Total Quality Management and Six Sigma

Post Graduate Program 2014-15

Session 7-8

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Recap

- Statistical process control
  - Manufacturing and service sector applications
  - Implementation challenges
  - Advanced control charts for phase 2 implementation
- Six Sigma
  - DMIAC Approach at Academic Medical Hospital

Agenda

- Samsung case
  - Analysing qualitative data
- Design of Experiments
- Design for Six Sigma
  - QFD
  - FMEA

Case Questions

- Create an affinity diagram for the complaints provided in Exhibit 1.
- Come up with as many categories as you like
  - But beyond 15 would be way too many!
  - Some complaints could fit into multiple categories. Not an issue!
- What items need immediate attention? Which of them need attention in the near term?
- What other insights(if any) can you offer?

Samsung Electronics case

- Affinity Diagrams
- Pareto charts

Erasers in the space experiment

- Collect your material
- Prepare a catapulting device
- Launch away!!!

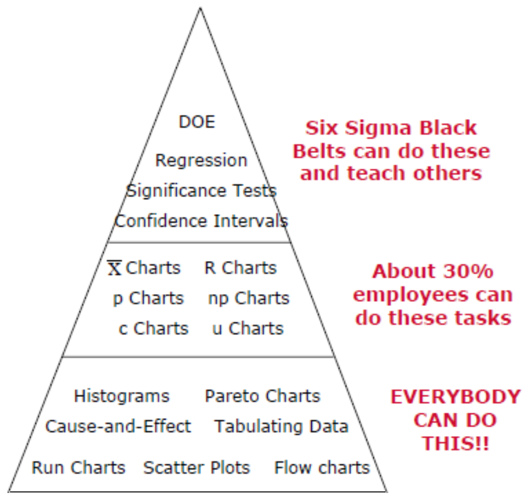
Structural Elements

- Response: Launch distance
- Inputs
  - With/without cover
  - Slant used

Results

- Confounding & Randomization
  - Practice makes man perfect
- How to judge?
  - The impact of incline!
- Protocol
  - Were you using the same person!
- Blocking
  - Should I have designed it differently!
- Factorial crossing and interaction

Statistical Techniques in quality



Strategy of Experimentation

- **"Best-guess" experiments**
  - Used a lot
  - More successful than you might suspect, but there are disadvantages…
- **One-factor-at-a-time (OFAT) experiments**
  - Sometimes associated with the "scientific" or "engineering" method
  - Devastated by interaction, also very inefficient
- **Statistically designed experiments**
  - Based on Fisher's factorial concept

Terminology

- Response variable
  - Measured output value
    - E.g. total execution time
- Factors
  - Input variables that can be changed
    - E.g. cache size, clock rate, bytes transmitted
- Levels
  - Specific values of factors (inputs)
    - Continuous (~bytes) or discrete (type of system)

Example: Improving Golf Score by DOE*

- In golf, the objective is to sink a ball in each of 18 holes using the fewest strokes of the driver
- How could someone who likes to play golf (but doesn't like to practice) lower his golf score? Some influential factors may be:

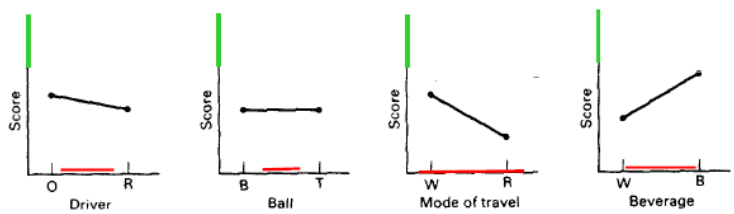
  (1) The type of driver used (oversized or regular).

  (2) The type of ball used (balata or three-piece).

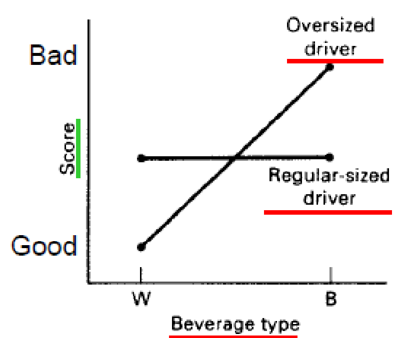
  (3) Walking/carrying the golf clubs or riding in a cart.

  (4) Drinking water or beer while playing.

- **One-factor-at-a-time approach**: Select a starting point or baseline set of levels for each factor, then successively vary each factor over a range with the other factors held constant at the baseline level.



Potential Interactions



Factorial Designs

- In a factorial experiment, **all possible combinations** of factor levels are tested
- The golf experiment:
  - Type of driver
  - Type of ball
  - Walking vs. riding
  - Type of beverage
  - Time of round
  - Weather
  - Type of golf spike
  - Etc, etc, etc…

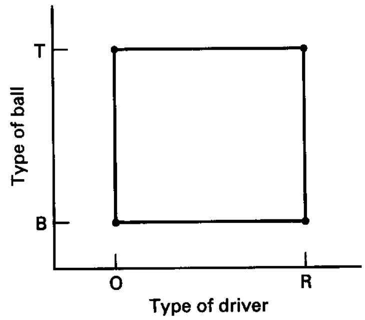


Figure 1-4 A two-factor factorial experiment involving type of driver and type of ball.

Factorial Design

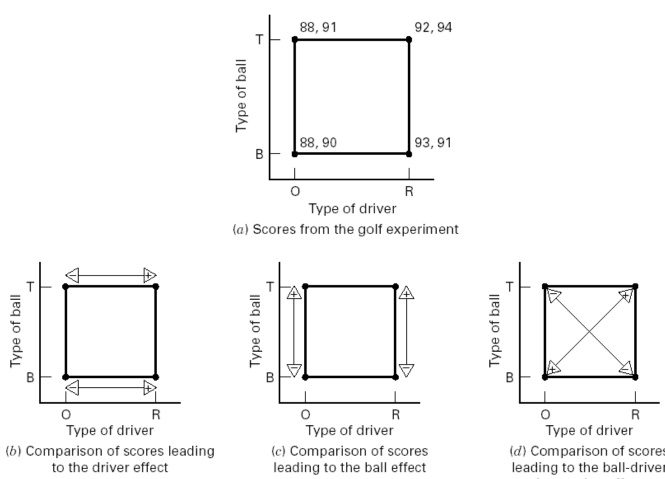


Figure 1-5 Scores from the golf experiment in Figure 1-4 and calculation of the factor effects.

Factorial Designs with Several Factors

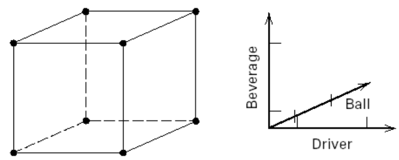


Figure 1-6 A three-factor factorial experiment involving type of driver, type of ball, and type of beverage.

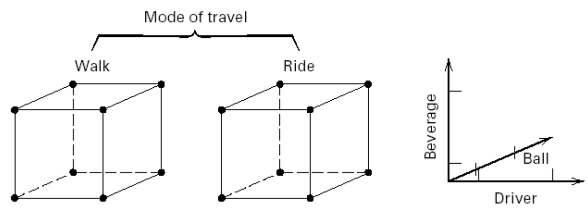


Figure 1-7 A four-factor factorial experiment involving type of driver, type of ball, type of beverage, and mode of travel.

Factorial Designs with Several Factors A Fractional Factorial

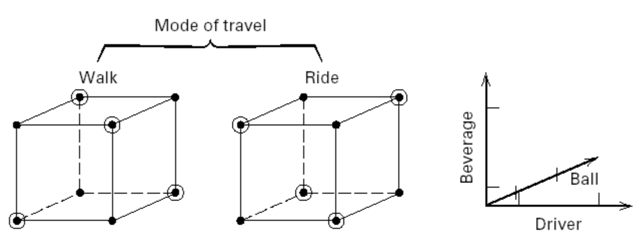


Figure 1-8 A four-factor fractional factorial experiment involving type of driver, type of ball, type of beverage, and mode of travel.

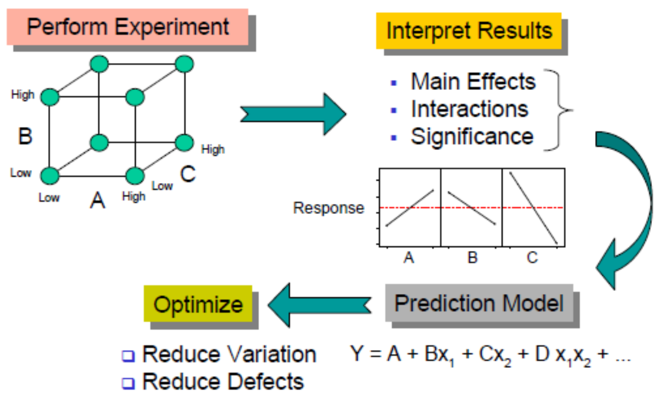
Planning, Conducting & Analyzing an Experiment

1. Recognition of & statement of problem
2. Choice of factors, levels, and ranges
3. Selection of the response variable(s)
4. Choice of design
5. Conducting the experiment
6. Statistical analysis
7. Drawing conclusions, recommendations

Why DOE?

- Control Charts: Online process control, passive process
- DOE: Offline process control, active process
- Based on the process view
  - Multiple factors impact the output
  - One factor at a time

The DOE process



Recall: One-Factor ANOVA

- Separates total variation observed in a set of measurements into:
  1. Variation within one system
     - Due to random measurement errors
  2. Variation between systems
     - Due to real differences + random error
- Is variation(2) statistically > variation(1)?
- *One-factor experimental design*

ANOVA Summary

Variation	Alternativ es	Error	Total
Sum of squares	SSA	SSE	SST
Deg freedom	$k-1$	$k(n-1)$	$kn-1$
Mean square	$s_a^2 = SSA/(k-1)$	$s_e^2 = SSE/[k(n-1)]$	
Computed F	s_a^2/s_e^2		
Tabulated F	$F_{[1-\alpha;(k-1),k(n-1)]}$		

Generalized *Design of Experiments*

- Goals
  - Isolate effects of each input variable.
  - Determine effects of interactions.
  - Determine magnitude of experimental error
  - Obtain maximum information for given effort
- Basic idea
  - Expand 1-factor ANOVA to *m* factors

Terminology

- Replication
  - Completely re-run experiment with same input levels
  - Used to determine impact of measurement error
- Interaction
  - *Effect* of one input factor depends on *level* of another input factor

Two-factor Experiments

- Two factors (inputs)
  - A, B
- Separate total variation in output values into:
  - Effect due to A
  - Effect due to B
  - Effect due to interaction of A and B (AB)
  - Experimental error

Example – User Response Time

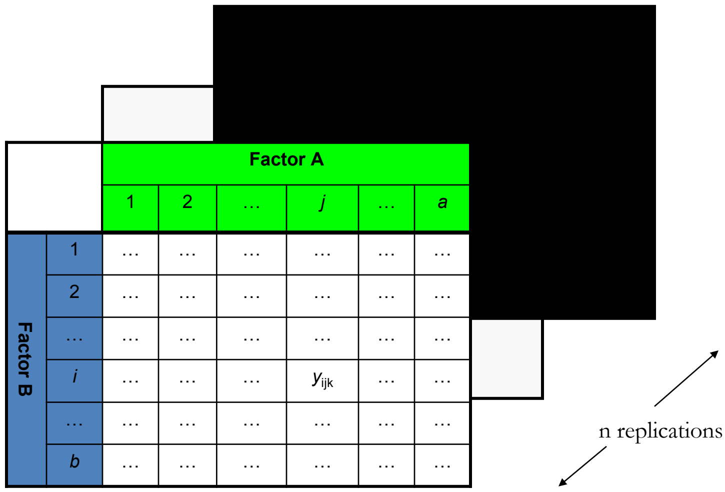
- A = degree of multiprogramming
- B = memory size
- AB = interaction of memory size and degree of multiprogramming

	B (Mbytes)		
A	32	64	128
1	0.25	0.21	0.15
2	0.52	0.45	0.36
3	0.81	0.66	0.50
4	1.50	1.45	0.70

Two-factor ANOVA

- Factor A – *a* input levels
- Factor B – *b* input levels
- *n* measurements for each input combination
- *abn* total measurements

Two Factors, *n* Replications



Recall: One-factor ANOVA

- Each individual measurement is composition of
  - Overall mean
  - Effect of alternatives
  - Measurement errors

$$y_{ij} = \bar{y}_{..} + \alpha_i + e_{ij}$$

$$\bar{y}_{..} = \text{overall mean}$$

$$\alpha_i = \text{effect due to A}$$

$$e_{ij} = \text{measurement error}$$

Two-factor ANOVA

- Each individual measurement is composition of
  - Overall mean
  - Effects
  - Interactions
  - Measurement errors

$$y_{ijk} = \bar{y}_{...} + \alpha_i + \beta_j + \gamma_{ij} + e_{ijk}$$

$\bar{y}_{...}$ = overall mean

α_i = effect due to A

β_j = effect due to B

γ_{ij} = effect due to interactio n of A and B

e_{ijk} = measurement error

Sum-of-Squares

- As before, use sum-of-squares identity

SST = SSA + SSB + SSAB + SSE

- Degrees of freedom
  - *df*(SSA) = $a - 1$
  - *df*(SSB) = $b - 1$
  - *df*(SSAB) = $(a - 1)(b - 1)$
  - *df*(SSE) = $ab(n - 1)$
  - *df*(SST) = $abn - 1$

Two-Factor ANOVA

	A	B	AB	Error
Sum of squares	SSA	SSB	$SSAB$	SSE
Deg freedom	$a-1$	$b-1$	$(a-1)(b-1)$	$ab(n-1)$
Mean square	$s_a^2 = SSA/(a-1)$	$s_b^2 = SSB/(b-1)$	$s_{ab}^2 = SSAB/[(a-1)(b-1)]$	$s_e^2 = SSE/[ab(n-1)]$
Computed F	$F_a = s_a^2/s_e^2$	$F_b = s_b^2/s_e^2$	$F_{ab} = s_{ab}^2/s_e^2$	
Tabulated F	$F_{[1-\alpha;(a-1),ab(n-1)]}$	$F_{[1-\alpha;(b-1),ab(n-1)]}$	$F_{[1-\alpha;(a-1)(b-1),ab(n-1)]}$	

Need for Replications

- If n=1
  - Only one measurement of each configuration
- Can then be shown that
  - SSAB = SST – SSA – SSB
- Since
  - SSE = SST – SSA – SSB – SSAB
- We have
  - SSE = 0

Need for Replications

- Thus, when n=1
  - SSE = 0
  - $\rightarrow$ No information about measurement errors
- Cannot separate effect due to interactions from measurement noise
- Must *replicate* each experiment at least twice

Example

- Output = user response time (seconds)
- Want to separate effects due to
  - A = degree of multiprogramming
  - B = memory size
  - AB = interaction
  - Error
- Need replications to separate error

	B (Mbytes)		
A	32	64	128
1	0.25	0.21	0.15
2	0.52	0.45	0.36
3	0.81	0.66	0.50
4	1.50	1.45	0.70

Example

A	B (Mbytes) 32	64	128
1	0.25	0.21	0.15
	0.28	0.19	0.11
2	0.52	0.45	0.36
	0.48	0.49	0.30
3	0.81	0.66	0.50
	0.76	0.59	0.61
4	1.50	1.45	0.70
	1.61	1.32	0.68

Example

	A	B	AB	Error
Sum of squares	3.3714	0.5152	0.4317	0.0293
Deg freedom	3	2	6	12
Mean square	1.1238	0.2576	0.0720	0.0024
Computed F	460.2	105.5	29.5	
Tabulated F	$F_{[0.95;3,12]} = 3.49$	$F_{[0.95;2,12]} = 3.89$	$F_{[0.95;6,12]} = 3.00$	

Conclusions From the Example

- 77.6% (SSA/SST) of all variation in response time due to degree of multiprogramming
- 11.8% (SSB/SST) due to memory size
- 9.9% (SSAB/SST) due to interaction
- 0.7% due to measurement error
- 95% confident that all effects and interactions are statistically significant

Advanced DOE

- Full Factorial design
- Fractional factorial design
- Orthogonal array designs
- Response surface designs
- Robust Design

DFSS Activity Categories

- **Concept development**
- **Design development**
- **Design optimization**
- **Design verification**

We'll look at each of these in detail

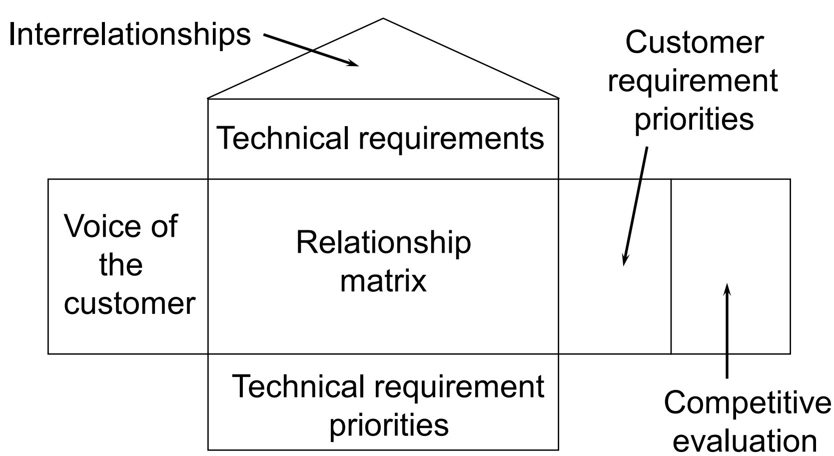
Concept Development

- Based on:
  - Customer requirements
  - Technological capabilities
  - Economic considerations
- Tools
  - Quality Function Deployment (QFD)
  - Concept engineering

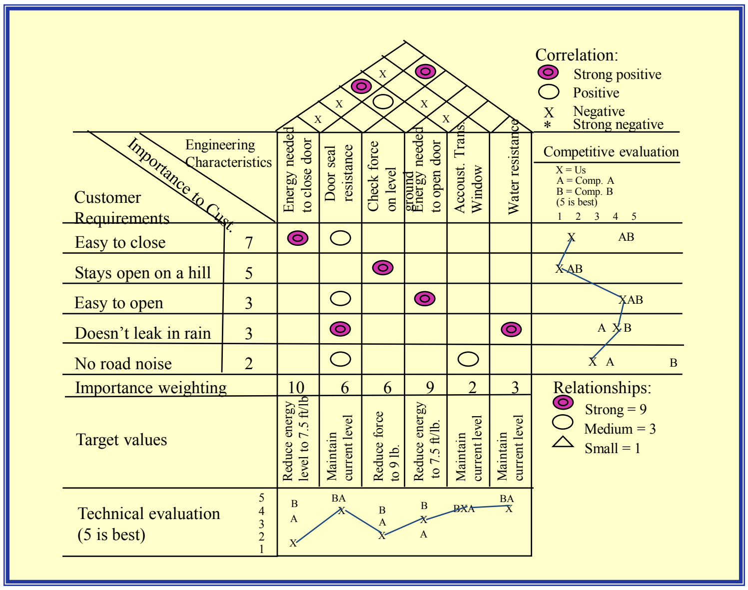
Quality Function Deployment (QFD)

- Structured approach for design
- Developed at Mitsubishi's Kobe shipyards
- "House of quality" – built on relationships
  - Customer requirements
  - Design requirements
  - Competitive assessment
  - Technical assessment
- 4 layers: product, part, process, production (quality plans)

House of Quality



QFD Example



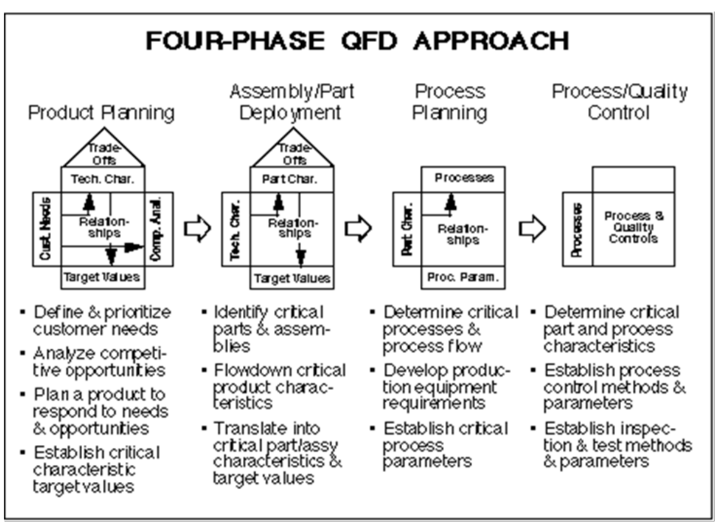
QFD Steps - 1

1. Identify/ prioritize customer requirements
2. Determine technical requirements
3. Relate customer requirements to technical requirements
4. Compare ability to meet requirements against competitive products

QFD Steps - 2

5. Set targets for technical requirements and determine capability
6. Look for high opportunity requirements to satisfy customer
7. Continue QFD process to the next level.

QFD Levels



Class exercise

- Pizza delivery
- Gym
- Laundary Service

Design Development

- Product and process performance issues
- Focus on ability to meet requirements in operations
- Tools
  - Tolerance design and process capability
  - Design failure mode and effects analysis (DFEA)
  - Reliability prediction

Tolerance Design - 1

- Specification
  - Translation of customer requirements into design requirements
  - Consists of nominal value and tolerances
- Nominal value
  - Ideal dimension or target value for meeting customer requirement
- Tolerance
  - Allowable variation above and/or below nominal value
  - Recognizes natural variation (common causes)

Tolerance Design - 2

- Consider tradeoff between costs and performance
- Too tight tolerances = unnecessary cost
- Too loose tolerances = not meeting customer requirements
- End result: too loose or too tight is going to cost you money!

DFMEA

- Design failure and effects analysis (DFMEA)
- Identify all the ways failures can occur
- Estimate effects of the failures
- Recommend changes in design

Failure Mode and Effects Analysis

Analyst *J.A. White*

Product *2C Lamp*

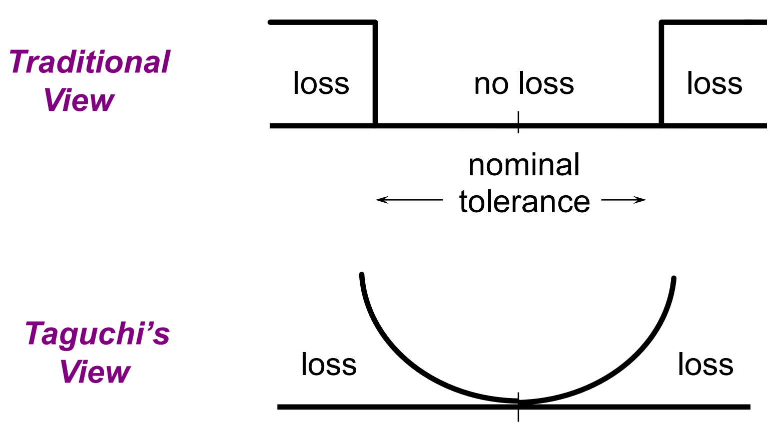
Date *10 Jan. 1995*

Component Name	Failure Mode	Cause of Failure	Effect of Failure on System	Correction of Problem	Comments
Plug part no. P-3	Loose wiring	Use vibration, handling	Will not conduct current; may generate heat	Molded plug and wire	Uncorrected, could cause fire
	Not a failure of plug per se	User contacts prongs when plugging or unplugging	May cause severe shock or death	Enlarged safety tip on molded plug	Children
Metal base and stem	Bent or nicked	Dropping, bumping, shipping	Degrades looks	Distress finish, improved packaging	Cosmetic
Lamp socket	Cracked	Excessive heat, bumping, forcing	May cause shock if contacts metal base and stem; may cause shock upon bulb replacement	Improve material used for socket	Dangerous
Wiring	Broken, frayed, from lamp to plug	Fatigue, heat, carelessness, childbite	Will not conduct current; may generate heat, blow breakers, or cause shock	Use of wire suitable for long life in extreme environment anticipated	Dangerous; warning on instructions
	Internal short circuit	Heat, brittle insulation	May cause electrical shock or render lamp useless	Use of wire suitable for long life in extreme environment anticipated	
	Internal wire broken	Socket slipping and twisting wires	May cause electrical shock or render lamp useless	Use of indent or notch to prevent socket from turning	

Design optimization

- Minimize variation in processes
- Seek robust design (Taguchi)
  - Insensitive to process variations or the use environment
- Tools
  - Taguchi loss function
  - Optimizing reliability

Loss Functions



Taguchi Loss Function Calculations

$$L(x) = k(x - T)^2$$

Example: *Specification = .500 ± .020*
Failure outside of the tolerance range costs $50 to repair. Thus, $50 = k(.020)^2$. Solving for k yields k = 125,000. The loss function is:

$$L(x) = 125{,}000(x - .500)^2$$

Expected loss = $k(\sigma^2 + D^2)$ where D is the deviation from the target.

Optimizing Reliability

- Standardization
- Redundancy
- Physics of failure

Design Verification

- Ensure that process capability meets the appropriate sigma level
- Meet specifications (AND customer requirements)
- Tools
  - Reliability testing
  - Process capability determination

Reliability Testing

- Life testing
- Accelerated life testing
- Environmental testing
- Vibration and shock testing
- Burn-in

Process Capability

- The range over which the natural variation of a process occurs as determined by the system of common causes
- Measured by the proportion of output that can be produced within design specifications

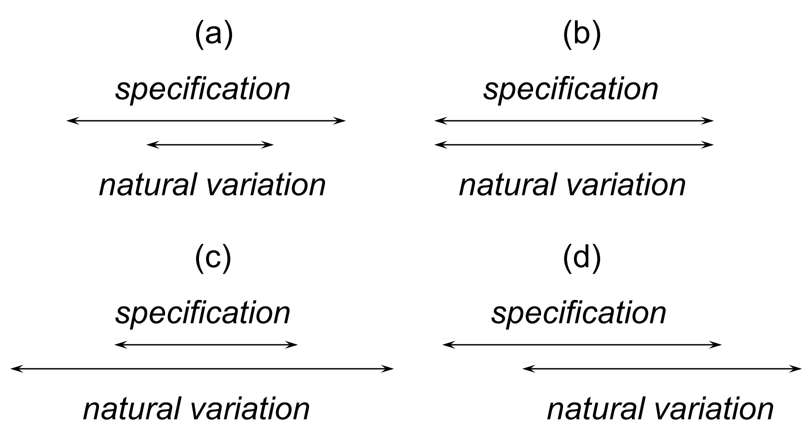
Types of Capability Studies

- **Peak performance study**
  - How a process performs under ideal conditions
- **Process characterization study**
  - How a process performs under actual operating conditions
- **Component variability study**
  - Relative contribution of different sources of variation (e.g., process factors, measurement system)

Process Capability Study

- Choose a representative machine or process
- Define the process conditions
- Select a representative operator
- Provide the right materials
- Specify the gauging or measurement method
- Record the measurements
- Construct a histogram and compute descriptive statistics: mean and standard deviation
- Compare results with specified tolerances

Process Capability



THANK YOU