Lecture 21:
Variation Risk Management

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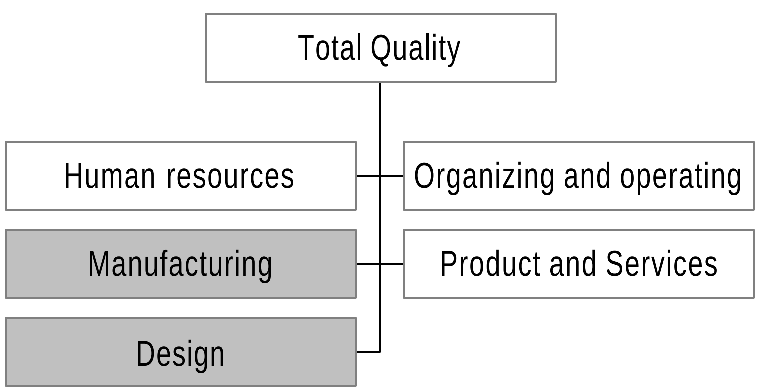
Quality Types



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What is variation?

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- 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

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Nominal vs. Variation

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- 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

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Complex Product

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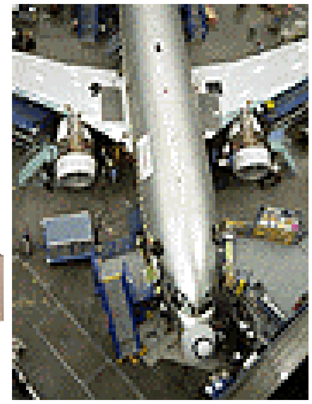

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Why is this an interesting problem?

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There are thousands of articles on variation and robust design

but….

Companies continue to struggle with variation and its effects

why?

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Didn't Taguchi solved this problem already?

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- 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

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What problems have not been solved

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- 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

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Source of Complexity

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

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Complexity
Methods of Managing Data

Key characteristics:

The set of small set of product features whose variation will create significant loss

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Key Characteristics Flowdown

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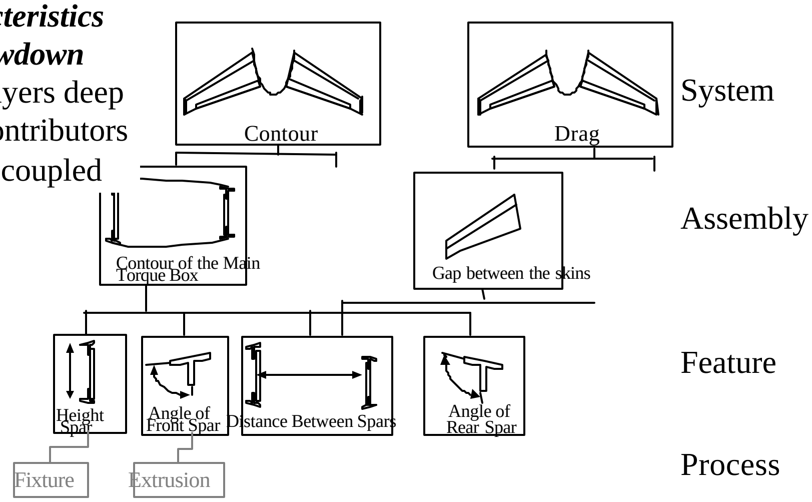
Complexity · Prioritization ·Data Sources

Characteristics of flowdown

- Many layers deep
- Many contributors
- Cross coupled



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Example from a medical product

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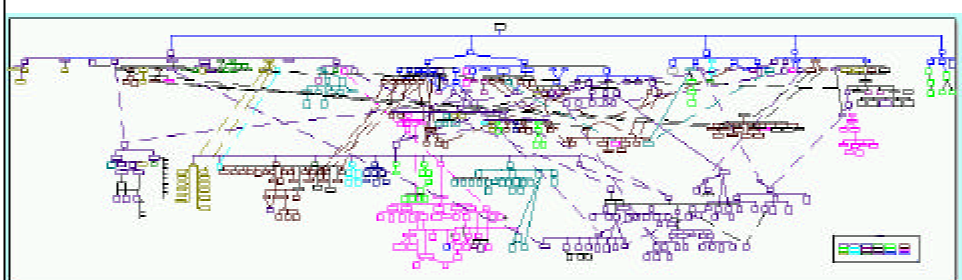
Complexity · Prioritization ·Data Sources



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Mathematical Model

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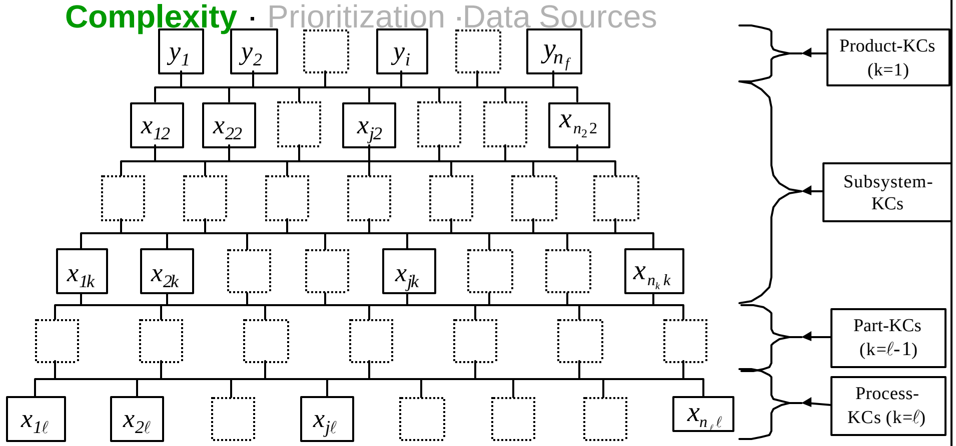
Complexity · Prioritization ·Data Sources



$$x_{ij} = f\left(x_{1(i+1)}, x_{2(i+1)}, \ldots, x_{n(i+1)}\right)$$

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Variation Model

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Complexity · Prioritization ·Data Sources

$$y_i = f(x_1, x_2, \ldots, x_n)$$

$$\Delta y_i = \frac{\partial y_i}{\partial x_1}\Delta x_1 + \frac{\partial y_i}{\partial x_2}\Delta x_2 + \ldots + \frac{\partial y_i}{\partial x_n}\Delta x_n$$

$$s_i = \sqrt{\left(\frac{\partial y_i}{\partial x_1} s_1\right)^2 + \left(\frac{\partial y_i}{\partial x_2} s_2\right)^2 + \ldots + \left(\frac{\partial y_i}{\partial x_n} s_n\right)^2}$$

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

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Matrix Representation

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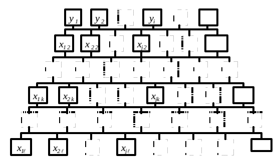
Complexity · Prioritization ·Data Sources

$$\ddot{\mathbf{a}}_{\mathbf{K}} = \begin{bmatrix} \frac{\partial x_{1k}}{\partial x_{1(k+1)}} & \frac{\partial x_{1k}}{\partial x_{2(k+1)}} & \cdots & \frac{\partial x_{1k}}{\partial x_{n_{k+1}(k+1)}} \\ \frac{\partial x_{2k}}{\partial x_{1(k+1)}} & \frac{\partial x_{2k}}{\partial x_{2(k+1)}} & \cdots & \frac{\partial x_{2k}}{\partial x_{n_{k+1}(k+1)}} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial x_{n_k k}}{\partial x_{1(k+1)}} & \frac{\partial x_{n_k k}}{\partial x_{2(k+1)}} & \cdots & \frac{\partial x_{n_k k}}{\partial x_{n_{k+1}(k+1)}} \end{bmatrix} \qquad \hat{\mathbf{o}}_{\mathbf{K}} = \begin{bmatrix} \left(\frac{\partial x_{1k}}{\partial x_{1(k+1)}}\right)^2 & \left(\frac{\partial x_{1k}}{\partial x_{2(k+1)}}\right)^2 & \cdots & \left(\frac{\partial x_{1k}}{\partial x_{n_{k+1}(k+1)}}\right)^2 \\ \left(\frac{\partial x_{2k}}{\partial x_{1(k+1)}}\right)^2 & \left(\frac{\partial x_{2k}}{\partial x_{2(k+1)}}\right)^2 & \cdots & \left(\frac{\partial x_{2k}}{\partial x_{n_{k+1}(k+1)}}\right)^2 \\ \vdots & \vdots & \vdots & \vdots \\ \left(\frac{\partial x_{n_k k}}{\partial x_{1(k+1)}}\right)^2 & \left(\frac{\partial x_{n_k k}}{\partial x_{2(k+1)}}\right)^2 & \cdots & \left(\frac{\partial x_{n_k k}}{\partial x_{n_{k+1}(k+1)}}\right)^2 \end{bmatrix}$$

$$\mathbf{D} = \ddot{\mathbf{a}}_1 \ddot{\mathbf{a}}_2 \ddot{\mathbf{a}}_3 \ldots \ddot{\mathbf{a}}_{(\ell-1)} \qquad \mathbf{T} = \hat{\mathbf{o}}_1 \hat{\mathbf{o}}_2 \hat{\mathbf{o}}_3 \ldots \hat{\mathbf{o}}_{(\ell-1)}$$

$$\mathbf{b_f} = \mathbf{D}\mathbf{b}_\ell \ \textit{and} \ \acute{\mathbf{o}}_{\mathbf{f}}^{\mathbf{2}} = \mathbf{T}\acute{\mathbf{o}}_\ell^2$$



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Debate

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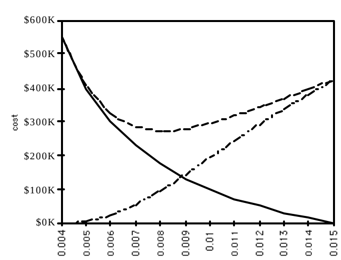
Complexity · **Prioritization** ·Data Sources

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**



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Problem definition

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Complexity · **Prioritization** ·Data Sources

"Quality is Free", but

Quality requires an investment of resources

and there are limited resources in a company.

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Why is prioritization non-trivial?

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Complexity · **Prioritization** ·Data Sources

- 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

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Data sources

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Complexity · Prioritization · **Data Sources**

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

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Process capability data

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Complexity · Prioritization · **Data Sources**

- 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

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Process Capability Databases

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Dimensional measurements taken from part → Dimensional target values noted → Process parameters entered into PCDB → Data values entered into PCDB

The Purpose of PCDBs

- Manufacturing improvement
  - Process control/diagnostics
  - Historical reference
  - Manufacturability analysis
- Design improvement
  - Part redesign
  - New part design
  - Manufacturability analysis

- PCDB creation
  - Manufacturing process results are measured, entered into PCDB
  - Process target values are documented
- Data may be organized by:
  - Material
  - Process
  - Feat...
  - Machine
  - Operat...

The Problem

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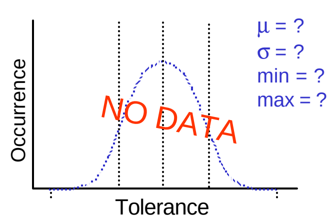
Missing Data in PCDBs Hinders Design

- Missing data is caused by
  - No data collection from process

    OR
  - New process: no precedent

Tolerance query for process X



- 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

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- 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.”

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Risk

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- Two parts to risk
  - Chance of failure (P)
  - Cost of failure (C)
- Mean cost of variation
  - C*P

		Chance of Failure	
		low	*high*
Cost of Failure	*low*	Minimal risk	?
	high	?	High Risk

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VRM Stages

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- 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

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Variation Sensitive Customer Requirements

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

Identification • Assessment • Mitigation

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Two methods of Assessment

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- 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

Identification • **Assessment** • Mitigation

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Assessment

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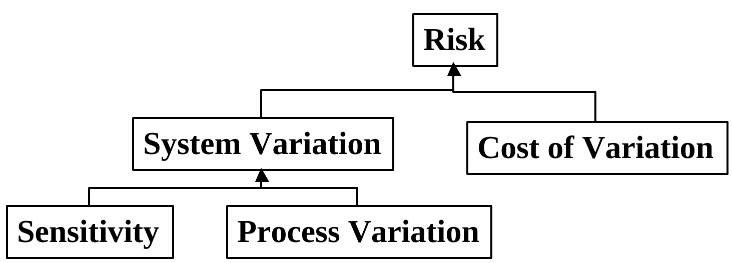
- Three parts to assessment
  - Sensitivity to variation
  - Process variation
  - Cost of system variation



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Failure rate

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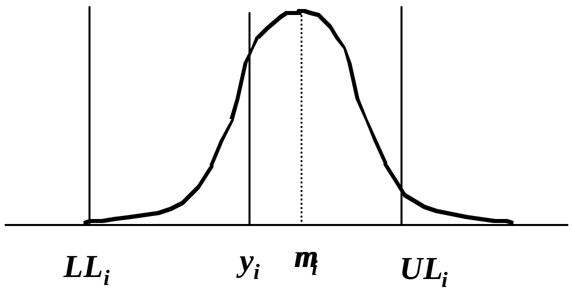

$$P_{failure} = 1 - \int_{LL}^{UL} pdf(y)$$

$$C_p = \frac{U - L}{6s}$$

$$C_{pk} = \min\left(\frac{m - LL}{3s}, \frac{UL - m}{3s}\right)$$

Identification • **Assessment** • Mitigation

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Relationship between Tolerance and s

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- For a Cpk = 1.33 (normal accept levels)

$$1.33 = \frac{UL - LL}{6s}$$

$$UL - LL = 8s$$

Identification • **Assessment** • Mitigation

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Cost of Variation: Taguchi Loss function

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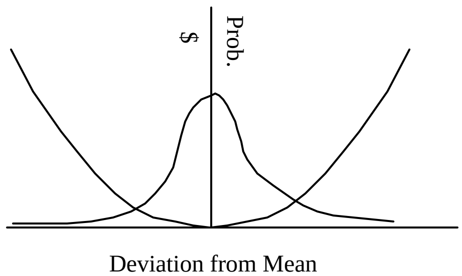

$$L = k(y - m)^2$$

$$k = \frac{\text{Cost of a defective product}}{(\text{Tolerance})^2}$$

$$k = \frac{A}{\Delta^2}$$

$$\sigma^2 = \text{mean value of } (y - m)^2$$

$$L_{mean} = k(b^2 + \sigma^2)$$

Identification • **Assessment** • Mitigation

Variation risk mitigation strategies

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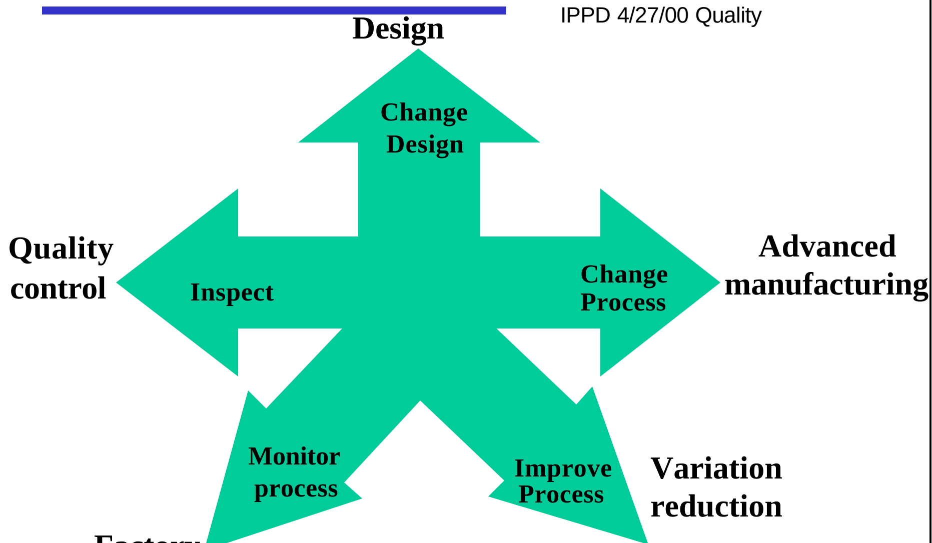

Identification • Assessment • **Mitigation**

Mitigation during design

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- 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

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- 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

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	Yield Improvement	*Recurring Costs*	*Non-recurring Costs*	*Strategic Impact*
Design Change	High	None - Low	High-Medium	High
Process Change	High-Medium	Medium - Low	High - Medium	High
Variation reduction	Medium	Low	Medium	Medium
Process Monitoring	Medium-low	Medium - Low	Low	Medium
Inspection	Low	Low	Low	Low

Identification • Assessment • **Mitigation**

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How to select

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

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Documentation system

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- 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

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Summary

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- 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

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