OHSU OGI Class

ECE-580-DOE : Statistical Process Control and Design of Experiments

Steve Brainerd

• Statistical Quotes

• **Quotes:**

• It is a capital mistake to theorize before one has data. Insensibly one begins to twist the data to suit the theories, instead of theories to fit the facts. *Sir Arthur Conan Doyle*

• *First get your facts, them you can distort them at your lesisure.* *Mark Twain*

• Statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write. *H.G.Wells*

• *Lest men suspect your tale untrue, keep Probability in view.* *John Gay*
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Data: Steve Brainerd

• What is this Class about?

• It’s about data!

• How to collect data.

• What do do with data once we have it.

• How to effectively use data make sound decisions to make money or improve the quality of life!
Data: Steve Brainerd

- **3 types of data:**
  - **Random Variable:** measured *continuous* or discrete data such as a dimension, a resistance value or # cars in parking lot.
  - **Parametric:** data from a normally distributed population
  - **Attribute:** measured *discrete data* such as “pass or fail”, “good or bad”, “accept or reject” and “on or off”.
  - **Non-Parametric:** Data from a non-normally distributed population. Measured data that can out be ranked from best to worst or highest to lowest.
Random variables can be continuous or discrete

- **Continuous random variable**: can take any value (real number) within its valid range.

  Examples:
  
  - Electrical current
  - Length of an element
  - Temperature
  - Density
  - Forces, etc.

- **Discrete random variable**: can take only a limited (discrete) number of points in the real line.

  Examples:
  
  - Number of cars in a parking lot
  - Number of people in a theatre
  - Number of defective computer chips in a shipment of 10,000 chips
  - Number of votes in an election, etc.
What good is statistics? WHO CARES?

Practical application of probabilities to increase profits or make new discoveries rapidly!

Statistical Quality Control:

**STATISTICAL:** With the assistance/help of numbers,

**QUALITY:** We study characteristics of our process.

**PROCESS:** The system we are trying to dominate, rule or control.

**CONTROL:** We force the process to behave the way we want it to behave.
What good is statistics?

This class we will discuss only practical applications! There will be very little theory. Techniques and procedures you can apply will be taught.

You need to be a “variation detective”

Variation reduction is why process engineers exist!

Examples from integration circuit manufacturing:

- Reduce etch rate non-uniformity
- Improve implant depth for As
- Improve Registration control
- Reduce across the wafer CMP polish rate non-uniformity
- Reduce Cu plateup Rs variation
- Improve BCB low k dielectric lot to lot variation
What good is statistics?

- It’s all about not making “educated guesses” or listening to “word of mouth hearsay” to solve process variation problems.
- It is about making educated decisions with established or known degrees of certainty.
- Knowing the level of probability that your decision is likely to be correct.
- *It is a tool all modern process engineers need to employ to ensure their careers are successful and their companies remain profitable!*
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- Statistical Process Control System
- (How it all fits together.) or the logical sequence
  - Define problem to solve
  - Ensure measurement system is precise: S/N ratio
  - Generate clues: Multi-vari or control charts
    - Define known/possible variables list
  - DOE to establish significant parameters
  - Split lots Better process Vs Current: B vs C
    - F test/T tests
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- **Statistical Process Control**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Statistical Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Statistical distributions</td>
<td>Basic material for statistical tests. Used to characterize a population based upon a sample.</td>
</tr>
<tr>
<td>2</td>
<td>Hypothesis testing</td>
<td>Decide whether data under investigation indicates that elements of concern are the “same” or “different.”</td>
</tr>
<tr>
<td>3</td>
<td>Experimental design and analysis of variance</td>
<td>Determine significance of factors and models; decompose observed variation into constituent elements.</td>
</tr>
<tr>
<td>4</td>
<td>Response surface modeling</td>
<td>Understand relationships, determine process margin, and optimize process.</td>
</tr>
<tr>
<td>5</td>
<td>Categorical modeling</td>
<td>Use when result or response is discrete (such as “very rough,” “rough,” or “smooth”). Understand relationships, determine process margin, and optimize process.</td>
</tr>
<tr>
<td>6</td>
<td>Statistical process control</td>
<td>Determine if system is operating as expected.</td>
</tr>
</tbody>
</table>
### Statistical Process Control

**Table 2: Engineering Tasks in Semiconductor Manufacturing and Statistical Methods Employed**

<table>
<thead>
<tr>
<th>Engineering Task</th>
<th>Statistical Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process and equipment control (e.g., CDs, thickness, deposition/removal rates, endpoint time, etest and sort data, yield)</td>
<td>Control chart for $\bar{x}$ (for wafer or lot mean) and $s$ (for within-wafer uniformity) based on the distribution of each parameter. Control limits and control rules are based on the distribution and time patterns in the parameter.</td>
</tr>
<tr>
<td>Equipment matching</td>
<td>ANOVA on $\bar{x}$ and/or $s$ over sets of equipment, fabs, or vendors.</td>
</tr>
<tr>
<td>Yield/performance modeling and prediction</td>
<td>Regression of end-of-line measurement as response against in-line measurements as factors.</td>
</tr>
<tr>
<td>Debug</td>
<td>ANOVA, categorical modeling, correlation to find most influential factors to explain the difference between good versus bad material.</td>
</tr>
<tr>
<td>Feasibility of process improvement</td>
<td>One-sample comparisons on limited data; single lot factorial experiment design; response surface models over a wider range of settings looking for opportunities for optimization, or to establish process window over a narrower range of settings.</td>
</tr>
<tr>
<td>Validation of process improvement</td>
<td>Two-sample comparison run over time to ensure a change is robust and works over multiple tools, and no subtle defects are incurred by change.</td>
</tr>
</tbody>
</table>
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• Statistical Process Control Class Goals

• There have been thousands of books, seminars, and corporate programs over the past 20 years proclaiming the wonders of SPC and DOE. Much of this hype has focused on “management organization” and “corporate culture”.

• “Design for manufacturability”! “6 sigma Process”

• This class will focus on real world practical application of specific techniques.

• 4 Key ideas, goals, or themes I want to stress in this class are:

  1. **Identify**: Chronic quality problems. What is causing the “failure”?

  2. **Question everything**: Logic and reason. (Everyone has a theory!) Test data yourself. Do not believe “hearsay”!

  3. **Measurement**: Ensure proper and precise (Shainin Isoplot and gauge study)

  4. **Plan**: Apply proper robust statistically based technique (The 2 “R”s and blocking). Document, document, and document everything. Do not use “word of mouth”.
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• Statistical Process Control History: Key Contributors
  • Jakob Bernoulli (1654-1705) Swiss mathematician (uncle to Daniel)
  • Denis Poisson (1781-1840)
  • Carl F. Gauss (1777-1855)
  • W.S. Gosset (Pseudonym “Student”) 1908 : Chemist at Guiness Brewery
  • Walter Skewhart: 1924 Control charts
  • Sir Ronald Fisher (1920-1930’s): Agricultural applications F test
  • Box and Wilson: (1951) RSM
  • Western Electric : Control Chart rules
  • Dr. W.Edward Deming (1940 –1980s): Japan reconstruction
  • Dr Joseph M. Juran USA; Dorian Shainin USA; Taguchi Japan (fractional factorials): Consultants
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- Statistical Process Control SPC and DOE

- **Class has 2 basic sections:**
  - I: Basic concepts, distributions, control charts, establishment of an effective measurement system, Clue generating techniques
  - II. Inductive statistics Comparisons, ANOVA’s, factorials, and fractional factorials.
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• Section I: Statistical Process Control SPC items and “clue generating techniques”.
• Tests for normal data
• Normal Probability plots
• Control Charts and rules
• Process Capability: Cp CpK
• Sampling plan and OC curves
• Isoplot: Shainin
• Gage study
• B Vs C: Shainin
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• Section II: Statistical Designed experiments
  • T test
  • F test
  • ANOVA
  • Factorial designed experiment
  • Blocked designs
  • Fractional factorials
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• Statistical tests (data that is from a normal distribution) List: We will focus on “BOLD” ones

1. Z test Large sample test for one mean when either sigma is known or n > 30, normal pop. distb.
2. t test Small sample test for one mean when both sigma is unknown and n ≤ 30, normal pop. distb.
3. **Z test Large sample test** for two means where each n > 30, independent sample from normal pops., variances =
4. **t test Small sample test** for two means where at least one n ≤ 30, independent samples from normal pops., variances =
5. **t test A test for two means for dependent** (paired, related) samples where d is normally distb.
6. Z test Large sample test for one proportion.
7. Z test Large sample test for two proportions.
8. X² Chi-square goodness of fit, or multinomial distb., where each expected value is at least 5.
9. X²_{ij} Chi-square for contingency tables (rows & columns) where each expected value is at least 5. Either a test of independence, a test of homogeneity, or a test of association.
10. X² Test for one variance or standard deviation.
• Statistical tests (data that is from a normal distribution) List: We will focus on “BOLD” ones

1. **F Test** for two variances or standard deviations for independent samples from normal props.
2. **F\text{ANOVA} Test** for three or more means for independent random samples from normal pops., variances =
3. Tukey Q Multiple comparison test for equal sample sizes.
4. Scheffe' F, Multiple comparison test for unequal sample sizes.
5. Hartley H Test for homoscedasticity, homogeneity of variances (=).
6. Bartlett Test for homoscedasticity, homogeneity of variances (=).
7. Pearson r Pearson product moment correlation coefficient.
8. Slope Test on the slope of the linear regression line.
9. Intercept Test on the y-intercept of the linear regression line. Nonparametric Statistics
• Statistical tests List continued … Non-Parametric (data that is not from a normal distribution) tests:

1. Runs test Used to determine whether the sequence of data are random.

2. **Mann-Whitney U test** Analogous to **t test** Small sample test.

3. Sign test Analogous to #2 (single sample median) or #5.

4. **Wilcoxon Signed-Rank** test Similar to the sign test, but more efficient, analogous to **test A test for two means for dependent**

5. Kruskal-Wallis test Analogous to **F Anova test** for 3 or more means.

6. Spearman $r_s$ Rank correlation, analogous to Intercept Test on the y-intercept of the linear regression line.
• Introduction and Overview

• A process **Engineer** is employed to characterize, optimize, and control processes.

• One effective tool to achieve these goals efficiently (least cost) and with a high degree of success is through the use of statistical techniques such as DOE and SPC and DOE.

• SPC: Statistical Process Control
  SQC Statistical Quality Control > A set of methods based on statistical probabilities used to monitor, improve, or measure how consistent a process is! How consistent does it produce the end product!

• DOE or DOX : Design Of Experiments

• Every industry can benefit from the use of these techniques and they maybe the only way they stay in business.
Basic Statistics

- Variation: 1970's a new way of looking at process control and profits!
• Introduction and Overview

• So what are we trying to do?
• Basically it boils down to:

• **Data is only meaningful in a mathematical model relationship.**
• So we are trying to find models that can describe the outcome (data) as related to the input variables.
• Key is finding and controlling those input variables that have significant effects on the output desired response.
• Hopefully this class will show you some useful techniques in finding those key input variables.
Introduction and Overview

An experimenter is faced trying to decide which factors are important, out of many that may effect their process. They need to:

1. Identify the primary factor.
2. Identify the region of interest for these primary factors
3. Develop useful models in the region of the optimal settings of these factors
4. Confirm the results
• Introduction and Overview

• An **Experiment** is a test in which we purposely change input variables and measure effects on responses.

• Purpose of this class is to teach methods of designing and analyzing an experiment that produces the maximum information at the least cost and effort.

• We will deal with input variables (independent variables) and output or response variables (dependent variables).

• **Independent variables:** Time, Temperature, agitation, pressure and flowrate.

• **Response variables:** Etch rate, grain size, resistance,
1. **variables**: seat height (26, 30 inches), generator (off, on), tire pressure (40, 55 psi)  
   responses: time to complete fixed course on bicycle and pulse rate at finish
2. **variables**: amount of yeast, amount of sugar, liquid (milk, water), rise temperature, rise time  
   responses: quality of bread, especially the total rise
3. **variables**: number of pills, amount of cough syrup, use of vaporizer  
   responses: how well twins, who had colds, slept during the night
4. **variables**: speed of film, light (normal, diffused), shutter speed  
   responses: quality of slides made close up with flash attachment on camera
5. **variables**: hours of illumination, water temperature, specific gravity of water  
   responses: growth rate of algae in salt water aquarium
6. **variables**: temperature, amount of sugar, food prior to drink (water, salted popcorn)  
   responses: taste of Koolaid
Montgomery’s DOE Theorems:

**Theorem 1.** If something can go wrong in conducting an experiment, it will.

**Theorem 2.** The probability of successfully completing an experiment is inversely proportional to the number of runs.

**Theorem 3.** Never let one person design and conduct an experiment alone, particularly if that person is a subject-matter expert in the field of study.

**Theorem 4.** All experiments are *designed* experiments; some of them are designed well, and some of them are designed really badly. The badly designed ones often tell you nothing.

**Theorem 5.** About 80 percent of your success in conducting a designed experiment results directly from how well you do the pre-experimental planning (steps 1-3 in the 7-step procedure in the textbook).

**Theorem 6.** It is impossible to overestimate the logistical complexities associated with running an experiment in a “complex” setting, such as a factory or plant.