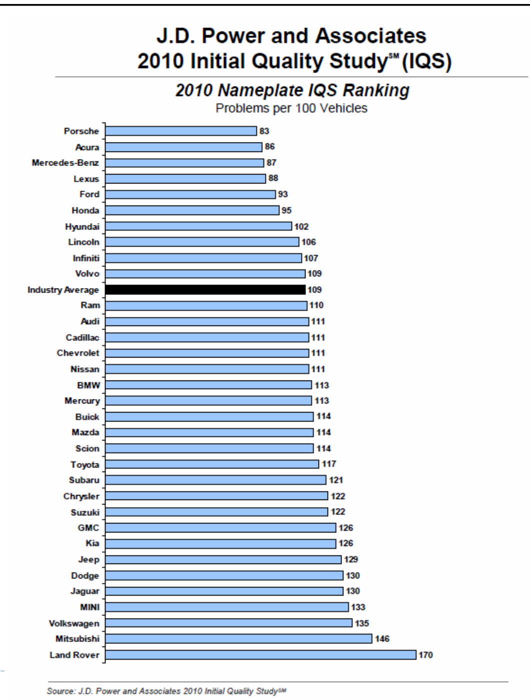
Introduction to Quality Management and Statistical Process Control

Outline for Quality Management Module

- Introduction
- Quality Control
  - Inspection vs. process control
  - Common Causes, Special Causes
  - Control Charts
- Process Capability
  - Performance limits, Specification limits
  - Capability index, Six-Sigma.

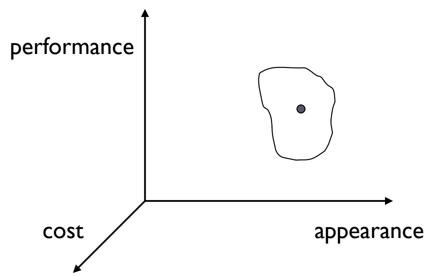
Quality Perceptions



Quality: Strategic and Operational issues

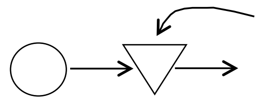
- Quality of design
  - product positioning (strategic)
- Quality of conformance
  - minimizing deviations from the target (operational)

JD Power Initial Quality Study:
"The study captures problems experienced by owners in two distinct categories– quality of design and defects and malfunctions".



Quality Management: Statistical Process Control

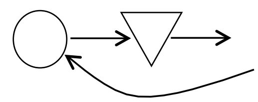
Quality Control



Inspection

- Objective: Sort out bad product before it reaches your customers.
- Procedure:
  - *Detect* deviations from quality standards
  - Reject/accept output

Detection



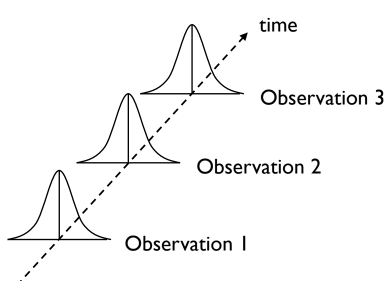
Process Control

- Objective: Control the quality of product by controlling/improving the process.
- Procedure:
  - *Track* quality metrics.
  - Determine if process is stable.
  - Find root causes and improve continuously.

Prevention

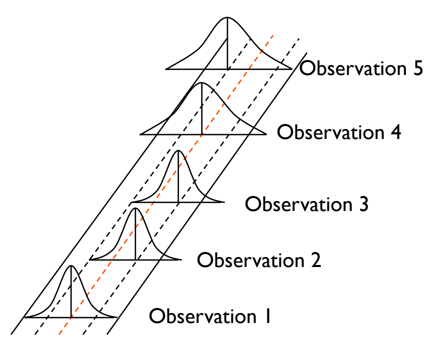
Different sources of variability

- Process in-control



  - Pattern is predictable.
  - Subject to *Common Causes* of variability

- Process out-of-control



  - Pattern changes over time.
  - Subject to *Special Causes* of variability.

Why do we care if it is Common or Special causes?

Common causes

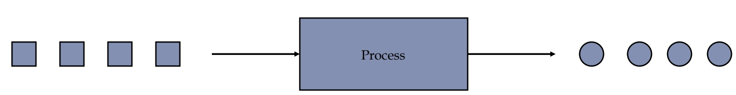
- Natural variation given by the design of the process
- Cannot be traced to a single factor (background noise)
- To reduce it, process needs to be changed.
- Examples
  - product design
  - work method

Special causes

- External forces which can sometimes be traced to specific factors.
- Can be corrected without fundamentally changing the process.
- Examples
  - design changes
  - Production start-up

Different actions need to be taken to improve quality depending on whether the process is in or out of control.

Monitoring Processes: Control Charts



- Objective:
  - Use data to determine if the process is in-control.
  - Detect variability due to *special causes*.
- Tool: Control Charts

- Attribute characteristics:
  - good or bad, defective or not, etc.

→ P-chart

- Measurable characteristics:
  - size, weight, strength, time, etc.

→ X-bar chart, R chart

Application: Customer Service in Retail

Construction of P-Chart

- Take m samples (e.g., $m=100$)
- The i^{th} sample contains n_i units, $i=1,\dots,m$
- D_i = number of defective units in the i^{th} sample
- Plot D_i/n_i, $i=1,\dots m$
- Calculate:

$$\bar{p} = \frac{\text{total number of defects}}{\text{total number of observations}}$$

Our best prediction of the probability of failure.

$$UCL_i = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}$$ Upper Control Limit

$$center\ line = \bar{p}$$

$$LCL_i = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}$$ Lower Control Limit

Falling outside control limits could be due to:

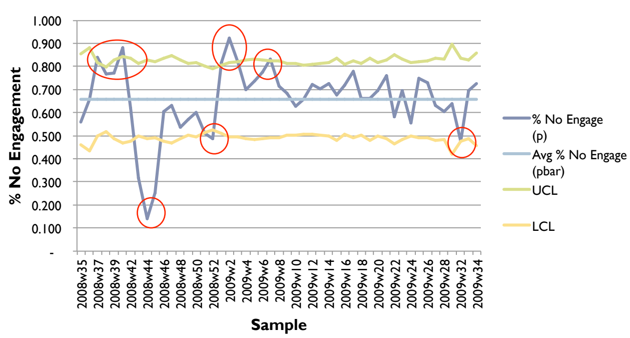
1. A rare even (3/1000) if process is in-control.
2. Process is out-of-control.

Assume process is out-of-control.

Application: Sales Engagement

Application to Customer Engagement Data

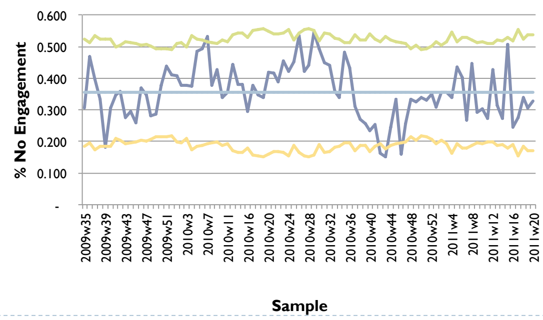
- Defects: customer is not engaged by sales associate.
- Select sample:
  - One store, optics area, group data by week.
  - Total of 52 weeks.



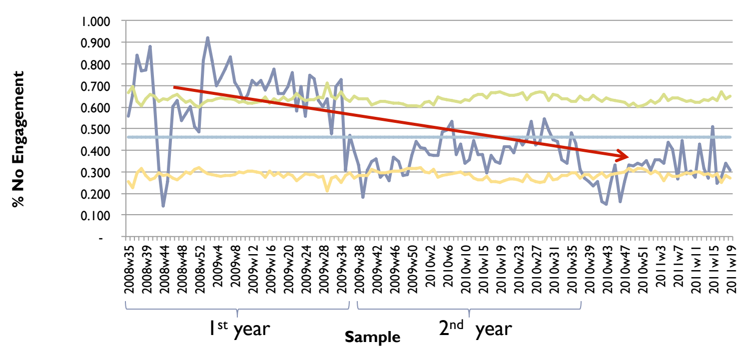
What did this retailer do?

- Weekly reports to store manager providing feedback on engagement performance.
- Financial incentives to store managers based on reports.
- Group discussions with sales associates to identify problems and solutions.

One year later…



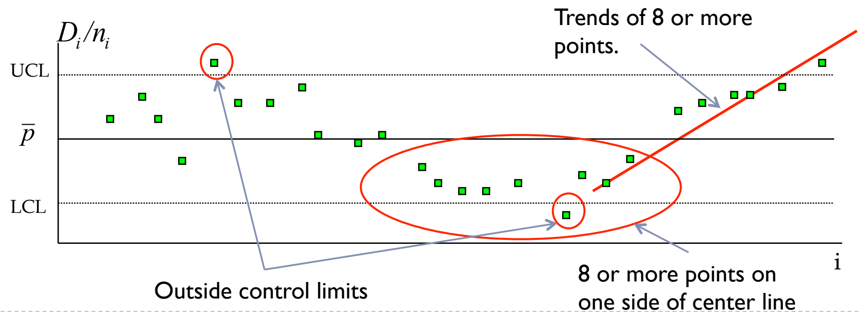
What if we pool all the data in one P-chart?



•In one year, engagement rate dropped from 65% to 34%.

Using Control Charts

- *Objective:* diagnose the state of the process (in or out of control).
- *Diagnosis:* look at observations or patterns which would be unlikely to be generated by an in-control process (e.g. 3/1000).



Choosing Sample groups

- Sample is chosen so that variation *between* and *within* samples capture different sources of variability.

Source of Variability	Type of variation in Control Charts
Common Causes	-*Within sample* variation.
Special Causes	-*Between sample* variation. -Captured by differences *across* groups.

- Sample size:
  - Variation within smaller samples is more likely to reflect pure common-cause variation.
  - Larger samples size makes it easier to detect when process is out-of-control (i.e. reduces the chances of mistakenly concluding the process is in-control when it is truly out-of-control).

Control Chart for Measurable Characteristics: X-bar chart

Construction of X-bar Chart

1) Take samples of data. Let n_j be the sample size of sample *j*.

$$\underbrace{(X_{11}X_{12}\cdots X_{1n_1})}_{\text{sample 1}}\cdots\underbrace{(X_{j1}X_{j2}\cdots X_{jn_j})}_{\text{sample j}}\cdots\underbrace{(X_{m1}X_{m2}\cdots X_{mn_m})}_{\text{sample m}}$$

2) Compute mean and standard deviation for each sample.

$$\overline{X}_j = \frac{X_{j1} + X_{j2} + \cdots + X_{jn_j}}{n_j} \quad \text{(sample mean)}$$

$$S_j^2 = \frac{(X_{j1} - \overline{X}_j)^2 + (X_{j2} - \overline{X}_j)^2 + \cdots + (X_{jn_j} - \overline{X}_j)^2}{n_j - 1} \quad \text{(sample variance)}$$

$$S_j = \sqrt{S_j^2} \quad \text{(sample std. dev.)}$$

3) Compute

$$\overline{\overline{X}} = \frac{\overline{X}_1 + \overline{X}_2 + \cdots + \overline{X}_m}{m}$$ (Overall average)

$$\overline{S} = \frac{S_1 + S_2 + \cdots + S_m}{m}$$ (Average sample std. dev.)

4) Estimate the process mean and standard deviation (when it is in-control).

unknowns	estimates
$\mu = \mathrm{E}[X]$	$\hat{\mu} = \overline{\overline{X}}$
$\sigma = \mathrm{std}[X]$	$\hat{\sigma} = \overline{S}$

5) **Draw X-bar Chart**: tracks the **mean** of the process output.

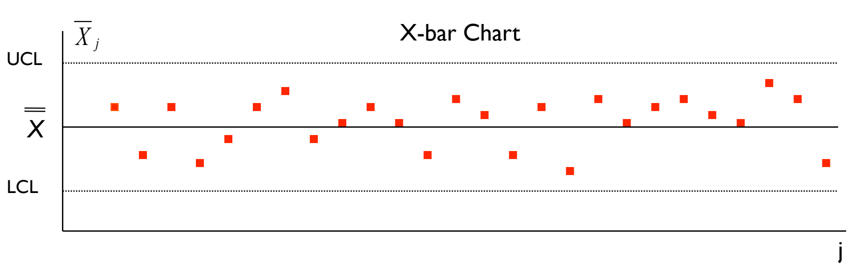
Plot $\overline{X}_j,\ j = 1,\ldots,m$ with

$$\mathrm{UCL} = \overline{\overline{X}} + \frac{3\overline{R}}{d_2\sqrt{n}}$$

$$\mathrm{Center\ Line} = \overline{\overline{X}}$$

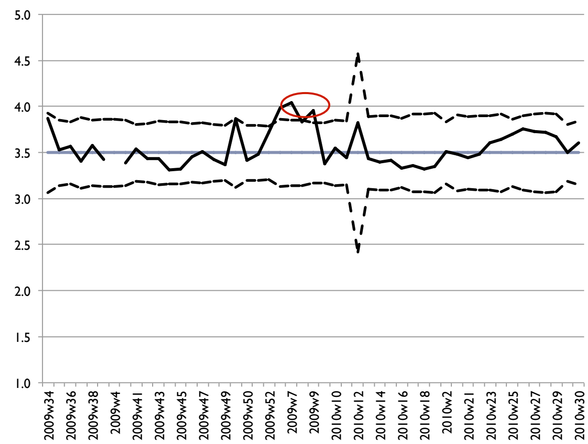
$$\mathrm{LCL} = \overline{\overline{X}} - \frac{3\overline{R}}{d_2\sqrt{n}}$$

Falling outside control limits is a rare event when the process is in-control. => We assume the process if out-of-control.



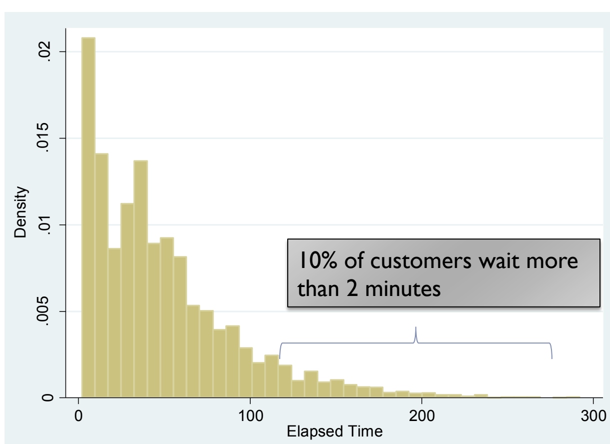
Customer Service Example

X-bar chart for the logarithm of **engagement time**.



It is in-control, but is it a "good" process?

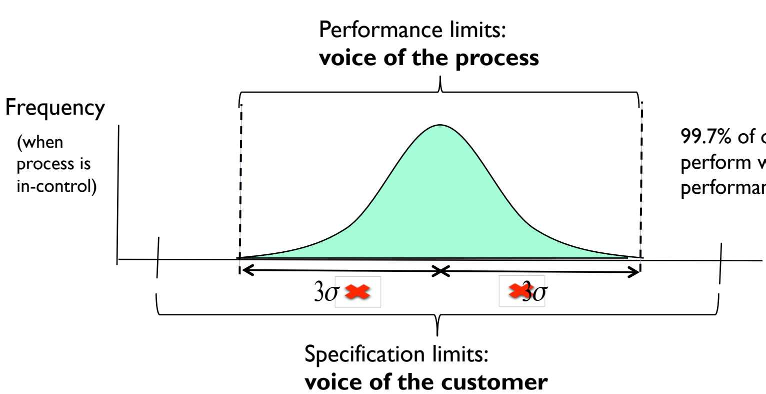
Histogram of engagement time



Quality Management: Process Capability

What about the customer?

- If the process is in control, then it will produce *statistically* predictable outputs.



Indicate chosen or desirable tolerances. They represent the "customer's" definition of quality and reflects "fitness for use."

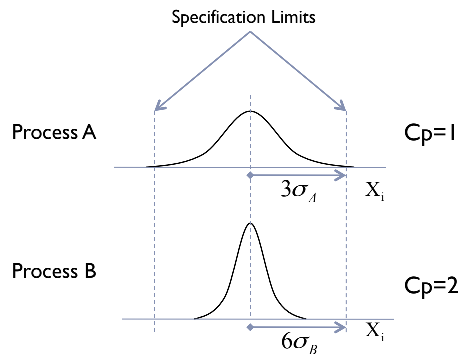
Process Capability Index (Cp)

$$C_p = \frac{\text{allowable process spread}}{\text{actual process spread}} = \frac{\text{upper spec limit - lower spec limit}}{6\sigma}$$

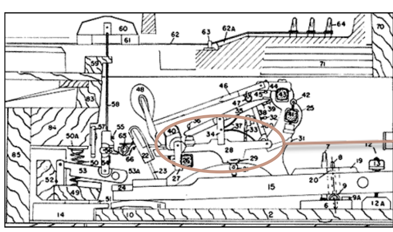
-Capable: Cp = 1

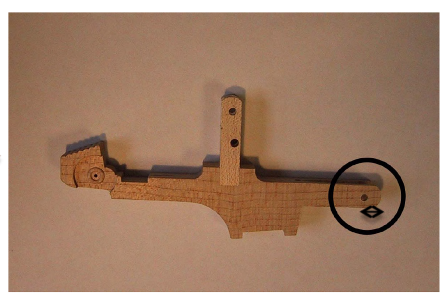
-Some companies set as target: Cp = 1.33

-Motorola's **Six Sigma** Quality: Cp = 2



Example – Steinway Piano Action Mechanism





Each piano key has an *action mechanism.*
Each action contains 58 parts.

Adapted from the case "Technology and Quality at Steinway & Sons", E. Johnson, J. Hall and D. Pyke, Tuck School of Business, Dartmouth.

Part #28
- Hole drilled through slotted shaft.
- Pin slides through hole to attach to other pieces.

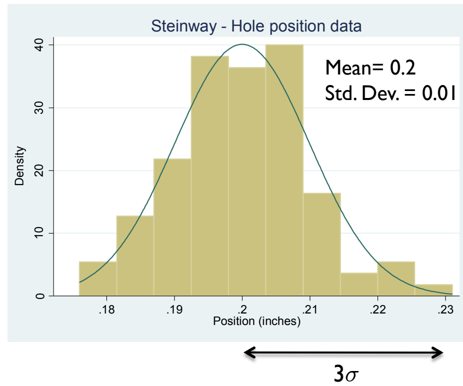
Engineering specifications:
0.200 inches from the end of shaft, plus or minus 0.015 inches.

Specification Limits →

…Example

100 items measured

Item #	Distance
1	0.208
2	0.200
…	…
99	0.202
100	0.197



$$C_p = \frac{2 \times 0.015}{6 \times 0.01} = 0.5$$

SPC- Takeaways

- Monitor the *process* to *prevent* defective output.
- Consistency in output= Process is in-control.
  - Measure common causes of variability.
  - Tools to detect special causes of variability.
  - Eliminate special causes by finding its root cause.
- In control process <u>is not</u> the same as high quality.
  - Specification limits are determined by the customer.
  - Process capability: ability of process to meet customer specifications.
  - Reduce variation caused by common causes to ensure output is within specifications.

Next Class…

- Preparation for Ritz Carlton case:
  - Work with your group.
  - Download data on Angel.
  - Focus on one defect category.
  - Think carefully on how you choose samples.
  - Read case preparation questions and bring case write-up to class.