Variation is assessed at the system
– The user sees the paper jam not the roller diameter

Variation is controlled at the feature level

There aren’t enough resources to control every dimension or process

Important thing is to find the critical few
Data sources

- Knowledge of the system is scattered throughout the organization
- Process capability data is available but not used
- Cost data is scattered

Process capability data

- Measurements taken on existing products in production
- Surrogate data used to predict variation in future products
- 90% of all companies we interviewed had capability data
- 10% of them used the data during design
Process Capability Databases

The Purpose of PCDBs

- PCDB creation
  - Manufacturing process results are measured, entered into PCDB
  - Process target values are documented

- Data may be organized by:
  - Material
  - Process
  - Feature
  - Date
  - Machine
  - Operator

The Problem

Missing Data in PCDBs Hinders Design

- Missing data is caused by
  - No data collection from process
  - New process: no precedent

- Missing data results in
  - Unreliable prediction of process capabilities
  - Less efficient design processes and manufacturing plans

Project Goal

- Develop methods to reliably predict values for missing data
  - Mean
  - Variance
Variation Risk Management

• Definition
  – Systematic identification, assessment and mitigation of variation risk through the design process to most effectively reduce the impact of variation given limited resources

• Assumption
  – Variation will always cause degradation in quality.
  – Design/manufacturing/quality expend resources to reduce the magnitude and/or impact of variation
  – Problem is “where do you put resources to most effectively reduce the cost of variation.”

Risk

• Two parts to risk
  – Chance of failure (P)
  – Cost of failure (C)

• Mean cost of variation
  – C*P

<table>
<thead>
<tr>
<th>Chance of Failure</th>
<th>low</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal risk</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>High Risk</td>
<td>?</td>
<td></td>
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</tbody>
</table>
VRM Stages

- Identification
  - Identify variation sensitive system requirements
  - Identify system, sub-system, feature and process characteristics that may contribute to the system variation
- Assessment
  - Quantify the probability of variation (P)
  - Quantify the cost of variation (C)
- Mitigation
  - Select mitigation strategy based on costs, schedule and strategic impact
  - Execute the strategy

Variation Sensitive Customer Requirements

- What requirements are likely to be sensitive to variation?
  - Examples
    - Steps and gaps
    - Flakes in printing
    - Uneven ink deposition
- What are the tolerances/latitudes
Two methods of Assessment

- Aggregated
  - Using a models of variation to take process capability and flow it up to check quality
  - RSS, VSA
- Desegregated
  - Using models of variation to allocate variation down the tree
  - Tolerance allocation
- Used in conjunction

Assessment

- Three parts to assessment
  - Sensitivity to variation
  - Process variation
  - Cost of system variation

Risk

System Variation

Cost of Variation

- Sensitivity
- Process Variation
**Failure rate**

\[ P_{\text{failure}} = 1 - \int_{LL}^{UL} pdf(y) \]

\[ C_p = \frac{U - L}{6\sigma} \]

\[ C_{pk} = \min \left( \frac{\mu - LL}{3\sigma}, \frac{UL - \mu}{3\sigma} \right) \]

**Relationship between Tolerance and \( \sigma \)**

- For a \( C_{pk} = 1.33 \) (normal accept levels)

\[ 1.33 = \frac{UL - LL}{6\sigma} \]

\[ UL - LL = 8\sigma \]
### Cost of Variation: Taguchi Loss function

\[ L = k(y - m)^2 \]
\[ k = \frac{\text{Cost of a defective product}}{(\text{Tolerance})^2} \]
\[ k = \frac{A}{\bar{A}^2} \]
\[ \delta^2 = \text{mean value of } (y - m)^2 \]
\[ L_{\text{mean}} = k(b^2 + \delta^2) \]
Mitigation during design

- Design change
  - Change the geometry, features, parts to make the product less sensitive to variation
  - Robust design
- Process change
  - Specify a more precise process to reduce variation

Mitigation during production

- Variation Reduction
  - Focused efforts to reduce variation in processes
  - Standard operations, maintenance schedules, etc..
- Statistical Process control
  - Ongoing control to prevent process degradation
- Inspection
  - Each part is looked at individually
  - If it fails inspection it is either scrapped or reworked.
Comparison of strategies

<table>
<thead>
<tr>
<th></th>
<th>Yield Improvement</th>
<th>Recurring Costs</th>
<th>Non-recurring Costs</th>
<th>Strategic Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Change</strong></td>
<td>High</td>
<td>None - Low</td>
<td>High - Medium</td>
<td>High</td>
</tr>
<tr>
<td><strong>Process Change</strong></td>
<td>High-Medium</td>
<td>Medium - Low</td>
<td>High - Medium</td>
<td>High</td>
</tr>
<tr>
<td><strong>Variation reduction</strong></td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Process Monitoring</strong></td>
<td>Medium-low</td>
<td>Medium - Low</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Inspection</strong></td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Identification • Assessment • Mitigation

How to select

- Resource availability
- Cost of effort
- Benefit of effort
  - Calculated by
    - baseline without control
    - cost with control
Documentation system

IPPD 4/27/00 Quality

• Documentation of variation risks
• Several common industry methods
  – IPPD data sheets
  – Tailored databases
  – Keys on drawings
• Weakness
  – No common approach to documentation
  – No commercial systems
  – Every team invents a new system

Summary

IPPD 4/27/00 Quality

• Most companies address variation
  – late in the design process
  – depend on SPC/inspection rather than design changes
  – prioritize efforts based on qualitative assessments
• Barriers
  – Lack of good models usable in the early stages of design
  – Lack of good documentation systems
  – Lack of good process capability databases