3. Statistical Process Control

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SE 3730 / CS 5730 Lecture Notes
Outline

- About Deming and Statistical Process Control
- Statistical Process Control Tools
- The Red Bead Experiment
- Deming’s 14 Quality Principles
- The Deming Cycle for continuous process improvement and Software Life Cycles
Who is Deming?

- The W. Edwards Deming Institute
- The Deming Prize
Dr. W. Edwards Deming

- https://www.youtube.com/watch?v=GHvnIm9UEoQ
- https://www.youtube.com/watch?v=mKFGj8sK5R8
- https://www.youtube.com/watch?v=6WeTaLRb-Bs

1. Who is Deming?
2. What is your understanding of SPC?
3. What SPC methods were mentioned in the video?
4. What is Deming’s cycle?
5. What is the key to winning the Deming’s prize?
6. What conclusions can we get from the red bead experiment?
Software Process Management

- **Software Process:**
  - A structured set of activities required to develop a software system.

- Four responsibilities of software process management:
  - **Define** the process
  - **Measure** the process
  - **Control** the process
  - **Improve** the process
Statistical Process Control:

- process control using statistical methods
- monitor and control a process by analyzing variations.

Controlled process

- stable
- predictable results
- capability measurement

Continuous improvement
Two Sources of Process Variation

- **Chance** variation:
  - Inherent in process
  - Stable over time
  - **Common Cause** variation (Deming)

- **Assignable** variation
  - Uncontrolled
  - Unstable over time
  - Result of specific events outside the system
  - **Special Cause** variation (Deming)

Why Statistical Technique?

- We need to understand the current performance of a process.
  - Then we can determine if a process gets better or worse under different conditions.
  - Then we can statistically identify outliers and study what made them different from other instances.
    - We expect process outcomes to be normally distributed about the process mean (average).
    - Outliers are anomalies, either very good or very poor outcomes. We would not expect outcomes this good or bad just by chance.
    - Often we can learn more about a process by studying outliers than by studying normal outcomes.
Understand Your Data

- Organize and summarize your data
- Look for patterns, trends and relationships
  - Scatter diagrams
  - Run charts
  - Cause-effect diagrams
  - Histograms
  - Bar charts
  - Pareto charts
  - Control charts
Application Areas for Analytic Tools

Problem Identification
- Check sheet
- Brian storming

Problem Analysis
- Cause-effect diagram
- Run chart
- Bar charts
- Pareto chart
- Control chart
- Histogram
- Scatter diagram
- Process capability analysis
- Regression analysis
A plot of observed values that shows how one variable has behaved relative to another.

**Defects per KLOC vs. Levels of inheritance**
Look for correlations or relationships.

Often used as the first step in the search of cause-effect relationship.

- Does the size of the system determines the amount of effort put to the project?
- Does the length of training have anything to do with the # of defects one engineer injects?
- Are there any obvious trends in the data?

Limitation: only deal with two variables at a time.
Run Chart

A plot of individual values arranged in a time sequence.

Run Chart: Failures by time of day

- Failures per hour
- Time of day
Run Chart

- **Monitor the process**: what is the trend?

- Often trends become apparent in a run chart and can lead to an understanding of the cause.
  - Something is happening at 1:30am.

- Also used for tracking the improvements to determine whether an approach is successful or not.

- An average/mean line can be added to clarify movement of the data away from the average.

- Precursor to control chart: not every variation is important.
Cause-Effect Diagram (Fishbone)

A graphical display to list a set of possible factors that affect a process, problem or outcome.
Cause-Effect Diagram

- Often called *Ishikawa charts* or *fishbone charts*.
- Can be used for
  - Exploring the behavior of a process
  - Locate problems
  - Search for root causes
- When assembling CE diagrams, involve
  - People who actually work in the process
  - Experts in different parts of the process
  - *Brain storming sessions!*
- Three types:
  - Dispersion analysis type
  - Cause enumeration type
  - Production process classification type
Dispersion Analysis CE Diagram

- Constructed by repeatedly asking “Why does the dispersion/scatter occur?”
- **Pros**: Organize and relate factors that cause variability in products and other process outcomes.
- **Cons**: dependent on the views of people making it.

[Dispersion Analysis CE Diagram Image]
How to Draw a Dispersion Analysis CE Diagram

- **Step 1:** Write down the effect to be investigated and draw the 'backbone' arrow to it.
- **Step 2:** Identify all the broad areas in which the causes of the effect being investigated may lie.
- **Step 3:** Write all the detailed possible causes in each of the broad areas. Each cause identified should be fully explored for further more specific causes which, in turn, contribute to them.

Generic broad areas

- Methods
- Machine (equipment)
- Materials
- Measurement
- People
- Policy
- Procedures
- Environment
- ...

Cause Enumeration CE Diagram

- Constructed by listing all possible causes and then organizing them to show their relationships to the aspect of product/process quality.
- Principal categories: people, methods, materials/inputs, tools, etc.
- May end up with a similar CE diagram as dispersion analysis type, but are more free-form.
- **Pros**: less likely to overlook major causes.
- **Cons**: may be hard to relate small twigs to the end result hard to draw and interpret.

Production Process Classification CE Diagram

- Constructed by stepping mentally through the production process.
  - Process steps are displayed along the backbone in boxes;
  - Causes are depicted on lines that feed into either a box or backbone connections.
- **Pros**: easy to construct and understand.
- **Cons**: same causes may appear multiple times.

Exercise (CE Diagram)

- A large-scale online shopping system
- Server hosted at Platteville

1. Server maintenance
2. Requirement Engineer
3. Developer
4. Customer service
5. Project Manager
6. Facility Manager
7. E-Commerce Expert
Bar chart and histogram

Organize data based on frequency of occurrence.
Bar chart: categorical data
Histogram: continuous data

<table>
<thead>
<tr>
<th>Lifecycle Phase</th>
<th>Defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements Review</td>
<td>12</td>
</tr>
<tr>
<td>Design Review</td>
<td>6</td>
</tr>
<tr>
<td>Unit Testings</td>
<td>34</td>
</tr>
<tr>
<td>Integration Testing</td>
<td>15</td>
</tr>
<tr>
<td>Alpha Testing</td>
<td>8</td>
</tr>
<tr>
<td>Beta Testing</td>
<td>5</td>
</tr>
<tr>
<td>Post Deployment</td>
<td>4</td>
</tr>
</tbody>
</table>
Histogram

- Easy to compare distributions and see central tendencies and dispersions.
- Helpful trouble shooting aids.
- Useful for summarizing the performance of a process w.r.t. specification limits. → assess the process capability
Pareto Chart

Frequency counts in descending order.

<table>
<thead>
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<th>Lifecycle Phase</th>
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</thead>
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<td>Unit Test</td>
<td>34</td>
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<td>5</td>
</tr>
<tr>
<td>Post Deploy</td>
<td>4</td>
</tr>
</tbody>
</table>
Pareto analysis is a process for ranking causes, alternatives or outcomes to help determine which should be high-priority actions for improvement.

Separate the “vital few” from the “trivial many”.

Pareto charts can be used

- to analyze the frequency of causes/problems in a process;
- to analyze broad causes by looking at their specific components;
- at various stages to help select the next step;
- to figure out most important causes/problems;
- to create common view within a group.
Often we are more interested in the total cost of a certain problem.

Cost Weighted Pareto
Total cost to fix various defects types
Control Chart

- Also known as Shewhart charts or process-behavior charts
Types of Control Chart

- **X-bar chart**: average chart. Show the observed variation in center tendency.
- **R chart**: Show the observed dispersion in process performance across subgroups. Work well for sample size of 10 or less.
- **S chart**: standard deviation chart. Work better for sample size larger than 10.
- **XmR chart**: individuals and moving range chart
- **p chart**: proportion non-conformance.
- And more...
Controlled Process
Out-of-Control Process
Control Chart: How to Draw

- Time or Sequence Number
- Quality Statistic

Subgroup averages
Subgroup ranges
Moving averages
Moving ranges

CL: Centerline (CL)
CL + 3σ
CL - 3σ

Upper Control Limit (UCL)
Centerline (CL)
Lower Control Limit (LCL)

Traditional limits

Process average
Stability Detection Rules

**Test 1:** A single point falls outside the 3-sigma control limits.

**Test 2:** At least 2 out of 3 successive values fall on the same side of, and more than 2 sigma units away from the centerline.

**Test 3:** At least 4 out of 5 successive values fall on the same side of, and more than 1 sigma unit away from the centerline.

**Test 4:** At least 8 successive values fall on the same side of the centerline.
Stability Detection Rules

Test 4: 8 successive points on same side of centerline

Test 3: 4 out of 5 points in zone B

Test 2: 2 out of 3 points beyond zone B

Test 1: Single point outside zone C

3 sigma
2 sigma
1 sigma
X-bar and R charts: How-To

- X-bar and R charts can portray the process behavior when you can collect multiple measurements within a short period of time under basically the same condition.

1. Compute the average \( \bar{X} \) and range \( R \) for each subgroup of size \( n \), for each of the \( k \) subgroups:
   \[
   \bar{X}_k = \frac{X_1 + X_2 + \ldots + X_n}{n}
   \]
   \[
   R_k = |X_{MAX} - X_{MIN}|
   \]

2. Compute the grand average \( \overline{\bar{X}} \) by averaging each of the \( k \) subgroup averages:
   \[
   \overline{\bar{X}} = \frac{\bar{X}_1 + \bar{X}_2 + \ldots + \bar{X}_k}{k}
   \]

3. Compute the average range \( \overline{R} \) by averaging each of the \( k \) subgroup ranges:
   \[
   \overline{R} = \frac{R_1 + R_2 + \ldots + R_k}{k}
   \]
**X-bar and R charts: How-To**

**Average (X-bar) Chart Limits:**

\[
UCL_X = \bar{X} + A_2 \bar{R} = \text{grand average} + A_2 \text{ times average range}
\]

\[
CL_X = \bar{X} = \text{grand average}
\]

\[
LCL_X = \bar{X} - A_2 \bar{R} = \text{grand average} - A_2 \text{ times average range}
\]

**Range (R) Chart Limits:**

\[
UCL_R = D_4 \bar{R} = D_4 \text{ times average range}
\]

\[
CL_R = \bar{R} = \text{average range}
\]

\[
LCL_R = D_3 \bar{R} = D_3 \text{ times average range}
\]

\[
\sigma_X = \frac{A_2 \bar{R}}{3}
\]

**Table: Sample Size Values**

<table>
<thead>
<tr>
<th>n</th>
<th>d₂</th>
<th>A₂</th>
<th>D₃</th>
<th>D₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.128</td>
<td>1.880</td>
<td>—</td>
<td>3.268</td>
</tr>
<tr>
<td>3</td>
<td>1.693</td>
<td>1.023</td>
<td>—</td>
<td>2.574</td>
</tr>
<tr>
<td>4</td>
<td>2.059</td>
<td>0.729</td>
<td>—</td>
<td>2.282</td>
</tr>
<tr>
<td>5</td>
<td>2.326</td>
<td>0.577</td>
<td>—</td>
<td>2.114</td>
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<tr>
<td>6</td>
<td>2.534</td>
<td>0.483</td>
<td>—</td>
<td>2.004</td>
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<tr>
<td>7</td>
<td>2.704</td>
<td>0.719</td>
<td>0.076</td>
<td>1.924</td>
</tr>
<tr>
<td>8</td>
<td>2.847</td>
<td>0.373</td>
<td>0.136</td>
<td>1.864</td>
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<tr>
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<td>2.970</td>
<td>0.337</td>
<td>0.184</td>
<td>1.816</td>
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<tr>
<td>10</td>
<td>3.078</td>
<td>0.308</td>
<td>0.223</td>
<td>1.777</td>
</tr>
</tbody>
</table>

\(n\) is the sample size.
Mr. Smith is a software manager at XYZ company.

He is responsible for

- A follow-up release for an existing product
- Support service to users of that product:
  - Require 40 staff-hours per day
  - Everyone on the development team must be available to provide support service at any given time.
  - If the daily effort to support service requests exceeds the plan, it will hurt the release development schedule.

He has data from the past 16 weeks.

Does he need to change the support service procedure?
If the sample size is 1, how do we calculate sigma?

- We attribute the changes that occur between two successive values to the inherent variability in the process.

- **X**: individual values

- **mR**: moving range.
Stability Investigation Process

1. Select process
2. Identify product or process characteristics that describe process performance
3. Select the appropriate type of control chart
4. Measure process performance over a period of time
5. Use appropriate calculations based on measurement data to determine center lines and control limits for performance characteristics
6. Plot measurement data on control charts
7. Are all measured values within limits and distributed randomly around centerlines?
8. Process is stable; continue measuring
9. Process is not stable
10. Identify and remove assignable causes
Software differs from manufacturing in several aspects:

- lack of well-defined specifications based on customer requirements in terms of metrics.
- only design and development, no production.
- the assumption that data variation is from homogeneous sources is not met:
  - multiple common causes: tools, methods, types of software/module, skills, etc
  - the control limit calculated is often too wide.
- within one organization, multiple processes are often used and changes fast.

Use control chart in a relaxed manner in SE!
Pseudo-Control Chart of Test Defect Rate in an IBM project

- take several iterations: remove outliners and reconstruct chart
- used to decide priority for improvement.
Pseudo-Control Chart Example 2

From chapter 5.7, Metrics and Models in Software Quality Engineering By Stephen H. Kan

Pseudo-Control Chart of Inspection Effectiveness

IE = \frac{\text{# of defects removed in a phase}}{\text{# of defects found in and after that phase}}

I0: high level design review
I1: low level design review
I2: code inspection
The Red Bead Experiment

http://www.youtube.com/watch?v=JeWTD-0BRS4

“The biggest enemy of the system is common sense.” -- Deming

- 6 willing workers
- 2 QA engineers
- 1 Inspector
- 1 Recorder

Take 20 beads out from the pool with minimum # of red beads!

- Will it help if we
  - enhance rigid and precise procedure?
  - put motivating slogans around the room?
  - set numerical objectives?
  - reward by salary increase and punish by firing?
Lessons Learned From the Red Bead Experiment

- It’s the system, not the workers.
- Management owns the system and quality is the outcome of the system ➔ quality must start with management.
- Rigid and precise procedures are not sufficient to produce the desired quality.
- Extrinsic motivations is not effective.
- Numerical goals and production standards can be meaningless.
- By using rewards and punishment, management was tampering with a stable system.
- And many more...
Deming’s 14 Quality Principles

1. Create a constant purpose toward improvement
2. Adopt the new philosophy
3. Cease dependence on mass inspection
4. End lowest tender contracts (Use a single supplier for any one item)
5. Improve every process constantly and forever
6. Institute training on the job
7. Institute leadership
8. Drive out fear
9. Break down barriers between departments
10. Eliminate exhortations (Get rid of unclear slogans)
11. Eliminate arbitrary numerical targets
12. Permit pride of workmanship
13. Encourage education
14. Top management commitment and action

https://www.mindtools.com/pages/article/newSTR_75.htm
How can we relate Deming’s 14 quality principles to the 12(13) principles behind Agile?

http://agilemanifesto.org/principles.html
The Deming Cycle

- **Plan**: define your objectives and determine how to achieve them
- **Do**: execute your plan and collect data
- **Check**: evaluate results and look for deviations.
- **Act**: identify root causes of deviations; decide what need to be improved

- Continuous improvement: successive PDCA cycles – each one refining the process or product more.
- The “wheel within a wheel”: the relationship between strategic management and business unit management.
Apply Deming Cycle: Waterfall

- Waterfall model:
- PDCA can be loosely applied
  - P, D, C, A at each phase
  - Don’t progress to the next phase until we are satisfied that we have achieved the goals for the first phase.
Apply Deming Cycle: Spiral

- Spiral Model:
- Very clear mapping of the Spiral model to the Deming cycle
Apply Deming Cycle: RUP

- Rational Unified Process:
  - Easy mapping to the Deming cycle
Summary

- SPC: process stability and capability
- 2 types of variations: common cause (chance) and special cause (assignable)
- SPC tools:
  - Scatter diagrams
  - Run charts
  - Cause-effect diagrams
  - Histograms
  - Pareto charts
  - Control charts: X-bar, R, S, XmR
- Deming’s 14 quality principles
- Apply Deming cycle to Software process models