



Concepts - Chapters 1 & 2

Key Terminology

Six Sigma: A data-driven management strategy

Quality: Fitness for use

Two aspects: a) Quality of design - high quality?

b) Quality of conformity - is the high quality consistent?

Characteristics or "dimensions of quality" that affect fitness for use as a product

(i) Performance performs required job (ii) Aesthetics product appearance

(iii) Reliability how often will it fail (iv) Features what the product does

(v) Durability lifetime → will it meet it (vi) Perceived Quality Reputation

(vii) Scrutability easy to repair (viii) Conformance to Standards

Producing a Service... list those dimensions of quality

(i) Responsiveness time to reply to requests

(ii) Professionalism knowledge, timeliness

(iii) Attentiveness caring, personalized attention

Hidden Factors: The part of the plant the customer doesn't see which affects w/bd quality

Quality Engineering: Consists of activities to ensure that ① that quality characteristics are at desired levels, and ② variability is at its minimum

→ **Quality Characteristics:** Important elements of a product/service to the customer

Variability: Describes or quantifies differences within a set of data or parts or c2qc

→ **Statistical Methods:** Analysis, interpretation, and presentation of numerical data

→ **Spec-Reading:** Desired measurements for quality characteristics This is your target value

Nonconformity: Failure to meet spec

Defect: Nonconforming that hurts usc

Variability

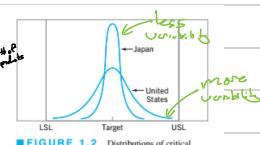
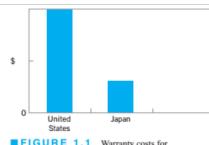
• Quality is inversely proportional to variability

◦ Variability will impact all quality dimensions

• Variability leads to greater cost & waste

example to right compares domestic vs. imported car quality

• Why variability leads to more cost for a company



Quality Costs

Prevention Costs	Internal Failure Costs
Quality planning and engineering	Scrap
New products review	Rework
Product/process design	Restest
Process control	Failure analysis
Burn-in 6-Sigma comes 20 or less	Downtime
Training & Process	Yield losses
Quality data acquisition and analysis	Downgrading (off-specing)
Appraisal Costs	External Failure Costs
Inspection and test of incoming material	Complaint adjustment
Product inspection and test	Returned product/material
Materials and services consumed	Warranty charges
Maintaining accuracy of test equipment	Liability costs
	Indirect costs

- Products found in plant outside of specifications result in higher costs and waste
- Prevention & Appraisal costs are cheaper costs and result in more consistent products and cheaper costs down the line

Internal Failure & External Failure costs > Prevention & appraisal costs!

Example: Cost of Variance ← Find manufacturing cost per good product

Illustrative Example: We are making 100 mechanical components per day where 75% of the parts conform to specifications, and the other 25% are non-conforming. Of the 25% of nonconforming, 60% can be reworked and the other 40% are scraped. Each part costs \$20 to manufacture and an additional \$4 to be reworked.

$$\frac{\text{cost}}{\text{good}} = \frac{\text{cost to make} (\# \text{ made total}) + \text{cost to rework} (\# \text{ reworked})}{\# \text{ of goods sold}}$$

$$= \frac{\$20(100) + \$4(100)(0.25 \cdot 0.60)}{70 + 15} = \$22.69$$

Now, the Benefit of Improvement ← Find manufacturing cost per good product

Illustrative Example: We improve the previous process such that now 95% of the parts conform to specifications, and the other 5% are non-conforming. Similar to before, of the 5% of nonconforming, 60% can be reworked and the other 40% are scraped. Each part costs \$20 to manufacture and an additional \$4 to be reworked.

$$\frac{\text{cost}}{\text{good}} = \frac{\$20(100) + \$4(100)(0.05)(0.60)}{95 + 3}$$

$$= \$20.53$$

Quality Engineering

Process: A system of inputs and outputs

Example: Doing a process

Example: A hospital is trying to increase the quality of drug administration. To do this, it is considering providing patients with bar-coded wristbands to help guide workers. Your team is charged with studying the effects of bar-coding by carefully watching 250 episodes in which drugs are given to patients without bar coding and 250 episodes with bar coding. Every time a drug is administered you will check the amount, if any, of discrepancy between what was supposed to be given and what was given.

Control Charts: A process monitoring technique which tracks averages in a quality characteristic with time or sample number

- **Control:** Where the characteristic should be; find abnormal sources of variation
- **Control Limit:** Defined by statistics. Alert the user to unusual variability
↳ Different than spec limits

Designed experiments: Discovers very variable factors have a significant influence on quality characteristics in a process

Six Sigma

Broader Definition: Statistical based, data driven, management approach and continuous quality improvement methodology for eliminating defects in a product, process, or service

↳ Reduces variability to a level where defects are unlikely

Three Elements of Six Sigma

- (i) **Quality Planning:** Listening to the voice of your customer
- (ii) **Quality Assurance:** Establishing a system to prevent quality issues from arising
- (iii) **Quality Control & Improvement:** A set of specific steps and tools to ensure products meet requirements and are continuously improved

Name Meaning: Refers to the quality level target such that sigma (σ , or variance σ^2) should be small enough so that 6σ is within the specification limits

Sigma Quality Level: The Probability that product/service is non-defective

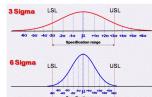
Why is Six Sigma Selected?

Suppose 100 parts: 3σ : $(.9973)^{100} = .7631$ is probability non-defective $\rightarrow 24\%$ defects
 6σ : $(.9999998)^{100} = .99999998$ non-defective $\rightarrow \sim .000002\%$ defects

Some companies use other multiples of σ , depending on what required by company/customers

Example of Six Sigma (will be on HW)

Illustrative Example: Let's say you are making a part that has a radius of 10 mm. Specification limits are between 9 (LSL) and 11 (USL) mm. Before you applied quality improvement, the standard deviation (sigma - a measure of variability) was 1 mm, and after you applied improvements, the standard deviation (sigma) decreased to 0.1. Is the new process 6 sigma quality?



$$\frac{|USL - LSL|}{\sigma \text{ (standard deviation)}} = \frac{|10mm - 10mm|}{1mm} = 1 \quad \text{For old 1\sigma level!}$$

$$= \frac{|10mm - 10mm|}{0.1mm} = 10 \quad \text{For new 10\sigma level!}$$

Lean Manufacturing

Def: Another management philosophy aimed at eliminating waste (e.g., time and materials)

Process Cycle Efficiency (PCE): $(\text{Value added time}) / (\text{Process time})$

$\hookrightarrow \text{Value added time} = \text{time spent making the product more valuable}$

(Number of units)

Process Cycle Time (PCT): $(\text{Number of items in progress}) / (\text{Completion rate})$ \hookleftarrow backlog issues as an example

Why is a slow process (low PCE or high PCT) an expensive process?

- Hidden Factory \rightarrow

- (i) Customers don't like waiting
- (ii) More handling = more personnel
- (iii) More opportunity for damage or loss
- (iv) Inventory has to be higher
- (v) More documentation

DMAIC Process

Def: A Project-based 5-step process and problem-solving procedure

\hookrightarrow Define \rightarrow Measure \rightarrow Analyze \rightarrow Improve \rightarrow Control

Toll gates: Where projects are reviewed to ensure on track

5 stages of DMAIC (will be on HW too)

(i) Define Stage

- Main Obj: Identify a great opportunity and verify that it represents a legitimate value opportunity or breakthrough

◦ Breakthrough: Major improvement to a process or product

◦ Value Opportunity: The financial opportunity at stake

- Tools used

◦ SIPOC diagram: High level map of process

\rightarrow Suppliers: Those who provide information, material or other items that are used in the process

\rightarrow Input: The actual information or material provided

\rightarrow Process: The set of steps required to do the work

\rightarrow Output: The product delivered to the customer \rightarrow Other dept. in same company

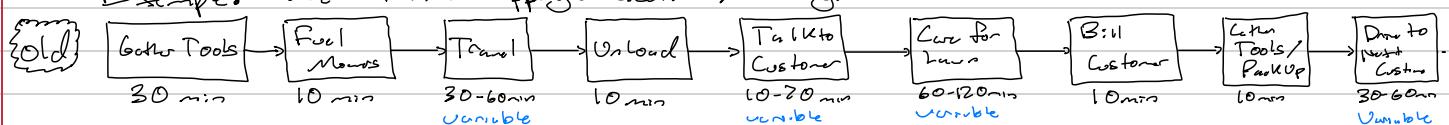
\rightarrow Customers: who buys the product (internal or external)

- Process Mapping: Involves creating flow diagrams for systems

◦ Value stream mapping: A variant of process mapping where engineers focus on steps which could be eliminated or simplified to reduce waste

- Value stream: The min amount of processing steps from raw material to customer

Example: Value Stream Mapping (Lawn Mowing)



Possible Improvements: Using customer's lawnmower, store SOP (home on truck), protocol, personnel/intense, eliminate/reduce customer interactions, optimize route (graph shortest distance)/logistics

- Pareto charting: Plots frequency (# of parts) or cost (time/money) against causes

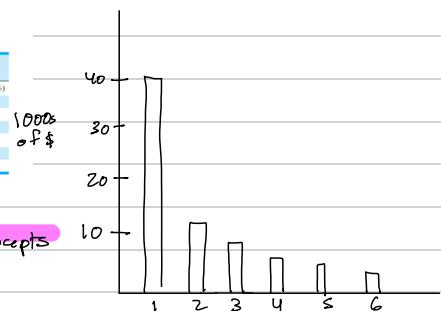
◦ Pareto Rule: 80% of the effects come from 20% of the causes

• Graph Pareto by Hand (Example)

Often in order from largest cost to smallest

Cost or % defects is on y-axis, category is on the x-axis

Monthly Quality-Costs Information for Assembly of Printed Circuit Boards		
Type of Defect	Percentage of Total Defects	Scrap and Rework Costs
1 Insufficient solder	42%	\$37,500.00 (52%)
2 Missing components	20	12,000.00
3 Defective components	15	8,000.00
4 Missing components	10	5,000.00
5 Cold solder joints	7	3,000.00
6 All other causes	5	4,600.00
Total:	100%	\$72,200.00



Can also do this with Lean concepts

Project Charter: Short document
with clear focus to product.

Example to right, but worse across companies

Business Case	Opportunity Statement																					
<ul style="list-style-type: none"> This project supports the business quality goals, namely (a) reduce customer resolution cycle time by x% and (b) improve customer satisfaction by y%. 	<ul style="list-style-type: none"> An opportunity exists to close the gap between our customer expectations and our actual performance by reducing the cycle time of the customer return process. 																					
Goal Statement	Project Scope																					
<ul style="list-style-type: none"> Reduce the overall response cycle time for returned product from our customers by x% year to year. 	<ul style="list-style-type: none"> Overall response cycle time is measured from the receipt of a product return to the time that either the customer has the product replaced or the customer is reimbursed. 																					
Project Plan	Team																					
<table border="1"> <tr> <th>Activity</th> <th>Start</th> <th>End</th> </tr> <tr> <td>Define</td> <td>6/04</td> <td>6/30</td> </tr> <tr> <td>Measure</td> <td>6/18</td> <td>7/06</td> </tr> <tr> <td>Analyze</td> <td>7/15</td> <td>8/09</td> </tr> <tr> <td>Improve</td> <td>8/15</td> <td>9/30</td> </tr> <tr> <td>Control</td> <td>9/15</td> <td>10/30</td> </tr> <tr> <td>Track Benefits</td> <td>11/01</td> <td></td> </tr> </table>	Activity	Start	End	Define	6/04	6/30	Measure	6/18	7/06	Analyze	7/15	8/09	Improve	8/15	9/30	Control	9/15	10/30	Track Benefits	11/01		<ul style="list-style-type: none"> Team Sponsor Team Leader Team Members
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(i:) Measure Stage

- Objectives:** Explain & understand the current state of the process
- Tools Used:** Quantify what the current process is performing at
- Measurement Capability:** Assess if the current measurement systems are adequate
- Measure Performance:** Check to understand variability
- Tools Used:** Histograms, bar charts, run charts, scatter diagrams

(ii:) Analyze Stage

- Objectives:** Use data to begin to determine cause and effect relationships and sources of variation

Common Causes of Variability: Internal Sources (noise)

Assignable Causes of Variability: External Sources

Tools Used

- Control Charts:** Used to separate the common and assignable causes of variation
- Hypothesis Testing & Confidence Intervals:** Used to determine if different conditions produce significant results
- Regression Analysis:** Allows models of the process to be built
- Failure Modes & Effects Analysis (FMEA):** A method for identifying and prioritizing sources of variability or defects in a process or product

↳ For each item, we determine:

(i) Likelihood something will go wrong | (not likely) - 10

(ii) Ability to detect the failure or defect | (likely) - 10

(iii) Severity | (not severe) - 10

Risk Priority #: (i) x (ii) x (iii)

Example

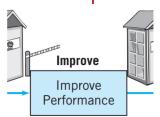
- Severity, 1 (not severe) - 10
- Probability of occurrence, 1 (not likely) - 10
- Probability of detection, 1 (likely) - 10

$$RPN = A \times B \times C$$



$RPN = RPK$ Priority Number

FAILURE MODE & EFFECTS ANALYSIS (FMEA)					Date: 1/1/2018
Process Name: Left Front Seat Belt Install Process Number: SBT 445 Revision: 1.3					
Failure Mode	A) Severity	B) Probability of Occurrence	C) Probability of Detection	Risk Preference Number (RPN)	
1) Select Wrong Color Seat Belt	5	4	3	60	Audited
2) Seat Belt Bolt Not Fully Tightened	9	2	8	144	
3) Trim Cover Clip Misaligned	2	3	4	24	



(i) Improve Stage

- Objectives
 - Generate and quantify potential solutions
 - Evaluate and select final solution
 - Verify and gain approval for final solution

• Objectives: Use creative thinking & info gathered previously to make specific suggestions that will lead to desired solution process. Confirmation is important

• Tools Used

- Mistake Proofing (example)
- Optimization
- Pilot Testing
- Conformance Experiments

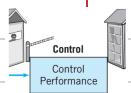
- Documentation
 - (i) Solution obtained
 - (ii) Alternatives considered
 - (iii) Confirmation tests
 - (iv) Risk Analysis

(ii) Control Stage

• Objectives: Complete all remaining work and hand off to improved process so gains in progress are institutionalized

• Tools Used

- Control Charts
- Transition Plans



- Objectives
 - Develop ongoing process management plans
 - Mistake-proof process characteristics
 - Develop out-of-control action plans

Quantifying Stats in Quality Characteristics - Chapter 3

Statistics

Sample Mean: Average Value

$$\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n} = \frac{\sum_{i=1}^n x_i}{n}$$

n is the number of data points in the sample
and $x_1, x_2, x_3, \dots, x_n$ are data points

For this data set: 12, 12, 15, 18, 21, 22, 22, 23, 25, 25, 26, 27, 28, 29, 30, 30, 31

$$\bar{x} = \frac{12+12+15+\dots+31}{17} = \frac{396}{17} = 23$$

Sample Variance:

{Example var: $\sum(x_i - \bar{x})^2$ }

$$s^2 = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}$$

Standard Deviation: $s = \sqrt{s^2}$

{Example var: $\sum(x_i - \bar{x})^2$ }

For this data set: 12, 12, 15, 18, 21, 22, 22, 23, 25, 25, 26, 27, 28, 29, 30, 30, 31

$$s^2 = \frac{(12-23)^2 + (12-23)^2 + \dots + (31-23)^2}{17-1} = 37$$

$$s = \sqrt{37} \approx 6.08$$

MINITAB: Stat > Basic Statistics > Display Descriptive Statistics > In Variables add data

Illustrative Example

Sample 1	Sample 2
$x_1 = 1$	$x_1 = 1$
$x_2 = 3$	$x_2 = 5$
$x_3 = 5$	$x_3 = 9$
$\bar{x} = 3$	$\bar{x} = 5$

Sample 3
$x_1 = 101$
$x_2 = 103$
$x_3 = 105$
$\bar{x} = 103$

Sample 1: $s = 2$

Sample 2: $s = 4$

Sample 3: $s = 2$

Tools to Describe Data Numerically and Visualize Variables

↳ Often easier to arrange sorted (lowest to highest) data

- **Percentiles:** Tells us how much of the data is below a certain point

12, 12, 15, 18, 21, 22, 22, 23, 25, 25, 26, 27, 28, 29, 30, 30, 31

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

↳ Values

↳ Rank (1-indexed)

- **Lower Quartile (Q_1 , or 25th perc.):** Value with rank = $(n+1)(\frac{1}{4})$

here: $\frac{17+1}{4} = \text{rank of } Q_1 \rightarrow \frac{18+1}{2} = 10.5$

- **Middle Quartile (Q_2 , or median, or 50th perc.):** Value with rank = $(n+1)(\frac{1}{2})$

here: $\frac{17+1}{2} = \text{rank of } Q_2 \rightarrow 10.5$

- **Upper Quartile (Q_3 , or 75th perc.):** Value with rank = $(n+1)(\frac{3}{4})$

here: $(17+1)(\frac{3}{4}) = \text{rank of } Q_3 \rightarrow 28.5$

- **Interquartile Range ($Q_3 - Q_1$):**

here: $Q_3 - Q_1 = 28.5 - 10.5 = 18$

- **Whisker Limits:** Max Limit = $Q_3 + 1.5(Q_3 - Q_1)$

Min Limit = $Q_1 - 1.5(Q_3 - Q_1)$

here: Max Limit = 43, Min Limit = 6

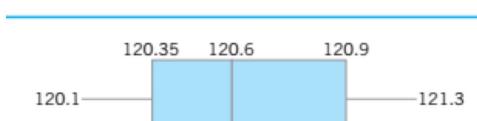
MINITAB: Stat > Basic Statistics > Display Descriptive Statistics > In Variables add data

- **Box Plot Features**

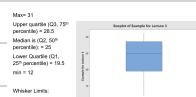
Displays 25th, 50th and 75th quartiles (ends and middle of the box)

- 25th and 75th are the ends of the box
- Median (50th percentile) is a single line through box
- The min and max of data (whiskers)
- Limits of whiskers (check) that the max and min do not go past (points that fall outside this can be outliers, represented as single data points and the new min or max is the next data point within the limit) – limit formula on next slide

TABLE 3.4 Hole Diameters (in mm) in Wing Leading Edge Ribs		
120.5	120.4	120.7
120.9	120.2	121.1
120.3	120.1	120.9
121.3	120.5	120.8



here:



Minitab: Graph > Boxplot > Simple > input data column into graph variables

Excel

- StDev is for sample data (use most often)
- StDevP is for entire population

• **Histograms:** Plots of frequencies of data occurring w/ the data sorted into bins/intervals

↳ **Bins:** The range that data will be sorted into $\# \text{ bins} = \text{ceil}(\sqrt{n}) \leftarrow \text{round up}$ bin size = $\frac{\text{max-min}}{\# \text{ bins}}$

i. Need to determine the bin range for continuous data

ii. Best if bins are the same size

iii. Rule of thumb: number of bins = square root of number of observations
(round up if not a whole number)

Note: for categorical data or discrete data, each category is its own bin

For this data set: 12, 12, 15, 18, 21, 22, 22, 23, 25, 25, 26, 27, 28, 29, 30, 30, 31

$$\text{# of bins} = \sqrt{17} = 4.1 \rightarrow 5$$

$$\text{bin size} = \frac{31-12}{5} = 3.8$$

Bin 1: $\text{min} + \text{bin size} \rightarrow 12 + 3.8 \rightarrow [12, 15.8)$ Inclusive below, Exclusive above

Bin 2: $\text{bin 1 end} + \text{bin size} \rightarrow 15.8 + 3.8 \rightarrow [15.8, 19.6)$

⋮

Can be fraction w/ round
but data must not overlap